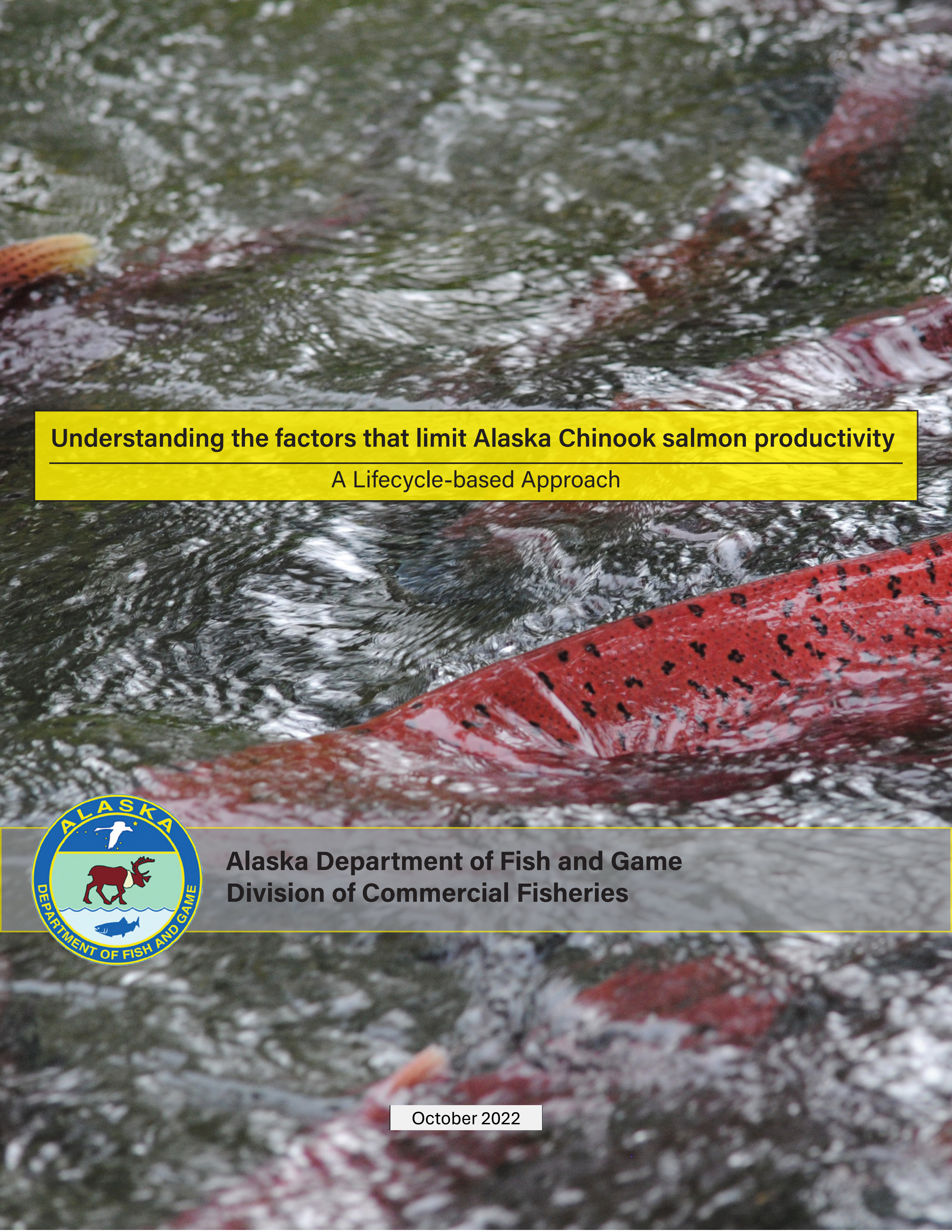

Understanding the factors that limit Alaska Chinook salmon productivity

A Lifecycle-based Approach

Alaska Department of Fish and Game
Division of Commercial Fisheries

October 2022

Overview

Chinook salmon are one of the most iconic of Alaska's fishes, and they support the cultural well-being, economy, and livelihood of many. However, Chinook salmon abundance across Alaska has suffered in recent years, leading to tremendous hardships to Alaskans. Chinook salmon numbers returning to many Alaska rivers began to decline in 2007, at times requiring painful restrictions on fisheries that harvest these stocks. While populations of Chinook salmon in Alaska have historically shown periods of alternating higher and lower production, the fishery restrictions caused by this extended period of low runs have created social and economic hardship across many communities in both rural and urban Alaska. These restrictions have not been limited to fisheries directed at Chinook salmon, but in some situations have resulted in changes to timing and gear, reduced fishing opportunity, and closures to concurrent fisheries directed at chum and sockeye salmon.

The State of Alaska invests considerable resources into Chinook salmon stock assessment including weir, sonar, aerial survey, and mark-recapture projects to estimate run size; sampling projects to estimate age, sex, size and stock composition; and research and management staff to identify and maintain escapements in a range that maximize sustained yield. The State also engages in habitat protection efforts through culvert assessments and improvements instream flow reservations and cost share programs to encourage responsible streamside development.

More recently, in 2022 the State of Alaska renewed and expanded research efforts to understand the causes for the smaller run sizes of Chinook salmon and other salmon species and, where possible, to identify the means to reduce the effects that it has on Alaskans and Alaska communities. First, in recognition of the lack of information during the marine phase of the salmon lifecycle, the Alaska Department of Fish and Game (ADF&G) committed to funding research efforts investigating the marine ecology of juvenile salmon in the Bering Sea and Gulf of Alaska, a period that is known to be important for the survival of Chinook salmon. Two examples are the new Salmon Ocean Ecology Program (SOEP[1]) at ADF&G and investment of resources and staff participation in the international 2022 Pan-Pacific Salmon Survey of the North Pacific[2]. Second, the State has encouraged stakeholder involvement in the issues around of incidental take of Chinook salmon in Alaska groundfish fisheries by convening the Alaska Bycatch Review Task Force. These responses are the beginning of investments into a wider coordinated effort to understand the causes of continuing low productivity or survival and to identify actions that can be taken to improve the number of salmon available to Alaskans and/or to mitigate the hardship to individuals and communities that rely on Chinook salmon.

