4-2018

Big Fish, Big Data: Discussing the State of Salmon and Improving King Salmon Regulation Through a Population Model

Creed Coram
DePauw University

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Creed Coram ‘18

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HoScho Thesis
4/12/2018

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"All I've done my life is fish. I don't have anything else, I don't know anything else," exclaimed Mira, a commercial troller from Port Alexander, Alaska. For her the fishing industry means her livelihood as it has her whole life. Recently, however, increasingly tighter regulations, particularly on king salmon, have caused her to worry about her economic future. In the summer of 2017, king salmon fishing in Southeast Alaska was cut early – for both commercial and sport fishermen. This unexpected action, unfortunately, was deemed necessary.

Despite a 5% higher catch in 2017 – 213 million salmon were caught, 9 million more than the forecast – King numbers are low (Welch). Southeast Alaska recently put out the lowest forecast for Kings since the 1970s when records began (*Daily Sitka Sentinel*). The Stikine and Taku, major spawning rivers for Kings in the southeast region, are expected to see only 7,000 and 5,000 fish return, respectively; which is sixty percent lower than last year's prediction and in the case of the Taku river, four times less than the goal range of 19,000 – 36,000 (Leffler). It's not just the southeast that is seeing low returns: the Yukon River, which winds through the heart of mainland Alaska and down into western Canada, has seen low numbers since 2011 and has, until recently, enforced a ban on commercial fishing in the area (Demer). A similar downward trend has commenced along the west coast of North America: in the Oregon and Washington area, king numbers have dropped by 60% in abundance in Puget Sound since the EPA began keeping record in 1970s (EPA); California, which historically has seen millions of fish return, is now seeing only a fraction of that number (Yoshiyama et al.). To be fair, king salmon are returning to some areas. Their sharp decline lately in specific regions and a general decline overall in the Pacific, however, are causing concern about the health of wild stocks. Salmon naturally operate on a cycle, for example: a Pink spends a year in the ocean before going back to its spawning stream, other species of salmon, such as Coho, can spend a couple years growing in the ocean. Kings, most impressively, are capable of spending between 2 and 8 years in the ocean before returning to spawn. So fluctuations in salmon populations occur normally. The current low numbers, however, have not seen increases in years. Alaska, notably, manages through a sustained approach. Even going as far as putting it in their state constitution: "Fish, forests, wildlife, grasslands, and all other replenishable resources belonging to the State shall be utilized, developed, and maintained on the sustained yield principle, subject to preferences among beneficial uses" (AK Const.). Meaning the health of the population is put first and the quota, determined by an escapement goal, is decided second. Escapement is the number of fish that return to spawn; an escapement goal is a target number for returning salmon to reach. Assuming this management style works, it seems unlikely that over-fishing has led to the sharp decline in Kings in recent years. Nonetheless, fishermen are feeling the effect of low returning numbers.

Within the past year, Mira has started seal hunting, making handicrafts and clothing from their fur as a source of alternative income. With the amount it brings in, she can handle less time on the water better than other commercial fisherman in town. Sealskins, however, are only available to her because she is a Native American. For others in Port Alexander, tighter fishing restrictions could force them to move and find work elsewhere; little, if any, economic opportunity exists outside of fishing in this town. The 40 people who live there year-round have a rugged way of life, but it is also a fragile one. Routine barge runs from Sitka, Alaska – 80 miles away by boat – provide the town with groceries, mail, and fuel. People putting up buildings, or in need of big materials, usually load their supplies on scows to be boated into Port Alexander. Fishing charters depend on floatplanes to get clients in and out in a timely manner. This whole infrastructure, however, depends on the money generated by salmon. With fewer days to fish, Coho and King trollers have a smaller amount of time to make, for the most part, their annual income. If enough people leave because they can't support themselves from fishing, the barge may not be able to run profitably; as it is, the government already subsidizes postage. If the chain of transportation between Sitka and Port Alexander breaks, the town could easily die out. In such an isolated area, a collapse of the town would have a relatively low impact, most likely unnoticed by the rest of the state – certainly unnoticed by the rest of the country. In a bigger town, however, a collapse of the king salmon fishery would be catastrophic.

Ninety miles north on Baranof Island lies Sitka or, as it is nicknamed, *Sitka by the sea*. The town has a deep Russian history: before Alaska was bought by the United States, Sitka was one of only two Russian "permanent settlements" in the region (Arnold, 161). The influence shows in the architecture of older buildings and historical markers. On clear days, the peaks of the staggering Pinnacle mountain range loom overhead as their bases jut into the ocean. Sitka's Russian roots and picturesque setting make the location a big tourist attraction during the summer. Cruise boats flood the town when they unload for the day, increasing the population of the town from roughly 8,800 people well into the 10,000s for a couple of hours. While these visits contribute to the town's summer revenue, the money made from tourism is still lower than in other Alaskan cities. Instead, fishing continues to be the life and soul of the town and has the biggest impact on Sitka's economy. In fact, Sitka has the largest commercial fishing fleet in Southeast Alaska. Of the 2062 vessels that harbor there, 669 are commercial fishing vessels (Sitka.net). When charter-fishing boats are considered, the number is even greater. Seasonal fishing vessels may also boost the number of total fishing vessels during season. In addition to the salmon fishery, the area also attracts angling attention because of its halibut, black cod, and herring fisheries. From the local population, 19% of people sixteen and above are directly involved in Sitka's seafood industry (Sitka.net). In reality, everyone in the town depends on and is connected to the seafood industry; in 2015, Sitka brought in $48,019,694 in processed seafood. Salmon are not the sole reason for these numbers, but even a small moratorium on the king salmon fishery would have economic whiplash for fishermen in the town and disrupt Alaska's normal supply of the fish.

