Sustainable Management of Alaska's Kenai River Chinook Salmon in its Economic, Cultural, and Scientific Contexts

A REPORT SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI'I AT HILO IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

TROPICAL CONSERVATION BIOLOGY AND ENVIRONMENTAL SCIENCE PROFESSIONAL INTERNSHIP TRACK

By

Wilson L. Malone

Internship Committee:

Robert Begich, Fishery Biologist III[1]

Lisa K. Canale, TCBES Professional Internship Coordinator[2]

[1] Division of Sport Fish, Alaska Department of Fish and Game, Soldotna, Alaska 99669, USA

[2] Tropical Conservation Biology and Environmental Science, University of Hawai'i at Hilo, Hilo, Hawai'i 96720, USA

Abstract

This internship focuses on Alaska's Kenai River salmon populations. The role consists of working as a Fish and Wildlife Technician II for the Alaska Department of Fish and Game. Responsibilities included operating a research boat on the river as part of the in-river test netting project, working on a creel survey crew, and other research projects as needed. This project provides data on the adult returns of Chinook salmon *(Oncorhynchus tshawytscha),* such as catch rates, age, and genetic composition used to manage the fishery. Age-structured data is used in models to predict future returns of Chinook salmon, which provides valuable insight into the population's health and long-term trends. Genetic comparison enables sub-population management of the Chinook salmon. Creel surveys are designed to monitor sport fishing harvest rates and connect the fishery's social and scientific aspects. The Chinook salmon population is maintained under the principle of sustained yield. Recent declines in this population's numbers and size have caused problems for the management of the population. Political strife caused by allocation decisions complicates management decisions. The salmon populations in this region are significant economically and socially and form a large portion of local culture and identity. Efforts to maintain economically important salmon species are essential for the region's economy and social fabric. This position contributes directly to that goal. Through this position, partial requirements of the Master's of Science in Tropical Conservation Biology and Environmental Science internship track have been fulfilled.

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List of Abbreviations and Symbols

ARIS	Adaptive Resolution Imaging Sonar
α	Recruits Per Spawner
β	Density Dependent Effect on Growth Rate
CPUE	Catch Per Unit Effort
HPUE	Harvest Per Unit Effort
METF	Mid Eye to Tail Fork
RM	River Mile

Introduction

Background

I have had a long-running relationship with salmon. As a teenager, I would go on fishing trips for sockeye salmon (*Oncorhynchus nerka)* with my parents in the protected ocean waters of Southeast Alaska. Far from a weekend of fun with fishing poles, we deployed drift nets from our boat to catch the elusive sockeye salmon. The salmon were in their migration along Lynn Canal toward their spawning grounds in the Chilkat and Chilkoot rivers. I fondly remember racing against opportunistic seals as they plucked trapped fish from the net, a strategy they learn well for a quick meal. What I have described is a common shared experience among people who grew up in that part of Alaska, and it is a part of what formed the foundation of my journey into conservation.

From Hawai'i

The Tropical Conservation Biology Environmental Science (TCBES) program at the University of Hawai'i at Hilo (UH Hilo) gave me a breadth of ecological training that I do not believe I could have achieved elsewhere. The island archipelago of Hawai'i is a natural laboratory that elucidates the foundational principles of adaptive radiation and speciation. My time in Hawai'i and at UH Hilo expanded my mind to new ways of thinking and seeing the natural world. Simultaneously, the experience amplified my pre-existing interest in how living things interact with the world. Efforts in conservation and research in Hawai'i inspired me to apply scientific and ecological thinking to my interests. The challenges of conservation in an isolated island environment made me appreciate how crucial careful management is to sustaining living systems under threat or heavy use. Ecological thinking is one of the most important things that I have gained from the program that I will carry with me.

To the Kenai

I eventually moved away from Southeast Alaska and to the river town of Soldotna, located on the Kenai River. The Kenai River is on the Kenai Peninsula's Western side. The peninsula is an outcropping of Southcentral Alaska that separates Cook Inlet from the Gulf of Alaska. The river empties several tributaries into Cook Inlet, and runs from East to West.

The Kenai River supports four species of anadromous salmon (Figure 1). Anadromous means they migrate from salt to fresh water as a part of their spawning cycle. Salmon are also semelparous, meaning that they die after reproducing once.

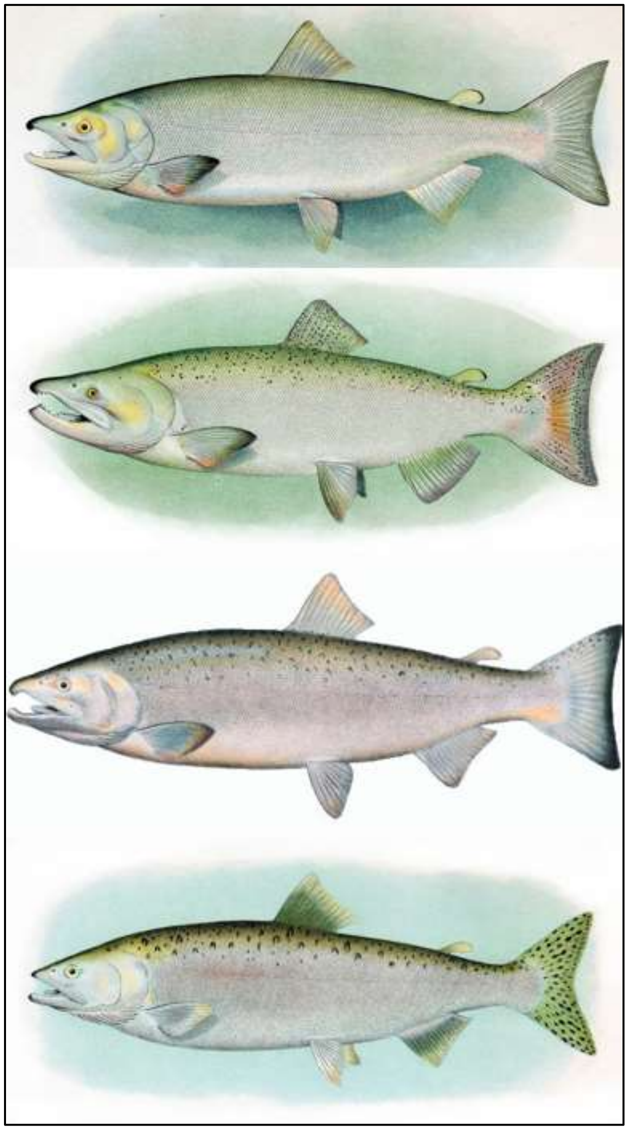

Figure 1: Pacific salmon identification focusing on Kenai River species. From the top, sockeye (Oncorhynchus nerka), Chinook (Oncorhynchus tshawytscha), coho (Oncorhynchus kisutch), and pink (Oncorhynchus gorbuscha). Images in Public Domain.

Sockeye salmon form the majority of the salmon run in the Kenai River and provide the most significant commercial benefit to fisheries in the area (Loring 2016). These commercial fishers can deploy drift nets that drift freely out in Cook Inlet or set nets tethered to shore. For sport fishers who spend their days up-river, both sockeye salmon and Chinook salmon are the commonly fished salmon species. Chinook salmon, also known as king salmon, run in much lower numbers but are sought after by sport anglers for their legendary status as the largest salmon in North America. The Chinook salmon are silvery in their ocean state with small golden-yellow eyes and a black colored mouth. Unlike the more plentiful sockeye, Chinook will bite fishing lures and will fight more vigorously when caught due to their large size. When they enter freshwater to spawn, they quickly begin turning a pinkish red. The thrill of angling and their pleasing coloration make these fish highly sought after by sportsmen. The females deposit eggs in a gravel nest site called a redd, and the males fertilize the nest. Once they are finished spawning, the salmon's bodies quickly deteriorate and die. This influx of biological nutrients from the ocean becomes important for riparian ecosystems.