There is an urgent need for a comprehensive plan that will guide future investment towards understanding this decline and provide information necessary to develop creative solutions to support the resiliency of Alaska's iconic Chinook salmon into the future. This document outlines a coordinated effort by the State of Alaska that will remain adaptive to changing situations and stakeholder input. This document provides (1) a brief update on the status of Chinook salmon and the fisheries that depend on them in Alaska; (2) a review of prior Chinook salmon research initiatives upon which this research program will build a knowledge base; and (3) a framework for developing a cooperative and inclusive research program to determine root causes of the sustained decline as well as possible management and policy actions based on these findings.

Status of Alaska Chinook salmon stocks

The current abundance and productivity of Chinook salmon populations statewide began to decline in 2007 and have been lower than the historical average since 2008. Information from the State of Alaska Chinook Salmon Research Initiative (CSRI) indicator stocks and some additional stocks with consistent assessments and run reconstructions extending from at least 1997 illustrate this pattern from within broad geographical areas (Figure 1). These summaries are presented as percent deviations from the average of each of the time series to account for differences in run sizes and allow for comparison across regions. Both regionally and statewide the pattern of consistent and prolonged lower productivity within these broad geographic areas is concerning. While individual stocks might have greater or lesser trends in declining abundance, at the broader scale it appears that production is fluctuating around a lower, but somewhat stable level. range is unlike any pattern observed for other salmon species in Alaska. Average run sizes for the CSRI indicator stocks for the most recent 14 years for which data are available (2007-2020) are 36% to 71% lower than the average run sizes immediately prior to the recent downturn (1997-2006; Table 1).

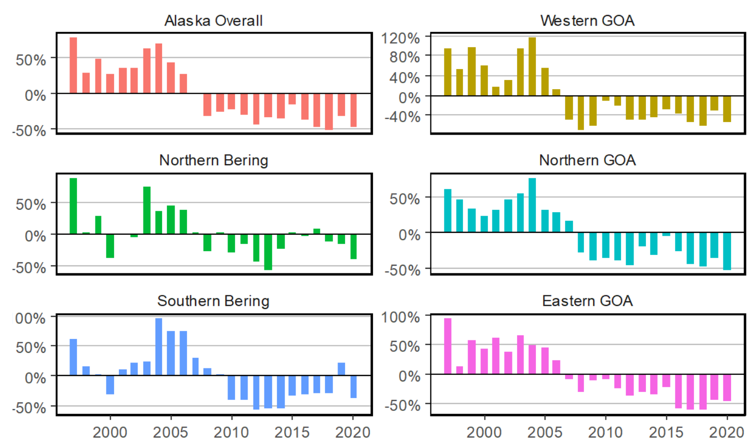

Figure 1. Average percent deviations of Chinook salmon run size estimates by major geographic ocean basins and freshwater habitats within Alaska (1997-2020). **Eastern Gulf of Alaska**: Southeast Alaska (Unuk, Stikine, Taku, Alsek, and Situk rivers); **Northern Gulf of Alaska**: Copper River, Cook Inlet (early and late-run Kenai River, **Susitna River**: Deshka, Eastside, Talkeetna, Yentna sub-basins); **Western Gulf of Alaska**: Karluk and Chignik rivers; **Southern Bering Sea**: Kuskokwim and Nushagak rivers; **Northern Bering Sea**: Yukon River (Canada stock). Note change in scale of y-axis.

[1]http://www.adfg.alaska.gov/index.cfm?adfg=salmonoceanecology.main
[2] https://yearofthesalmon.org/2022expedition/

Table 1. Current status of the run sizes for the 12 Chinook salmon indicator stocks used in the Chinook Salmon Research Initiative. Colors match the regions in Fig. 1.

Stock	Average 1997–2006 Run Size	Average 2007–2020 Run Size	2021 Fishery Restrictions?
Yukon (Canada)	109,000	70,300	Yes
Kuskokwim	252,100	141,700	Yes
Nushagak	244,900	135,200	Yes
Karluk	9,700	2,800	
Chignik	6,200	2,500	
Kenai early run [a]	11,400	4,900	Yes
Kenai late run [a]	57,800	24,100	Yes
Susitna (Deshka) [b]	40,200	17,000	
Copper	82,600	46,200	
Chilkat [a]	4,700	2,700	Yes
Taku [a]	60,600	23,100	Yes
Stikine [a]	54,000	22,600	Yes
Unuk [a]	6,800	4,000	Yes

[a] Runs include catch and escapement and are for large-sized fish, fish ≥ 770 mm mid-eye-to-tail-fork for the Kenai River stock and ≥ 600 mm mid-eye-to-tail-fork for the Chilkat, Taku, Stikine and Unuk Rivers stocks.
[b] The Deshka River stock serves as a surrogate for the Susitna River stock.

Escapement

The State manages salmon fisheries to meet escapement goals designed for sustained yield (5 AAC 39.222). Chinook salmon escapement is monitored in many systems throughout Alaska with escapement goals established for 56 stocks or stock aggregates, with over 70% of these located in the Central and AYK regions (Munro and Brenner 2022). Between 2001 and 2006, an average of 83% of the escapement goals in Alaska were met annually. Since the decline in productivity, on average, only 56% of the escapement goals have been met annually (Munro 2022). The decline in escapements and the inability to consistently meet escapement goals despite restricted fishing and other management measures is further illustrated when examining the CSRI indicators stocks (Table 2). Average escapement for the 2007-2021 period is 43 to 69% lower than previous 10-year period. The exceptions being the Copper River (15% lower), and the Yukon River Canadian stock (6% lower); the latter having lower productivity since before the recent downturn. For the indicator stocks, the number of times escapement has been below the escapement goal in the most recent five years has varied, but about half of the stocks have been below the escapement goal 3 or more times, despite management actions.

Stocks of Concern

While no Chinook salmon stocks in Alaska are near critical conservation levels, 15 stocks are listed as stocks of concern; 13 of these were listed in the past decade[1]. For the CSRI indicator stocks, seven of the stocks are listed as stocks of concern (Table 2), with Yukon River Canadian stock having been listed since 2000. In response, the fisheries that directly or indirectly harvest Chinook salmon have been restricted or closed multiple times during the past 5-10 years to allow as many fish as possible to enter the rivers to spawn and achieve escapement goals.

[1]https://www.adfg.alaska.gov/index.cfm?adfg=specialstatus.akfishstocks

Table 2. Current status of the escapements and stock of concern designations for the 12 Chinook salmon indicator stocks used in the Chinook Salmon Research Initiative. Colors match the regions in Figure 2.

