Developing a Research and Restoration Plan for Arctic-Yukon-Kuskokwim (Western Alaska) Salmon

Committee on Review of Arctic-Yukon-Kuskokwim (Western Alaska) Research and Restoration Plan for Salmon, National Research Council

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Preface

The Arctic-Yukon-Kuskokwim (AYK) Sustainable Salmon Initiative (SSI) was created through a congressional appropriation in 2002 to develop and expand a research program to understand better the causes for the recent declines in salmon in western Alaska. To ensure that the appropriated funds will be spent wisely, an AYK Research and Restoration Plan needs to be developed. A National Research Council (NRC) committee was established to assist the AYK SSI in developing this plan. We (the NRC AYK committee) were not assigned the task of writing the plan, only to assist with the writing and then provide a review of that plan. The committee included experts within and outside of Alaska, whose areas of expertise ranged from fisheries management to genetics to physical oceanography. The committee began its work with visits to coastal communities along the Bering Sea in the fall of 2003 and winter of 2004. This fact-finding tour enabled committee members to interact with stakeholders and resource managers. From these discussions, it was clear that we were dealing not with an abstract issue but rather with a subject that was embedded in the fabric of the communities. Salmon are vital to the way of life in these communities because subsistence fishing is an important part of their survival and culture. The communities are concerned about the variability in salmon returns, and they want to help find solutions to this problem.

While the variability of salmon returns along the coastal Bering Sea is the problem, there seem to be no obvious, quick, and easy corrective actions that can be taken. Opinions differ about whether the variability is caused by changes in stock recruitment, fishing, or ecosystem influences, or possibly a combination of them. The geographical scope of the problem is enormous: salmon habitat ranges from freshwater streams to the deep central North Pacific Ocean. Both long-term (decades and longer) and short-term (storm events) factors appear to influence various portions of the ecosystem. Thus, a holistic approach is likely to be the best way to address this problem rather than trying to identify a single cause in space and time.

The challenge is to persevere until our knowledge of salmon variability improves our ability to accurately forecast future salmon returns. This assumes that the ecosystem has some degree of predictable variability. Without improved understanding of this variability and appropriate management actions, there is a risk that salmon stocks in the region could be severely depleted. A positive circumstance is that many other ocean-observing programs have begun or will be initiated in the near future that will inform the AYK salmon program, so needed research can seek support from a variety of relevant programs.

We thank all the members of the communities of Bethel, St. Mary's, Aniak, Nome, Unalakleet, and surrounding villages who met with us and provided testimony. They presented valuable information and ideas. We thank the host communities for their hospitality and willingness to share their food with us. Of course, we greatly appreciated the salmon that they provided.

We thank the members of the NRC staff for their assistance. David Policansky, NRC Project Director, guided our efforts and provided valuable insights on Alaska, its salmon, and the NRC processes. John Brown made sure that we all had a place to sleep and food to eat, as well as other logistics that we required. The varied airport transits will be long remembered. Leah Probst organized the meetings and was invaluable in the preparation of this report.

I thank the members of the committee for their unselfishness in donating their time to this project. They were willing to travel great distances and to work long hours to produce this document. I look forward to our continued teamwork in reviewing the AYK SSI Research and Restoration Plan.

Thomas Royer
Chair, Committee on Review of
AYK (Western Alaska) Research
and Restoration Plan for Salmon

Acknowledgments

REVIEWERS

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council (NRC) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their review of this report:

Milo Adkison, University of Alaska Fairbanks, Fisheries Division
Patricia Cochran, Alaska Native Science Commission
Lewis S. Incze, Bioscience Research Institute, University of Southern Maine
Irv Kornfield, University of Maine
Molly McCammon, Alaska Ocean Observing System
Robert T. Paine, University of Washington
Jay Stinson, Kodiak, AK
Robert Wolfe, San Marcos, CA

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Ed Houde, University of Maryland, Solomons, MD. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

SITE VISITS

The committee visited several sites during its meetings and is grateful to the many people who provided information, shared their facilities, provided hospitality, and provided valuable information there. See Appendix B for summaries of these site visits.

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Developing a Research and Restoration Plan for Arctic-Yukon-Kuskokwim (Western Alaska) Salmon

Summary

INTRODUCTION

Salmon and freshwater fish have been critical to the survival and well-being of the people and wildlife in the Arctic-Yukon-Kuskokwim (AYK) region (Figure S-1) for thousands of years. Salmon influence human societies in the region, and humans affect the lives and numbers of salmon. Modern technology and economies, which make it possible to deplete salmon populations easily, have strained that relationship.

Recent declines in the abundance of salmon in the AYK region have created hardships for the people and communities that depend heavily on this resource. The low salmon returns resulted in lower catches and increased regulatory restrictions on fishing, which in turn resulted in reduced revenue for cash-short communities along the region's rivers. Those losses forced fishers, especially in the lower reaches of the rivers, to reduce fishing times and use less expensive and less efficient gear. Restrictions on subsistence fishing and lower catches also affected all aspects of the lives of people in the region. Especially in interior regions, where other subsistence foods were less abundant during recent salmon declines and groceries are either extremely expensive or not available, people were short of food and had to rely on government subsidies. The loss of subsistence food and reliance on other food sources results in cultural changes—subsistence is a central feature of Native cultures in the region—that include the loss of traditional knowledge and language, and change in cultural priorities. The losses are progressively harder to reverse with time.

FIGURE S-1 Map of Alaska showing the Arctic-Yukon-Kuskokwim region. The region of concern for the purposes of this study includes the Yukon River drainage, the Kuskokwim-Goodnews drainage, and the drainages between Shishmaref in the north and Cape Newenham in the south. The area of study does not include North Slope drainages and the northern part of the Northwestern region drainages. Source: Adapted from USGS 2004.

The reasons for the drop in salmon returns are not well understood, which makes it difficult for fishery managers and scientists to identify appropriate management actions, although they likely involve aspects of the life cycles of the fish and their environments in freshwater and in saltwater as well as human impacts.

The AYK Sustainable Salmon Initiative (SSI) was created through a $5M congressional appropriation in 2002 to undertake an expanded research program toward gaining an understanding of the declines of salmon and to support sustainable salmon management in the region (an additional $8.5 million has been appropriated through 2004). An AYK Research and Restoration Plan is being developed by the Scientific and Technical Committee (STC) of the AYK SSI. It is intended to identify the best way to investigate and understand this complex system and ultimately to devise a means to anticipate or predict future sizes of salmon populations.

THE PRESENT STUDY

To help the AYK SSI prepare the research and restoration plan, the STC of the AYK SSI requested the help of the National Research Council (NRC). The committee's statement of task is in Box S-1.

The committee has met three times, beginning September 27-30, 2003, when it held public sessions in Bethel, St. Mary's, Aniak, Nome, and Unalakleet. The committee attended an AYK SSI workshop in Anchorage, November 18-20, 2003, and some committee members and staff attended a meeting of the Tanana Chiefs Conference Natural Resources Coalition in Fairbanks, January 22-23, 2004. The committee held its next meeting February 2-6, 2004, which included public sessions in Nome and Unalakleet. In this first of two reports, the committee is charged with providing insights from the AYK SSI workshop, public sessions, briefings, relevant science plans, published literature, and the committee members' expertise to help the STC avoid difficulties and pitfalls as it develops a draft research and restoration plan. After the AYK SSI submits that plan, this committee will produce a second report that reviews the plan.

BOX S-1 NRC Committee Statement of Task

The NRC committee will assist the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (AYK SSI) in developing a high-quality, long-range restoration and research (science) plan for the AYK region. The committee will assess the current state of knowledge, describe ongoing research in the region, and identify research questions of greatest relevance to the region. It will outline essential components of a successful, long-term science plan, identify research themes that the science plan should be based on, and identify critical research questions within the research themes. The committee will later review the research and restoration plan drafted by the Scientific and Technical Committee of the AYK SSI.

SUBSISTENCE

Subsistence as it applies to rural Alaska Natives is not easy to define, but it is integral to their way of life. Its importance is reflected in their language and culture and in placement of their settlements. It is a way of obtaining food, clothing, and other necessities; it is a way of life; it is a connection to the land and the water; and it has been encoded in state and federal laws, which protect it or give it priority over other uses.

This report focuses on subsistence mainly as an activity that takes fish, but a failure to understand the context of its integral and fundamental importance to Alaska Native ways of life and culture would make any discussion of it misguided at best.

LIFE HISTORIES OF SALMON SPECIES IN THE REGION

The life histories of the five species of Pacific salmon—Chinook, coho, chum, pink, and sockeye—found in the AYK region share several general characteristics. All species are anadromous: spawning occurs in freshwater, juveniles then migrate to the marine environment where they obtain 90-99% of their total growth, and mature adults return to freshwater to spawn. Little or no food is taken by returning adults in freshwater. Individuals of all species typically home rather precisely to their natal area to spawn. All species are semelparous, spawning only once and dying a few days or weeks later. Typically, females select a redd site and dig a depression in the gravel where they deposit eggs in a series of pockets; they cover each pocket in turn. Males fight among themselves for proximity to a female to increase their chances of fertilizing her eggs; small males may successfully fertilize eggs by sneaking into the nest depression when the female releases her eggs. After spawning, a female typically spends her last few days of life defending her nest site against late-arriving females. In the AYK region, salmon eggs usually hatch in early to midwinter and the young salmon remain in the gravel until they emerge in spring. During this time, they live on the energy reserves in their yolk sac and they can be quite active, often burying more deeply into the gravel, presumably to avoid being disturbed by floods.

After the salmon emerge from the gravel in the spring, the life histories of the five species diverge. Most pink and chum salmon begin their migration to the ocean within a few days of emergence when they are still small. The other three species—sockeye, coho, and Chinook salmon—spend 1 or 2 years in freshwater and reach a larger size before going to sea. The migration of all species typically occurs soon after spring breakup (May to June), and the fish arrive in the marine environment in early summer.

At ocean entrance, juvenile salmon often first aggregate in intertidal (littoral) waters; then as they grow they gradually move offshore to shallow, pelagic areas near shore or over the continental shelf, from low-tide mark down to a depth of about 200 m. There is no evidence of overlap in distribution of Bering Sea and Gulf of Alaska salmon stocks at the juvenile stage for any salmon species. Gradual offshore movements of juvenile AYK salmon continue throughout their first summer and fall in waters over the Bering Sea shelf, where they are distributed in surface or near-surface waters (to a depth of about 20 m). After their first summer at sea, salmon from the AYK region range widely throughout the Bering Sea and Aleutian Islands, the central and eastern North Pacific Ocean, and the Gulf of Alaska during extensive ocean feeding migrations.

Data are inadequate to infer migration patterns between juvenile and immature life history stages of AYK salmon. The extent of their offshore movements in the Bering Sea and North Pacific Ocean in late fall and winter is not known. In general, western Alaskan stocks migrate farther offshore in winter than stocks from more southerly regions of North America. Many or most AYK juvenile sockeye, chum, pink, and coho salmon move south through the Aleutian passes into the central and eastern North Pacific Ocean in late fall or winter. Winter trawl surveys have shown that all species of salmon in their first winter at sea can be caught in offshore waters of the North Pacific Ocean by January and February. The area where juvenile AYK salmon are distributed at the end of their first winter at sea may vary from year to year depending on species, stock, age, growth, and environmental conditions. That area could be the approximate high-seas location where they begin their adult return migrations to natal streams.

Upstream migrations of AYK salmon begin between the first of June and the end of October. Interspecific patterns of upstream migrations are similar across the AYK region, with Chinook salmon entering rivers first, followed by summer chum and pink salmon, and fall chum and coho salmon entering last. Very little is known about the marine life history of AYK salmon. Within this broad framework, each species has unique life history characteristics that set it apart from the others. These characteristics include the number of years spent in the freshwater and marine environments and the use that fish make of freshwater and marine habitats.

The fact that mature salmon home rather precisely to their natal areas means that fish spawning in different parts of a drainage are reproductively isolated, and local adaptations can evolve. This has far-reaching implications because these reproductively isolated groups (stocks or populations) often evolve life history characteristics that adapt them to the unique conditions they encounter in the habitats they use for spawning and rearing. As a result, there is considerable stock-specific variation in life history characteristics that fits particular stocks to their particular habitats.

RECENT CHANGES IN FISHERY CATCHES OF SALMON FROM KUSKOKWIM, YUKON, AND NORTON SOUND RIVERS

Although there is a general perception that salmon populations in the AYK region have declined in recent years or even decades, the trends have differed among species and in different parts of the region. In both Norton Sound and the Yukon River, chum fisheries were reduced well before Chinook restrictions. In contrast, in the Kuskokwim region, catches of Chinook, chum, and sockeye were simultaneously reduced in 1993, increased somewhat, and then reduced again in 1996.

DEVELOPMENT AND ESSENTIAL COMPONENTS OF A RESEARCH AND RESTORATION PLAN FOR THE AYK REGION

The elements of a restoration and scientific research plan include a focus of the program, strategies to develop research themes, assemblage of prior research and restoration efforts, and integration of the study plan with existing, ongoing research programs. For the development of research themes, three example approaches are presented in Chapter 4. These approaches are (1) development of a conceptual framework, (2) studies of mortality and productivity rates and of the metapopulation structure, and (3) studies of the resilience of the AYK salmon structure in the face of millennia of environmental change and human exploitation. The existence of numerous research programs in the North Pacific, Bering Sea, and Arctic Ocean will enhance the ability to develop AYK salmon research programs through coordination. The development of a restoration plan depends on the results guided by the research plan, along with what is already known about AYK salmon. It is difficult to develop an effective restoration plan before the general factors that affect AYK salmon abundance are better understood. The committee judges that, aside from a few actions that could only help with no risk of doing harm or a few actions that should be undertaken on an experimental basis, it is premature to develop a detailed restoration plan until better research results are available.

ESSENTIAL COMPONENTS OF AN AYK SSI SCIENCE PLAN

- A mission and/or vision statement: the mission is an intellectual statement that defines AYK SSI's role, and the vision statement comes from informed imagination.
- Background information: this includes a brief regional description, present state of knowledge and other relevant science plans.
- Research and restoration issues and needs the plan will address: these include fishery management and ecosystem concerns along with other scientific issues.
- An overarching theme: the theme is the thread that binds the individual research topics together.
- A set of research themes and approaches to accomplish the needed research: this set often includes topics such as processes and variability in the physical environment, species responses to perturbations, food web dynamics, contaminants, essential habitat, monitoring, modeling, process-oriented studies, and retrospective studies.
- Implementation and protocol issues: these include topics such as policies for cooperation, identifying and addressing user needs, data quality, management and dissemination, logistics, outreach and education, and community involvement.