Alaska is responsible for a major share of the wild salmon consumed in the US. According to the 2017 Commercial Salmon Harvest Summary, conducted by the state of Alaska, 224.6 million wild salmon were caught this past year, valued at $678 million (Alaska.gov). Most of the catch comprise of sockeyes and pinks, totaling 86% percent of the harvest and 73% of the overall value (Alaska.gov). While it is no surprise that sockeyes and pinks made up most of the catch, Kings accounted for less than one percent of the total harvest. At 251,141 fish, king salmon had a preliminary value of $17.8 million. As the southeast is responsible for the majority of Alaska's king salmon harvest, numbers could very well drop further. The scarcity of the fish seems to spur on global demand, as if its lack of abundance makes it more appealing. Its importance as a source of nutrition and valuable commodity, though, are nothing new.

Before the obsession with Copper River salmon or the extravagant flying fish at Pike Place Market in Seattle or high-end restaurants that made the fish famous – before it was iconized – salmon had a much simpler relationship with people. Perhaps no other group has had as simple and bountiful of a bond with the fish than Native Americans. The Tlingits of Southeast Alaska, during the pre-contact period, give insight into this relationship: though a source of food, salmon were more than just sustenance for them. These fish held incredible social value as well. Salmon fishing, for instance, was not just an occupation, but also a way of life, serving as a "microcosm of Tlingit culture" that expressed "the social relationships and values that knit the society together" (Arnold, 160). When harvested, Salmon was first distributed based on need, but surplus salmon was a source of wealth and garnered renown. This surplus was often used to heighten the status of a clan through items of cultural importance, like totem poles (160). Despite the wealth that abundant runs of salmon symbolized and the fact that Tlingits could apply "extreme pressure on salmon populations," they practiced a subsistence lifestyle (159). Their dependence on and deep reverence for the fish prompted various fishing ceremonies where fishing was banned; breaking such rules resulted in the confiscation of fishing gear (159). These customs regulated the impact their fishing had and kept the natural resource from being overexploited. The introduction of Europeans and Russians, however, ignited a cascading shift in harvesting salmon; even though the Tlingit relationship with salmon did not change, new markets and an infringement on native property rights led to the beginning of salmon exploitation in the area.

The early-contact period with Europeans began the integration of western culture in Native life; as these two worlds became more entwined, the more inequitable the relationship became. Initial contact between the two groups was beneficial for both: Tlingit's would trade fur and receive "luxury" items in return. Since the trade mostly centered on fur, the Tlingit people maintained their autonomy and continued their practice of subsistence living (161). However, as Russians began moving into southeast Alaska, disregard for native fishing areas – and other aspects of native life – developed and tension arose. This neglect continued to grow – and with the United States' purchase of Alaska – the salmon canning industry was born. It was a double-edged sword for the Tlingit people: on one side, they had more economic opportunity and access to western items, on the other, the industry introduced large-scale fishing, which disrupted the symbiotic relationship the Tlingits had developed with salmon and completely ignored native rights to the natural resource. Built for mass production, canneries required large numbers of salmon to operate. To meet this need, salmon were harvested in greater number and with little regard to the health of wild populations. As a result, inefficient and wasteful methods were used: massive waste occurred due to fish weirs, traps, and damming of spawning streams. Ignorance of native identity and customs was reflected in the poor management of salmon – as if the two were exploited at the same rate – a collapse of two great identities caused by the greed of capitalist America. Native groups fighting for their rights; their current relationship with salmon. Uphill battle that began with first contact. Global demand outweighs historical and cultural rights. Fast-forward a couple of decades and the demand for salmon is still present. In fact, it is growing. As its grandeur has grown, people have grown hungry. They want to eat a king salmon or an Alaskan salmon but hardly consider the natural resource itself.

In response to this demand, aquaculture, the practice of rearing fish or aquatic plants for sale, has become a prominent sector in the seafood industry. In the case of salmon, fish are either reared in a 'fish farm' or at a hatchery. The difference between the two is notable. In a fish farm, salmon are kept in saltwater pens or freshwater tanks until they reach the desired size. In some cases, salmon remain in freshwater tanks the entirety of their lives. A hatchery uses incubation tanks and freshwater pens as farms do, but upon reaching a certain size, the hatchery releases the fish into the wild. Upon returning to the hatchery to spawn, the fish are then harvested and sold, though profit is not guaranteed since salmon returns are never certain. This distinction between the two approaches in rearing salmon result in different nutritional values. When comparing farmed fish with wild fish, farmed fish contains 46% more calories and a significantly higher amount of Omega–6 fatty acids (Fish, Salmon, Atlantic). Additionally, higher amounts of toxins have been found in farmed raised salmon than in wild populations (Foran et al); interestingly, European farmed fish have shown higher amounts of contaminants than salmon farmed in South and North America (Foran et al). Perhaps the biggest difference, when comparing farm-raised fish to hatchery or wild salmon, is that farmed fish are often genetically modified to grow at a faster and more efficient rate. For some, this genetic modification is enough to question the integrity of the fish: Lisa Murkowski, an Alaska state senator, refers to these salmon as "fake fish." It is a sentiment shared by commercial fishermen and hatcheries alike – though their economic bias should be considered. Overall, the hatchery process is more natural than the farming method because salmon are released into the wild for the majority of their lives, instead of being kept in a pen. However, with the demand for salmon only increasing, and a significant portion of global salmon farmed, a dependence on such facilities may be needed.