Stock	1997–2006 Escapement	2007–2021 Escapement	Escapement Goal	No. Years Below Goal 2017–2021	Stock of Concern Status [a]
Yukon (Canada)	50,700	47,700	42,500–55,000	3	Yield
Kuskokwim	166,700	95,600	65,000–120,000	0	--
Nushagak	172,800	79,600	55,000–120,000	4	--
Karluk	8,300	2,600	3,000–6,000	2	Management
Chignik	4,600	1,700	1,300–2,700	4	--
Kenai early run [b, c]	8,400	4,000	3,900–6,600	2	--
Kenai late run [b, c]	37,000	16,100	15,000–30,000	2	--
Susitna (Deshka) [d]	34,100	15,400	9,000–18,000	3	Management [d]
Copper [e]	31,900	27,100	24,000	2	--
Chilkat [b]	4,000	2,100	1,850–3,500	2	Management
Taku [b]	49,200	17,200	19,000–36,000	5	Management
Stikine [b]	37,500	14,600	14,000–28,000	5	Management
Unuk [b]	5,400	2,500	1,800–3,800	2	Management

[a] Ordered in increasing severity: Yield, Management, and Conservation. The list of designated stocks of concern can be found at: https://www.adfg.alaska.gov/index.cfm?adfg=specialstatus.akfishstocks

[b] Runs include catch and escapement and are for large-sized fish, fish ≥ 770 mm mid-eye-to-tail-fork for the Kenai River stock and ≥ 600 mm mid-eye-to-tail-fork for the Chilkat, Taku, Stikine and Unuk Rivers stocks.

[c] The Kenai early and late run escapement goals switched from goals based on counts of all fish to goals based on counts of large-sized fish beginning in 2017. For comparison purposes, escapements prior to 2017 were converted to escapements of large-sized fish using a correction factor based on run information.

[d] The Deshka River stock serves as a surrogate for the Susitna River stock. The Alexander Creek and Eastside Susitna River stocks in the Susitna Drainage are not included, but are also designated as stocks of management concern.

[e] The Copper River escapement goal was revised to 21,000–31,000 fish in 2022.

Changes in historical harvests of Chinook salmon within Alaska

Local area harvests of Chinook salmon may be from a single stock or from a mixture of stocks. During periods when productivity and run abundances trend downward, management of fisheries becomes more restrictive to achieve established escapement goals. As a result, harvests should decrease while escapements remain stable during periods of poor production. The average annual inshore harvest of Chinook salmon in all Alaska fisheries during the recent 14-year period (2007–2020; Table 3) has significantly decreased when compared to the 13-year period prior to coherent downturns in run abundance (1994–2006; Figure 3). There has been more than a 30% reduction in average harvest between these two periods: subsistence and personal use – 177,000 to 106,000 fish, about a 40% reduction; commercial – 580,000 to 388,000 fish, about a 33% reduction; and sport – 178,000 to 119,000 fish, about a 33% reduction (Table 3).

Decreases in commercial harvest of Chinook salmon have occurred in all management areas of Alaska. Harvest in subsistence fisheries in western Alaska management areas were most affected by the downturn in abundance, whereas decreased harvest in sport fisheries was most notable in the Southeast, Copper River, and Cook Inlet areas. Poor Chinook salmon abundance has also led to decreased harvest in other salmon stocks where Chinook salmon are incidentally caught in the fisheries.

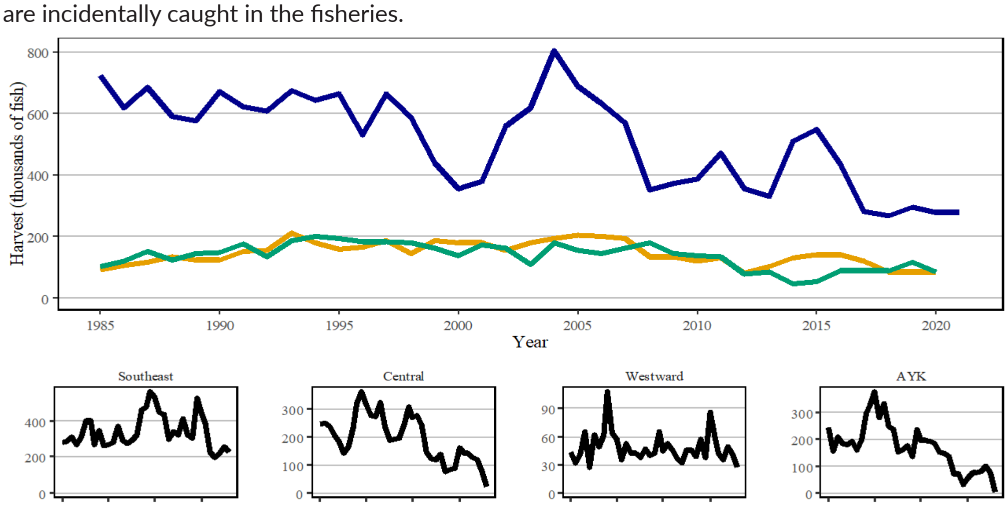

Figure 2. Number (thousands) of Chinook salmon harvested in Alaska (1985–2021). Top panel is total commercial (blue dashed line), subsistence (green dot-dash line), and sport (orange solid line). Bottom row is total harvest (commercial, subsistence, and sport) by ADF&G Commercial Fisheries Regions. Note: 2021 data for sport and subsistence harvest not available at this time.

Table 3. Average coastal and federal waters harvests during the periods 1994–2006 and 2007–2020.