FRAMEWORKS FOR UNDERSTANDING THE ECOSYSTEMS OF SALMON

The committee concluded from its review of other research programs as well as from the members' own experiences that the best way to develop a research plan is to begin with a model or framework of how the system works. In the present case, the system can be defined in a variety of ways, each with a variety of possible boundaries. They include a biophysical system, a socioeconomic system, a sociocultural system, and a legal system as well as other possibilities. The committee used three system models or frameworks: one based on the life cycle of salmon; another based on human social, economic, cultural, and political linkages; and another based on a historical perspective on the resilience of the AYK salmon-human system. Using three frameworks allows each to provide different insights and can lead to different questions. However, some of the questions that arise are common to all the frameworks.

DEVELOPMENT OF RESEARCH THEMES

Research has developed an enormous amount of information in the AYK region. However, because the region is so large and so sparsely populated, an even greater amount of information remains unknown. The committee has reviewed previous, ongoing, and planned research in the region, as described in Chapter 3. On the basis of that review, the committee concludes that the following questions are of great importance to the region's stakeholders.

- What can be learned about the role of predation in the population dynamics of Pacific salmon? How does predation interact with other factors regulating abundance and determining year-to-year variability in abundance? To adequately address questions about predation mortality of AYK salmon, better information is needed on the distribution, life history, ecology, and population dynamics of the major predators of salmon and their trophic community structure in the Bering Sea and North Pacific Ocean. Essential components of a successful research program include both field research and computer modeling.
- What anthropogenic factors might increase predation mortality of AYK salmon (climate change, hatchery releases, and large-scale marine fisheries)?
- What are the effects of climate-, fishery-, and hatchery-induced changes in Bering Sea and North Pacific marine ecosystems on predation mortality of AYK salmon at each ocean life history stage (juvenile, immature, maturing, and adult)?
- What knowledge is required to identify excessive fishing mortality so that in-season regulation can be effectively applied to reduce this excess mortality?

- Can we identify genetically distinct breeding populations of the five species of salmon in the AYK region? Current information on chum and Chinook salmon is more extensive than that for coho, pink, and sockeye salmon, for which much more extensive analysis is needed throughout the range.
- For the major breeding populations, can we measure the relative abundance and vital rates of the population to predict future population trends? Little is known about the baseline measures of population viability even in the salmon that have been distinguished as separate breeding populations. We need to know fecundity, survival, escapement, and straying rates among these populations if we are to predict their future.
- Are there identifiable trends in fishing mortality within a given stock from current or recent sampling?
- Can we use simulation models, based on estimated vital rates of local populations, to assess the impact of fishing mortality on population viability?
- Can we measure gear- or time-specific mortality on separate stocks within the mixed-stock stream fisheries?
- Can we measure gear- or time-specific mortality on separate stocks within the mixed-stock ocean fisheries?
- In the meetings and workshops with residents of the AYK region as part of this review, the continued harvest and use of salmon was stated as being of paramount importance for sustenance, livelihood, community sustainability, and cultural continuity. What level of harvest can be sustained during the short term (5, 10, or 15 years)? Recognizing that salmon populations generally have been declining in the past decade or more, and harvests have been restricted and curtailed in many instances, what amount of harvest, if any, can be expected in each region, for each species, during rebuilding of salmon stocks? What level of harvest can be sustained over the long term (20 or 40 years)? What role can salmon play in the livelihood of families and communities during the next two generations? Salmon have been a major contributor to the economic and cultural continuity of many communities in the AYK for centuries. Major changes in community economies have become necessary with continued declines in salmon abundance. However, estimates of future salmon abundance are important for community self determination.

HOW TO INTEGRATE TRADITIONAL KNOWLEDGE AND TRADITIONAL SCIENCE

Traditional knowledge and Western science might be woven together best by someone who has grown up with a traditional indigenous upbringing and then gained an understanding of the scientific method through standard research techniques learned on the job or within a university setting. This method could be better than relying on a university-educated person to meet, learn about, and build relationships with an indigenous community or someone raised within an indigenous community attempting to apply the scientific method without proper training. It is often difficult and can take decades for outside researchers to gain the trust and support of indigenous community members. Because of this, many researchers often are not given the "whole story" because a trust relationship has not developed. The encouragement of scientific interests of Native students could help nurture community involvement in the scientific work.

Traditional knowledge and indigenous researchers should be involved in the research within their traditional homelands and about the resources they depend on. Indigenous people have an extensive, historical, and indivisible affinity with the land they call home and a fundamental interest in the outcome of all research pertaining to that land. Their greater involvement in all stages of the research would benefit both the research and the people of the region.

This can be achieved by identifying and encouraging indigenous and collaborative research projects that weave traditional science and traditional knowledge with Western science. Included in this would be consolidating salmon research into a library, including geographical information system data. Local communities should be involved in scientific research. Flow of information should be bidirectional. Entire populations, from elders to schoolchildren, should be represented where appropriate.

CONCLUSIONS

The data show clearly that salmon returns in the AYK region in the 1990s and early 2000s were lower than previously. Those low returns have caused considerable social and economic hardship in the region. The committee concludes further that current scientific information is not sufficient to explain the reasons for the low returns with any confidence. It is at least possible that the low returns represent population fluctuations rather than a long-term declining trend.

Identifying the nature of the declines (or fluctuations) in salmon runs and their causes will take a great deal of research. Conducting that will require much time and money—much more money than the $13.5 million that has been appropriated and even more than the total of $18.5 million whose appropriation is hoped for. However, at least some of that research will need to be completed before a fully developed restoration plan is undertaken, if indeed one proves to be needed. The committee judges that insufficient information is currently available to initiate a large-scale restoration program, although some small-scale local programs appear to be worth investigating. This judgment does not extend to the potential benefits of management actions to reduce fishing mortality or competition with hatchery fish at sea if such actions are supported by available information.

An encouraging aspect of the research enterprise in the region is the degree to which it involves Alaska Native organizations and communities. Any increase in that involvement is likely to benefit the research and the communities themselves even more. In addition, the AYK SSI appears to recognize the need to coordinate and partner with other research programs in the region and elsewhere. Given the large spatial extent of the region (and hence the research problem) and the relatively modest amount of money available, such coordination is essential, as are partnerships.

The committee has not explicitly considered research into social and economic matters for their own sake. That is, the committee has considered social and economic research that is directly tied to the sustainability of salmon runs, but not if it is tied mainly to the sustainability of the communities in the region. The committee interpreted its charge as guiding it in that manner.

RECOMMENDATIONS

Research

This report has described a large number of research themes and questions. Those questions all have scientific interest and all have some potential to shed light on the relationship between human and environmental factors and fluctuations in runs of AYK salmon. However, if results that are useful to management are required in a reasonable amount of time, then prioritization is required. The committee suggests the following approaches to prioritizing research funding. We assume that the ultimate goal of the AYK SSI is management, that is helping to ensure that salmon runs can be exploited sustainably, and our suggestions for research prioritization are made in that context. The committee judges that focusing the research effort on the topics below would be cost-effective and productive.

- The greatest research need appears to be better information on the numbers and distribution in space and time of the various species and stocks of AYK salmon. We need to know more about population sizes and productivity (how many fish there are) and more about the genetic makeup of species and populations. The latter information is a prerequisite for assessing the interaction of human and environmental factors with salmon populations, because different salmon populations have different growth rates, fecundity, productivity, and in general can respond differently to those factors. Better assessments are needed of the numbers of salmon of the five species originating in the various drainages at all life stages and in all the environments they inhabit. Without analyses of numbers and of genetic makeup, analyzing the effects of fishing, including fishing on mixed stocks, is not possible. This research theme is pervasive and the knowledge it embodies is a prerequisite for answering many of the more detailed questions we have described elsewhere.
- It would be of great value to be able to partition factors that affect AYK salmon runs into those that operate mainly in freshwater and the adjacent landscapes, and those that operate mainly in the marine environment. If such partitioning of factors can be achieved, it should be possible to learn whether the most important factors are marine or freshwater; or whether at certain times they are marine, and at other times freshwater; or whether both marine and freshwater factors are important most of the time. For freshwater, this requires a better understanding of habitat variations and their effects on AYK salmon than we now have.
- Better information is needed on the extent, nature, and distribution in time and space of human activities that affect salmon, and the degree to which they affect salmon. In the AYK region, those activities are mainly fishing. In particular, better information is needed on the amount and consequences of recreational fishing and the amount and

effects of bycatch and directed fishing at sea. Better information about the spatial and temporal distribution and landings of subsistence and commercial fishing within and near the rivers of the AYK also would be helpful, as well as about the dependence of that variation on the number and kinds of salmon available. We need to understand factors that influence the development, promulgation, and enforcement of fishing regulations and people's compliance with them. This research theme also is pervasive and a prerequisite for answering many more detailed questions.

Restoration

The committee does not recommend the initiation of a large-scale restoration plan until better information is produced by the research outlined above. However, small-scale local initiatives might hold promise. They include the following:

- Controlled-design experiments to assess the effects on salmon populations in small streams of existing hatcheries if any are re-opened, and on incubation boxes and other enhancement techniques.
- Retrospective analyses should be done on hatchery and incubator systems, both those currently in operation and those that have ceased operations. Such analyses should include North Pacific and Bering Sea hatcheries that seem likely to shed light on issues within the region.

Implementation

The implementation of this research program should use monitoring, process studies, retrospective analyses, and theoretical studies. Models are useful tools in many of these research activities. In addition, adaptive management has the potential to be effective and to contribute to knowledge that could help to form the basis of a restoration plan. In many if not all cases, this would require the cooperation and involvement of management agencies, especially the Alaska Department of Fish and Game (a member of the AYK SSI). Management actions should be designed to include the gathering of scientific data; in other words, they should be thought of as if they were controlled experiments. In truth, management actions often are experiments, but they usually have poor or no experimental controls.

The resources required to address salmon variability in the AYK region are significant because the problem has a variety of geographical scales and it has interdisciplinary aspects. Salmon variability could depend on very small-scale influences such as stream temperature or flow. It also might depend on oceanic conditions that affect the ocean carrying capacity of the Bering Sea and the North Pacific Ocean. Physical, biological, and chemical variations in the ocean, atmosphere, and terrestrial environment could play important roles. This is a large, complex problem, and the ecosystem will be continually changing. This daunting task is made easier through interactions with ongoing and future science programs in the region. The AYK SSI would benefit from coordinating with them, perhaps to the extent of joint funding of research projects. Examples of such programs include the North Pacific Research Board, the Exxon Valdez Oil Spill Gulf Environmental Monitoring Program, the Alaska Ocean Observing System, Ecosystem Fisheries Oceanography Coordinated Investigations, the Bering Sea Ecosystem Study, the Bering-Aleutian Salmon International Survey, the Norton Sound Sustainable Salmon Initiative, the United States/Canada Yukon River Joint Technical Committee Program, the World Wildlife Fund/National Science Foundation Program, and the National Oceanic and Atmospheric Administration Arctic Program.

In addition, the committee recommends monitoring programs as being likely to provide useful information and having the potential to provide long-term data sets. Managing, coordinating, synthesizing, and making available the data collected by all these programs, including research funded by the AYK SSI, are important challenges that need careful consideration in any research plan.

1

Introduction

No, a thousand times no; there does not exist a category of science to which one can give the name applied science. There are science and the applications of science, bound together as the fruit to the tree which bears it. — Louis Pasteur, 1871

BACKGROUND

Alaska salmon and other marine and freshwater fish have been critical to the survival of the people and wildlife in the Arctic-Yukon-Kuskokwim (AYK) region (Figure 1-1) for thousands of years. Salmon and people probably arrived in the region 10,000 years or more ago (Adovasio and Page 2002). Their relationships are complex and intense. Salmon influence the structure of human societies in the region and the places where people live (Glavin 2000); humans, through their various activities, affect the lives and numbers of salmon. Modern technology and economies make it easier than it has ever been for people to deplete salmon populations.

The AYK region, which encompasses more than 40% of the state, includes the Norton Sound region, the watersheds of the Kuskokwim and Yukon Rivers within Alaska, and the coast from the Bering Sea to the Arctic Ocean up to the Canadian border. For this study the area of concern was defined in the memorandum of understanding that established the AYK Sustainable Salmon Initiative (SSI). It includes the river drainages that flow into the Bering Sea north of Cape Newenham and south of Shishmaref (Figure 1-1), as well as the "near and off shore areas" adjacent to them. This committee has not assumed any sharp seaward boundary to the region, but instead has considered all the marine areas used by salmon inhabiting the rivers between Cape Newenham and Shismaref in this study.

In recent years, salmon landings and salmon runs in the region have been lower than they were in the 1970s and the 1980s (Figures 2-1, 2-2, 2-3). Those declines (either natural or human-induced and either reflecting long-term trends or shorter-term fluctuations) in the abundance of

FIGURE 1-1 Map of Alaska, showing the Arctic-Yukon-Kuskokwim region. The region of concern for the purposes of this study includes the Yukon River drainage, the Kuskokwim-Goodnews drainage, and the drainages between Shishmaref in the north and Cape Newenham in the south. The area of study does not include North Slope drainages and the northern part of the Northwestern region drainages. Source: Adapted from USGS 2004.

salmon have created hardships for the people and communities that depend heavily on this resource. The reasons for the drop in salmon returns are not well understood, which makes it difficult for fishery managers and scientists to identify appropriate management actions. Potential factors that cause the declines likely involve aspects of the life cycles of the fish and their environments in freshwater and in saltwater as well as human impacts—mainly fishing—on salmon and their environments.

STAKEHOLDER GROUPS AND THE AYK SUSTAINABLE SALMON INITIATIVE

In response to the recent salmon declines, regional organizations have joined with state and federal agencies to form a partnership to cooperatively address salmon research and restoration needs. This partnership includes the Association of Village Council Presidents; the Tanana Chiefs Conference; Kawerak, Inc.; the Bering Sea Fishermen's Association; the Alaska Department of Fish and Game (ADF&G); the National Marine Fisheries Service (NMFS); the U.S. Fish and Wildlife Service; and additional Native, governmental, and nongovernmental organization ex-officio partner institutions.

The AYK SSI was created through a $5 million congressional appropriation in 2002 to undertake an expanded research program toward gaining an understanding of the declines of salmon in the region and to support sustainable salmon management in the region. In 2003, an additional $5 million was appropriated and $3.5 million was added in 2004. An additional $5 million is in a FY 2005 appropriations bill, which has not been acted on as of July 2004. The funds are available for use through 2020. The AYK has a Steering Committee, which has broad policy responsibility, and a Scientific and Technical Committee (STC), which provides scientific and technical advice to the Steering Committee.

The AYK region includes more than 100 communities, most of which strongly depend on subsistence. To help ensure that the appropriated funds target high-priority issues, an AYK Research and Restoration Plan is being developed by the STC of the AYK SSI. It is intended to identify the best way to investigate and understand the complexity of the system and ultimately to devise a means to anticipate or predict future runs of salmon. Currently available knowledge will be evaluated to assess where it is sufficient to guide harvest and management decisions. Areas with deficient knowledge will be targeted by research funded by the initiative. A responsibility of the STC will be to prioritize the importance of different knowledge gaps. Then they will recommend the funding of projects based on technical merit and on the priority of the knowledge gap they address.