AquaBounty, a major aquaculture company, aims to be one of the major produces of farmed fish in North America. As demand continues to grow for seafood and salmon alike, AquaBounty could help lesson pressure off wild populations through their genetically engineered Atlantic salmon, dubbed the "AquAdvantage® Salmon" (AquaBounty). The salmon contains a growth hormone gene from king salmon and a "genetic switch" from the ocean pout, a fish, which allows the growth hormone to stay on – typically, it is only on some of the year (nytimes). The idea is to decrease production time and get the fish to an acceptable "market size" quicker than is typical. In terms of domestication, this process has been seen with everything from corn to chicken, so it is not unheard of. Unlike those, salmon are a bit more efficient. Aquabounty claims the AquAdvantage® Salmon has a 1:1 ration in terms of size to feed, meaning for every 1 kilogram of feed a salmon eats, they put on 1 kilogram of body weight. When compared to cows or chickens, which have 8:1 and 2:1 ratios, the difference is substantial (AquaBounty). However, AquaBounty relies on wild fish for the Omega-3 fatty acids salmon are known to have. So even though they can produce salmon more quickly than the wild can, they are still dependent on the wild.

Following the early closure on king salmon in the Southeast this past summer, a ban on king salmon is under consideration for the end of the winter season. Cities all along the west coast, from Alaska to Washington, are considering this measure as well. This concern shows the necessity to ensure regulations reflect what is best for the fish; the impact such regulation can have on the fishing industry should also be taken into account. Regulations can only be made from good data and currently there is a lack of it. Baranof Island received a late, but large return of Kings in the summer of 2017. The season had been cut early, though, and no one was allowed to fish them. This decision didn't make sense for a couple of reasons: first, although they had returned to spawn, it was too late in the year for the migration to spawning grounds, so they died. Second, even when targeting Coho, fishermen were still catching Kings and had to release them – this practice resulted in many dead Kings as by-catch. Lastly, the kings were not native to southeast Alaska and were not returning to streams that are currently in question – according to local fishermen. Part of the issue is the ability of the sustainable yield approach to react quickly to new data. Harvest numbers are based on an abundance index (AI). Though the AI provides an informed way to set quotas, it is not an exact tool. For this reason, tension ensues between fishermen and Fish and Game. Often, forecasts are wrong. When these errors occur, fishermen want to fish and don't understand why they can't.

Kings are disappearing. Why?

Salmon are vital not only for their economic value, but also as a food source. King salmon, in particular, carry a symbolism with them: they elicit feelings of vitality and spirit. Perhaps no other animal has the same violent beauty they do. For these reasons, their reduced abundance within the last decade needs to be understood in depth. When considering their decline, fishing pressure, food source, human urbanization, and water conditions are among the top factors.

Fishing pressure, the combined impact that subsistence, sport, and commercial fishing have on wild populations, should be considered heavily. Subsistence and sport have relatively small ramifications when compared to commercial fishing. Due to its massive scale, commercial fishing has the biggest affect on wild populations of salmon. There are three distinct ways to commercially fish for salmon: trolling, seining, and gillnetting. Each type of fishing uses a different technique. Seiners, also called “purse seiners,” deploy a mesh net, encircling large schools of salmon. Once the circle is completely formed, the bottom of the net is hauled in. Pulling in the bottom, while the top of the net keeps its circle shape on the surface of the water, creates a “purse” effect in the net. Gillnetting, on the other hand, uses a long net that stands vertically upright underwater. When subsistence fishing, people often deploy gillnets near the coast or by mouths of rivers. When commercial fishing, gillnets are often tied off of a vessel and allowed to drift in the current at a targeted depth. When salmon swim through the net, as the name suggests, their gills get caught and they are unable to swim away. Lastly, trolling. Trollers tow a series of long-lines, each with multiple hook sets, which are held away from the vessel by outriggers (trolling poles). Able to fish multiple depths, it is not uncommon for a troller to set a “deep” line and a “shallow” line; this functionality allows them to target multiple schools at the same time. Each one of these fishing styles is a refined process developed to catch the maximum amount of fish possible.