Fishery	Average Harvest (1994–2006)	Average Harvest (2007–2020)	Change in Harvest Between Periods
Federal waters bycatch	Bering Sea/Aleutians: 47,000 Gulf of Alaska: 19,000	Bering Sea/Aleutians: 31,000 Gulf of Alaska: 23,000	Bering Sea/Aleutians: -34% Gulf of Alaska: +21%
Norton Sound Kotzebue	Subsistence: 7,000 Commercial: 3,000 Sport: 1,000	Subsistence: 3,000 Commercial: < 1,000 Sport: < 500	Subsistence: -57% Commercial: -67% Sport: -50% or more
Yukon	Subsistence: 52,000 Commercial: 59,000 Sport: 1,000	Subsistence: 31,000 Commercial: 9,000 Sport: < 500	Subsistence: -40% Commercial: -85% Sport: -50% or more
Kuskokwim	Subsistence: 89,000 Commercial: 31,000 Sport: 2,000	Subsistence: 50,000 Commercial: 10,000 Sport: < 1,000	Subsistence: -44% Commercial: -68% Sport: -50% or more
Bristol Bay	Subsistence: 16,000 Commercial: 77,000 Sport: 8,000	Subsistence: 14,000 Commercial: 33,000 Sport: 10,000	Subsistence: -13% Commercial: -57% Sport: +25%
Chignik/Alaska Peninsula	Subsistence: < 1,000 Commercial: 17,000 Sport: 4,000	Subsistence: < 500 Commercial: 22,000 Sport: < 1,000	Subsistence: -50% Commercial: +29% Sport: -75% or more
Kodiak	Subsistence: < 500 Commercial: 19,000 Sport: 8,000	Subsistence: < 500 Commercial: 13,000 Sport: 9,000	Subsistence: 0% Commercial: -32% Sport: +13%
Cook Inlet	Subsistence: 3,000 Commercial: 17,000 Sport: 74,000	Subsistence: 2,000 Commercial: 8,000 Sport: 32,000	Subsistence: -33% Commercial: -53% Sport: -57%
Copper River/ Prince William Sound	Subsistence: 8,000 Commercial: 49,000 Sport: 10,000	Subsistence: 5,000 Commercial: 16,000 Sport: 8,000	Subsistence: -38% Commercial: -67% Sport: -20%
Southeast	Subsistence: 1,000 Commercial: 306,000 Sport: 71,000	Subsistence: < 1,000 Commercial: 278,000 Sport: 59,000	Subsistence: 0% Commercial: -9% Sport: -17%
Total	Subsistence: 177,000 Commercial: 580,000 Sport: 178,000 Federal: 66,000	Subsistence: 106,000 Commercial: 388,000 Sport: 119,000 Federal: 53,000	Subsistence: -40% Commercial: -33% Sport: -33% Federal: -20%

Prior Chinook Salmon Initiatives

Chinook Salmon Research Initiative

In 2012, ADF&G initiated the CSRI[1] in response to what was at the time a 6-year decline in Chinook salmon abundance across the state. At the planning stage, a team of department scientists and biologists, in collaboration with federal agencies and academic partners, identified key knowledge gaps, set research priorities, and developed a research plan with recommended studies designed to better understand the factors affecting Chinook salmon abundance in Alaska. This plan outlined a "framework of new and continuing stock assessment and research programs among a suite of indicator stocks across Alaska designed as a long-term commitment to address fundamental knowledge gaps, elucidate causal mechanisms behind observed trends, and improve management capabilities." The first phase of this plan was funded by the Alaska Legislature in 2013. The core of the plan was stock specific, life history-based research focused on 12 indicator stocks, representing diverse life history and migratory characteristics across a broad geographic range within Alaska (Figure 1). For more information see the Chinook Salmon Stock Assessment and Research Plan (ADF&G 2013).

[1] http://www.adfg.alaska.gov/index.cfm?adfg=chinookinitiative.main

Figure 3. Map of Alaska showing the locations of the 12 Chinook indicator stocks identified in the Chinook Salmon Research Initiative (CSRI) with major drainages highlighted.

It has been 10 years since CSRI was initiated and during that time many projects and studies were completed. However, some projects were never implemented or were discontinued due to lack of funding. Many stock assessments were improved using CSRI project funds however identification of the underlying drivers behind prolonged low Chinook salmon abundance remains a research need.

Arctic-Yukon-Kuskokwim Sustainable Salmon initiative

Also in 2012, the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (AYK-SSI)[3] convened a Chinook Salmon Expert Panel to develop the Chinook Salmon Research Action Plan (AYK SSI Chinook Salmon Expert Panel 2013). The panel consisted of thirteen salmon scientists with diverse areas of expertise that extended over the entire freshwater and marine life cycle phases of salmon.

The panel formulated a set of hypothesized mechanisms that most plausibly could have contributed to the observed declines in Chinook salmon and a synthesis workshop was held in May 2012. At the workshop, existing and new information was presented on the patterns of decline within Chinook salmon stocks in the AYK region and the hypotheses developed by the panel were evaluated. During the workshop, participants generated recommendations for future research to increase our understanding of the key variables potentially affecting Chinook salmon in the AYK region. The Action Plan was developed from the results of this workshop and included a compilation of evidence of the declines of the Chinook salmon stocks in the Yukon, Kuskokwim and Southern Norton Sound region, comparative analysis of the population dynamics of fifteen Chinook Salmon stocks from across the state, including four stocks from the AYK region. In addition, a description of the seven hypothesized stressors or drivers of the Chinook salmon declines, which included discussions of the biological plausibility, summary of the evidence available for each hypothesis, and a set of research themes and questions to guide future research. Finally, prioritized recommendations for future critical research were provided. This Chinook Salmon Research Action Plan has formed the basis for AYK-SSI-funded research for the past decade.

Lessons Learned

Prior Chinook salmon research initiatives have undoubtedly enabled important advancements in our knowledge and understanding of poor Chinook abundance patterns across the state. The CSRI provided a statewide approach by using representative indicator stocks and included a long-term plan with the ability to adapt in the future. The CSRI concentrated on improving assessments and updating subsistence information, data needs that are very appropriate for a management agency. The AYKSSI Chinook Research Plan provides a spatially concentrated approach (AYK Region-specific) that draws on a broad set of experts from universities, state and federal agencies, and stakeholders. The AYKSSI Chinook Research Plan is well-developed with defined hypotheses, and researchers funded under the plan are encouraged to engage stakeholders. Both initiatives have offered many strengths and insights into poor Chinook salmon abundance patterns.

[3]https://www.aykssi.org/

However, there are also lessons that can be learned from these efforts for designing future research programs and clearly the work is not complete. The CSRI had limited funding spread over many stocks, allowing for only 1-3 projects per stock, and the funding did not occur over a long enough period of time to enable a full implementation and completion of most projects. Neither the CSRI nor AYKSSI efforts have had a complete synthesis of findings across projects, or a clear means of combining information for stocks across the state. Projects and results for these initiatives were not integrated with one another, and project results are not all widely available. For CSRI, there was also limited stakeholder involvement in the development of projects. Neither initiative has been updated in many years.