The AYK SSI is directed by a seven-member steering committee that sets policy and allocates funds. The STC, an advisory committee of six independent scientists, is charged with developing a comprehensive research plan for the AYK region and providing review of technical research proposals for the steering committee.

This project differs from other planning activities in the region in that it is broader in geographic scale and will include the Bering Sea, North Pacific, and western Alaska drainages; will coordinate among smaller-scale activities (Norton Sound, Yukon River, and Bering Sea); and will integrate across marine and freshwater disciplines.

THE PRESENT STUDY

To help the AYK SSI prepare the research and restoration plan, the help of the National Research Council (NRC) was requested by the STC of the AYK SSI. The committee's statement of task is in Box 1-1.

The committee is aware of research on the structure of the fishing industry, on processing, and on marketing (e.g., Link et al. 2003, Gilbertsen 2003, Marine Advisory Program 2003). However, it took its task to exclude social and economic research for its own sake. It considered

BOX 1-1 NRC Committee Statement of Task

The NRC committee will assist the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (AYK SSI) in developing a high-quality, long-range restoration and research (science) plan for the AYK region. The committee will assess the current state of knowledge, describe ongoing research in the region, and identify research questions of greatest relevance to the region. It will outline essential components of a successful, long-term science plan, identify research themes that the science plan should be based on, and identify critical research questions within the research themes. The committee will later review the research and restoration plan drafted by the Scientific and Technical Committee of the AYK SSI.

social and economic research only to the degree that it seemed directly relative to the sustainability of salmon in the region.

The committee held its first meeting September 27-30, 2003. During this meeting, it held public sessions in Bethel, St. Mary's, and Aniak. The committee attended the AYK SSI workshop in Anchorage, November 18-20, 2003. Several committee members and staff also attended the Tanana Chiefs Conference Natural Resources Coalition meeting in Fairbanks, January 22-23, 2004. The committee held its next meeting February 2-6, 2004, which included public sessions in Nome and Unalakleet. More information about the meetings can be found in Appendix B.

The committee is scheduled to produce two reports. In this first report, the committee is charged with providing insights from the AYK SSI workshop, briefings, public sessions, relevant science plans, published literature, and the committee members' expertise to help the STC develop a research and restoration plan. This report outlines essential components of a successful, long-term science plan; summarizes other existing research plans for the region that are relevant to the AYK region; refines research themes related to the goals of the AYK SSI, around which the science plan can be organized; and identifies critical research questions that should be addressed within research themes. A benefit of a science plan is the insight for restoration that the research produces, and its application to restoration. That connection is described in this report as well.

After the AYK SSI submits its draft research and restoration plan, the committee will produce a second report that reviews the plan. The NRC committee will evaluate the plan in light of concerns, themes, and questions identified throughout the study process; will recommend actions that agencies and universities can take to implement research programs that will address the plan; and will assess the ability of the plan, over time, to help understand the causes of the decline of these stocks and to provide for sustainable salmon management.

SUBSISTENCE

Subsistence as it applies to rural Alaska Natives is not easy to define, and its meaning is not easily retrieved from most dictionaries, which often include the adjectives "meager" and "mere." Those adjectives are not appropriate for Alaska Native subsistence activities, which are integral parts of their way of life. Its importance is reflected in their language and culture and in the placement of their settlements. It is a way of obtaining food, clothing, and other necessities; it is a way of life; it is a connection to the land and the water; and it has been encoded in state and federal laws, which protect it or give it priority over other resource uses. Reduced salmon runs reduce the opportunities for subsistence in the region. Simply importing groceries from outside the region, while it might provide essential calories, cannot satisfy the social, cultural, and economic deficits that result from a reduction of subsistence activities.

The Alaska Native Interests Land Claims Act (ANILCA) of 1980 defines subsistence as "the customary and traditional uses by rural Alaska residents of wild, renewable resources for direct personal or family consumption as food, shelter, fuel, clothing, tools or transportation; for the making and selling of handicraft articles out of nonedible byproducts of fish and wildlife resources taken for personal or family consumption; for barter or sharing for personal or family consumption; and for customary trade." Recently, the Federal Subsistence Board (FWS 2003a) has clarified that customary trade includes the selling of whole or processed subsistence products as long as the sale is not to a business or made by a nonrural resident.

The following definition of subsistence by a group of the International Whaling Commission provides additional insight into the nature of subsistence to Alaska Natives: "Aboriginal subsistence whaling means whaling, for purposes of local aboriginal consumption carried out by or on behalf of aboriginal, indigenous or native peoples who share strong community, familial, social and cultural ties related to a continuing traditional dependence on whaling and on the use of whales." This applies to the use of salmon as well as to the use of whales.

In this report, we focus on subsistence mainly as an activity that takes fish, but a failure to understand the context of its integral and fundamental importance to Alaska Native ways of life and culture would make any discussion of it misguided at best. This description provides only the briefest introduction to subsistence in Alaska. A good introduction to subsistence in southwest Alaska is provided by Barker (1993).

FISHING IN THE REGION

Commercial, subsistence, and recreational fishing all occur in the AYK region. Commercial fishing is very different from the industrial-scale operations many people think of when they hear the term and that occur elsewhere in Alaska. Often, the gear and boats used for commercial fishing are the same as those used in subsistence fishing, and the proceeds of commercial fishing subsidize subsistence fishing to a considerable degree. Most commercial and subsistence fishing is done with gill nets in and near the rivers. It takes place throughout the region, far into the interior. Most of the boats are small and are outboard-powered.

Recreational fishing in the AYK region is not as widespread as it is in Bristol Bay and central Alaska drainages, and there are not as many anglers there as in many other parts of Alaska. This is related to the relative lack of facilities for anglers in the region. Nonetheless, some especially favored rivers and areas see considerable fishing pressure, with anglers usually guided by local or other outfitters and guides but sometimes self-guided. Some conflicts have occurred between members of local communities and recreational anglers from outside the region, but in some cases local communities provide the guiding and lodging services for anglers.

UNDERSTANDING THE ECOSYSTEMS OF SALMON

The committee concluded from its review of other research programs as well as from the members' own experiences that the best way to develop a research plan is to begin with a model of how the system works. In the present case, the system can be defined in a variety of ways, each with a variety of possible boundaries. They include the biophysical system, the socioeconomic system, the sociocultural system, and the legal system as well as other possibilities. The committee has not tried to write a research and restoration plan; instead, its task is to advise the AYK SSI on how best to do that. Therefore, instead of picking one model of the system to develop its own ideas of important research questions, it has used three, which are discussed in detail in Chapter 4. The use of three models has the additional advantage that each provides different insights and can lead to different questions, although some of the questions that arise are common to all the models.

REPORT ORGANIZATION

Chapter 2 provides background information on salmon life history and fisheries issues in the AYK region. Chapter 3 explains historical and recent fisheries research in the region. Chapter 4 details the foundations for developing a salmon research and restoration plan. Chapter 5 summarizes the committee's conclusions and recommendations. Appendix A outlines the legal context of Alaska salmon fisheries, and Appendix B describes the committee's open meetings and information-gathering sessions.

2

Salmon Life History and Background

LIFE HISTORIES OF SALMON SPECIES IN THE AYK REGION

The following sections describe the life histories of the five species of Pacific salmon (*Oncorhynchus* spp.) found in the Arctic-Yukon-Kuskokwim (AYK) region. These sections focus on habitat use over the course of their life histories; more detailed information on reproduction, foraging, predation, and other aspects of salmon life history is provided in other sections of this report. The concluding section presents some information on recent variations in run sizes, catches, and revenue from commercial fishing in the AYK region.

Testimony presented by village elders and others during the 2003-2004 National Research Council (NRC) site visits showed that there is a substantial body of traditional knowledge about salmon life history in the AYK region that has yet to be integrated with information from the published scientific literature. Much of the information in this chapter is summarized from more detailed reviews by Burgner (1991) (*O. nerka*, sockeye or red salmon), Healey (1991) (*O. tshawytscha*, Chinook or king salmon), Heard (1991) (*O. gorbuscha*, pink or humpback salmon), Salo (1991) (*O. keta*, chum or dog salmon), and Sandercock (1991) (*O. kisutch*, coho or silver salmon).

The Norton Sound Scientific Technical Committee (NSSTC) reviewed life history information specific to AYK salmon (Mundy et al. 2002). Brodeur et al. (2003) reviewed U.S. research on the ocean life history of juvenile salmon—that is, salmon in their first year at sea (ocean age .0, before January 1 of their second year at sea).[1] Information on the ocean life history of immature and maturing AYK salmon is based largely on extensive high-seas research gill net, purse seine, longline, and trawl surveys; tagging experiments; and stock identification studies conducted as part of the research programs of the International North Pacific Fisheries Commission (INPFC) from 1953 to 1992 and the North Pacific Anadromous Fish Commission (NPAFC) from 1993 to present. Detailed research methods and results are presented in the annual report, bulletin, statistical yearbook, and technical report series of INPFC and NPAFC (also see reviews by Burgner 1992, Myers et al. 2000). Broad syntheses of the INPFC/NPAFC data were used to develop conceptual models of the movements of immature and maturing salmon on the high seas (coho salmon, Godfrey et al. 1975; sockeye salmon, French et al. 1976; chum salmon, Neave et al. 1976; Chinook salmon, Major et al. 1978; pink salmon, Takagi et al. 1981), although these models need to be updated with new information. Additional sources of information are cited throughout the text.

General Life History Characteristics

The life histories of all five species of Pacific salmon found in the AYK region share several general characteristics. All species are anadromous: spawning occurs in the fall, usually in freshwater, and juveniles then migrate to the marine environment. In the ocean, salmon grow to maturity, and mature adults return to freshwater to spawn. Individuals in all species typically home rather precisely to their natal area to spawn. All species are semelparous, spawning only once and dying a few days or weeks later.

Within this general framework, many other life history characteristics are common to all species. Mature females bury their relatively

[1]Age and life history are designated by the European method. For example, an age 1.3 Chinook salmon spent one winter in freshwater (F) and three winters in the ocean (W). The number before the dot designates the number of winter annuli laid down on the fish's scales while in freshwater, and the number after the dot designates the number of winter annuli formed in the ocean. The Alaska Department of Fish and Game may designate the age of an adult salmon by its total age (T) at return, where T = F + W + 1 (for example, a 1.3 Chinook is 5 years old). This calculation accounts for the fact that scales do not form until after the fish hatch, so the first winter of life spent as a developing egg and alevin in the stream gravels is not recorded on the scales.

large (5-10 mm) eggs in stream gravels, and, in the case of beach spawning sockeye, along lake shores. Average fecundities range from 1,200 for pink salmon to 17,000 for Chinook salmon. Typically, a female selects a redd site and digs a depression in the gravel, where she deposits her eggs in a series of pockets, and covers each pocket in turn. Males fight among themselves for proximity to a female to increase their chances of fertilizing her eggs, and small males may fertilize eggs by sneaking into the nest depression at the time the female releases her eggs. After spawning, a female typically spends her last few days of life defending her nest site against late-arriving females.

The female protects her eggs from predators and environmental extremes by burying them in the gravel. She also selects a habitat that will provide her offspring with suitable conditions for development. Principal requirements of eggs are a temperature regime that provides sufficient degree-days for development, adequate dissolved oxygen for respiration and growth, and adequate through-gravel flow to supply oxygen and remove waste products. The temperature regime in the spawning gravels is closely related to the time at which salmon spawn. Spawning occurs earlier in areas where the water in the gravel cools to near freezing early in the winter, and it occurs later in areas where upwelling groundwater maintains relatively high intragravel temperatures during winter. In the AYK region, salmon eggs typically hatch in early to midwinter and alevins remain in the gravel until they emerge in spring. During this time, they live on the energy reserves in their yolk sac and can be quite mobile, often burying more deeply into the gravel, presumably to avoid being disturbed by floods.

Salmon fry emerge from the gravel in spring, typically at night, and at this point their life histories diverge. Most pink and chum salmon begin their migration to the ocean within a few days of emergence when they are still small fish (approximately 1 g, 25-35 mm) and concurrently undergo the physiological, morphological, and behavioral changes associated with smolting. These changes prepare them for their downstream migration and for entering the marine environment. The other three species—sockeye, coho, and Chinook salmon—will spend 1 or 2 years rearing in freshwater and reach a larger size (8-20 g, 70-150 mm) before smolting. The smolt migration of all species typically occurs soon after spring breakup, a time associated with increasing water temperatures and flows, and the fish arrive in the marine environment in early summer.

At ocean entrance, juvenile salmon often first aggregate in intertidal (littoral) waters; then, as they grow, they gradually move offshore to neritic habitats (shallow, pelagic areas near shore or over the continental shelf, from low-tide mark down to a depth of about 200 m). Tagging experiments have revealed that the direction of movement and migratory routes of juvenile salmon in coastal waters are inherited or specific to regional stock groups. Initial coastal movements of AYK juvenile salmon may be in the direction of prevailing ocean currents. AYK juvenile salmon spend most or all of their first summer and fall at sea in waters over the continental shelf in the Bering Sea, Aleutian Islands, and Arctic Ocean. Distributions of Bering Sea and Gulf of Alaska salmon stocks at the juvenile stage do not overlap for any salmon species.

Gradual offshore movements of juvenile AYK salmon continue throughout their first summer and fall in neritic waters over the Bering Sea shelf, where they are distributed in surface or near-surface waters (to a depth of 20-30 m). Salmon (surface trawl) surveys in the eastern Bering Sea in July-September by the National Marine Fisheries Service (NMFS), Auke Bay Laboratory, Ocean Carrying Capacity (OCC) indicate substantial annual, seasonal, and spatial variation in distribution by species and stock (Farley et al. 1999; 2000a,b; 2001). These surveys also suggest that oceanic conditions, especially as indicated by coccolithophore blooms, influence the distribution and migration routes of juvenile salmon. Studies in other regions indicate that vertical distribution of juvenile salmon in neritic habitats is influenced by biotic (species, age, size, and forage location) and abiotic (water temperature, salinity, season, light, turbidity, currents, tides, and bottom topography) factors. Seasonal use of neritic habitats by juvenile salmon in other regions has also been linked to many factors, such as species-, stock-, and size-specific preferences for water temperature and distribution and availability of their preferred prey.