There is no doubt they are fantastic methods at harvesting salmon, but their effectiveness has two sides. Collapse of the Atlantic salmon and cod fishery are proof of the destructive power fishing pressure holds and a warning of what mismanagement can result in. Year after year, king salmon – and the four other salmon species – are taken from the ocean without pause. Regulations actively work to manage wild fisheries sustainably, however, they differ across regions and countries. While Canada and the United States formed the Pacific Salmon Committee (PSC) in 1985 to ensure a collaborative approach in managing salmon, they often approach managing fisheries differently. The PSC only gives a recommendation: quotas and rules are made by Canada Oceans and Fisheries (DFO) in Canada and National Oceanic and Atmospheric Administration (NOAA) in the United States. The arrangement between the two has also had its problems and with the PSC ending soon, issues could arise. Allowing the United States and Canada to set a quota independent of one another can work against management styles each country has put in place. Regulation has improved, but it's tough to decipher how well it works.

Herring, another highly prized commercial fishery, are vital to the Pacific's ecology and a major food source for salmon. For adult Chinook, herring comprise about 60% of their diet (Herring Migratory Behaviour). However, the health of these stocks is also a matter of concern. In Sitka, Alaska, the same region where some king salmon stocks are in question, a battle over herring regulation has just ended. In recent years, the Sitka Tribe of Alaska, a federally recognized government for about 4000 Tribal citizens, has tried to get the commercial harvest of herring reduced. They believe that harvest rates are causing a "change in the herring – how they spawn, where they spawn" – ultimately impacting the needs of subsistence harvesters (Kwong). Despite their pleas, Fish and Game have not adjusted harvest levels, claiming that the herring biomass is big enough to fish sustainably. In light of historical accounts of the area, however, the fishery appears to sit in a dire position. While there is no quantifiable data available, audio testimony from a 1997 Board of Fisheries meeting speaks to a time when "the channel used to be full of herring" and "the whole bay used to be covered with spawn" (Kwong). Sherri Dressel, a fisheries scientist for Fish and Game, attributes the current low period of herring to environmental factors. While both sides – Fish and Game backed by data and predictive models and Tribes and subsistence harvesters with their historical knowledge – present compelling arguments, the health of the herring fishery remains unclear. While data show that the herring biomass fluctuates naturally, I am inclined to believe that the herring fishery is in trouble. Local accounts and shifts in the nature of herring spawning seem like a greater – and perhaps more compelling – indicator than Fish and Game's predictive model. Despite these to conflicting sides, one thing remains clear: herring support the oceanic food chain. They are harvested for their row or eggs, which are predominantly exported to Asian markets. Male herring are not desirable because they carry no eggs; they are still caught, even though there is no market for them. Food source will mean little, however, if salmon cannot reach their spawning grounds.

As a general rule, man-made stream blockages, like dams, are detrimental to salmon streams because they cutoff access to spawning areas and prime rearing habitat further upstream. While many rivers have been dammed, perhaps the story of the Elwha River speaks best on the negative impacts of damming and the success that can come from rehabilitation projects. Located in the Olympic National Park in Washington, the river was once home to massive Kings and all five species of Pacific salmon. Increasing expansion in Western coastal cities in the 1900s prompted the construction of dams for water and electricity (Power For The People). However, state and territorial constitutions in Washington and Oregon, respectively, mandated that any river known to have salmon in it could not be dammed unless a fish passage was constructed (Power For The People). The Elwha Dam, constructed from 1910 to 1913, however, was built without a fish passage, leaving only 7.8km of lower river for salmon to spawn in. Behind the dam, 140km of tributary habitat existed (Duda). The governor at the time, Ernest Lister, and his fish commissioner, Leslie Darwin, came up with the idea that a hatchery be attached to the dam and in this way gain a state sanctioned fish obstruction (Power For The People). While the dam became legal, it did so through a loophole. Unfortunately, the practice of attaching a hatchery to a dam spread; the early constitution of the state was either ignored, forgotten, or not enforced and healthy salmon rivers fell victim to urbanization. For the Elwha, construction of the dam decimated returning populations of salmon: in the 1990s salmon downstream of the Elwha dam were estimated at 1% of their pre-dam numbers (Duda). There is hope yet for the Elwha Kings, however.

Congress, in 1992, mandated The Elwha River Ecosystem and Fisheries Restoration Act, which called for the removal of the Elwha dam and Glines Canyon Dam (Duda). The restoration project was the biggest dam-decommissioning project in U.S. history "in terms of the projected release of sediment and the size of the existing hydroelectric projects." (Duda). There are a number of other rehabilitation projects in Puget Sound that aim to revert the damage done to river ecosystems. Unfortunately, effects are still being felt from blockages built in the early 1900s: Puget Sound Kings, which represents not just the Elwha River Chinook, but also all Kings within Puget Sound, are currently listed as threatened under the U.S. Endangered Species Act. Though dams have and continue to affect salmon populations, low returns to free flowing rivers indicate that another factor may be responsible for the recent decline in Kings.

When compared to the previous factors, water conditions have the potential to impact salmon populations the most. Temperature during significant early life stages can have impactful consequences on growth and survival: warmer water generally spurs on growth, while cold water retards it; extreme temperatures at either end, however, cause an adverse environment for eggs. After hatching, temperature continues to affect growth rate and age at maturity as salmon continue to grow (Lewis et al). In particular, higher temperatures may be responsible for early maturation at a smaller size. In some areas of Alaska, salmon have shown to decrease in size because of early age at maturity: in the 1980s, King spawners across ten different sights primarily returned after spending 4-years in the ocean, by 2012, however, the spawners were smaller and the majority comprised of age 2 and 3 fish (Lewis et al).