Therefore, there is now an opportunity to leverage the lessons learned from these prior initiatives and further that work by developing an approach that can efficiently and holistically tackle the questions around the cause of poor Chinook abundance statewide. The remainder of this document outlines a research plan that would build upon the excellent work of CSRI and AYKSSI Chinook salmon research initiatives, but with an emphasis on a cooperative and inclusive program structure that investigates “Likely Suspects” responsible for poor Chinook salmon abundance, in a Gravel-to-Gravel research assessment that is intended to be holistic and intensive over a 5-to-6-year period.

Framework for a Cooperative Research Program

Program Structure

We propose here a strategic plan to guide future investment of available resources toward improved understanding and management of Alaska Chinook salmon within the current context of changing climate, changing ecosystems, and changing patterns of human use. This plan will be most effective with meaningful stakeholder engagement. Therefore, we propose a framework that can be applied to any stock and includes a technical scientific team and a stakeholder advisory team, who will work alongside one another with the help of a coordinator. This type of parallel structure of teams offering different expertise was useful in the successful implementation of the Western Alaska Salmon Stock Identification Program (WASSIP)[4].

Technical and stakeholder teams will be tasked with jointly identifying root causes of sustained poor Chinook salmon abundance and potential policy and management actions that may be taken to address identified root causes. To do this teams will:

1	2	3	4
Synthesize existing data from scientific research projects (technical team) and local and traditional knowledge (stakeholder team)	**Identify most relevant Likely Suspects driving poor Chinook salmon abundance (see below) across the life cycle for the focal stock.**	**Recommend and prioritize new or continuing information collections for a Gravel-to-Gravel assessment (see below) and synthesize new results alongside previous information**	**Provide input based on updated information and improved understanding of the system.**

Gravel-to-Gravel Assessment

For each stock selected for study, an intensive suite of studies will be implemented concurrently over a 5 to 6-year period. Together, the suite of projects should address all relevant Likely Suspects driving poor Chinook salmon abundance and life stages, ideally with overlap across multiple projects. In addition to data collection studies, retrospective analyses and modeling efforts will be useful to “bring it all together” by consolidating data across suites of projects and integrating data from separate studies. This synthesis will highlight critical factors or life stages limiting Chinook salmon adult run abundance and inform potential policy and management actions. Research approaches that are intensive and holistic, employing coordinated and focused examinations of all Likely Suspects at once, have been particularly successful for identifying factors most important to survival and productivity of salmon in other areas (e.g., Salish Sea Marine Survival Project), and it is expected that the Gravel-to-Gravel assessment approach will be similarly successful.

The goals of a Gravel-to-Gravel assessment are to:

- Coordinate and integrate across focal stock studies to provide a holistic perspective of the limitations to Chinook salmon life-cycle productivity that lead to poor run abundance.
- Identify the principal factors affecting Chinook salmon run abundance for the focal stock.
- Identify policy and management actions that may help re-build abundance of focal Chinook salmon stocks.
- Provide insight for other Alaskan Chinook salmon stocks exhibiting chronic poor productivity and run abundance.

[4] https://www.adfg.alaska.gov/index.cfm?adfg=wassip.main

The ultimate production of any cohort of salmon is the result of a series of events in the lives of the individuals as they proceed from the eggs spawned in the gravel through to the time when survivors return to lay eggs in the gravel. During the life span of the cohort events that occur reduce the number of surviving individuals, such that subsequent events act on new and lower limits on the number of potential survivors returning to the rivers and spawning. Because these events accumulate as the cohort progresses from eggs in gravel to adults laying eggs studies which focus on a bottleneck at an individual life stage offer results which are confounded by all prior events.

The Gravel-to-Gravel assessment acknowledges the interplay among life stages, aquatic environments, and human activities with potential effects accumulating across the lifecycle. This allows for research activities to be designed and implemented in an efficient and coordinated fashion. It also enables results to be compiled in the context of related projects and results. The knowledge gained through any research or assessment project can be useful when considered in isolation, however, the value of that information expands greatly when understood in context.

Unlike previous efforts focused on individual hypotheses driving Chinook salmon productivity, a holistic Gravel-to-Gravel assessment would enable evaluation of individual Likely Suspects as well as an understanding of cumulative effects of multiple stressors across hypotheses. This approach requires a well-coordinated suite of studies that span Likely Suspects and life stages, therefore results from very different research projects will be more easily synthesized into a clear story of the life of these stocks. The Gravel-to-Gravel studies will also help us identify specific management or policy actions that will be most effective in supporting the resilience and sustainability of these Chinook salmon stocks.

Likely Suspects Driving Poor Chinook Salmon Abundance

There are several Likely Suspects that may explain why Chinook salmon abundance is so poor throughout their distribution, including across Alaska. While it is generally believed that the most likely suspects are those that can explain these geographically broad declines, it is possible that more than one factor may be influencing Chinook abundance. Similar, or closely related, Likely Suspects may explain patterns occurring for different stocks, particularly if the magnitude and timing of abundance declines are somewhat different across stocks. It may also be informative to explore how Likely Suspects affect Chinook salmon differently than other salmon stocks that have not experienced poor abundance, because of species-specific life history, behavior, or other characteristics. Many of these Likely Suspects may act at more than one life stage or could act in conjunction with one another. This conceptual framework of the interaction of these Likely Suspects and the Chinook salmon lifecycle are illustrated in Figure 4.

When prioritizing most relevant Likely Suspects for consideration for each focal stock, technical and stakeholder teams should consider:

- Whether the geographic footprint of the Likely Suspect is consistent with the geographic scope of the decline in Chinook salmon abundance for the focal stock.
- Whether the timing patterns in the Likely Suspect are consistent with the timing patterns of the decline in Chinook salmon abundance for the focal stock.
- Whether available abundance information exists for non-adult life stages that may inform which life stages are most influential to the adult abundance pattern for the focal stock (e.g., smolt mark-recapture data can inform the relative role of marine vs. freshwater influences on adult run abundance), and which Likely Suspects act on those most vulnerable life stages.
- Which Likely Suspects may act on focal stocks differently than they would on species and stocks that have been experiencing strong abundance patterns, and therefore may simultaneously explain poor abundance on focal stocks but not on other species/stocks.
- Which Likely Suspects have the greatest information gaps for their focal stock.