After their first summer at sea, salmon from the AYK region of western Alaska range widely throughout the Bering Sea and Aleutian Islands, the central and eastern North Pacific Ocean, and the Gulf of Alaska during extensive ocean feeding migrations. Historical International North Pacific Fisheries Commission/North Pacific Anadromous Fish Commission (INPFC/NPAFC) data are inadequate to infer migration patterns between juvenile and immature age 0.1 life history stages of AYK salmon. The extent of their offshore movements in the Bering Sea and North Pacific Ocean in late fall and winter is unknown. In general, western Alaskan stocks migrate farther offshore in winter than stocks from more southerly regions of North America. Based on the distribution of age 0.1 salmon the following spring, many or most AYK juvenile sockeye, chum, pink, and coho salmon move south through the Aleutian passes into the central and eastern North Pacific Ocean in late fall or winter. Winter trawl surveys have revealed that all species of salmon in their first winter at sea can be caught far offshore in the North Pacific Ocean by January and February, although the stock composition of these catches is not known. The area where juvenile AYK salmon are distributed at the end of their first winter at sea may vary from year to year depending on species, stock, age, growth, and environmental conditions and could be the approximate high-seas location where they begin their adult return migrations to natal streams.

Data from INPFC/NPAFC tagging experiments show that the ocean distributions of AYK salmon and of salmon from other regions of North American (central and southeast Alaska, British Columbia, and the U.S. West Coast) overlap primarily in the Gulf of Alaska (defined as northeast of 50°N 170°W), the northeastern North Pacific Ocean (defined as southeast of 50°N 170°W), and the southeastern Bering Sea (Myers et al. 1996). The offshore distribution and migration patterns of AYK salmon are more similar to Asian (Russian and Japanese) salmon than to other regional stocks of North American salmon. The distributions of Asian and AYK salmon are known to overlap eastward from about 170°E, across most of the Bering Sea and Aleutian Islands, North Pacific Ocean, and western and central Gulf of Alaska. The extent of overlap in the distributions of AYK and Asian salmon in the Russian exclusive economic zone (EEZ) in the Arctic Ocean, western Bering Sea, and western North Pacific Ocean is not known.

Knudsen (2003) and NSSTC (Mundy et al. 2002) reviewed information on the marine life history of adult salmon returning to the AYK region (sex ratios, ages, sizes, travel and stray rates, milling time in the vicinity of river mouths, and upstream migration timing). Upstream migrations of AYK salmon generally occur between the first of June and the end of October. Interspecific patterns of upstream migrations are similar across the AYK region, with Chinook salmon entering rivers first, followed by summer chum and pink salmon, and with fall chum and coho salmon entering last. Knudsen (2003) concluded that very little is known about the marine life history of AYK salmon at this time.

Species-Specific Life History Characteristics

Within this broad framework, each species of salmon has unique life history characteristics that set it apart from the others. Some of these characteristics include the number of years spent in the freshwater and marine environments and the use fish make of freshwater and marine habitats. Adults of the five species in the AYK region are often smaller than their counterparts farther south.

Pink Salmon

Pink salmon are distinguished by their obligate 2 year life cycle and brief freshwater residence. All fish have a 0.1 life history. Because of this obligate life cycle, there are even- and odd-year runs that do not interbreed. Pink salmon in the AYK region typically spawn close to the ocean, often in short coastal streams.

Outmigration of juvenile pink salmon from the Yukon River peaks before mid-June, and they seem to move rapidly through delta habitats to the delta front. Recent (2002-2003) OCC surveys over the eastern Bering Sea shelf and Kotzebue Sound show that in the fall juvenile pink salmon are found in offshore habitats between 60°N and 63°N (Farley et al. 2003a,b; Murphy et al. 2003). Historical INPFC/NPAFC data on the distribution of age 0.1 fish the following spring suggest that many or most AYK pink salmon move south through the Aleutian passes into the central and eastern North Pacific Ocean in late fall or winter. Pink salmon, averaging 30 cm long, are broadly distributed across the southern Gulf of Alaska in January and February. In the North Pacific Ocean west of 180°, pink salmon are distributed south of 46°N in January-March. Early in their second summer at sea, maturing AYK pink salmon begin their homeward migration and are distributed in the northeastern North Pacific in early spring (April) and in the central North Pacific Ocean, Aleutian Islands, and Bering Sea in June and July, reaching their spawning grounds in western Alaska in middle to late summer. Pink salmon are the smallest of the five species and mature adults typically weigh 1-2.5 kg.

Chum Salmon

Chum salmon migrate to the ocean soon after they emerge from the gravel, but, unlike pink salmon, the length of their marine residency is variable. Life histories for AYK chum salmon stocks are predominantly 0.3 and some mature at age 4. A significant percentage mature as 0.2 and 0.4 fish at ages 3 and 5, respectively. Two distinctly different races of chum salmon exist in Alaska: summer chum and fall chum. By convention, adults returning before July 15 are termed summer chum, and those returning after July 15 are termed fall chum. Summer chum spawn in late summer in clearwater runoff rivers, often in areas of upwelling flows. Fall chum spawn later, in early winter, typically in areas of groundwater upwelling on glacially influenced streams.

In the Yukon River, the outmigration of juvenile chum salmon peaks in late June when millions of small fry (approximately 40 mm) are dispersed by high river discharges through numerous distributary channels into coastal habitats. Catches of rearing fry in Yukon delta habitats decrease as water temperatures increase (18-21°C) in mid-July, and fish are found in coastal and delta front habitats from June through early August. Similar movements of juvenile chum salmon have been observed in Norton and Kotzebue Sounds. Genetic (allozyme) stock-identification analysis of samples of juvenile chum salmon collected in fall 2000 and 2002 surveys in the eastern Bering Sea recently has provided more detailed information on the distribution of AKY chum early in their first summer at sea. This work shows that: (1) Kotzebue Sound chum salmon are distributed as far south as the Yukon River, suggesting a southerly migratory pathway; (2) Yukon River fall chums are widely distributed from off the mouth of the Yukon River, eastward to 62°N 172°W, and as far south as Nunivak Island (60°N), suggesting a southwesterly migration pathway along the Bering Sea shelf; (3) Kuskokwim fish are narrowly distributed south of Nunivak Island from the mouth of the Kuskokwim River, south to 58°N and as far west as 168°W, suggesting a westerly migration pathway along the Bering Sea shelf; and (4) northern Russia stocks (mainly Gulf of Anadyr watersheds) are distributed as far east as 62°N 171°W (Farley et al. 2003a,b; Murphy et al. 2003). Recent (2002-2003) OCC surveys in neritic habitats over the eastern Bering Sea shelf and Kotzebue Sound show that juvenile AYK chum salmon are generally north of 58°N in the fall. Based on the distribution of age 0.1 fish the following spring, many or most of these individuals are thought to move south through the Aleutian passes into the central and eastern North Pacific Ocean in late fall and winter.

In subsequent years of ocean life, immature AYK chum salmon are distributed in the northeastern Pacific Ocean in fall (November), in the Gulf of Alaska in fall (November), spring (May), and summer (May-August), in the Aleutian Islands in late spring and summer (June-August), and in the Bering Sea in summer (July). Maturing AYK chum salmon are distributed in the central and eastern North Pacific Ocean in spring (April-May), in the Gulf of Alaska in spring and summer (April-August), in the Aleutian Islands in spring and summer (May-July), and in the Bering Sea in summer (June-August). Summer chum salmon reach their spawning areas by middle to late summer, and fall run fish reach their spawning grounds in fall and early winter. Adult chum salmon in the AYK region typically weigh 2.5-4.5 kg.

Sockeye Salmon

Sockeye salmon are distinguished from the other species of Pacific salmon in that they spend a significant amount of time rearing in freshwater lakes. As a result, large sockeye runs are restricted to systems with suitable lakes. In Alaska, sockeye are particularly abundant in the lake systems of Bristol Bay, although smaller but significant stocks do exist in the drainages farther north. Life histories in the Kuskokwim River are predominantly 1.3, 2.3, and 1.2. Sockeye spawn in lake inlet and lake outlet streams and, in some systems, along lake shores. Fry migrate into the lake after emergence and spend one or two summers rearing there before smolting.

Recent (2002-2003) OCC surveys over the eastern Bering Sea shelf and Kotzebue Sound show that by fall, juvenile sockeye salmon, primarily Bristol Bay stocks, are broadly distributed across the eastern Bering Sea shelf south of 59°N (Farley et al. 2003c). Based on the distribution of age 0.1 salmon the following spring, many or most AYK juvenile sockeye then move south through the Aleutian passes into the central and eastern North Pacific Ocean in late fall or winter. By January and early February relatively few juvenile sockeye salmon remain in the Bering Sea, and they are broadly distributed across the central and eastern North Pacific Ocean. Their winter high-seas distribution in the North Pacific extends southward to about 46°N in the central North Pacific and 48-51°N south of the Alaska Peninsula. Their migrations are extensive, covering an estimated distance of 1,300-1,850 km at a travel rate of at least 14.8-18.5 km per day.

Subsequent movements see immature western Alaska sockeye salmon (mostly Bristol Bay, ocean age 0.1 and 0.2) widely distributed in North Pacific waters south of 50°N from the Gulf of Alaska to about 175°E during midwinter. In early spring they may move farther south to feed on the first plankton blooms, and by midspring they move northward over a broad east to west front between about 175°E and 155°W. By June they are distributed in the boundary region between westward and eastward flowing currents (sometimes called the *ridge domain*) and in the narrow (less than 30 km wide), high-velocity (more than 50 cm/s), and westward flowing Alaska current, immediately south of the Aleutian

Islands, where they may remain through the summer. Summer migrations of immature sockeye salmon in this region are initially westward, and at least some immature fish make extensive migrations to the west and northwest through the Aleutian passes and into the central and western Bering Sea. In fall and early winter, immature fish move south and are joined by a new brood of age 1 and 2 fish. Maturing fish remain throughout the winter and spring in more northerly waters of the North Pacific Ocean than immature fish. Sockeye salmon that mature after only one winter at sea (jacks) may remain throughout the fall, winter, and spring in eastern Aleutian Islands and Bering Sea waters. Sockeye reach their spawning grounds in midsummer. Adult sockeye salmon typically weigh 2-3 kg.

Coho Salmon

Coho salmon are distinguished from pink and chum salmon by a period of freshwater rearing and from sockeye salmon by the fact that they typically rear in streams rather than in lakes. Life histories of AYK coho salmon are typically 2.1, so fish are 4 years old when they spawn. Some male coho mature after only a few months at sea and these are known as jacks. Jacks typically have a 1.0 life history, having grown rapidly in freshwater and smolted after 1 year. Coho salmon spawn in small streams in coastal areas of the AYK region and in spring-fed streams in the interior. The timing of spawning is later than for other species, with the exception of fall chum: late summer in coastal systems and early winter in the interior. After emerging from the gravel in spring, coho salmon fry feed on drifting invertebrates in streams, moving to faster, deeper water as they grow. Coho salmon also make considerable use of off-channel habitats such as beaver ponds, side channels, and oxbows for summer feeding and also will rear in lakes when these are available. Like most salmonids that use small streams, coho spend much of the winter concealed in cover, typically under stream cobbles, and they often migrate to overwinter in off-channel habitats or small streams.

Recent (2002-2003) OCC surveys over the eastern Bering Sea shelf and Kotzebue Sound found juveniles in nearshore habitats during fall, suggesting juvenile coho salmon spend a considerable part of their first summer near shore. During salmon research (purse seine) fishing operations in the eastern Bering Sea and Aleutians in July, Hartt and Dell (1986) also caught juvenile AYK coho salmon in small numbers in the eastern Bering Sea in July, August, and September. Based on the distribution of age 0.1 salmon the following spring, many or most AYK juvenile coho salmon move south through the Aleutian passes into the central and eastern North Pacific Ocean in late fall and winter. In the North Pacific Ocean west of 180°, coho salmon are distributed south of 46°N in January-March and well offshore in the central Gulf of Alaska. Maturing AYK coho salmon are distributed in the northeastern Pacific Ocean in spring, while in summer they occur in the central North Pacific Ocean to the western Gulf of Alaska. Maturing coho salmon reach their spawning grounds in late summer. Adult AYK coho salmon typically weigh 2.5-3.5 kg.

Chinook Salmon

The life history of Chinook salmon in the AYK region resembles that of coho salmon in some ways, but they are distinguished by their longer marine residence and larger body size. With few exceptions, AYK juvenile Chinook salmon smolts are stream-type (predominantly freshwater age 1.) and differ from those found farther south, which are the ocean-type (freshwater age 0.). Most Yukon River Chinook have 1.3 or 1.4 life histories, maturing at age 5 or 6. However, age at maturity is quite variable; significant numbers of males also mature at ages 4 and 7, and significant numbers of females mature at age 7. Chinook salmon spawn in small streams in coastal areas of the AYK region and in clearwater runoff streams in the interior. Their use of small streams in coastal areas resembles coho salmon, but, unlike coho, very few Chinook spawn in spring-fed streams in the interior. Instead, they resemble chum salmon in their choice of clearwater runoff systems, where they generally spawn in the tails of large pools and in runs in areas where downwelling predominates. Upon emergence from the gravel, Chinook salmon feed on drifting invertebrates, moving to faster deeper water as they grow. Chinook fry and fingerlings may migrate upstream from spawning areas to feed in smaller streams; they also may move downstream to feed in larger glacially influenced systems, where the turbidity may provide protection against predators. Chinook are also less likely than coho to use off-channel habitats such as beaver dams. Juvenile Chinook typically are found in larger streams, concentrated in areas where there is woody debris, often along the outside of meander bends in pools. This woody debris undoubtedly provides cover from predators but also may provide velocity refuges and generate systems of vortices that small fish can use to reduce the energetic cost of foraging.

Upon migration to the ocean, Chinook smolts from the Yukon River do not appear to use littoral habitats in the vicinity of the delta, contrasting with ocean-type Chinook salmon in British Columbia (Healey 1991). However, recent (2002-2003) OCC juvenile salmon surveys over the eastern Bering Sea shelf and Kotzebue Sound reveal that juvenile Chinook salmon occur in nearshore marine habitats during fall, suggesting that they do not all move offshore as soon as they enter the marine environment. Traditional ecological knowledge also reveals that Norton Sound is a rearing area for Yukon River Chinook salmon juveniles in summer and fall. This finding (observation) is supported by recent tag recoveries of juvenile Yukon River Chinook salmon in Norton Sound. Salmon research on (purse seine) fishing operations in the eastern Bering Sea and Aleutians in July shows that some Chinook salmon do move offshore early in their first summer at sea (Hartt and Dell 1986). Juvenile Chinook salmon first appeared in eastern Bering Sea catches in late June, and they were also caught in all subsequent time periods. NMFS observer data indicated that in December at least some juvenile Chinook salmon are distributed in the international waters of the central Bering Sea. Data from INPFC/NPAFC tagging experiments show that immature AYK Chinook salmon are distributed in the central and eastern Bering Sea in winter and spring and in the central and western Bering Sea in summer. Maturing AYK Chinook salmon are distributed in the central and eastern Bering Sea in winter and spring. Chinook salmon are the largest of the five species, with recorded weights of up to 45 kg; in the AYK region adults typically weigh 5-10 kg.