History of Salmon Fishing in Cook Inlet

Salmon fishing has been conducted in Cook Inlet from pre-recorded history, starting with the Dena'ina people, who are a cultural-linguistic group of native Alaskans. Around the year 1000 AD, this cultural group transitioned from a nomadic hunting and fishing society to a sedentary one focused on the harvest of anadromous salmon. The Dena'ina innovated the use of fish weirs, a type of dam constructed of poles and wicker, which allows water to pass through, but not salmon. The weirs were used in slower-moving tributaries instead of the river's main stem. The other main innovation of the Dena'ina cultural group was the use of underground cold storage, which allowed fish to be cleaned, dried, and stored for the long term. The cold storage pits would be lined with birch bark, moss, and dried fish and grass. These innovations enabled the sedentary nature of settlements and caused changes in their overall social structure. Today, several tribes descending from this cultural group still rely heavily on the fishery to meet physical and cultural needs (Boraas 2004).

Because Alaska had status as a U.S. owned territory between 1912 and 1959, fisheries were managed at the level of the Federal government, and had little control from the local level. Federal management allowed the excessive use of fish traps, which were the source of many problems. Fish traps would be placed in shallow water in the bays and inlets, and sometimes directly in rivers. They consisted of a maze of wire and wood that funneled salmon into a holding pen, allowing for easy harvest and transport to canneries. This fishing method was popularized by the canning industry, which held a virtual monopoly on Alaska's fish resources at the time. The heart of the problem was that salmon populations were rendered less available for other fishing groups. The federal government managed the fisheries through the U.S. Fish and Wildlife Service, which failed to conduct the necessary research on salmon populations. This lack of basic research led to a catastrophic decline in salmon populations across Alaska, so much so that the declining fisheries received a federal disaster designation (King 2009).

The influence that canneries had on Alaska was enormous, and fish traps remained in use well into the 1950s even though there was broad public opposition. The fish traps, weak government regulations, and the canning industry that benefited from them were, in large part, responsible for the collapse of the state's fisheries. Alaskans saw the industry was under outside control, benefiting people who did not live within the state. The pressure to ban fish traps was included in Alaska's constitutional convention when the territory was on its way to statehood (King 2009).

Formation of the Alaska Department of Fish and Game

The basis for the Alaska Department of Fish and Game (ADF&G) comes directly from the state of Alaska's constitution. The constitutional convention sought to remedy the effect of fish traps on salmon populations by introducing a set of founding principles that would guide the state's conservation efforts. The first principle is that the state's resources must be set aside for common use without any special privileges regarding who can use fish or wildlife resources. The second important law was that any utilized population should be managed under the principle of sustained yield, a mathematical concept in population biology. To that end, ADF&G deals with scientific aspects of sustainable management and conducting research. They set escapement goals for salmon populations using collected data and mathematical models to determine the available harvest. The fisheries expect ADF&G to act quickly based on continuing seasonal research to restrict or liberalize the fishing in the middle of a season if there is an under-escapement or an over-escapement. Escapement refers to the number of salmon that successfully reach their spawning grounds. (King 2009).

Board of Fisheries

The state legislature designed the Board of Fisheries to represent the people and fishing groups subject to resource allocation. Based on fisheries research conducted by ADF&G, the Alaska Board of Fisheries manages the political aspects of harvest allocation among user groups. The Board of Fisheries consists of seven members appointed by the Governor. Each of the board members has an extensive background in the area and resources under their management. ADF&G then implements regulations adopted by the Board of Fisheries. The separate missions of ADF&G and the Board of Fisheries are intended to produce good compromises for the resources and people in question (Loring 2016).

Fishing User Groups

There are four major fishing groups within the Cook Inlet area, each with their unique gear and primary location of operations. There are commercial set-net groups, which operate on the East and West sides of Cook Inlet. Set-netters tether their nets close to shore and target salmon following the coastline. The commercial drift-net group operates from the middle of the inlet and uses large drifting nets to target salmon migrating through the middle of the inlet. The sportfishing group consists of anglers, who primarily operate in the river and target salmon, trout *(Oncorhynchus mykiss),* and dolly varden *(Salvelinus malma)*. Another group is the dip-net group. Dip-netting is a method where fishers hold nets up to 5ft in diameter in the water along a defined region near the river mouth. This type of fishery is conducted from either shore or boat using long poles. Dip-netting is only allowed for residents of the State of Alaska to give them a chance to harvest salmon for their personal use. Each user group competes for a portion of the same population of fish. Regulations adopted by the Board of Fish manage these fisheries by location or temporally to allow for the greatest harvest possible while achieving escapement goals. Even with carefully designed regulations, conflict still exists, and local politics can become contentious over the allocation of fish resources (Loring 2016).

Purpose of the Professional Internship Project

The Kenai River in-river driftnet test fishery provides in-season data on returning sockeye, coho, pink, and Chinook salmon runs. This data is collected in conjunction with sonar counts to provide a highly accurate picture of the Chinook salmon’s in-season status. The in-river netting project focuses on Chinook salmon stock assessment and fills in the gaps that a sonar cannot provide, such as male/female ratios, age compositions, and the proportion of Chinook salmon under 75 cm that sonar cannot differentiate from other salmon species. For management purposes, all fish measuring 75 cm or longer appearing in sonar images are presumed to be Chinook salmon. Other species are less likely to be larger than that (Fleischman & Reimer 2017). The Adaptive Resolution Imaging Sonars (ARIS) are accurate for counting fish and taking measurements of fish length, but they cannot differentiate between smaller salmon species like the in-river driftnet project can.

This intensive research is one defining feature of the ADF&G that contrasts it from the historical federal management system; data is collected, and decisions are rendered in-season. Another research study is the creel survey that interviews Kenai River Chinook salmon anglers. The purpose of this is to measure sport harvest, in-season angler effort, catch and harvest rates, and to collect age, sex, length, and genetic samples from harvested Chinook salmon. Programs to measure the number of incoming salmon, as well as harvest by sport fishing have been in operation in the area since the mid-1980s (Perschbacher 2018).

Learning Objectives

Professional Development Objectives

Individuals who are a part of the Kenai River driftnet test fishery and creel survey provide vital data. They must learn the principles of accurate data entry, species identification, and handling of biological samples. They learn the basics of river-boat operations, first aid, and net repair while in this position. This position is an introductory level position within the agency and gives technicians a view into the structure and operations of ADF&G. The foundational skills gained give technicians an advantage in fisheries conservation. Additionally, ADF&G expects technicians to be friendly and knowledgeable about the fishery and reflect well on the agency.

Graduate Student Learning Objectives

This position fulfills the 600-hour requirement for a professional internship. The work is ideal for career-focused graduate studies which leads to meaningful connections with the mentoring agency. I used data collected by this project and other projects such as the East Side Setnet Fishery crew (ESSN) to show how Chinook salmon populations within the river are structured by age and size. Additionally, I used historical data collected from the fishery for population models that project the fishery's future total-run and age structure. This position fosters increased skills in boat handling, live fish handling, scientific data collection, biological sample collection, and public interviews.

Professional Internship

Role and Responsibilities

My role within the ADF&G was as a Fish and Wildlife Technician II. ADF&G tasks technicians in the Kenai River test net fishery with operating a state-owned river-boat in the lower Kenai River (Figure 2: The geographic region and important landmarks of the Lower Kenai River creel survey and the in-river netting project.).