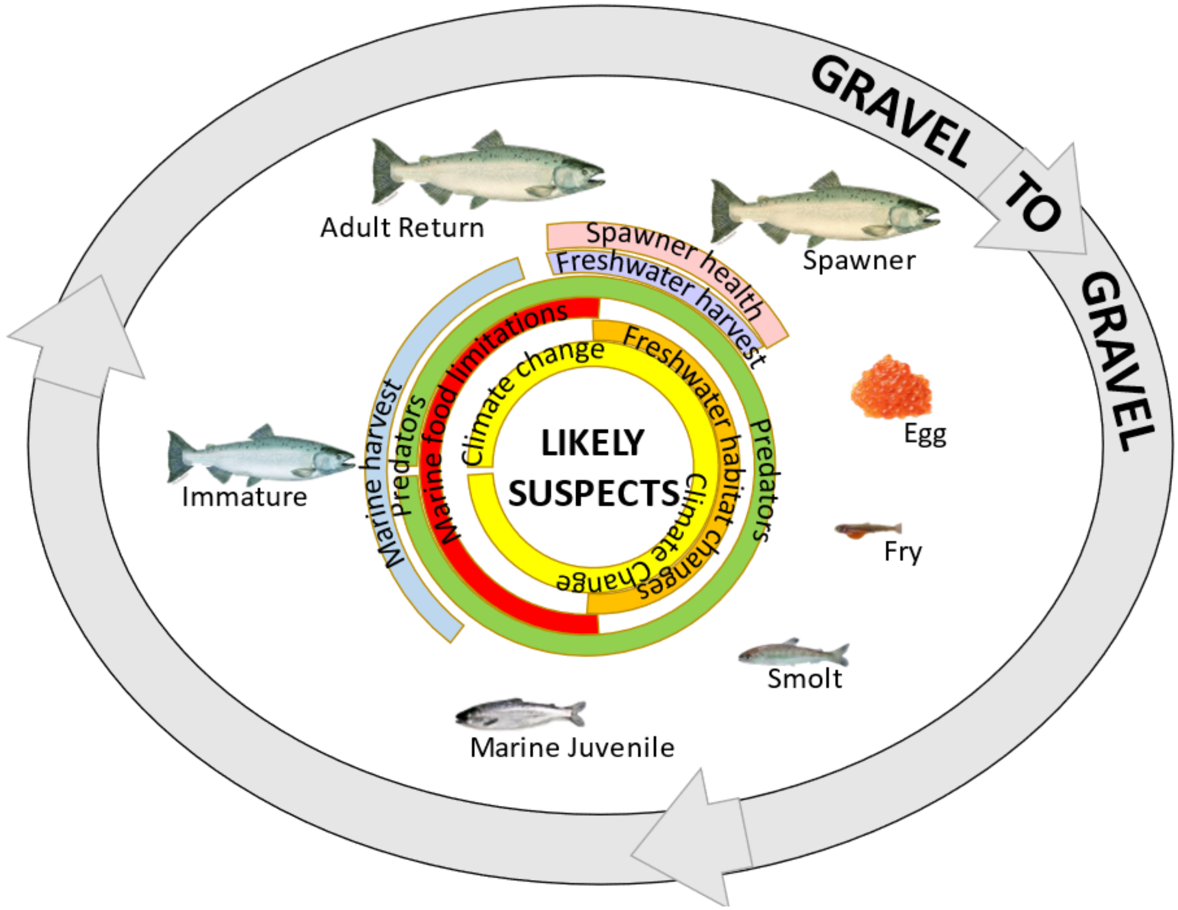

Figure 4. A Gravel-to-Gravel life cycle overview of potential Likely Suspects for the decline of Alaskan Chinook salmon productivity.

Likely Suspects driving poor Chinook salmon abundance	
Changing climate conditions	**Life stage(s): All stages / Geographic footprint: Statewide** In recent years Alaska has experienced record high temperatures in terrestrial and marine systems. Unusually intense droughts, floods, wildfires, marine heat waves or other environmental phenomena have also been noted in many areas. Climate-related phenomena may have direct physiological impacts on salmon stocks, such as heat stress that can compromise the success of returning spawners. Alternatively, climate-related phenomena may have indirect impacts on salmon through changes in the timing of various processes (e.g., timing of smolt emigration out of rivers), changes to food web dynamics, changes to migration patterns, and changes to the size and locations of suitable habitat at different life stages. An example study would be a project investigating the prevalence of heat stress in returning adult salmon and the impacts this has on successful spawning and reproduction.
Freshwater, Estuarine and/or Marine Predation	**Life stage(s): All stages / Geographic footprint: Depends on predator's habitat** Changes to predator abundance and/or susceptibility to predation is also a possible explanation for declines in productivity of Alaskan Chinook salmon. Predation occurs throughout the salmon life cycle, but is generally not believed to be a primary driver of changes to production unless an imbalance occurs in the natural world (Fresh 1997). This imbalance may occur due to an introduced non-native species, change in geographic range or magnitude of the predator abundance outside of what is typical, or a particular vulnerability of the salmon prey species, such as greater susceptibility to predation due to a weakened immune system or poor nutrition. Predation can be particularly difficult to assess, especially in estuarine and marine environments where there are many potential predators and observations of predation are challenging to obtain. We often know very little about the abundance of different predator species, or their seasonal movement patterns, making it difficult to assess overlap with Chinook salmon and potential impacts. An example of a project investigating this Likely Suspect would be a study examining whether the abundance and distribution of northern Pike, and other freshwater species that feed on young life stages of Chinook salmon, is associated with the abundance and productivity of Chinook salmon focal stocks.