In summary, there are many factors that influence the stocks of wild salmon. In order to have effective regulation and ensure the safety of wild stocks, understanding the ecology of these beautiful creatures has to take priority. As a solution, I am making my own population model.

<u>My solution – an analytic approach</u>

In the summer of 2017 I was in Port Alexander fishing for salmon. On the third day out on the water, king salmon fishing got cut early and all kings that were caught were required to be released. I have been fishing the southern tip of Baranof for the past ten years and the possibility of not being allowed to catch Kings never occurred to me until that moment. It was on returning one of the Kings back into the ocean that I began to wonder who collected data on salmon population levels? What methods are used? And who makes the regulations on salmon fishing? In that moment, something clicked inside me; I knew I wanted to take part in protecting this beautiful species. As a senior who had to return to school though, my options were limited. I considered the many conversations I had with fisherman and hatchery staff and felt generally confused by what was happening to the salmon. So, I thought a population model, focusing on the factors that seemed most important, based on those conversations and research, was the best way to make sense of it all.

In order to fully understand how the algorithm works, an overview of the salmon life cycle is helpful: Salmon are anadromous fish, meaning they migrate from saltwater (the ocean) into freshwater (rivers) to spawn. They fight their way against the river current – and various other obstacles – until they reach the spawning grounds. Once there, females hollow out small areas in the gravel floor, called redds; these nests are the starting place of the salmon life cycle. Females deposit eggs in these redds which male salmon fertilize as they swim past. Egg incubation varies across species, but for king salmon it takes about three months. Water temperature allows for slight variations in the timing of emergence: colder water slows growth, while warmer water spurs it forward. When they emerge from the egg, the salmon are in the alevin phase. As an alevin, salmon have a yolk-sac attached to their bellies. It serves as their source of nutrition for the next couple weeks. They remain in this stage for about 3 months. Once their yolk-sacs are eaten and they emerge from the gravel, they are considered fry. Depending on the species, the fry stage lasts a different amount of time. For kings, it can last between a couple months and a whole year, then the migration toward the ocean begins. As fry get ready to leave the river they were born in they go through a process called "smoltification" – as they get closer to they are exposed to brackish water. Having only lived in freshwater, their bodies need to adapt to saltwater. During this time, they are known as smolt. Once they are ready, smolt head out into the ocean. Typically, king salmon spend 2 to 6 years out in the ocean, though they can remain up to 8 years in the ocean. During this time, they migrate thousands of miles along the western coast of North America and further out in the Pacific until returning to spawn.

My model focuses on the Dungeness River in the Straight of Juan De Fuca. I considered other rivers but decided upon the Dungeness for three reasons: its geographical location, known data on the river, and the presence of a hatchery. The Straight of Juan De Fuca has historically been an abundant area for wild salmon; it is the pathway between the Pacific Ocean and Puget Sound. The Dungeness Management Unit Profile (MUP) from the Correspondence from NOAA Fisheries on the 2017 Puget Sound Chinook Harvest Management Plan gives great insight into the salmon of the Dungeness River. Looking at data going back to 1988, the MUP gives the distribution of years-in-ocean (YIO) for returning spawners (see table1), the egg to smolt survival rate (5.03%), and hatchery information that is pertinent when considering hatchery influence. The Dungeness hatchery, in recent years, has tried aiding the dwindling number of kings in the Dungeness River by repopulating some of the streams salmon population with hatchery-reared fish.

A king salmon population model, even before considering factors, is complicated. King salmon can spend anywhere from 2 to 8 years out in the ocean before returning to their home stream to spawn. Because of their ability to spend multiple years in the ocean, a returning population in a year is not affected by the year before it, but instead, anywhere from two to eight years before it. The MUP on the Dungeness river shows king salmon returning to the Dungeness River typically spend three to five years in the ocean (see Table1).

	Age 3	Age 4	Age 5+

Mean proportion of age of salmon in a returning population	0.1795	0.6003	0.2202

Table 1 – These values are calculated from the years 1988 – 2016. After the year 2000, hatchery salmon return to the stream and are considered when determining the total number of spawners. Due to this, the proportion above may not be fully representative of what a strictly wild returning population age distribution would look like.

For explaining purposes, assume 300 salmon return in 2005. To figure out how many are three years old, perform the calculation: 300 * 0.1795 = 53.85. Out of the 300 fish that returned, roughly 53 of them were three years old (or from the year 2002). To find the number of four or five age fish, the same calculation is performed, but using the percent that corresponds to the desired age. Now that some fundamentals are covered, the algorithm as a whole can be inspected.