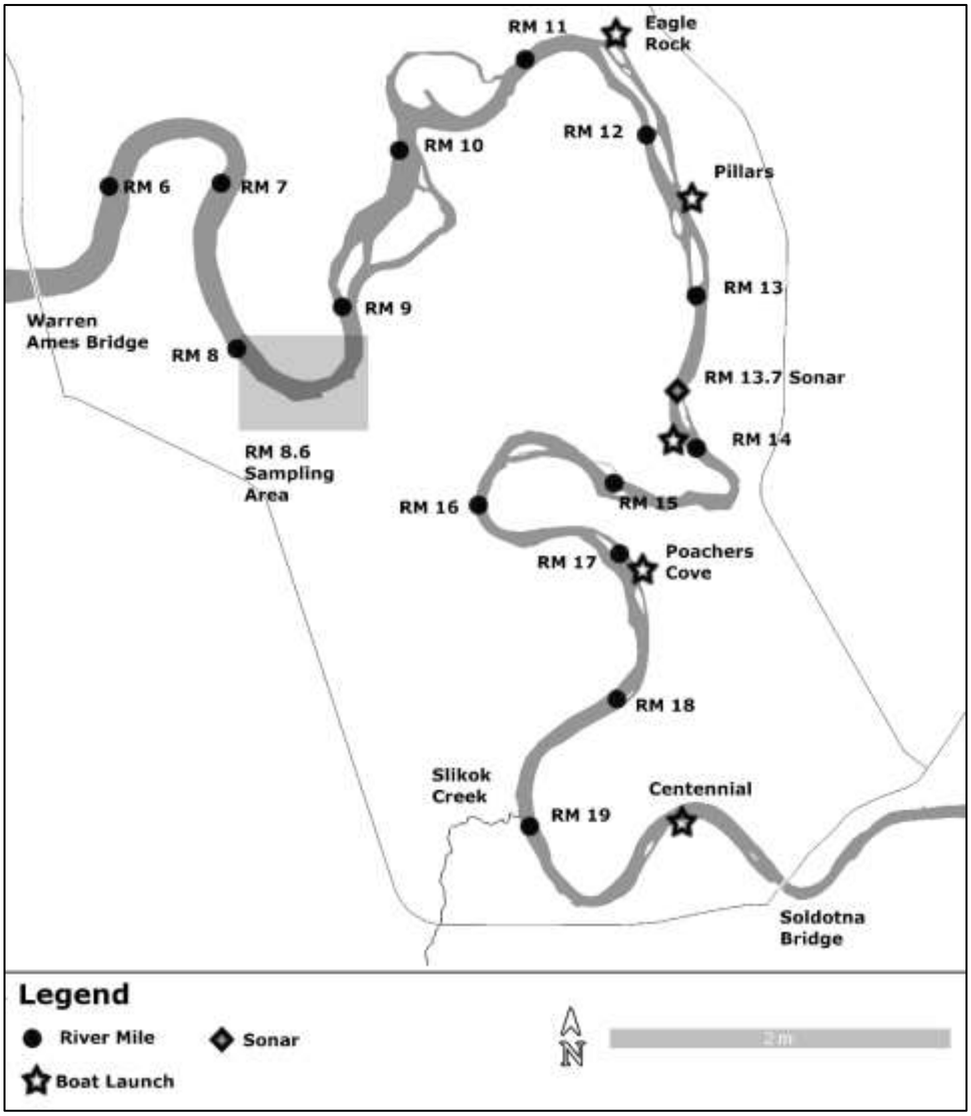

Figure 2: The geographic region and important landmarks of the Lower Kenai River creel survey and the in-river netting project.

The drift-net crew is responsible for deploying nets from the boat at specific shore locations and collecting data on four salmon species depending on the run and the season. Data collected are the number of fish species captured, sex, length, and age through scale samples. We collect Chinook salmon genetic samples for comparison of genetic loci and population-level management. Other data points we measure are the distance from the shore where the fish was caught, the time of day caught, and the river water's visibility. When working on the creel project, technicians interview anglers and take samples of Chinook salmon to measure angler harvest and effort.

Meaningful and Challenging Work

ADF&G technicians who collect the Kenai River Chinook salmon data enable the decision-making process about their management. The work requires diligence in safety when operating on the river and attention to detail when collecting samples. Data must be collected every day that the salmon are running in strength from May until August, making for a demanding schedule and a significant responsibility for the technicians

Outreach

Creel technicians and in-river test net technicians are the most frequently seen ADF&G employees on the Kenai River; therefore, our job and how we represent ourselves is critical for how the agency is perceived. Creel technicians have the added responsibility to conduct angler interviews through a data collection program that seeks to document harvest. They discuss the location an angler has been fishing, how long they were there, the number of species they caught, and the length of their fish. If the fish are still present with them, technicians ask for a scale sample, measure the length, and collect a genetic sample. Anglers sometimes reject sample-taking since Chinook salmon are prized fish for display, and the person may simply not want the fish's appearance altered.

Agency Jurisdiction

The ADF&G is tasked with managing all of Alaska's utilized fish and wildlife under the principle of sustained yield by the state's constitution. The constitutional mandate makes ADF&G unique among state agencies in that it, legally speaking, must sustainably manage fished and hunted populations. ADF&G acts as a technical advisor to the Board of Fisheries. They take part in the process of adopting and changing regulations that is open to public comment. ADF&G carries out the regulations that are adopted. ADF&G's primary purview is on the scientific aspects of fish and wildlife population assessment and management.

Gaining Knowledge of the Agency Ecosystem

Entry-level positions with the ADF&G are typically seasonal technician positions. These build foundational skills and experience with the mission of ADF&G and with the scientific methods used for conservation. The technicians report to project biologists, who manage the broader-picture elements of how a project fits into the agency conservation plans. The biologists set the sampling protocols, gear requirements and analyze the data. From there, higher-level biologists set the broader goals for management within a given region or fishery. They handle such things as setting escapement goals, setting season openings, and recommending emergency orders to respond to in-season changes in the fishery

Timeline

Table 1: Timeline of dates, events, and hours of the internship.

Event	Date	Hours
Start of Netting	May 16	7.5 hr/day, 5 day/wk
Temporary transfer to Creel	June 28-29	10 hr/day
Resuming Netting	June 30	7.5 hr/day, 6 day/wk
End of Season	August 20	

Approach

In-river Netting

The in-river netting program provides essential data for responsible fisheries management; first among them is the age and size composition of the incoming early run and late-run Chinook salmon. Managers use this data to estimate the total return by brood year for each run. Another data point is catch per unit effort (CPUE), which gives a metric of the number of fish caught per time spent netting. Genetic samples are collected for both sockeye salmon and Chinook salmon to conduct mixed stock analysis (MSA).

The netting project operates seven days per week, with two technicians at RM (River Mile) 8.6 in a defined netting area. There are three technicians in the netting project; however, we rotate our schedule to ensure everyone gets some time off. We use a flat hull river boat with a jet unit to enable netting near shore in shallow water. The nets we use are 60 ft long and are split in half between two panels of different size meshes to prevent capturing a sample of fish that is biased by length. One panel has a mesh of 4 in length, and the other panel has a mesh of 7.5 in lengthwise. The small mesh size is intended to catch smaller sockeye salmon, and the larger mesh is used to catch the largest Chinook salmon. We deploy nets from the boat in two locations within the river channel, either near-shore or mid-river. The two locations enable the entire river width to be sampled. The mid-river net is 30 ft deep, and the near-shore net is 15 ft deep to account for the difference in depth between the locations. The tide and the river flow rate influence the speed and direction of the river flow and the water level. Our sampling area is within the river's tidal zone, meaning that the ocean tides cause the water level to rise and fall. With that, the flow rate of the river can change from moving slowly to very quickly. During the flood stage of a large tide, the river can even flow upstream for a few hours. Quick moving water is dangerous, representing a particular challenge when dealing with a net that tends to snag on tree stumps, rocks, and logs on the river bottom. We have been met with occasions where the current combined with a stuck net threatened to swamp our small boat. Great care and skill are required to deal with these situations.

Sampling starts at 7:00 AM and ends at 1:00 PM. When we cast the net out of the boat, it is called a set. Each set lasts ten minutes, or until the end of the sampling area is reached. As a net is pulled in, we remove fish from the net, count them by species, and take biological samples. If we catch a Chinook salmon, its tail is tied with a tether and brought to a sampling cradle. We suspend the cradle over the boat's side so the fish can remain in the water. There, we measure its length and remove three scales. We take the genetic sample as a clipping of its dorsal fin. We remove the scales from the left side along a line posterior of the fish's dorsal fin connecting to the anal fin's anterior, three scale-rows up from the lateral line. We then place the scales on a card labeled with the fish's length and sex.

Determining the sex of a Chinook is a skill that is vital to the accuracy of the collected data. The most reliable method is to use the proportion of head length to width. The males tend to have a longer distance between their snout and eyes in proportion to the rest of their body, and the females have a shorter distance between snout and eyes (Merz & Merz 2004). We also look for the presence or absence of an ovipositor for additional characteristics.

The genetic sample taken from Chinook is from a clipping of the dorsal fin, whereas the samples taken from sockeye are a clipping of the axillary process taken from under the fish's pelvic fin. Typically, all Chinook genetic samples would be from the axillary process instead of the dorsal fin; however, the sampling cradle makes that too difficult to be practical. The genetic samples are placed on Whatman cards and preserved with salt and a dehydrator for analysis later.