Freshwater Habitat Changes	**Life stage(s): Spawner to Fry / Geographic footprint: Extremely localized** Salmon need specific freshwater habitat characteristics to successfully spawn and generate offspring that are more likely to survive during their freshwater residence. These habitats also need to be adequately connected and accessible during the spawning migration and subsequent juvenile dispersal. Much of Alaska's freshwater habitats are considered relatively pristine compared to those in lower latitudes where dams blocking fish passage, water diversions, pollution, and large-scale urbanization have been problematic. However, there are still challenges and opportunities to improve freshwater habitat for salmon in Alaska's waterways by improving fish passage, stabilizing adequate rearing habitat and removing invasive species, among other activities. An example of a project investigating this Likely Suspect would be a study examining the amount of spawning habitat that may be recovered by replacing inaccessible culverts with fish-friendly ones, and the resulting effect that increased habitat may have on future adult returns.
Marine Food Limitations	**Life stage(s): Smolt to Adult Spawner / Geographic footprint: Regional** Marine food limitations have been proposed as an explanation for reduced salmon productivity for many salmon species and stocks. Food limitation is often discussed either through reduced food availability, often using the term "carrying capacity" to express this concept (Cooney & Brodeur 1998, Aydin 2000, Honkalehto 1984, Shuntov & Temnykh 2005), or increased competition for food with other salmon and non-salmon species (Connell 1983, Ruggerone & Nielson 2004, Shuntov et al. 2017). It is extremely difficult to adequately estimate salmon carrying capacity in the ocean as carrying capacity is expected to be non-stationary, and spatially heterogeneous over the large marine habitats that Pacific salmon utilize. Moreover, salmon are generalist feeders that can rely on many different food sources and have many different salmon and non-salmon competitors. Several studies have attempted to characterize carrying capacity and/or competition for food in the North Pacific Ocean, but focus has often been on non-Chinook salmon species, which tend to have different food habits than Chinook salmon. These studies typically assess potential for food limitation indirectly, rather than direct assessment of the food base. An example of a project investigating this Likely Suspect would be an examination of spatial and diet overlap among salmon and non-salmon species from samples collected in marine surveys.
Marine and Freshwater Fisheries Harvest	**Life stage(s): Immature to Adult Spawner / Geographic footprint: Regional or localized** Considerable concern has been expressed for the role of harvest in marine fisheries, either as bycatch in groundfish fisheries or as harvest in coastal commercial fisheries, in reducing abundance of returning Chinook salmon for struggling salmon stocks. Generally, impact from these fisheries on returns of Alaska Chinook salmon have been estimated to be low (NMFS 2022). However, even though marine fisheries harvests are not expected to be the main driver of poor productivity for Chinook salmon stocks, there is interest in understanding the relative role of this cause of mortality as a secondary cause in further reducing adult run abundance patterns and inriver harvests for Alaskan stocks. Likewise freshwater and coastal harvests have also raised concerns in some instances, particularly when mixed stocks are encountered, there may be some uncertainty in the actual impacts of catches (e.g., mortality of fish caught and released but not counted towards harvest), or other challenges. An example of a project investigating this Likely Suspect would be a study examining whether premature mortality of fish caught and released in a fishery before reaching the spawning grounds, may lead to an overestimation of escapement in some systems, would negatively impact expected productivity and future run abundance of the stock.
Health and Condition of Returning Adults	**Life stage(s): Adult Spawner / Geographic footprint: Localized** In recent years, fishermen and biologists have noted changes to the health and condition of returning adult Chinook salmon in various river systems across Alaska. These changes include disease prevalence (e.g., increased occurrence of Ichthyophonus hoferi infections in Yukon River Chinook salmon), deficiencies in nutrient or fat stores (14), and changes to the size and age of adult returns (Lewis et al. 2015; Oke et al. 2020). These changes could affect the ability of returning adults to successfully reach the spawning grounds, to successfully spawn, the numbers of eggs produced and fertilized, and/or their ability to produce viable offspring. An example of a project investigating this Likely Suspect would be a study examining en route mortality (mortality occurring after fish have entered the river but before successfully spawning) associated with Ichthyophonus hoferi infections.

Priority Actions

In summary, the proposed framework recommends engaging parallel stakeholder and technical teams who will be tasked with prioritizing a Gravel-to-Gravel research program for a focal stock, focused on the most relevant Likely Suspects driving poor Chinook salmon abundance. This proposed research framework can be adapted to any salmon stock where productivity concerns arise. However, given this is a new research framework to address primary causes of poor productivity in Chinook salmon, and funding and capacity are limited, we propose that two focal stocks be first prioritized. We propose that this framework be initiated for two iconic, but different Alaskan Chinook salmon stocks: Yukon and Kenai rivers. These stocks are important for Alaskans, are among the stocks with chronic low production of Chinook, and missing information is attainable. These stocks represent some contrast in the kinds of systems where chronic low productivity is occurring. For example, the Yukon is a large river, and the Kenai is relatively much shorter; Yukon River Chinook salmon reside in the Bering Sea throughout their marine life while Kenai River Chinook salmon utilize Gulf of Alaska and North Pacific Ocean marine waters.

Gravel-to Gravel studies for focal stocks should address all relevant Likely Suspects discussed in this document. Combined, assessment projects should also touch on all life stages from spawners, through freshwater and marine phases, to adult returns. To provide some examples of what a suite of projects may entail in a gravel-to-gravel assessment, potential suites of projects to enable a gravel-to-gravel assessment are provided for Yukon River (Appendix 1) and Kenai River (Appendix 2) Chinook salmon stocks. Some of the projects in these examples have already been initiated in some capacity, some require broad partnerships, and some may require leadership by university, non-governmental organization, or agency expertise outside of ADF&G to be most effective. It will be necessary for the technical and stakeholder teams for these focal stocks to determine if additional projects are needed, if existing data already adequately address some Likely Suspects, and to prioritize projects.

Yukon River

The Yukon is the largest river in Alaska and the fifth largest river drainage in North America. The Yukon River and its tributaries drain an area of approximately 220,000 square miles within Alaska, while the Canadian portion of the river accounts for another 110,000 square miles. The river flows 2,300 miles from its origin 30 miles from the Gulf of Alaska to its terminus in the Bering Sea. Chinook and chum salmon are of the most importance to the Yukon River area. Sockeye, pink, and coho salmon, while present, are of minor importance. Yukon River Chinook salmon have the longest spawning migration of any salmon. Spawning populations of Chinook salmon have been documented throughout the Yukon River drainage. Chinook salmon begin entering the mouth of the Yukon River after ice breakup in late May or early June and continue to migrate upriver through mid-July. During their marine life stages, Yukon River Chinook salmon spend their entire marine life in the Bering Sea, migrating seasonally between the central Bering Sea basin and the Bering Sea shelf.

Chinook salmon have been in a prolonged period of low productivity, and this has resulted in much hardship to the residents of the Yukon River drainage. Excluding the greater Fairbanks area (an estimated 97,740 residents), there are nearly 22,380 rural residents in the Alaska portion of the drainage (Hunsinger 2018), the majority of whom reside in 43 small communities scattered along the coast and major river systems. Most of these people are dependent, to varying degrees, on fish and game resources for their livelihood. In addition to the U.S. fisheries, Aboriginal, commercial, sport, and domestic salmon fisheries occur in the Canadian portion of the Yukon River drainage, and management objectives for this transboundary river are governed under the Pacific Salmon Treaty.