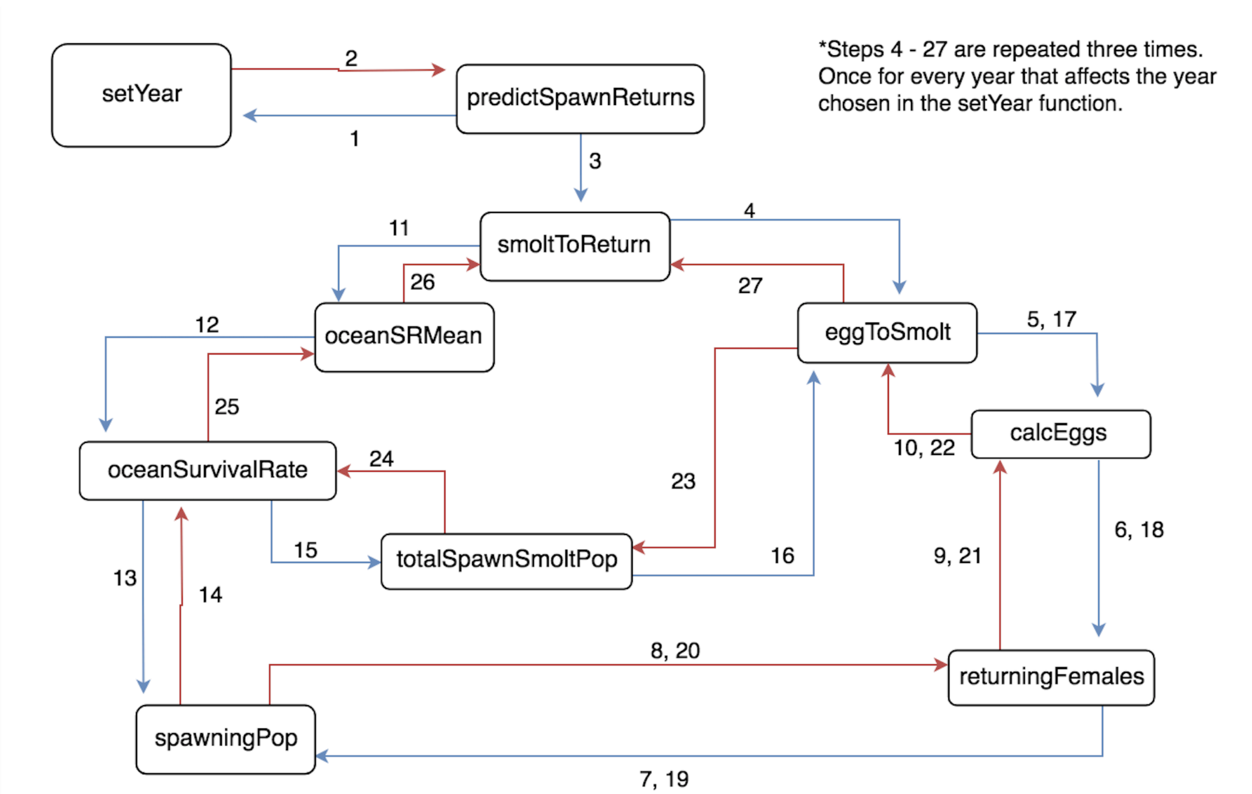

Figure 1 – The flow chart for the algorithm.

PredictSpawnReturns first calls the setYear function. For explaining purposes, 1991 will be the year spawners are being predicted for. The year is then passed to the smoltToReturn function. At this point, the algorithm "grabs" the years that affect 1991s spawning population – 1988, 1987, and 1986. The Dungeness river, from record taking, is known to have 17% of their spawners return after three years in ocean, 60% return after four years in ocean, and 22% return after five years (or more). After grabbing these three years, the third year away from the year being predicted for, 1988 in this case, is passed to the eggToSmolt function. From eggToSmolt the year is passed to calcEggs, then to returningFemales, and finally to spawningPop. SpawningPop returns the spawning population for the year it is given. In 1988, 335 salmon returned. Note: spawningPop works with actual data.

From this point, the algorithm "turns around" and follows the function path it took to get to spawningPop. Here is where calculations begin; everything up to this point was essentially passing the year that calculations should be done on. ReturningFemales assumes half of the returning spawners are female; in 1988 that would be 167 females. That figure is passed to calcEggs, which predicts how many eggs the females will produce. The number of eggs produced depends on the size of the female. I assume half are "small" and produce between 2000 and 3000 eggs apiece, while "large" females produce between 4000 and 5000 eggs apiece. For every female, the number of eggs they produce is randomly generated. The randomly generated number falls within the egg range that correlates to their size. This random number generation allows for fluctuations in the number of eggs produced. In this instance, calcEggs computes that 536,187 eggs are produced in 1988. Those eggs are passed to the eggToSmolt function where a survival rate is applied to them. The survival rate is currently set at 5.03%, so 26,970 eggs survive to become smolt; the survival rate was taken from a report on the Dungeness river. Before applying the marineSurvival rate to the number of smolts, the rate has to be calculated.