Once we sample the fish, we mark the Chinook's caudal fin with a hole punch to identify it if we catch it again. All fish are released, except for hatchery fish, an incidental variety of Chinook not expected in the Kenai. Hatchery fish are indicated with the absence of an adipose fin, which is clipped while they are young. Some populations of Alaska's Chinook salmon are supplemented with hatchery fish; however, the Kenai River population is not one of them, and hatchery fish are not released if caught. The removal of hatchery fish is due to concerns about introducing genetic traits from hatchery fish into the Kenai River population.

While there are four species of anadromous salmon in the Kenai River, ADF&G only intensively manages sockeye and Chinook in-season. The preferential management is because sockeye and Chinook are the most consistently targeted species by anglers, and because of budget constraints.

Chinook enter the river in two distinct runs, an early run and a late run, which, when graphed as the number of fish over time, appear as two distinct bumps with the separation around July 1 (Perschbacher 2018). The early run spawns in the tributaries to the Kenai, while the late run spawns in the river's mainstem. When the netting project starts up in the middle of May, the early run is only getting started. It is quite common for us not to catch any fish at all the first few days.

Location and Sense of Place

The in-river netting sampling area is within an area of low laying grassland and mud flats. The foliage consists of tall grass, scrubby spruce, and willow trees. The area supports a small population of caribou, some of which we see from the river banks during the work-day. We often see bear tracks on the muddy shoreline, confirming the presence of the secretive bruin scavengers. Eagles are ever-present in the trees surrounding the river. They catch dying salmon from the surface of the water. The salmon are usually too heavy to fly away with, so they swim with their wings to shore to enjoy their catch. I would always watch with admiration the display of dedication an eagle shows as it nearly drowns fighting a salmon out of the water. Upriver from there is the town of Soldotna, where the river banks are lined with homes and property. On any given day, we see a mixture of people fishing from small boats, sometimes private boats, other times guide boats with bright logos painted on them. We sometimes see anglers on the shore with rod and reel, ‘flicking’ for sockeye. Flicking is a fishing method where the angler attempts to guide the line across the mouth of passing sockeye. Sockeye will not try to bite a lure due to their suppressed appetite during spawning. This method involves almost accidentally hooking a fish in the mouth as it passes by. On Mondays, the only type of boat fishing allowed is from a non-motorized boat, typically a drift boat. Drift boats are operated by paddle and have a heavily curved flat hull to aid in directional control in the river’s current. Drift boaters put in at some upriver boat launch and fish while drifting downstream to a lower launch to take out.

Mornings on the river are spectacularly cold at the beginning of the project. When we start, there are often several areas of ground that still have snow cover. Mornings that start at 39°F are not uncommon at this time and require bundling up in layers of fleece and wool topped with rubber overalls and a raincoat. None of our boats have cabins, so there is often a 20 mile per hour wind on top of all of that. The water of the Kenai is frigid at this time, barely above freezing. This frigid water and air provide a challenge to working with salmon and nets because my hands would stop working as well in the cold. Trying to grip a thrashing salmon that splashes frigid water in your face, all while trying not to lose the net, and dealing with reduced grip strength is an everyday challenge in this role. Much of the water from the Kenai is of glacial origin, which gives it a light blue tint in the upper reaches. By the time the water reaches the tidal area where we work, the water is mostly light greenish-brown.

Seals are a perpetual nuisance for our project. They patrol our nets, waiting for unsuspecting fish to get tangled, and then eat them, leaving only their heads as if to taunt us. Seals come into the mouth of the river and spend time in the tidal zone hunting for salmon. As much of an inconvenience as they were for the project, they were interesting to see, and I always appreciated that I could see such wildlife as a regular part of my daily routine.

Incidental Species and Side Projects

Not every species of salmon migrates every year in the Kenai. Waves of pink salmon (*Oncorhynchus gorbuscha*) migrate every even-numbered year upriver. Recently biologists, and anglers have seen pink salmon migrating in larger numbers in odd-numbered years. 2019 was one such strange event for pink salmon. Department biologists initiated a project to collect otoliths (ear bones) from these mysterious pink salmon, and they tasked us with collecting the required number of fish for them. The otoliths help determine the fish's origin because unique bands of light and dark rings are imprinted on the otoliths when the salmon are still eggs. The banding is accomplished by thermal cycling in the hatchery, which imprints a pattern that corresponds to the hatchery of origin and the release group. When the fish return to the river to spawn, they can be collected, and the otoliths extracted to examine them (Peninsula Clarion 2018). There is still some question of whether they are hatchery fish or of natural origin, and the study is still being worked on (Medred 2019). It is a common request that projects beyond the Chinook salmon sampling be undertaken by in-river netting.

In 2017, technicians were tasked with deploying radio trackers and tags on sockeye to determine their transit time through the river system. The trackers and fish were located upstream with a combination of boat and aerial surveys. Knowing sockeye's time in transit enabled biologists to predict when a pulse of sockeye detected passing the sonar is likely to appear entering the Russian River, a tributary of the Kenai. The research that we contributed to will enable more precise timing of emergency orders and in-season changes to the management approach. (Eskelin & Barclay 2018).

Creel survey

The word 'creel' refers to a woven basket used by anglers to carry fish. This means a creel survey refers to taking count of the fish caught by anglers. There is an added component of public outreach where creel technicians must act as a friendly, knowledgeable representative of the department. The creel survey starts with an angler count by driving the boat along the complete survey area from the Warren Ames bridge to Slikok creek (Fig 2). We must keep track of the number of boats, the type of boat (whether guided or not), and the number of lines in the water for each one. Information about boats and anglers feeds into harvest per unit effort (HPUE) and catch per unit effort (CPUE). Technicians conduct angler interviews at a given boat launch to people coming in from the water. They are asked where they were fishing, for how long, and what they caught.

Angler interviews are usually cordial. ADF&G has taken the approach of leaving enforcement of fish and game regulations up to the Alaska Wildlife Troopers, which keeps the mission science-focused and alleviates the animosity that enforcement would create. Despite this, there is still some tension.

Mixed Stock Analysis

The ADF&G Gene Conservation Laboratory provides a higher degree of knowledge about sub-populations within a species than would be possible otherwise. Each species of salmon has several sub-populations that are genetically distinct from each other, and they have low enough gene flow to render them unique. These populations are separated either geographically into different tributaries, temporally by spawning time, or a combination thereof. There is strong evidence to suggest that salmon homing behavior is genetically inherited, where salmon return to their exact stream of origin after several years at sea with high reliability (Burger 1985). The department uses the latest in next-gen sequencing techniques to provide swift turnaround times for the samples we collect. The lab may process around 90,000 samples per year from all across the state (H. Hoyt, personal communication).

In the Kenai River, a mixed stock analysis looks at the different sockeye and Chinook salmon populations, and from which tributary each population originates. ADF&G operates an adaptive resolution imaging sonar at RM 13.7, which gives a total count of the fish passing that location, but not the proportion of those fish from each population. Genetic analysis helps estimate the proportion of salmon from each tributary and enables each population to be managed with a degree of independence from each other. Sockeye salmon are compared genetically to 69 upper Cook Inlet sockeye populations, using 96 single nucleotide polymorphism (SNP) loci. A similar analysis of Chinook salmon uses microsatellite markers to find sub-populations within the river system. The ability to track the populations down to the tributary of origin provides the ability to estimate the proportion of sonar counted fish that belong to each stock. Population-level tracking is vital for effectively managing each sub-population (Begich et al. 2010; Eskelin & Barclay 2018).

Age Proportions

Fish are aged using the scale samples collected from the netting and creel projects. The scales have striations that occur in a ring pattern, analogous to tree growth rings. The scales are hydraulically pressed onto acetate cards and then read in a microfiche projector. Interpreting the ring patterns gives the number of years that a fish has spent in freshwater and saltwater. Age is recorded as freshwater age and ocean age. The total age is the read freshwater age, plus the saltwater age, plus 1. Adult Chinook salmon enter the river system to spawn at varying ages. The bulk of the chinook run comprises saltwater ages three through five, or fish that are five to seven years old. The age proportions are used to predict returns by brood year (Begich 2019). The brood year of a fish is simply the year that it hatched. Because the fish return at different ages, each run has a mixture of brood years represented. Because sonar images cannot distinguish fish under 75 cm by species, the in-river netting project, among other collection projects, provides species proportions for those under 75 cm.