Stock-Specific Life History Differences

The fact that mature salmon home rather precisely to their natal areas means that fish spawning in different parts of a drainage are reproductively isolated and local adaptations can evolve. This has farreach ing implications because these reproductively isolated groups (stocks or populations) often evolve life history characteristics that adapt them to the unique conditions they encounter in the habitats they use for spawning and rearing. As a result, considerable stock-specific variation in life history characteristics exists that fits particular stocks to their particular habitats. Summer and fall chum salmon populations in the Yukon

River provide an example of this kind of local adaptation. The timing of their spawning migrations and the location of their spawning areas are distinct and adapt them to spawn at a time and place that will provide the correct thermal environment for egg development. Kuskokwim Chinook provide another example. Fish destined to spawn in upstream tributaries begin their upstream migration before fish bound for tributaries farther downstream; this is likely to be an adaptation that allows upstream stocks more time to reach the spawning areas at the appropriate time for spawning. Another example of local adaptation is the large body size of some Chinook salmon stocks. This is thought to have evolved as an adaptation for spawning in fast, deep water with a large spawning substrate. Conversely, small body size and drab coloration has evolved in sockeye salmon stocks that spawn in shallow streams subject to heavy predation by bears. Similar local adaptations of other life history traits undoubtedly exist, including characteristics such as egg size, fecundity, developmental rates, foraging and predator avoidance behavior, length of freshwater and marine residence, migratory timing, migratory routes, and reproductive behavior. This diversity of local adaptation is one of the characteristics that allow salmon to make such effective use of fresh water and marine environments and undoubtedly contributes to their abundance. This variability among a large variety of stocks within each species, and among species, likely provides resilience to environmental change. Changes in the marine environment, however, are likely to cause changes in all stocks because salmon spend most of their life at sea, where most of their growth and reproductive potential is attained. This variability among stocks within species serves to complicate conservation measures, for this variability contributes unique characteristics (phenotypic and genotypic) that should be preserved into the future (e.g., Hilborn et al. 2004). Management practices that do not recognize and preserve this diversity will endanger the resilience of the system.

RECENT VARIATIONS IN RUNS AND CATCHES

Here we present some information on the recent declines in run sizes, catches, and revenue from commercial fishing for AYK salmon. As we discuss in later chapters, it is not clear whether the recent declines reflect long-term trends or instead shorter-term fluctuations. In either case, they have been accompanied by hardship and anxiety among the region's residents and were a major reason for the establishment of the AYK Sustainable Salmon Initiative (SSI) and the present committee.

Figure 2-1 provides information on commercial catches of salmon in the Arctic-Yukon-Kuskokwim (AYK) region. The information before the 1980s cannot be used as an indicator of run sizes, because commercial catches do not depend only on run sizes. They depend also on the amount of fishing effort expended, which in turn depends on factors such as the price of salmon, the availability of salmon markets, the degree to which a community is involved in a cash economy, regulatory restrictions, and other factors. The declines in the past 15 years are at least somewhat reflective of declines in run sizes.

Figures 2-2 and 2-3 present information on gross earnings from commercial fishing in the Yukon-Koyukuk and the Wade Hampton census areas. The former area includes much of the interior part of the AYK region, focusing on the Yukon River drainage. The second area includes much of the downriver area of the Yukon River, including the delta. Recent commercial-fishing incomes in the Yukon-Koyukuk Census Area have been 78% less than they were in 1995.

The overall economic base of the Wade Hampton Census Area decreased 23% from 1995 to 1999. The decrease was primarily due to poor

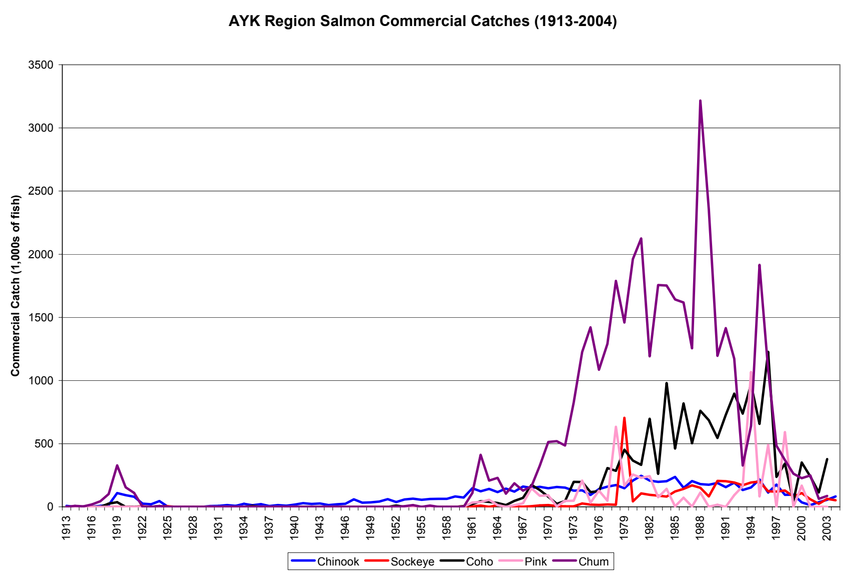


FIGURE 2-1 Historical trends in commercial catches of salmon in the Arctic-Yukon-Kuskokwim management region (1913-2004). Preliminary data for 2004 include only Chinook and sockeye salmon catches through July 9, 2004. Source: Alaska Commercial Fisheries Entry Commission 2004.

salmon runs beginning in 1996 and cutbacks in federal government spending. Gross earnings from commercial fishing were 24% less than what they were before the collapse of salmon runs.

The low salmon returns resulted in lower catches and increased regulatory restrictions on fishing. That resulted in reduced revenue for cash-short communities along the region's rivers. Those losses forced fishers, especially in the lower reaches of the rivers, to reduce fishing times and use less expensive and less efficient gear. Restrictions on subsistence fishing and lower catches also affected all aspects of the lives of people in the region. Especially in interior regions, where other subsistence foods were less abundant during that period and groceries are either extremely expensive or not available, people were short of food and had to rely on government subsidies. The loss of subsistence food and reliance on other food sources results in cultural changes—subsistence is a central feature of Native cultures in the region—that include the loss of traditional knowledge, language, and change in cultural priorities. Those losses are progressively harder to reverse with time.

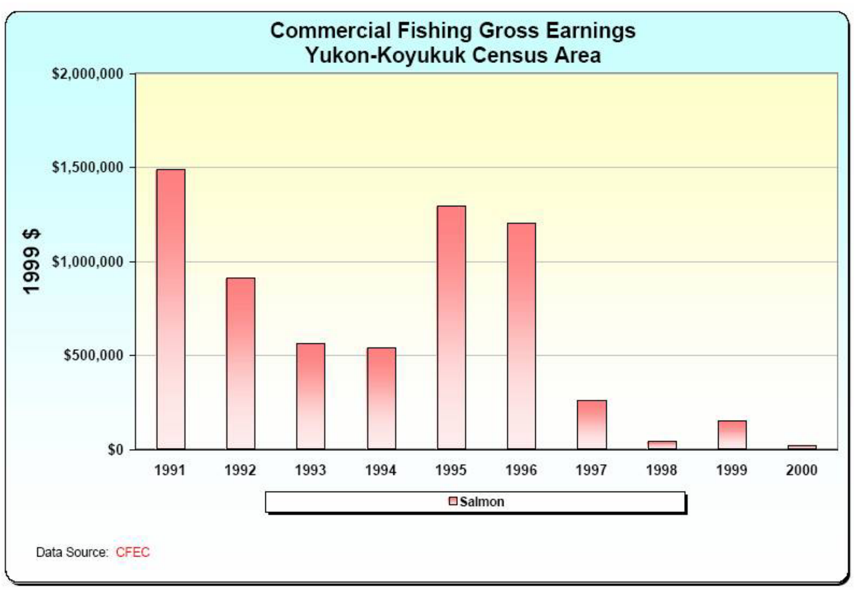


FIGURE 2-2 Gross earnings from commercial fishing in the Yukon-Koyukuk census area. Source: Alaska Commercial Fisheries Entry Commission 2004.

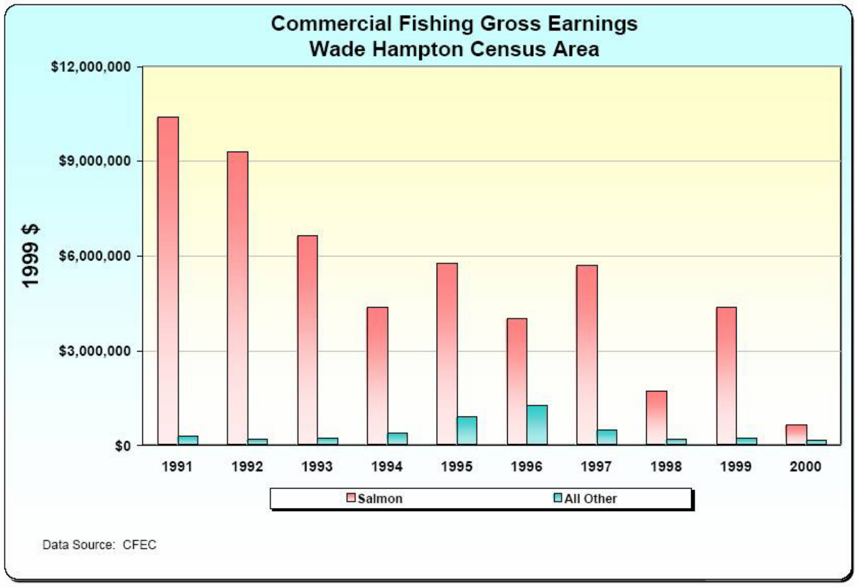


FIGURE 2-3 Gross earnings from commercial fishing in the Wade Hampton census area. Source: Alaska Commercial Fisheries Entry Commission 2004.

3

Historical and Recent Arctic-Yukon-Kuskokwim Research

This chapter is organized broadly into background information and outstanding questions on the physical environment of Arctic-Yukon-Kuskokwim (AYK) salmon; their population structure and life cycle; their ecological interactions throughout the life cycle; and the human dimension including population trends and resource use, legal and policy analysis, and restoration opportunities. It ends with a discussion of the importance of including traditional ecological knowledge in research on AYK salmon, along with strategies for achieving that goal. We have attempted to identify questions of most interest to scientists and stakeholders. Many of these questions emerged from site visits to AYK communities in 2003 and 2004 and from the workshop held in Anchorage in November 2003.

INFLUENCE AND CONSEQUENCES OF CHANGES IN THE PHYSICAL ENVIRONMENT

Regional Background

Since the 1960s and increasingly in the 1990s and 2000s, dramatic climatic changes have been occurring throughout the range of AYK salmon (BESIS 1997, Hunt et al. 1999, Schumacher and Alexander 1999, SEARCH SSC 2001, Schumacher et al. 2003). Marked changes in the wintertime climate of Alaska and the Bering Sea that occurred in 1976-1977 illustrate the magnitude and nature of some of these changes.

Among the effects documented are a step-like increase of nearly 2°C in air temperature (S.A. Bowling, Geophysical Institute, University of Alaska Fairbanks, personal communication, 1995), an approximate 5% reduction in sea-ice extent (Niebauer 1998), and a decrease in sea-ice thickness (Wadhams 1995). Many local residents around the Bering Sea also noted changes in ice thickness and strength (Huntington 2000). Permafrost temperatures measured in boreholes in northern Alaska are 2-4°C warmer than they were 50-100 years ago (Lachenbruch and Marshall 1986). Discontinuous permafrost (i.e., permafrost that is patchily distributed over the landscape) has warmed considerably and is thawing in some locations (Osterkamp 1994). In addition to the warming trend of air temperatures, marked changes have occurred in atmospheric pressure patterns, circulation, cloudiness, precipitation, and evaporation. Some North American regions are experiencing an increase in runoff (due to increased rain) of major rivers and changes in the time of river-ice breakup and the onset of the summer peak in river flow. In addition, south coastal Alaska glaciers have decreased because of melting, which has increased freshwater discharge rates nearly 15% (Arendt et al. 2002, Royer in press). Multiple air temperature signals exist in the climate record. One signal is a trend to warmer temperatures in recent decades, while many of the other natural patterns have alternating warm/cold periods, such as Arctic Oscillation (AO) and El Niño-Southern Oscillation (ENSO) (NRC 2001, 2003). The environment of AYK salmon is changing, possibly due to warming and associated climate variations that are occurring throughout the Bering Sea and Alaska.

This section emphasizes seasonal and longer fluctuations in the air, land, and sea environments. However, we recognize that episodic events can also influence salmon populations. Floods, as extreme hydrological events, can affect water quality and may scour gravels and deposit fine-grained sediment, thereby damaging spawning beds and/or flushing young fish out of the river (Brabets et al. 2000). Three major floods have occurred in the Yukon River basin since 1949 (Brabers et al. 2000): in 1964 (June/July, due to melt of large snow pack), in 1967 (12-18 August, in the middle and lower Tanana River basin with a magnitude estimated to be twice the 100-year flood discharge), and in 1994 (15-27 August, in the upper Koyukuk River basin). At the other extreme are droughts, which can inhibit upstream migration as well as affect eggs after spawning through increased water temperature, decreased concentration of dissolved oxygen, and even dewatering of the redds. Extended droughts also influence groundwater levels that, in turn, decrease the base flow of streams and springs that are critical salmon habitats. Notable droughts have occurred since 1949 (Brabets et al. 2000): in 1950-1957 (most of the upper Yukon River basin and upper Tanana River basin), in 1969-1970 (western portion of the Yukon River basin, including the Koyukuk River), in 1973-1980 (the most severe period in terms of low flow and length, primarily lower Yukon, Koyukuk, and Tanana rivers), and in 1996-1999 (deficit flows observed at several locations in some of these years on the upper Yukon including Eagle, Nenana, Stevens Village, and above the White River). In general, it appears that spawning habitat in the AYK region has been modified by humans in only a few limited locations, mostly from the effects of placer mining (Knudsen 2003). Other extreme events—for example, volcanic eruptions and earthquakes—can also have a major impact on salmon habitat.

Climate and Climate Change

Before delving into the impacts climate change may have on AYK salmon populations, we sought to understand what climate change means and to identify factors that cause changes. This allows us to define both the spatial and the temporal scales of climate change and the pathways through which climate change influences biota, and AYK salmon in particular. As defined in a recent National Research Council (NRC) report (2001), "Climate is defined as the average state of the atmosphere and the underlying land and oceans, on time scales of seasons and longer." This definition is broader than many people consider when they think of climate—that is, the atmosphere only—but it is essential when considering the life and times of salmon. Salmon spawn and develop from egg to smolt stages in the riverine environment before going to sea; therefore, the changing state of all three domains (atmosphere, land, and sea) is crucial to salmon.