During these calculations, the original year being looked at – 1991 – and the three years affecting it – 1988, 1987, 1986 – are not of concern. The oceanSRMean function gets the mean by running oceanSurvivalRate on the years from 1991 to 2016, adding the results together, and dividing by the range of years. Beginning with 1991, the oceanSurvivalRate function calls totalSpanSmoltPop and "grabs" the years affecting the spawners of 1991 – 1988, 1987, 1986. The smolts for each year are produced, but this time multiplied by the years in ocean distribution they correlate to. As an example, 1988: 27,438 (smolts) * 17.95% = 4,925 smolts. The same is done with 1987 and 1986, using 60.03% and 22.02%, respectively. The new smolt numbers are all added together – this figure represents the number of smolts that would return if no marine mortality occurred in the ocean. The actual returning population of salmon in 1991 is divided by the total number of smolts that could return in 1991. The result of the calculation is the marine survival rate for that year. The processed is repeated for every year after 1991 through the year 2016. The values are added together and divided by the range of years (25). Note: though population data goes back to 1986, this function does not consider any year before 1991. For any year that a marine survival rate can be calculated for, a preceding five years of population data is needed. In this case, oceanSRMean returns a value of 0.01264072. Due to the range of eggs that may be produced, the mean survival fluctuates, but by no greater than 0.0001. Using the 4,925.121 salmon that lasted until the smolt phase and are assumed to return – because of the years in ocean distribution – in 1991, the ocean survival rate of 0.01264 is applied. Following the calculations: 4,925.121 * 1.264% = 62.253, meaning roughly 60 salmon will return in 1991 from the year of 1988. This process is repeated for the years 1987 and 1986. The totals are added together and the sum is the predicted amount to return. In the case of 1991, 173 – 179 fish are predicted to return. When compared to the number of actual spawners, 163, the algorithm appears to work within some amount of accuracy. This is not the case, however. When looking at the population data (see appendix 1), dramatic peaks and valleys occur. My algorithm becomes extremely inaccurate when predicting for these years or when they affect a returning years population, but that is exciting because it shows that the model should be refined and include more factors in its calculations.

Future enhancements

Moving forward I would compare all the years that are accurate with the actual spawning data and try to find similarities between them. At the same time, I would look at differences between the predictions that were accurate and those that were not. I believe oceanic conditions, based of conversations with hatchery staff and commercial fishermen, play a big role in affecting salmon population. Temperature, in particular, seems like it could have a great impact on salmon, either directly, such as during incubation or indirectly, when it could impact a food source.

I also think my egg production function could go into greater depth and look at how egg size affects survival rate. Big females have a higher fecundity and produce a greater number and physically larger eggs, which tend to give offspring a greater size and chance of survival (Cogliati et al). Small females, on the other hand, produce fewer and smaller eggs, but these offspring have a faster growth rate in comparison (Cogliati et all). Including these types of factors would hone my calcEgg function.

Lastly, I want to convert my algorithm into a known model used by data scientists. Though I think my algorithm works the same conceptually, splitting the dataset into a "training set" and "testing set" and implementing a class would be a more efficient way to run through the functions.

Concluding Thoughts

In the end, the one factor that seems to have impacted salmon greater than all others is humankind. While once harvested sustainably – even when an integral part of native lifestyle and society – the health of wild salmon stocks are now put in question, specifically king salmon stocks. Fish farms and hatcheries produce fish to meet global demand and offset fishing pressure on wild numbers, but something, to me, seems wrong in replacing a wild salmon with a farmed one. That opposition was a big motivator in deciding to write this algorithm for my honor scholar thesis. Though I have my doubts about predictive models, I believe, short of stopping all fishing, the best way to manage fisheries lies in population models. My model may currently be inaccurate, but creating it was a wholesome experience. Not only did I expand my knowledge of programming, but I also learned new, exciting things about salmon. Beyond all else, the importance they hold, not just in their economic or nutritional value, but as a symbol of something wild and free, humbles me. Like Mira, I'm not sure what I would do without them.

Appendices

Year	1. Total Natural Spawners	2. Trap Count	3. Nat-Origin Spawners	4. Hatch-Origin Spawners
1986	238			
1987	100			
1988	335			
1989	88			
1990	310			
1991	163			
1992	153			
1993	43			
1994	65			
1995	163			
1996	183			
1997	50			
1998	110			
1999	75			
2000	218			
2001			17	436
2002			115	518
2003			123	517
2004			182	771
2005			304	651
2006		3	293	1112
2007			146	159
2008			86	54
2009			71	57
2010			76	269
2011			83	452
2012			212	296
2013			46	122
2014			21	87
2015			65	200
2016			135	273

Appendix 1 – The dataset I use for my algorithm. I look at the first column (Total Natural Spawners) for all years before 2001 and the third column (Natural-Origin Spawners) for years 2001 to 2016. At no point do I use column four (Hatchery-Origin Spawners) or column two (Trap Count) in my algorithm.

Function explanations

spawningPop()
returns the number of spawners for a given year

returningFemales()
This function returns the number of females in a returning population

calcEggs()
This function calculates how many eggs the females in a returning population produce

eggToSmolt()
This function returns the number of eggs that survived through the incubation and fry period, they are now considered smolt

smoltToReturn()
This function takes the number of smolt and applies a marine survival rate, the result is returned

predictRetSpawners()
This function calculates the returning number of spawners for the given year.

setYear()
This function asks users to input a year between 1991 and 2016.

totalSpawnSmoltPop()
This function returns the total number of smolt that could return for a given year, assuming no marine mortality occurs.

oceanSurvivalRate()
This function calculates the ocean survival rate for a given year

oceanSRMean()
calculates the ocean survival rate for the years between 1991 and 2016.
All survival rates are added together and then divided by the range of years (25)

Sources

AquaBounty. "Sustainability." *AquaBounty.com*, aquabounty.com/sustainable/.