Maximum Sustained Yield

Maximum sustained yield (MSY) is an idea developed out of population biology. It is a theoretical point where a population produces the largest difference between the number of spawners and the number of offspring in a given generation. Note that it is not the point where the largest number of offspring are produced in a generation. Instead, it is the largest difference between offspring and spawners. The Ricker stock-recruit model is usually applied to fisheries biology as a density-dependent model that incorporates intra-species competition (Ricker 1975).

$$R = \alpha S e^{-\beta S}$$

R is the number of recruits, α represents recruits per spawner, S is the number of spawners, and β is a density-dependent term representing the inverse of the number of spawners leading to peak recruitment.

The number of recruits is calculated as a function of the number of spawners using median values derived from historical counts of late-run Chinook salmon in the Kenai River

(Fleischman & Reimer 2017) (Fig. 3). The estimated intra-species competition is shown as a drop in productivity after 33,041 spawners yield 42,498 recruits. The drop is modeling resource competition between salmon of the same population.

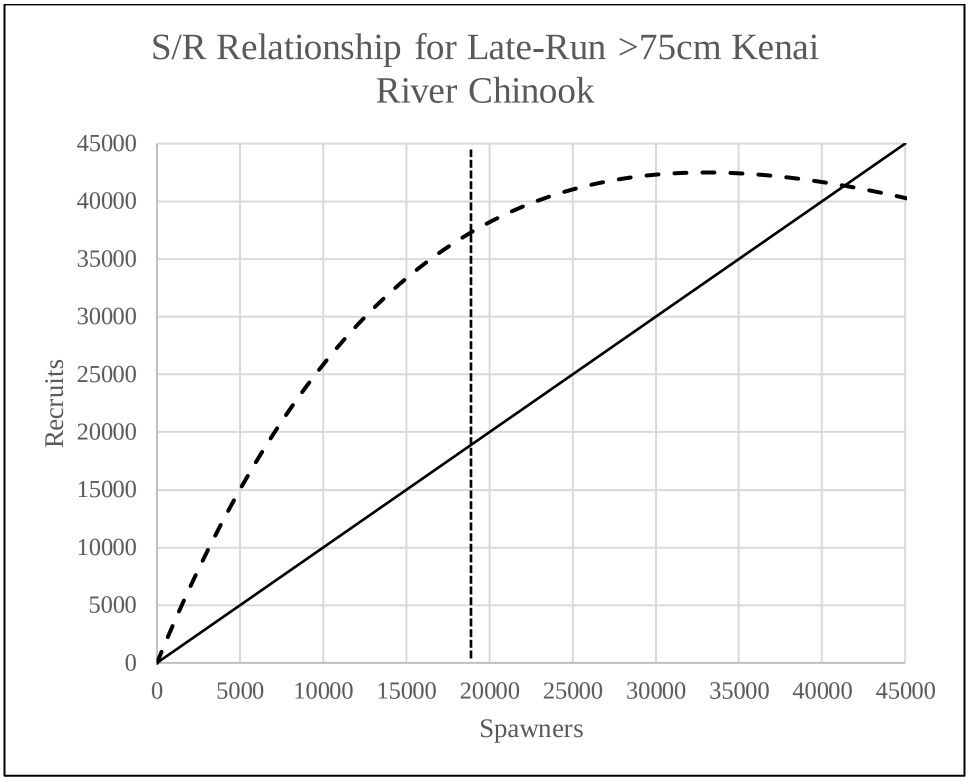

Figure 3: Recruits (R) for Kenai River late-run Chinook over 75 cm METF plotted as a function of the number of spawners (S) using the Ricker stock-recruit model and estimated parameters from the late-run Chinook salmon population. The arched dashed line represents the S/R relationship. The vertical dashed line represents the point of MSY as it intersects the S/R line. The solid line represents the point where S=R.

Maximum sustained yield is the maximum difference between the replacement line (S=R) and the stock-recruit line. In this calculation, the maximum increase of 18,470 salmon occurs at 18,477 spawners (Fleischman & Reimer 2017), which yields 36,947 recruits. There is inherent variability in the models used for these calculations, and the values presented are only one of a range of probable stock-recruit relationships for the late-run Kenai River Chinook. The goal is to keep the escapement as close to the number that yields MSY as possible. Allowing more spawners would have a diminishing return until, eventually, the number of recruits would be less than the number of spawners. Allowing fewer spawners or considerably more spawners would not allow the population to reproduce at its maximum potential.

The actual target escapement values for the late run Chinook starting in 2018 are between 13,500–27,000 fish 75 cm and longer. The range reflects variability in the spawning environment's effective carrying capacity, each spawner's fecundity, and ocean-stage survival (Fleischman & Reimer 2017).

Outcomes

Deliverables

In the 2019 Kenai River netting project and creel project, we succeeded in collecting CPUE and HPUE data necessary for proper in-season management of Chinook salmon. The scale samples gathered were added to archived data to inform about long-term trends in Chinook, construction of brood tables, population age, and size composition. Genetic samples were analyzed both in season and after for mixed stock management and analysis. We contributed to other valuable fisheries research through participation in projects aside from the in-river netting project. Analyzing historical data, trends, and population models can help make predictions about the salmon population into the future and can inform the needed direction of future research.

Skills Gained

Through the course of the internship, I learned skills in safe river operation and net deployment. I went from being unsure and unsteady in operating in the river environment to being the one asked to help new technicians learn boat operations. Working with large live fish posed unique challenges in data collection. Eventually, I gained the hands-on technical skills necessary for it. At the beginning of the project, I could only guess what species a salmon was. At the end, I had memorized the diagnostic characters of salmon identification in both their marine and spawning colors.

Contributing to Research

Aside from the main project of Chinook salmon sampling, my contributions helped several different projects, including one that tracked the transit time of sockeye salmon from the RM 13.7 sonar site to the Russian River (a tributary of the Kenai). at RM 74. The radio transmitters we deployed on live fish provided a way to locate them using receiving equipment. The genetic samples we provided from fin clippings will eventually be used to estimate the proportion of fish that come from each sub-population that migrates along the Kenai River several days before they can be counted at the up-river weir. This can jump-start management actions and allow managers to get ahead of changing conditions (Eskelin & Barclay 2018).

Through the creel project, we collected data about the intensity of fisheries resource usage by anglers. These interviews also provided an important aspect of outreach between the public and ADF&G. This position enabled me to practice the social aspects of scientific data collection by involving members of the general public for interviews. Both the creel project and netting project provided complementary data regarding the Kenai River sport fishery's management.

Analysis of Chinook Salmon Historical Age and Population Data

Through analyzing historical age proportion data for the late-run Chinook, I determined that the proportion of 5-year Chinook was increasing year over year, while the proportion of 6-year fish was decreasing over the 1986 through 2019 time period (Figure 4) (W.M., unpublished data). These results also reflect the findings of Lewis et al. 2015, who found similar trends for Chinook populations across rivers in Alaska. Reasons for this change are unknown, but some researchers have proposed climate change, predation, and fishing-induced pressure on the population as possible explanations to explore (Enberg et al. 2011: Ohlberger et al. 2018).