From a global perspective, the climate is a response to solar and geothermal heating (Woods 1984). Present-day climate on earth is controlled by solar fluxes that in turn affect the temperatures of the ocean and the atmosphere, the hydrologic cycle, and the winds. The major source of heat in the earth's global heat budget is incoming solar radiation, much of it in the visible wavelengths. Solar energy drives the atmosphere through differential heating that results from changes of heat per unit area with latitude—that is, there are higher rates of heating at low latitudes than at high latitudes. Greater input of solar (shortwave) radiation occurs at low latitudes, and this excess heat is transported poleward where it is reradiated as infrared (long-wave) energy (NRC 2001). The poleward transport of heat occurs through both oceanic and atmospheric circulation. There is a net heat loss at latitudes above about 38° (Trenberth et al. 1996). This differential heating is augmented by the tilt of the earth's axis of rotation (the cause of seasonal climate change). It is acted upon by the earth's rotation to create global pressure differences, and hence wind patterns, which in turn are influenced by regional features—for example, air-sea heat and moisture fluxes. Local features, such as mountain topography, in turn influence the regional atmospheric fields. The winds in these atmospheric systems in turn drive the surface ocean currents, which also transport heat and salt (freshwater). Thus, the two systems are coupled and work together to control the global heat and water budgets. Without the poleward heat transport, the high latitude temperatures would be much lower. Therefore, any processes that affect this transport, either in the ocean or in the atmosphere, will influence the climate. For example, if gases (commonly called "greenhouse" gases, which include CO_2 and CH_4) that trap energy by absorbing the outgoing long-wave radiation increase, then the result will be changes in atmospheric features and global warming.

Changes in cloud cover cause fluctuations in net surface solar radiation and outgoing long-wave radiation. Over the coastal waters where AYK salmon smolts enter the marine environment, latitudinal changes in net radiation could cause differences in smolt and juvenile habitat. Variations in this radiation (mainly the photosynthetically active radiation, or PAR) are a crucial aspect of time-varying forcing for climate and ecosystem change (Foukal 2003). Stabeno et al. 2004 examined net shortwave radiation (NSWR) in the eastern Bering Sea (Figure 3-1). The effect of latitude is evident: the northernmost station received about 21% less energy ($W \cdot m^{-2}$). The two series from nearly the same latitude appear in phase and of similar magnitude. There are, however, some years (1995, 1999) when they are different by >10 $W \cdot m^{-2}$, potentially a large enough difference to result in differences in primary/secondary production processes. These within-year differences are likely due to regional differences in cloud cover. The latitudinal differences imply a shorter, more intense period of production over more northern portions of the shelf than exists over the southeastern shelf. This may account for the observed differences in the dominant pathway of carbon cycling on the Bering Sea shelf (pelagic versus benthic); the northern shelf is predomi nantly a benthic system (McRoy 1993), whereas the southeastern shelf

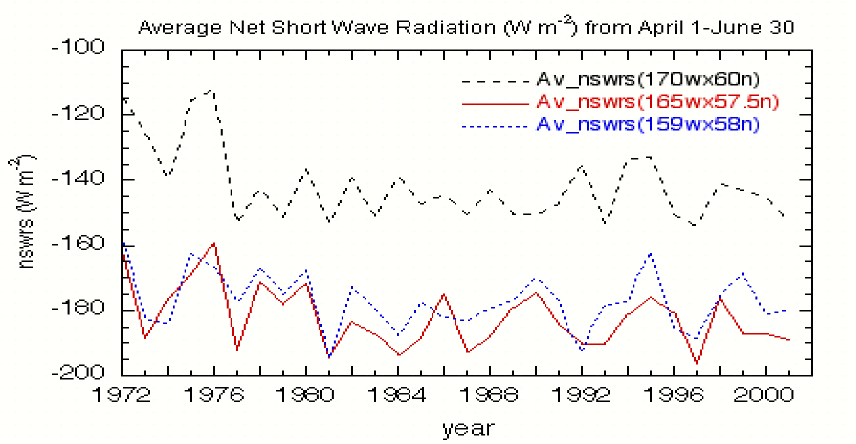


FIGURE 3-1 Daily averaged net shortwave radiation (NSWR) from the National Center for Atmospheric Research/National Center for Environmental Prediction (NCAR/NCEP) reanalysis data: April-June 30 (1972-2001). Minus sign signifies downward flux into the ocean. Source: Stabeno et al. 2004. Reprinted with permission; copyright 2004, John Wiley & Sons.

may be either pelagic or benthic, depending on the timing of spring blooms (Walsh and McRoy 1986).

The phasing of these two signals could be important to biota in the Gulf of Alaska, North Pacific, and Bering Sea. The sea-surface temperature pattern that the Pacific Decadal Oscillation (PDO) describes has a warm coastal northern North Pacific and cooler central North Pacific. This pattern reverses on interdecadal time scales (20-30 years). At a time when the PDO has a warm phase in the coastal waters, the occurrence of an ENSO event could be especially severe since this also increases the nearshore water temperatures in the Northeast Pacific.

The impact of humans on the earth and its climate is marked. How much of the present climate change is natural and how much is human-induced global warming remains a subject of debate. Most scientists agree, however, that the increasing trend in global temperature is due to greater concentrations of human-generated greenhouse gases (AGU Report 1999, IPCC 2001, Levitus et al. 2001), and a crucial point for AYK salmon is that the warming may be amplified in polar regions (Moritz et al. 2002). A recent American Geophysical Union (AGU 2003) position statement on human impacts on climate states, "human activities are increasingly altering Earth's climate, and natural influences alone do not explain the increase in global near-surface temperature in the latter half of the 20th century." The statement further notes that human impacts include air pollution and airborne particle and land alteration in addition to the more commonly recognized increase of atmospheric greenhouse gases. Human impacts interact with natural cycles, likely changing amplitudes and phases and making them less predictable.

Pathways from the Physical Environment to Biota

Because much of the variability in salmon survival appears to occur within a few months after smolt migration from freshwater to the sea (Pearcy 1992, Downton and Miller 1998, Beamish and Mahnken 2001) and because focusing on this stage may provide predictive modeling (Logerwell et al. 2003), our main focus in this section is the marine environment. To enhance our understanding of the marine ecosystem that the AYK smolts inhabit, we must elucidate processes and mechanisms that transfer changes in atmospheric climate through the ocean to biota.

Francis et al. (1998) developed pathways for the Northeast Pacific to identify key elements of ecosystem dynamics. That model was modified by Schumacher et al. (2003) for the eastern Bering Sea to include additional physical features such as sea ice, cloud cover, and precipitation. Our flow model (Figure 3-2) borrows from the latter schematic. Within each of the upper three boxes in the Pathways Model (Figure 3-2) are phenomena and features of the abiotic environment. Depending on location, the general contents of the boxes become more specific. While the Ocean box (Figure 3-2) incorporates both the nearshore zone (depth <10 m) and estuaries, there are processes in these regions that do not exist or are not important in the oceanic domain. In the nearshore zone, littoral drift (which is a form of horizontal current generated by breaking surface waves) is a dominant feature causing erosion and buildup of sediment features. Estuarine circulation, which incorporates horizontal flow and vertical mixing or entrainment of water, is a dominant mechanism generating both horizontal and vertical flow fields within an estuary, but typically it is not a major factor in oceanic circulation. Within the estuary, salinity decreases from oceanic values to near zero. The salinity gradient may influence salmon smolts when they first reach the estuary and also will influence returning adults.

Feedback exists between all boxes in Figure 3-2, as suggested by the two-way arrows. For example, water temperature can influence

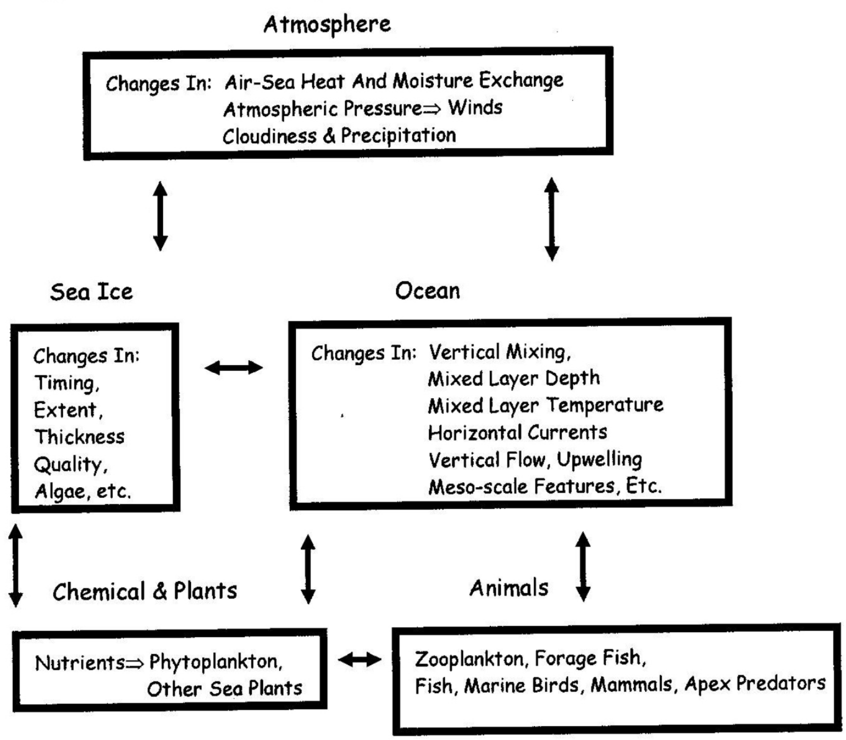


FIGURE 3-2 Schematic showing pathways through which air-sea interactions flow through the marine ecosystem. Within each box are features and/or processes that affect exchange within and between boxes. The Sea Ice box is seasonal; without ice, the arrows lead to the next box. Source: Schumacher et al. 2003. Reprinted with permission; copyright 2003, Elsevier.

AYK salmon both through its impact on the nutrient-phytoplankton-zooplankton sequence (bottom-up), which supplies prey, or by changing the zoogeographical boundaries for predators (top-down) and/or for the salmon themselves. How does phytoplankton influence atmospheric features? Variations within the phytoplankton community can induce intraseasonal fluctuations in sea surface temperature (SST) through regulation of solar radiation penetration due to absorption by chlorophyll and other optically active organic components (Gildor et al. 2003). Variations in SST in turn might affect the flux of heat and moisture into the atmosphere, thereby changing atmospheric features. In the Animals box, for simplicity, we show only a limited set of trophic levels. Humans are the predator that likely has the greatest impact on AYK salmon, but not explicitly shown as "the" apex predator.

For a terrestrial analog to the marine pathways model, the Ocean box would become the River/Terrestrial box and the Sea Ice box would be eliminated. Within the River/Terrestrial box important features would include time of ice cover, ice thickness and breakup, time/magnitude of the freshet, time/magnitude of increased sediment load due to human- or storm-induced erosion, changes in river morphology, and permafrost. Permafrost is defined as any subsurface earth material that remains at or below 0°C continuously for 2 years or more (Nelson 2003), and it represents a complex, integrated response to the energy balance at the earth's surface (Williams and Smith 1989). Permafrost regions in the Yukon River drainage basin are shrinking due to warming. As this occurs, the frozen soil is transformed into zones that are biogeochemically active. Water flowing through and across these zones is hypothesized to increase the flux of solutes to tributaries and the main stem, ultimately changing the water chemistry of the Yukon River (Schuster et al. 2002). The Chemical & Plants box would include changes in plant communities that are occurring as warming affects the ecosystem. Potential chemical pollutants associated with development of mines and other activities also would be included in this box. Neither of the pathway models includes disease and/or parasites, but to the degree these factors are influenced by the physical (including chemical and geological) environment, they must be considered.

Hunt et al. (2002) wove the elements of the marine pathways model together in creating the oscillating control hypothesis (OCH) for the southeastern Bering Sea shelf. As summarized by Stabeno et al. 2004, the OCH relies on a cascade of changes in a given year's abiotic and biotic features, including sea ice extent/timing, wind-generated turbulence, water column temperature, and timing/magnitude of primary production. In turn, these features impact changes in the abundance of higher trophic levels. The sequence of changes, known as a regime shift, is initiated by atmospheric changes on both interannual and decadal timescales. Changes in the abundance of Bering Sea salmon coincide with regime shifts associated with the PDO (Hare and Mantua 2000). Salmon smolts and juveniles from the Kuskokwim River, and to a lesser degree those from the Yukon River and Norton Sound, likely occur in the waters where dynamics of the OCH apply.

In essence, the OCH recognizes that late retreat of sea ice with the attendant low temperatures in the water column and early, short phytoplankton blooms are hallmarks of cold regimes. The associated impacts on biota include reduced survival of fish eggs and diminished abundance of zooplankton prey. Under this set of conditions, recruitment of pollock and other fishes will be nominal or weak. Bottom-up processes dictate the flow of energy through the ecosystem during a cold regime. Low water temperatures also can directly affect distributions of some forage fish species. The OCH allows that pinnipeds and piscivorous seabirds may thrive, even under cold conditions, if the population centers of forage fish change, resulting in their becoming more available as prey. During years when sea ice either is not present or retreats before there is sufficient NSWR to initiate a bloom, the spring bloom occurs later than during the cold regime, and water column temperatures are higher. Under this set of conditions, the spring bloom is prolonged and zooplankton production is expected to be high, resulting in readily available prey for larval and juvenile fish, and resultant strong year-classes of pollock and other piscivorous fishes.

The OCH accounts for top-down forcing through both cannibalism and other piscivorous fish, which is well recognized in the eastern Being Sea (Livingston and Methot 1998, Livingston et al. 1999). When there is a sequence of warm regime years, recruitment is above average, and the populations of adult predatory fish eventually will increase to a point where the control of future year-class strength is mainly a top-down process. As predation becomes greater, the abundance of young pollock and forage fish declines, and zooplankton become available for other populations (jellyfish, salmon, and baleen whales). In addition, with fewer fishes, declines in populations and/or productivity of pinnipeds and piscivorous seabirds would be expected (Hunt and Stabeno 2002).

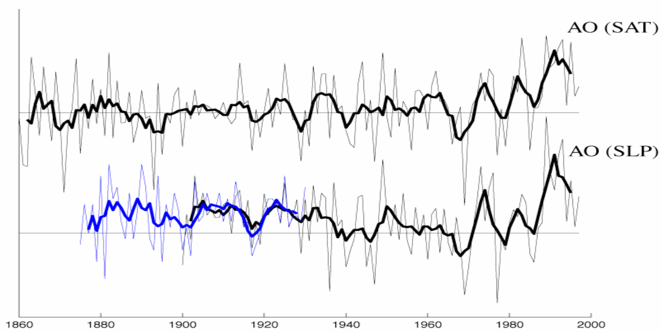
Features of the Environment of AYK Salmon

We begin our discussion of the AYK salmon environments with a discussion of the coupling of the ocean and atmosphere. Patterns in the atmosphere tend to be on hemispheric spatial scales and have temporal variability from years to decades. Variability of atmospheric patterns has profound impacts on marine ecosystems, particularly salmon (Mantua et al. 1997, Downton and Miller 1998, Hare and Mantua 2000, Hollowed et al. 2001), although the mechanisms that link atmosphere-ocean change to biological change are seldom clear.