A.K. Const. art VIII, § 4

Arnold, David, and Donald L. Fixico. "Work and Culture in Southeastern Alaska: Tlingits and the Salmon Fisheries." *Native Pathways: American Indian Culture and Economic Development in the Twentieth Century*, edited by Brian Hosmer and Colleen O'Neill, University Press of Colorado, Boulder, Colorado, 2004, pp. 156–183. *JSTOR*, www.jstor.org/stable/j.ctt46nvxp.12.

Cogliati KM, Unrein JR, Stewart HA, Schreck CB, Noakes DLG. Egg size and emergence timing affect morphology and behavior in juvenile Chinook Salmon, *Oncorhynchus tshawytscha*. Ecol Evol. 2018;8:778–789.

"Chinook Salmon." *EPA*, Environmental Protection Agency, 27 Mar. 2018, www.epa.gov/salish-sea/chinook-salmon.

Demer, Lisa. "Yukon River Fishermen Get First Chance to Sell Kings since 2011."*Anchorage Daily News*, Anchorage Daily News, 18 July 2017, www.adn.com/alaska-news/rural-alaska/2017/07/17/yukon-river-fishermen-get-first-chance-to-sell-kings-since-2011/.

Duda, J.J., Warrick, J.A., and Magirl, C.S., eds., 2011, Coastal habitats of the Elwha River, Washington— Biological and physical patterns and processes prior to dam removal: U.S. Geological Survey Scientific Investigations Report 2011–5120, 264 p.

"Fish, Salmon, Atlantic, Wild, Raw Nutrition Facts & Calories." *Nutrition Data Know What You Eat.*, nutritiondata.self.com/facts/finfish-and-shellfish-products/4102/2.

Foran, Jeffery A. et al. "Risk-Based Consumption Advice for Farmed Atlantic and Wild Pacific Salmon Contaminated with Dioxins and Dioxin-like Compounds." *Environmental Health Perspectives* 113.5 (2005): 552–556. *PMC*. Web. 4 Apr. 2018.

"Herring Migratory Behaviour." *Fisheries and Oceans Canada*, www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/herring-hareng/hertags/pages/default4-eng.htm.

"King Salmon Forecast In SE Lowest Since 1970s." *Daily Sitka Sentinel*, 17 Jan. 2018, p. 1.

Kwong, Emily, and Jacob Resneck. "Over 200 to Testify on Herring, Salmon Proposals at Board of Fish." *KCAW*, www.kcaw.org/2018/01/17/200-testify-herring-salmon-proposals-board-fish/.

Kwong, Emily, et al. "Alaska Board of Fisheries Gets Earful on Herring, Salmon Proposals." *KTOO*, 17 Jan. 2018, www.ktoo.org/2018/01/16/alaska-board-of-fish-gets-earful-on-herring-salmon-proposals/.

Leffler, June. "Staggeringly Low Forecasts for King Salmon in the Stikine." *Alaska Public Media*, 11 Dec. 2017, www.alaskapublic.org/2017/12/11/staggeringly-low-forecasts-for-king-salmon-in-the-stikine/.

Lewis, Bert et al. "Changes in Size and Age of Chinook Salmon *Oncorhynchus Tshawytscha* Returning to Alaska." *PLoS ONE* 10.6 (2015): e0130184. *PMC*. Web. 13 Mar. 2018.

"Power For The People." *King of Fish The Thousand-Year Run Of Salmon*, by David R Montgomery, Westview, 2003, pp. 181–182.

"Marine Services." *Sitka.net*. N.p., n.d. Web. 01 Feb. 2018. <https://www.sitka.net/marine-services>.

Pollack, Andrew. "Genetically Engineered Salmon Approved for Consumption." *The New York Times*, The New York Times, 19 Nov. 2015, www.nytimes.com/2015/11/20/business/genetically-engineered-salmon-approved-for-consumption.html.

"Seafood." *SEDA*, www.sitka.net/new-page-1/.

United States, Washington Department of Fish and Wildlife, "Dungeness Chinook." *Dungeness Chinook*. *Fortress*, fortress.wa.gov/dfw/score/score/species/population_details.jsp?stockId=1240.

Welch, Laine. "Alaska Salmon Catch Tops Forecast; Cod Kicks Off." *National Fisherman*, Nov. 2017, pp. 16–17.

Washington Department of Fsih and Game. Dungeness Management Unit Plan. WDFW, 2018.https://wdfw.wa.gov/conservation/fisheries/chinook/noaa_comments_2017_plan/01-09-18%20%20Dungeness%20Management%20Unit%20Profile%20NOAA%20comments.pdf. Date accessed: April 6, 2018.

Yoshiyama, R. M., Fisher, F. W. and Moyle, P. B. (1998), Historical Abundance and Decline of Chinook Salmon in the Central Valley Region of California. North American Journal of Fisheries Management, 18: 487-521.