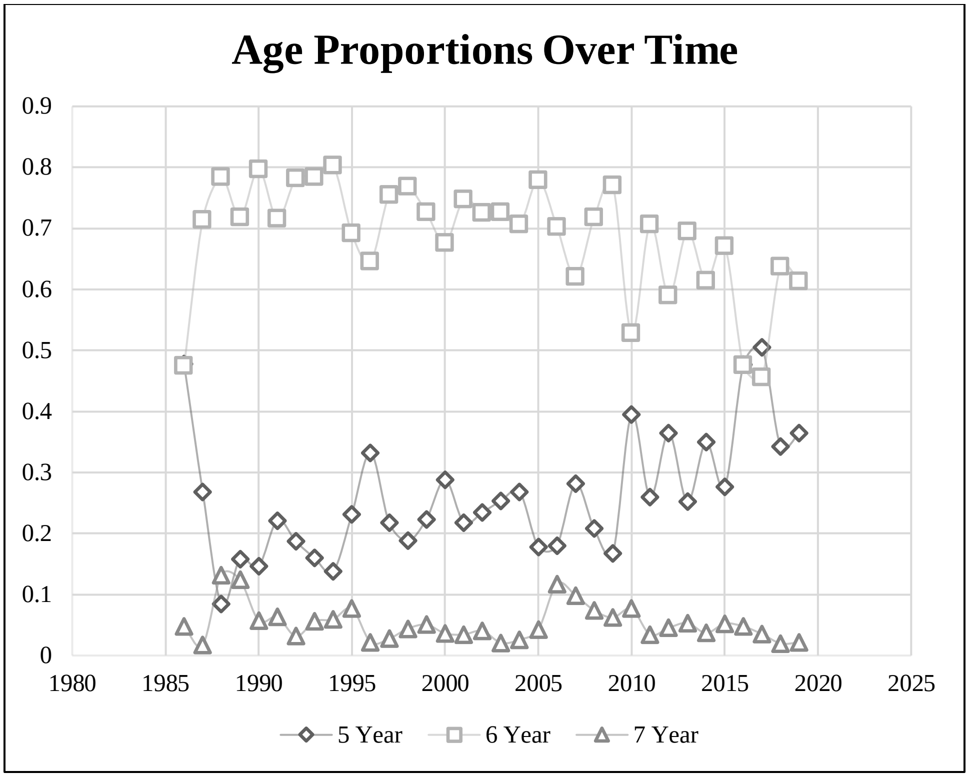

Figure 4: Age proportions over time for Kenai River late-run Chinook salmon over 75 cm METF between 5 and 7 years old.

Another analysis of this same data incorporated a stock-recruit simulation intended to calculate the probability of failures to meet the lower escapement goal given the latest trend in fecundity among late-run Chinook salmon. As a side note, the lower escapement goal for 2019 was not met, with 11,671 fish estimated to reach spawning areas, showing that the salmon are indeed struggling in some way (Brenner et al. 2020). This simulation predicted a mean of 2.7 lower escapement goal failures for 1,000 simulated runs of 20 years beginning in 2020. According to the model, a 30% reduction in harvest across all user groups did not show any significant difference in this failure rate. The lack of population response to harvest rates indicates that there is some factor beyond escapement numbers alone that is adversely affecting salmon numbers (W.M., unpublished data). This change is being felt in the fishery through declining sport fishery business and increased user group conflict, and it will remain a challenge to solve (Mazurek 2020).

Discussion

The methods of management and science-based decision making by ADF&G continues to maintain populations of salmon for harvest under the principle of sustained yield. The fast-response management style has proven to be effective, and keeping allocation decisions separate from the science proved to be an effective means of managing the human and political aspects.

Politics of Fish

Politics always makes its way into salmon in Alaska. That should be no surprise since salmon fisheries were in no small way a driver for statehood in the 1950s. Fisheries of Cook Inlet are represented by non-profit trade organizations that advocate for their respective fisheries' interests. Separate organizations represent the drift net user group, set netters, and sport fishers, and there are intense conflicts between these groups. Each uses different gear types, whether drift nets, set nets, or rod and reel. The problem at hand is that they all compete for the same resource at the same time. Debates run hot about how the limited run of Chinook should be apportioned and which user groups stand to lose the most from management decisions. One method proposed for easing conflict in such situations draws inspiration from ecology and coexistence theory. This theory is a model that explains how communities of species that have similar niches can assemble without driving others out through competitive exclusion. There are stabilizing and equalizing mechanisms at play in coexistence theory. The same theory can be applied to fishing user groups as if they were competing species. Equalizing involves reducing the effectiveness of one fishing method to put it on equal footing with the others. A stabilizing mechanism could involve encouraging one fishing group to target different species at different times of the fishing season, reducing the overlap in their niches (Loring 2016).

The public has, on occasion, heckled my team. On one occasion, a social media post taken by one of my co-workers of them holding a fish was used in a rant against government interference in the fisheries. I was present for one instance of heckling by a passing angler, who insisted that the fishery would be better off without the in-river netting project. I have heard second-hand accounts of tension between other sampling crews and fish processing plants when visiting. These instances show a genuine tension underlying the fisheries, possibly because the stakes are high and may involve people's livelihoods and food sources.

Maintaining a Cultural and Economic Resource

It is not uncommon for commercial fishers in the Cook Inlet area to hold a second job to fill in the gaps during the off-season (Loring 2016). The decision to pursue fishing in Cook Inlet is as much a cultural calling as it is an economic decision (Harrison 2013). Many people derive a sense of meaning and connection from the Cook Inlet and Kenai River fisheries. For commercial fishers, it is a connection to the ocean and a connection to family tradition that drives it. In that sense, fishing becomes an integral part of identity.

Many sport fishers understand that fishing is not always about the fish, but rather about seeking nature. Fishing is a point of pride for the communities of Cook Inlet. It is a way of life and a strong economic sector in the region. Each year, the commercial fisheries provide an economic boost to families in the region and support the export of commercially caught salmon to the world. Sports fishing brings people into the area, which causes downstream economic effects such as supporting the professional guide industry, bait and tackle shops, boat repair stations, grocers, retailers, and many other local businesses. The Kenaitze Indian Tribe operates an educational fishery at the Kenai River's mouth, which helps maintain a connection to traditional ways of life ("Educational Fishery – Kenaitze Indian Tribe," n.d.). Anything that disrupts the salmon has a downstream effect through the entire town, and maintaining the salmon as a resource becomes a matter of preserving tradition, the economy, and a way of life.

I have been fortunate to contribute to the local ecosystems and economy through working with ADF&G. My experiences have increased my appreciation for the hard work and diligence, and scientific skills that conservation requires. It has made me appreciate the intermingled social and political aspects affecting conservation and how that can both help and limit efforts at preserving a species or population.

Salmon Ecosystem Contributions

Salmon gather most of their biomass from feeding in the ocean during the years they live there. When they spawn, their carcasses degrade and release those nutrients into the surrounding systems. The nutrient isotopes that can be pinned down to an oceanic origin are carbon, nitrogen, and sulfur. Phosphorus is also a major input. The input of nutrients stimulates primary productivity in lake ecosystems in the form of phytoplankton. Phytoplankton is predated upon by salmon fry, which forms an advantageous nutrient cycle to salmon. Sediment studies on several river-connected Alaskan lakes have shown a reduction in marine-derived nutrients following the expansion of commercial fishing in the 20th century, which has a chain of effects on the riparian ecosystem. The mode of entry of nutrients into the ecosystem is through scavenging eggs and flesh of spawned-out salmon by invertebrates or other fish. Riparian plant communities benefit from this influx of nutrients, where a large percentage of nitrogen contained in vegetation adjacent to riparian zones has been discovered to be of oceanic origin. Scavengers like bears, eagles, and corvid birds benefit from directly scavenging fish carcasses and increased riparian productivity by eating berries and vegetation (Naiman et al. 2002).

Maintaining healthy populations of salmon has the compounded benefit of increasing nutrient availability and productivity of stream and riparian ecosystems. Salmon fry directly benefit from this increased productivity through predation of eggs, salmon carcasses, invertebrates, and phytoplankton. Nutrient input creates a feedback loop of productivity for the river environment that benefits many species.

Declining Numbers

The late run Chinook population has seen declines in recent years, and the reasons for that have not been determined with certainty (Figure 5). Reasons such as climate change, predation from marine mammals, and food scarcity have been proposed (Mazurek 2020). One study sought to correlate rainfall, stream temperatures, and ocean temperatures with Chinook salmon productivity. They found that higher rainfall during spawning, higher temperatures (in already-warm streams) during spawning and rearing, and higher ocean temperatures all cause decreased productivity (Jones et al. 2020).