Important climate signals are evident in atmospheric features of the Bering Sea and continental Alaska, including the AO, ENSO (as mentioned earlier), and the Aleutian low (AL). An oceanic feature closely related to the atmosphere but manifest as a pattern in SST is the PDO. These climate patterns are particularly well-studied for winter. Interest and awareness is growing, however, in climate variations and their importance during warm seasons. While these signals may not be as large as those during winter, they can stand out above background atmospheric conditions (Trenberth et al. 1998), and they can influence the upper ocean and its biota. For example, the unusually high SSTs in the eastern Bering Sea (summer 1997) were ascribed mainly to atmospheric anomalies that occurred concurrently with a strong El Niño (Overland et al. 2001). Marked changes in biota occurred that summer (Vance et al. 1998).

The PDO is the leading mode of SST variability in the North Pacific (north of 20°N) and has a dominant timescale of 20-30 years. Although important, the PDO explains only ~21% of the total variance of the monthly SST and is centered primarily on the central North Pacific rather than the Gulf of Alaska and Bering Sea. Signals with other periods, such as decadal, contribute to a lesser extent at times. The ENSO has widespread influence on global climate variability at timescales of 2-7 years. Often, a brief (on the order of months) general warming of the high-latitude North Pacific surface water takes place simultaneously with the ENSO, and a delayed subsurface oceanic warm signal has also been reported (Royer in press). The ENSO has, at times, a small influence (accounting for ~7% of the annual change in sea ice coverage) (Niebauer 1998) on the marine climate of the Bering Sea via atmospheric teleconnections (Niebauer et al. 1999, Hollowed et al. 2001, Overland et al. 2001). Further, the midlatitude decadal variability in the atmosphere can be explained without the ENSO processes (Barnett et al. 1999).

The AO represents the leading empirical orthogonal function of the winter sea level pressure (SLP) fields north of 20°N (Wallace 2000). The accompanying time/space patterns in surface air temperature (SAT) closely resemble those in SLP. While the AO is the mode that contains the greatest amount of energy, it accounts for <21% of the total variance in the SLP field. The strongest signal in the AO time series (Figure 3-3) is interannual, but it also contains decadal scale signals, having changed sign in 1976 and again in 1989 (Overland et al. 1999). One way the AO influences the AYK salmon's environment is through its effect on the



Standardized time series of the AO index based on SLP data and SAT data. Walker's NAO index is shown as the dashed blue line.

FIGURE 3-3 Time series showing the Arctic oscillation (AO) as surface air temperature (SAT) (upper) and as sea level pressure (SLP) (lower). Applying a running mean to the data (bold line) reveals a decadal signal that is not correlated with sunspots. The warming trend that is marked after the 1960s is likely a result of human-induced global warming. Source: Wallace 2000. Reprinted with permission by the author.

AL, which is the monthly or seasonal mean location of the center of low SLP resulting from storm passage typically along the Aleutian Island chain (Schumacher et al. as cited in Allen et al. 1983). The magnitude and position of the AL is a primary factor determining surface winds (advection and mixing of the upper ocean and production/advection of ice), heat fluxes (mixing and ice formation), and precipitation over the Bering Sea, North Pacific Ocean, and Alaska. Indices of atmospheric and oceanic features have been used together with indices of biota to identify abrupt or regime shifts in the ecosystem at decadal timescales (Mantua et al. 1997, Francis et al. 1998, Hollowed et al. 2001). Two regime shifts occurred in the past 30 years: winter 1976-1977, when the PDO and the AO both shifted, and after the winter of 1988-1989, when only the AO shifted (Sugimoto and Tadokoro 1998, Beamish et al. 1999, Hare and Mantua 2000). Some evidence exists that a third shift occurred after the winter of 1998-1999 (Schwing and Moore 2000, Peterson et al. 2002, Peterson and Schwing 2003). These regime shifts often are clearer in biological than in physical time series; salmon production in both Alaska and the Northwest fluctuates with these regime shifts. Several atmospheric and oceanic phenomena influence the habitat for AYK salmon, and the responses in biota are complex. For example, the phasing of these PDOs and ENSOs could be important to biota in the Gulf of Alaska, North Pacific, and Bering Sea. At a time when the PDO has a warm phase in nearshore waters, the occurrence of an ENSO event could be especially severe. Because of this, the impact of climate change on AYK salmon is unlikely to be systematic and repetitive; the response likely varies from one regime shift to another.

Changes in sea ice (Figure 3-4), the signature feature of the eastern Bering Sea, are driven mainly by changes in atmospheric phenomena. A synopsis of recent information (Niebauer et al. 1999, Stabeno et al. 2001, Hunt et al. 2002) provides the salient features of seasonal sea ice cover. Sea ice begins to form on the leeward side of coastlines in late fall. Frigid northerly winds blow the ice southward, with some formation in leads. Significant interannual variation in the timing of ice advance/retreat and percent coverage occurs; when the AL is farthest east and high pressure is strong over Siberia, ice coverage is greatest. While there is some indication of longer period signals, the most striking signal is interannual (Figure 3-4). Potentially important to AYK salmon smolts as they enter this marine region is the strong difference (~2 months) in

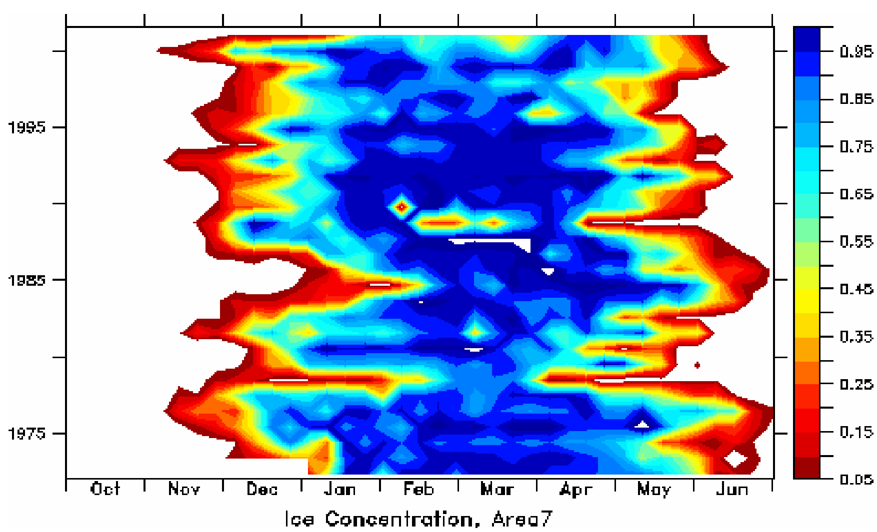


FIGURE 3-4 A time series of percent sea ice cover in the region bounded by 60.5-61°N and extending from the coast to ~176°W. The most complete coverage by sea ice occurred in winter 1976-1977. Source: S. Salo, PMEL/NOAA, unpublished material, 2001.

the time of ice melting. Melting has been 1-2 weeks earlier during 1990-1998 (the period after the second AO regime shift) than in 1978-1989 (the period after the first regime shift), and it is associated with changes in atmospheric temperature and circulation (Stabeno and Overland 2001). How this influences the primary/secondary production sequence that provides essential food for the smolts is not known; however, it could lead to a potential mismatch. The earlier melt does imply that water temperatures will be higher than when melting is later. Higher temperatures may lead to higher smolt growth and thus higher survival (Hunt et al. 2002).

A connection exists among climate change, transport (currents) of (Wespestad et al. 2000, Zheng et al. 2001, Wilderbuer et al. 2002). Transport itself does not lead to mortality but moves the early life history stages to regions of higher or lower survival due to prey limitation and/or predation pressures. Circulation (in this case a semipermanent eddy) also has been linked to alterations of salmon migration routes off southeast Alaska (Hamilton and Mysak 1986).

Circulation in the marine environment of AYK salmon is known (Schumacher and Stabeno 1998, Stabeno et al. 1999) to the degree that schematics can be constructed (Figure 3-5). The coastal flow indicated by arrows along the Alaskan Peninsula and the west coast of Alaska is typically weak (2-4 $cm{\cdot}s^{-1}$) in summer but persistent (Schumacher and Kinder 1983, Schumacher and Stabeno 1998). This coastal current is partially driven by baroclinic forcing (from runoff along the coast) and south of ~62°N is preferentially located in the vicinity of the 50-m isobath. As noted by Kachel et al. (2002), the coastal current flows parallel to the inner front, which is a transition zone (10 to >100 km wide) that separates the typically mixed coastal waters from the strongly two layered (in the presence of a buoyancy flux—for example, summer) from middle shelf domain ($50 \text{ m} < z < 100 \text{ m}$) waters (Schumacher and Stabeno 1998, Kachel et al. 2002). Recent information reveals that in 1998 the magnitude of the coastal current approximately doubled over historical values (P.J. Stabeno, NOAA/PMEL, personal communications, 2003). The impact on AYK salmon smolts by the coastal current and its interannual variation are not known. Further, little or no oceanographic research has been conducted in nearshore coastal waters, particularly in the regions off the Kuskokwim and Yukon Rivers.

The continental shelf shoals going northward so that off Norton Sound, the water column is generally <35 m deep, and tidal currents are much weaker than over the southeastern shelf; an analog to the inner and front does not exist over the northern portion of the shelf. In Norton

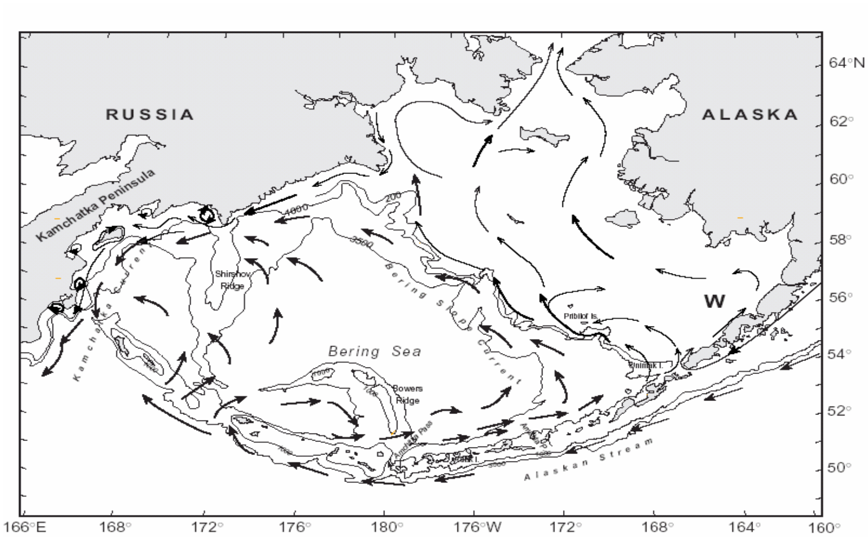


FIGURE 3-5 Schematic showing general circulation in the Bering Sea. This schematic does not show the nearshore currents or the bidirectional flow that occurs seasonally and at depth between the Beaufort and Chukchi Seas. Source: Stabeno et al. 1999.

Sound, oceanographic studies conducted between 1976 and 1978 show that the relatively shoal water column is two layered throughout the summer (Muench et al. 1981). The high bottom layer salinities result from brine ejection during sea-ice formation, and the low-salinity upper layer values result from freshwater addition from various rivers. During these oceanographic observations, there was no indication that the Yukon River entered the Sound east of Stuart Island; yet, characteristics of bottom sediments in the eastern Sound suggest a Yukon River source (Drake et al. 1980). Changes in the position and volume of the Yukon River plume could have a profound impact on the geophysical environment of Norton Sound. The changes that are expected to occur due to global warming (less ice and greater runoff) might dramatically alter the Sound's present thermohaline structure, which could affect salmon.

Water temperature strongly influences all life history stages of salmon. Changes in air temperature and wind-driven mixing (turbulence) are the factors that determine the mixed-layer temperature (MLT) and the depth of the mixed layer. MLT directly influences physiological rates and can alter predator distributions. Ishida et al. (2002) suggest that MLT influences distributions and densities of chum and sockeye salmon, affecting their survival and hence their abundance and growth in the central Bering Sea.

Likely Changes in AYK Habitat Due to Continued Warming

Over the last century, the average temperature in Anchorage has increased by ~2°C, and over the last 41 years of available data, precipitation has increased by ~10% in many parts of the state (EPA 1998). In the mid-1980s, measurements in boreholes indicated a 2-4°C increase over the preceding 100 years (Lachenbruch and Marshall 1986), and warming accelerated this change by ~3°C between the mid-1980s and 2002 (Nelson 2003). As the warming continues, the Yukon River drainage area is being affected. Nelson (2003) notes that large areas of central Alaska have experienced as much as 2.5 m of subsidence over the past 2 centuries and that such topographic changes have produced extensive hydrological and ecological impacts, with large areas of birch forest converted to fens and bogs (Jorgenson et al. 2001).

Many forecasts of future conditions have been made with global climate models. The following changes were presented by the U.S. Environmental Protection Agency (EPA 1998) and are based on projections made by the Intergovernmental Panel on Climate Change and results from the United Kingdom Hadley Centre's climate model (HadCM2, a model that accounts for both greenhouse gases and aerosols): by the year 2100, temperatures in Alaska could increase by 3°C in spring, summer, and fall (with a range of 1-5°C), and by 6°C in winter (with a range of 2-9°C). Precipitation is estimated to increase slightly in fall and winter (with a range of 0-10%) and by 10% in spring and summer (with a range of 5-15%). These changes in precipitation will increase the vertical and possibly the horizontal stratification of the ocean, increasing the baroclinic transports; they would affect stream flow and temperature as well. Other climate models will show different results depending on the formulation and extent of the mathematics used to represent processes that dictate flow of energy through the coupled atmosphere-sea-land system.

In the mid-1990s, a group of scientists well versed in atmospheric and oceanic phenomena of the North Pacific and the Bering Sea outlined the most likely impacts of global warming on this region (US GLOBEC 1996, Schumacher and Alexander 1999). They based their forecasts on projections from global climate model simulations (Hall et al. 1994) that indicate secular warming of the atmosphere over the North Pacific, especially at higher latitudes. A summary of those results, together with other suggested changes, is presented in Table 3-1. While it was challenging enough to predict these changes in the physical environment, to then extrapolate to how such changes would affect biota was beyond their corporate knowledge. Too many unknowns exist regarding what changes in the physical/chemical environment were most important to a given species, and it was often evident that our knowledge of most species is sorely lacking. For example, even for species as well studied as salmon, there are gaping holes in our knowledge of the distribution and factors dictating survival as smolts enter the marine environment and through their first year in the sea.