Kenai River

The Kenai River originates at Kenai Lake near the community of Cooper Landing and terminates in Cook Inlet adjacent to the city of Kenai. The river is glacial and approximately 82 miles in length. It is paralleled for much of its length by the highway road system, making it the most accessible of Alaska's major salmon-producing rivers.

The Kenai River supports two distinct Chinook salmon runs; an early-run and a late-run. The early-run usually enters the river in mid-May. The early-run fishing peaks in mid-June and is over by the end of June. The early-run fish primarily head for smaller Kenai River tributaries to spawn. Late-run Chinook salmon enter the river in early July, with the best fishing found from mid- to late July and are generally considered mainstem spawning fish. Kenai River fisheries for king, sockeye and coho salmon are the largest freshwater sport fisheries for these species in Alaska. The early run is managed for the inriver sport and guided sport fishery. Although harvest is known to be relatively minor, early-run fish are caught in the mixed-stock Cook Inlet marine sport fishery prior to their entry into the Kenai River. In addition, there are small numbers of early-run Chinook salmon harvested in the Kenaitze Indian Tribe educational fishery. Late-run stocks of Kenai River Chinook salmon are caught by the commercial drift gillnet fishery and the commercial set gillnet fishery along the east side of Cook Inlet, both of which target sockeye salmon. Harvest also occurs in the Kenai River personal use dip net fishery, which also targets sockeye salmon.

Key characteristics of proposed focal stocks for Gravel-to-Gravel assessment.

Yukon River	Kenai River
2,000 miles (longest salmon spawning migration)	80 miles
Drainage spans Yukon Territory, interior Alaska and western Alaska	Southcentral Alaska
Predominantly snow-melt and rain-fed (relatively minor glacially-fed tributaries)	Glacially-fed river
Empties into Bering Sea, with Bering Sea as primary marine habitat	Empties into Cook Inlet, with Gulf of Alaska primary marine habitat
Largely very remote	Most accessible major salmon producing river in Alaska
One Chinook salmon run	Early and late Chinook salmon runs
Predominant harvest from subsistence fisheries, historically large commercial fisheries	Predominant harvest from sport fisheries, incidental harvest of late-run Chinook salmon in sockeye-directed commercial fisheries
Transboundary river	US-only jurisdiction

Appendix 1: Proposed Yukon River Chinook salmon assessment projects in the gravel-to-gravel research assessment

Proposed Project	Hypothesis Addressed	Information provided	Funding	Approximate annual cost
Northern Bering Sea Juvenile Salmon Survey	• Changing climate conditions • Estuarine/marine predation • Marine food limitations	Marine juvenile abundance estimate; diet and condition of marine juveniles; assess available prey base in the northern Bering Sea; documentation of abundance of marine predators and predator wounds; forecast of adult returns.	Through 2023	$700.0[1]
Hormone biochronology	• Changing climate conditions	Temperatures, stress, marine habitats experienced	Pilot study 2022	$100.0
Yukon River Delta Smolt test fishery	• Changing climate conditions	Timing, diet, size at ocean entry, condition, potential abundance index.	Unfunded	$500.0
Yukon River smolt tagging	• Changing climate conditions • Freshwater predation	Timing and distribution, movement through freshwater and nearshore marine waters, survival from freshwater outmigration to nearshore marine habitats.	Unfunded	$1,000.0
Salmon shark and immature Chinook salmon tagging	• Marine predation	Movement and overlap between a known salmon predator and marine distributions of Chinook	Through 2023	$50.00
Predicting Chinook salmon marine distribution for bycatch avoidance	• Marine fisheries harvest	Movement of Chinook in association with environmental and fisheries factors	Through 2025	Fully funded
Adult return en route mortality study	• Health & condition of returning adults	Use radiotelemetry, mark-recapture techniques, a mid-river sonar, and other technologies to investigate mortality occurring between lower river assessment locations used for fisheries management and spawning locations fisheries management and spawning locations	Begin 2023 (1-3 years)	$550.0
Ichthyophonus study	• Health & condition of returning adults	Monitor disease, and food quality for human consumption	Through 2022	$280.0
Metabolic drivers of spawner quality	• Health & condition of returning adults	Monitor heat stress, health status, egg retention, and egg quality of returning adults, and their effects on productivity	Pilot through 2022	$100.0
Life cycle modeling synthesis	All hypotheses	Integrate gravel-to-gravel project data, along with existing datasets, to identify critical life history periods, and primary limiting factors.	Unfunded	$150.0

[1]Includes NOAA contributions of staff time, staff travel, equipment, and lab analyses. Increased vessel costs alone may approach $500,000 in the future.

Appendix 2: Proposed Kenai River Chinook salmon assessment projects in the gravel-to-gravel research assessment

Proposed Project	Hypothesis Addressed	Information provided	Funding	Approximate annual cost
Western Gulf of Alaska Juvenile Salmon Survey	• Changing climate conditions • Estuarine/marine predation • Marine food limitations	Marine juvenile abundance index; diet and condition of marine juveniles; assess available prey base in the western Gulf of Alaska; documentation of abundance of marine predators and predator wounds; Forecast of adult returns.	Pilot in 2023	$500.0
Hormone biochronology	• Changing climate conditions	Temperatures, stress, marine habitats experienced	Unfunded	$100.0
Kenai River smolt tagging	• Changing climate conditions • Freshwater predation	Timing and distribution, movement through freshwater and nearshore marine waters, survival from freshwater outmigration to nearshore marine habitats	Unfunded	$1,000.0
Salmon shark and immature Chinook salmon tagging	• Marine predation	Movement and overlap between a known salmon predator and marine distributions of Chinook	Through 2023	$50.0
Ichthyophonus study	• Health & condition of returning adults	Monitor disease, and food quality for human consumption	Unfunded	$100.0
Metabolic drivers of spawner quality	• Health & condition of returning adults	Monitor heat stress, health status, egg retention, and egg quality of returning adults, and their effects on productivity	Unfunded	$100.0
Life cycle modeling synthesis	• All hypotheses	Integrate gravel-to-gravel project data, along with existing datasets, to identify critical life history periods, and primary limiting factors.	Unfunded	$150.0

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