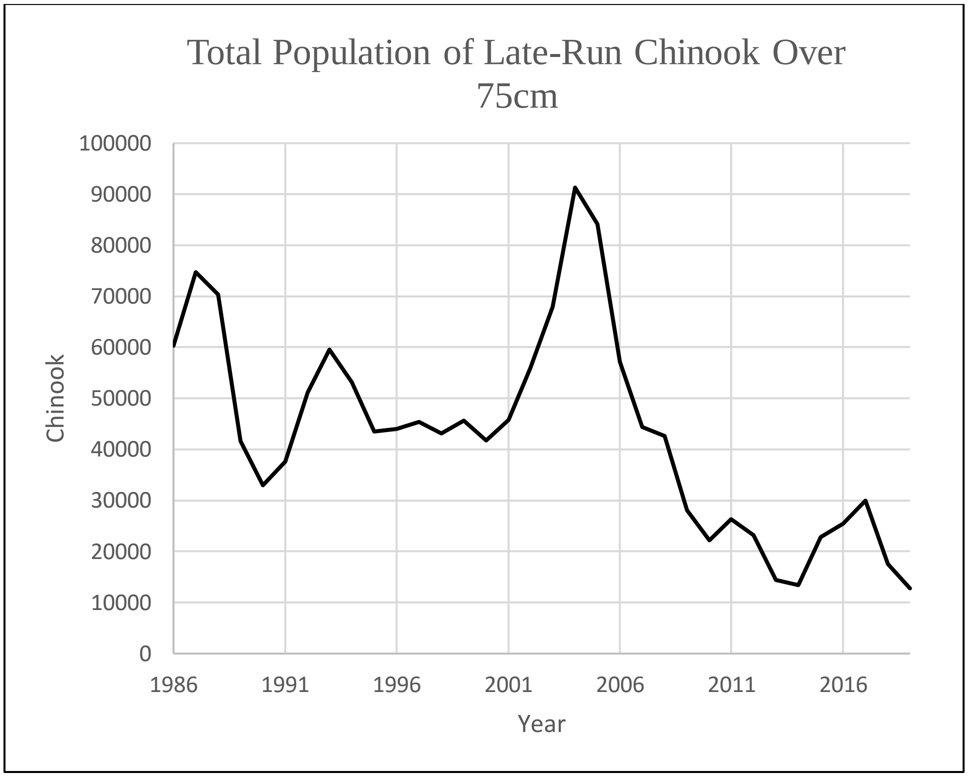

Figure 5: Total run numbers for Kenai River late-run Chinook salmon over 75 cm METF between 1986 and 2019.

From a model standpoint, this is analogous to reducing the effective fecundity. The ratio of recruits to spawners is graphed in (Figure 6), which shows that the ratio trended negative from 2003 through 2008, indicating a shrinking population during these years. (W.M., unpublished data).

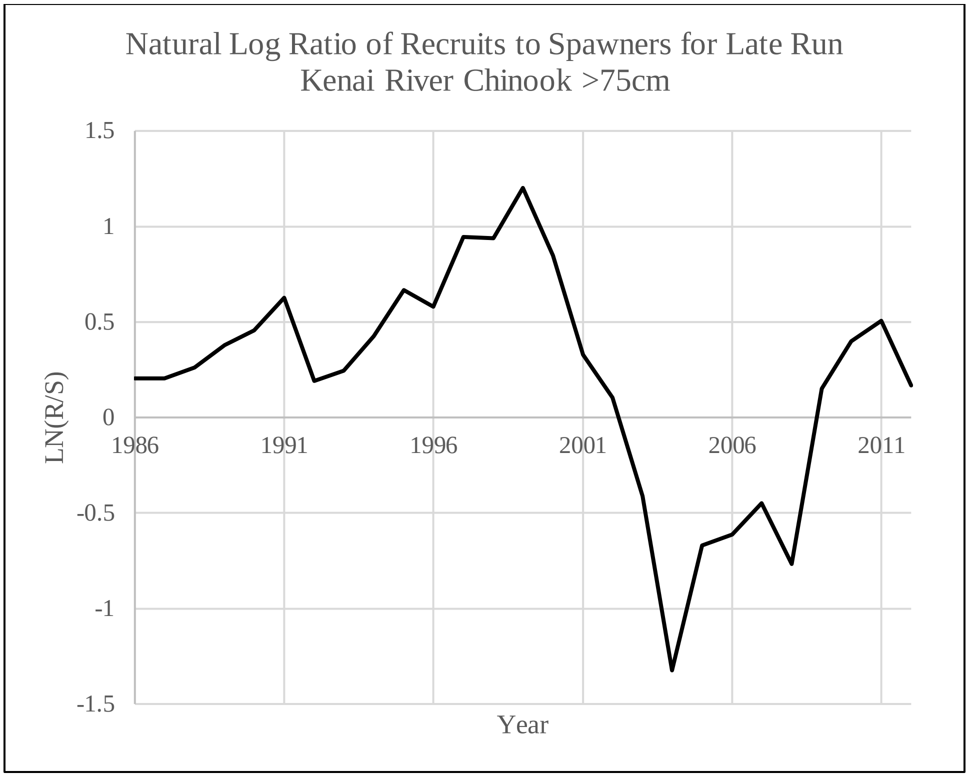

Figure 6: Natural Log Ratio of Recruits to Spawners for Late Run Kenai River Chinook >75 cm. When the ratio of recruits to spawners is positive, the population increases, and when it is negative, the population decreases.

The lower productivity opens the question of whether the problem is in the river environment or the ocean environment. Fewer nesting sites could cause fewer eggs to survive and hatch. Lower quality habitat for young salmon could limit survivorship into the ocean. In the ocean, increased predation or fewer food sources could limit the number of fish reaching maturity. The lower number of recruits per spawner represents a long term challenge for managing the late run Chinook into the future that will require new types of research.

More would need to be done to understand the life cycle of Chinook salmon in their ocean environment to address this problem. In the river environment, spawning salmon require specific habitat for creating a redd, and juvenile salmon require specific habitat for survival. Lower stream velocities, undercut banks, and diverse vegetation and organic material contribute to juvenile salmon's ideal habitat. Banks that are eroded, bare, or shored up with artificial materials contribute to higher stream velocities, fewer resting spots, and generally poorer salmon habitat. Further study, protection, and restoration of riparian spawning habitat may also be in order in this ecosystem to give juvenile salmon the best possible chance of survival (Burger 1983).

Warming Waters

As cold as the Kenai River starts at the beginning of the year, it has warmed up significantly by the middle of July. Warm temperatures are detrimental to salmon, which show signs of heat stress at around 55°F. In recent years, several salmon mortality events have occurred in Alaska. As the river temperatures warm, salmon become disoriented, sluggish, and are subject to higher mortality before spawning. This effect interrupts their natural spawning process and robs fish from the overall escapement. I have personally noticed on warm days a handful of salmon swimming around near the surface, disoriented. Otherwise uninjured fish were sometimes found in our net, dead. A changing climate is likely to blame for these warm-water events. The problem is made worse during periods of reduced water flow through the watershed (Joling 2019). Global warming is affecting every ecosystem on the planet. Keeping the watershed intact and making every effort to ensure that water flow is not interrupted will be the best way to counteract this.

Shrinking Salmon

The average length mid eye to tail fork (METF) of Chinook salmon has been shrinking from 1986 through 2018. Chinook length METF is strongly correlated to their age. The proportion of older 6-year fish has decreased over time, while the proportion of younger 5-year fish has increased. The largest 7-year fish have always formed a small proportion, which has not changed significantly over the recorded period. Over this same period, the number of anglers on the river swelled, and the fishing pressure on the populations of large Chinook salmon increased as well (Chihuly 2017).

Fishing induced evolution has been fielded as a cause of the reduction in size and age. Simply put, the more large salmon are taken out of the population, the less likely they are to pass on the traits that lead to their tendency to return at an older age and larger size. There is significant evidence to support the heritability of age of return for Chinook salmon. Larger females also have larger eggs and more of them, increasing the odds of success in spawning and the number of smolts (Skaugstad & McCracken 1991; Hankin et al. 1993). Competition of wild salmon stocks with salmon from hatcheries in the ocean environment has been implicated as a potential driver of reduced sizes and returns (Lewis et al. 2015). Efforts that increase the escapement of the largest salmon and perhaps remove the smaller ones may help reverse this trend. Put another way, selection pressure needs to be removed from the population of the largest salmon, allowing them to spawn (Ohlberger et al. 2018). As mentioned before, the number of surviving recruits per spawner has been decreasing in recent years. Any efforts that bolster productivity through improved fecundity, freshwater stage survival, or ocean stage survival would benefit the population. Unfortunately, understanding what affects the salmon in their ocean environment is logistically difficult compared to riverine research, and finding the exact cause of the selection pressure toward smaller size and younger ages in the ocean environment will be difficult.

Conclusion

From the start of my experiences as an undergraduate student in biology, I knew I wanted to enter the field of natural resource management. I recognize that the most demanding challenges exist where different user groups have different visions for the management and future of an ecosystem or species. The heavily used and contested fisheries of the Kenai River provided the perfect environment for experiencing that first-hand. I learned about the scientific aspects of fisheries management. I learned about the process and consequences of management decisions and how that affects the different people and industries that rely on fisheries.

On the one hand, the job of ADF&G technicians is easy, where we simply focus on the science and data collection and leave the political decisions to other organizations. On the other hand, we are outside in the public eye and have to be mindful of how we are perceived. The public does not always see conservation workers as unbiased seekers of scientific fact. We need to be aware of our perspectives and motivations, as well as the perspectives of other groups with a stake in contested resources. The experience of working in the Kenai peninsula broadened my acceptance of people’s vastly different priorities for a contested resource and enabled more collaborative thinking.

This position introduced me to monitoring population dynamics and inspired me to study the theories and mathematics of fish populations. Mathematics has always been one of my strongest interests, and being able to utilize that for a useful goal has been fulfilling. I believe going into the future that working in this position and learning all that I have will prepare me for the career of a fisheries manager.

The decline in numbers and the shrinking size of large late-run Chinook salmon is a management challenge that does not have easy answers. What is clear is the economic and social implications of a declining resource. User group conflicts will persist and escalate if the downward trend in population size and body size continues, and more restrictions are placed on fishing. Fewer anglers will come to the Kenai area searching for Chinook, leading to a decline in local economic activity and fewer opportunities for professional guides. Chinook salmon form a small proportion of the catch and revenue for commercial fisheries and therefore stand to lose less from the decline in this population since they can rely on other species. Nonetheless, if the population were to become un-fishable, the region would lose a critical portion of its local culture.

The Kenai River fisheries have significant challenges ahead. Declining size and numbers are an issue that compounds existing political strife in the region's fisheries. More research into the ocean conditions of salmon is required to know how to reverse these troubling trends. It is more important than ever to ensure that the fisheries are maintained to the best degree possible with equitable access for all user groups.

Literature Cited

Begich R. 2019. Kenai River Late Run Chinook salmon 2020 Outlook. Available from https://www.adfg.alaska.gov/static/fishing/pdfs/sport/byarea/southcentral/2020KenaiLateRunOutlook.pdf.

Begich R, Templin W, Barclay A, Seeb L. 2010. Development of Microsatellite Genetic Markers for Kenai River Chinook Salmon. Fishery Data Series **10**.

Boraas A. 2004. Dena'ina Prehistory. KPC.

Brenner R, Larsen S, Munroe A, Carroll A. 2020. Run Forecasts and Harvest Projections for 2020 Alaska Salmon Fisheries and Review of the 2019 Season. ADF&G Special Publication **20**.

Burger CV, National Fishery Research Center (U.S.). Alaska Field Station. 1983. Salmon investigations in the Kenai River, Alaska, 1979-1981. U.S. Fish And Wildlife Service, National Fishery Research Center-Seattle, Alaska Field Station, Anchorage, Alaska.

Burger CV, Wilmot RL, Wangaard DB. 1985. Comparison of Spawning Areas and Times for Two Runs of Chinook Salmon (Oncorhynchus tshawytscha) in the Kenai River, Alaska. Canadian Journal of Fisheries and Aquatic Sciences **42**:693–700.

Chihuly M. 2017, February 26. Alaska's mysteriously shrinking Kenai king salmon. Anchorage Daily News. Available from https://www.adn.com/alaska-life/we-alaskans/2017/02/25/our-mysteriously-shrinking-kenai-king-salmon/.

Educational Fishery – Kenaitze Indian Tribe. (n.d.). Available from https://www.kenaitze.org/tribal-member-services/tribal-fishery/ (accessed October 5, 2020).

Enberg K, Jørgensen C, Dunlop ES, Varpe Ø, Boukal DS, Baulier L, Eliassen S, Heino M. 2011. Fishing-induced evolution of growth: concepts, mechanisms and the empirical evidence. Marine Ecology **33**:1–25.

Eskelin T, Barclay A. 2018. Operational Plan: Russian River Early Run Sockeye Salmon Run Timing Study. ADF&G.

Fleischman S, Reimer A. 2017. Spawner-Recruit Analyses and Escapement Goal Recommendations for Kenai River Chinook Salmon. Fishery Manuscript Series **17**. ADF&G.

Hankin DG, Nicholas JW, Downey TW. 1993. Evidence for Inheritance of Age of Maturity in Chinook Salmon (Oncorhynchus tshawytscha). Canadian Journal of Fisheries and Aquatic Sciences **50**:347–358.

Harrison H. 2013, May. "This Is Who I Am": Perspectives On Economics, Policy, And Personal Identity And Culture Of Cook Inlet And Kenai River Salmon Fisheries. Thesis. University of Alaska Fairbanks.

Hoyt H. 2019. Tour of ADF&G Gene Conservation Laboratory.

Joling D. 2019, August 23. Alaska salmon deaths blamed on record high temperatures. Anchorage Daily News. Available from https://www.adn.com/alaska-news/wildlife/2019/08/23/alaska-salmon-deaths-blamed-on-record-high-temperatures/.

Jones LA, Schoen ER, Shaftel R, Cunningham CJ, Mauger S, Rinella DJ, St. Saviour A. 2020. Watershed-scale climate influences productivity of Chinook salmon populations across southcentral Alaska. Global Change Biology.

King B. 2009. Sustaining Alaska's Fisheries: Fifty Years of Statehood. ADF&G.

Lewis B, Grant WS, Brenner RE, Hamazaki T. 2015. Changes in Size and Age of Chinook Salmon Oncorhynchus tshawytscha Returning to Alaska. PLOS ONE **10**:e0130184.

Loring PA. 2016. Toward a Theory of Coexistence in Shared Social-Ecological Systems: The Case of Cook Inlet Salmon Fisheries. Human Ecology **44**:153–165.

Malone W. 2019. Changes in Age, Sex, and Length Proportions and Exploitation Trends for Kenai River Chinook Salmon. Unpublished.

Malone W. 2020. Simulating Future Escapements for the Late-Run Kenai River Chinook Salmon. Unpublished.

Mazurek B. 2020, June 21. Counting kings. Available from https://www.peninsulaclarion.com/news/counting-kings/ (accessed September 23, 2020).

Medred C. 2019, July 20. Humpies invade. Available from https://craigmedred.news/2019/07/20/humpies-invade/ (accessed September 23, 2020).

Merz JE, Merz WR. 2004. Morphological Features Used To Identify Chinook Salmon Sex During Fish Passage. The Southwestern Naturalist **49**:197–202.

Naiman RJ, Bilby RE, Schindler DE, Helfield JM. 2002. Pacific Salmon, Nutrients, and the Dynamics of Freshwater and Riparian Ecosystems. Ecosystems **5**:399–417.

Ohlberger J, Ward EJ, Schindler DE, Lewis B. 2018. Demographic changes in Chinook salmon across the Northeast Pacific Ocean. Fish and Fisheries **19**:533–546.

Peninsula Clarion. 2018, July 14. A look into how salmon hatcheries mark their fish. Available from https://www.peninsulaclarion.com/news/a-look-into-how-salmon-hatcheries-mark-their-fish/ (accessed September 23, 2020).

Perschbacher J. 2018. Operational Plan: Kenai River Chinook Salmon Creel Survey and In-river Netting Study, 2018–2020. Page 9. ADF&G.

Ricker W. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada **191**.

Skaugstad C, McCracken B. 1991. Fecundity of Chinook Salmon, Tanana River, Alaska. Fishery Data Series **91**.