Research Questions

The following questions arise from our present lack of knowledge and analyses of the critical questions. They provide topics for research regarding the impact of climate change on AYK salmon. A necessary adjunct to the list below is to determine the year-to-year variation for each item.

- Where and when do smolts enter the marine environment; what factors dictate when smolts arrive; what is the form of their out-migration (en masse or more extended through time); how sensitive is the out-migration to changes in the environment (temperature, salinity, and ice)?
- How does their initial distribution change with time; what role do currents play; where in the water column are the smolts, and how does this vary through light/dark periods and as they mature; does storm-generated turbulence affect predator/prey relations?
- What biophysical processes dominate the survival of smolts and the juvenile fish through their first winter at sea?

Can a reliable index of survival of young-year be developed to provide recruitment forecasts for managers (giving the op portunity to adjust fishing pressure for each upcoming year class) similar to the herring fishery in the Baltic Sea (Axenrot and Hansson 2003) and perhaps Oregon coho (Logerwell et al. 2003)?

- How are the variations in the large atmospheric-oceanic patterns (AO and PDO) manifest (wind speed, air temperature, and moisture fluxes) in the time/space domains relevant to salmon survival, mainly of smolts and juveniles (summer/fall in the coastal waters from Kuskokwim Bay to Norton Sound), in spawning/riverine life history stages (Kus-

TABLE 3-1 Hypothesized Changes in Physical Habitat of AYK Salmon Due to Global Warming

I.	**Atmospheric climate**	
	Storm intensity	Decrease
	Storm frequency	Increase
	Surface air temperature and humidity	Increase
	Sea level pressure	Lower in North Bering
	Southerly wind component	Increase
	Wind stress curl	Decrease
	precipitation, rain	Increase/shift north
	Snowfall	Decrease
	Freshwater runoff	Increase
II.	**Oceanic climate**	
	Sea ice extent, thickness, and brine flux	Decrease
	Volume of Alaskan Stream inflow	Decrease
	Bering Slope and Kamchatka Current flow	Decrease
	Sea surface temperature	Increase
	Cold pool extent/temperature	Decrease/increase
	Nutrient flux onto shelf	Decrease
	Sea level	Increase
	Coastal current	Unknown
III.	**Terrestrial climate**	
	Permafrost/erosion	Decrease/increase
	River/lake ice	Less
	Freeze up/breakup	Later/earlier
	Geochemical state	Unknown

Sources: BESIS 1997, Schumacher and Alexander 1999.

kokwim/Yukon River basins over appropriate time span), and perhaps to adults (Bering Sea/North Pacific all seasons)?

- Will there be changes in the predator/prey patterns with changes in climate?

POPULATION STRUCTURE AND LIFE CYCLE OF AYK SALMON

Population Genetics of AYK Salmon

It is important to identify the various salmon stocks in the AYK region because they might have similar or different responses to abiotic factors and fishing. Genetic analysis is a promising method for distinguishing among these salmon stocks. Utter and Allendorf (2003) provided a thorough review of information on the population genetics of AYK salmon and the potential role of population genetics in the management of AYK salmon populations. Available data derive from nuclear markers (allozymes and microsatellites) and mitochondrial DNA haplotypes. The allozyme database for chum salmon is the most detailed database available, but it can distinguish only three major AYK population groups: (1) northwestern Alaska summer chum salmon, which includes all coastal western Alaska rivers, the lower Yukon, and the lower Kuskokwim; (2) Yukon fall chum salmon; and (3) upper Kuskokwim chum salmon. Allozyme data do not work for separating U.S. and Canadian fall chum salmon in the Yukon River. For Chinook salmon, lower and upper river populations can be distinguished in the Yukon River but not in the Kuskokwim River. Coho salmon data are limited but indicate differences between lower and upper and Yukon, AYK coastal, and Bristol Bay populations. AYK pink and sockeye salmon data are insufficient to estimate population structures.

Fishing and Genetics of AYK Salmon

Ricker and Wickett (1980) attributed the decrease in size of coho salmon in British Columbia to evolutionary change caused by fishing. Similar claims were made as early as 1952 for freshwater trout (Cooper 1953). Ricker and Wickett's argument was that fishing acts through directional selection to produce fish with smaller size at age or at maturity by removing those fish that grow quickly or attain large size by the age of maturity. Left in the population are fish that became reproductively mature at smaller sizes. Because these fish are subject to lower fishing mortality, they live longer, reproduce more, and have a greater influence on the subsequent genetic composition of the species. This paper and the ideas it contained was met with skepticism by fisheries scientists, many of whom thought evolutionary change required more time than the span over which fisheries operated to cause genetic change.

The idea that fishing could be an agent of evolution relies on two important assumptions: (1) a genetic basis to phenotypic variations in the population exists, such as in growth rates, size or age at maturity, and run timing; and (2) fishing acts to cause differential reproduction in different genotypes (Policansky 1993a), potentially within as little as two or three generations (Policansky 1993b). Even fishing that does not selectively take different phenotypes (fish of a particular size or age or fish that migrate at different times) can affect genotype frequencies and thus cause evolution by favoring one life history pattern over another (Policansky 1993b). For example, high fishing mortality can change a fish population with many year classes or long life spans into one with only a few year classes and shorter life spans because the overall probability of surviving more than 1 or 2 years can become vanishingly small (Murphy 1968). In such a case, a genotype that reproduced early would be favored.

Experimental-breeding studies on the Atlantic silverside (*Menidia menidia*) reveal that growth is heritable (Conover and Present 1990, Conover 2000), while studies of salmonids also indicate mixed heritability of several traits (Policansky 1993a,b). Although simple in concept, identifying evolutionary change can be difficult. Factors such as compensatory growth, a "fishing-up effect" (in which cumulative mortality of slow-growing older fish hides selectivity effects), migration, and environmental changes can obscure real evolutionary change (Policansky 1993a).

In recent decades, these ideas have been gradually embraced. A series of papers demonstrated rapid evolutionary change in Trinidadian guppies (*Poecilia reticulata*) in the face of predators (Reznick et al. 2001, 2002; Bronikowski et al. 2002; O'Steen et al. 2002), often in less than a decade. Magurran (2001) reported that predation resulted not only in size changes but also in fundamental changes in sexual behaviors. Silliman's experimental "fishing" of *Talapia* in the laboratory pointed to evolutionary change as a direct result of fishing (Silliman 1975). The first publications that supported similar rapid evolution in salmon appeared recently (Hendry et al. 2000, Hendry 2001). Whereas previous studies indicated that evolutionary change required 30 generations or more (Unwin et al. 2000), these papers revealed that sockeye salmon can become reproductively isolated and show changes in genetic frequency in fewer than 13 generations. In many studies the predation is not by humans, but others have directly linked fishing to evolutionary change (Haugen and Vollestad 2001). Other important traits of Pacific salmon, including run timing, are heritable and thus clearly are subject to the selective effects of some kinds of fishing (Geiger et al. 1997, Hebert et al. 1998, McGregor et al. 1998).

When different local populations mix in the ocean or as they return to their natal spawning habitats, they will be subject to common mortality factors, even though the local populations exhibit different vulnerabilities. Abundant, growing (productive) populations will be able to withstand fishing mortality better than less-productive or depleted populations, which can be extirpated by this same fishing effort. Unless the population mixture is known, in addition to their respective vulnerabilities to fishing mortality, we cannot tailor management regulations to ameliorate excess mortality on vulnerable populations.

Fishing affects populations not only directly through selection on various traits but also indirectly through changes in the ecosystem (Policansky and Magnuson 1998, Conover 2000, Heino and Godø 2002). Species are differentially affected by harvest through changing the abundance of predators or prey or through habitat disturbance. Results from these disturbances have been difficult to predict and are not well studied for the AYK region. Before discussing the limited information available from this region, a brief review of the general knowledge of population structure of Pacific salmonids is helpful.

Metapopulation Structure

All five North American species of Pacific salmon are found in the AYK region[1], although more is known about chum in this region than the other species. In other regions, these five species are thought to form metapopulations where local populations are largely isolated in a stepping-stone type model due to the high degree of natal homing and subsequent reproductive isolation (Rieman and Dunham 2000, Jones in press). Local populations are adapted to local conditions as a "home-stream colony" typified by small local breeding units that are isolated from local populations in other streams or reaches of streams (Moulton 1939; Thompson 1959, 1965; NRC 1996). Each local population is vulnerable to extinction from natural or anthropogenic causes, and suitable habitats where fish have been extirpated must be recolonized through straying from other viable local populations (Policansky and Magnuson 1998).

The Takotna River provides one of the few documented examples of how long this process can take (Gilk and Molyneaux 2004). The local Chinook salmon population was extirpated, probably by fishing and habitat alteration by miners who used the Takotna River to access the Innoko mining district, in the early part of the twentieth century. Salmon finally returned in the 1980s to repopulate this habitat.

[1]Two additional Pacific salmon species, the amago (*Oncorhynchus rhodurus*) and masu (*O. masou*), occur only in Asia (Kato 1991).

The evolutionary advantage of a metapopulation lies in its overall resiliency to extinction. Early modeling work by Levins (1969, 1970) demonstrated that persistence was greater for a metapopulation than for a patchily distributed population of similar size. This has since been confirmed. Healthy populations can act as sources that reinforce the viability of marginal populations within the metapopulation (Pulliam 1988, Pulliam and Danielson 1991, Fogarty 1998, Policansky and Magnuson 1998). This biological and environmental variation has recently been called "biocomplexity" and has been linked to the sustainability of fisheries (Hilborn et al. 2004).

The ability of a metapopulation to sustain the species can be compromised when sufficient habitat is lost so that the exchange of migrants is hampered by distance and when the overall population becomes too small to contain sufficient genetic variation to meet new environmental challenges. Arguably, this is happening along the coasts of California to Washington and Canada for coho and other salmon (NRC 1996) and in Maine for Atlantic salmon (*Salmo salar*) (NRC 2004a). However, salmon populations in Alaska are less depleted and have been subject to much less habitat destruction. In the AYK region, habitat remains largely intact.

In the AYK region, we know most about the genetic structure of chum and Chinook salmon because of their importance to commercial fisheries and declining abundance. Salmon in northwest Alaska, which includes all AYK and Bristol Bay populations, are distinguishable from all other North American and Asian populations based on an analysis of 20 allozyme loci from 356 chum salmon populations (Seeb et al. 2004). Within the northwest Alaska region, three finer-scale groups of chum salmon can be distinguished: (1) northwest Alaska summer (includes Kotzebue Sound, Norton Sound, Yukon River summer, Kuskokwim Bay, lower Kuskokwim River, and Bristol Bay), (2) Yukon River fall, and (3) upper Kuskokwim River. Further analysis and more sampling are bound to reveal even more differences among local populations. Northwest Alaska chum salmon populations are caught in the southeastern Bering Sea pollock fishery as a mixed stock. Similarly, they are subject to mixed stock fishing as they return to their natal streams to spawn. As a mixed stock, different local populations respond differently to this fishing mortality, and the effect on local populations and their persistence is unknown.

Twenty-nine populations of Chinook salmon have been identified in the southeastern Alaska and AYK region. Southern and eastern populations have diverged considerably in contrast to those fish in the AYK region (Utter and Allendorf 2003). Populations have differentiated in the upper and lower Yukon River but not in the Kuskokwim River. As is true for chum, Chinook are subject to mixed-stock fishing as they return to spawn in their natal streams. As with chum, virtually nothing is known about the effects of fishing mortality on these mixed stocks.

Even less is known about the other three salmon species of the AYK region (coho, pink, and sockeye). Only a few studies have been done that included coho populations from the AYK region. In these studies, Alaskan populations group together and separate from those of Puget Sound and Georgia Strait (Beacham et al. 2001). There is also evidence of extinction of the western group and subsequent repopulation on geologic time scales, thereby explaining the more limited differentiation in coho. Even so, coho in the AYK region are now sufficiently distinct to be managed separately. Pink salmon have a different structure than the other four species in that they are less spatially separated but are more temporally separated. Data from even-year spawners separate northwestern Alaska from Aleutian Island and Asian populations. Unfortunately, insufficient data are available to analyze population structure in odd-year spawners. Finally, genetic information on sockeye salmon in the AYK region is even more limited, and certainly insufficient to determine population structure.

Throughout their range, efforts are being made to restore lost salmon populations and to revitalize those populations in decline. In the southern part of the U.S. range of Pacific salmon, severe habitat degradation has limited the effectiveness of restoration attempts. Unlike the situation in Canada or the coast of Washington to California, the AYK region has experienced little habitat loss. Nonetheless, the region's salmon populations are in decline. Because these salmon populations have been relatively less affected by habitat degradation than others, they also have received far less attention. In contrast to Pacific Northwest salmon, AYK salmon declines are relatively recent in origin (Lackey 2003) and consequently have not received the same attention.

Research Questions

A discussion of potential research topics in population genetics discussed at the AYK Sustainable Salmon Initiative workshop in Anchorage emphasized the need to develop genetic baselines that provide finer stock structure than current allozyme databases. For example, the Gene Conservation Laboratory, Division of Commercial Fisheries, Alaska Department of Fish and Game (ADF&G), is interested in developing single nucleotide polymorphism (SNP) markers to distinguish AYK salmon stocks. There are many potential research and fishery management applications once databases that can distinguish AYK salmon populations are available. However, not all genetic variation is necessarily evolutionarily significant (Lewontin 1974, Spidle et al. 2004).

Without analysis of stock structure for most species, an analysis of fishing effects on separate stocks in a mixed-stock fishery is impossible. The first step in understanding the effects of fishing on the genetics of a species is to distinguish the interbreeding units that constitute local populations. The next step is to estimate the abundance, vital rates, and migration rates to distinguish source and sink groups and to establish the "health" of each local population. On the basis of this knowledge, the proportion of catch and the genetic composition can be analyzed to determine whether fishing mortality is having a disproportionate effect on vulnerable local populations. Thus, once populations are identified as experiencing excessive mortality, sufficient knowledge would exist to enact in-season regulations to eliminate this excess mortality. Within this conceptual framework the following research questions are of greatest concern:

- Can genetically distinct breeding populations of the five species of salmon in the AYK region be identified? Only a refined analysis of chum and increased sampling of Chinook salmon might be needed, while more extensive analysis throughout the range for coho, pink, and sockeye salmon must be undertaken.
- For the major breeding populations, can the relative abundance and vital rates of the population be used to predict future viability? Little is known about the baseline measures of population viability even in the salmon that have been distinguished as separate breeding populations. The fecundity, survival, escapement, and straying rates among these populations must be known if their future viability is to be predicted.
- Are there identifiable trends in fishing mortality within a given stock from current or recent sampling?
- Can simulation models be used, based on estimated vital rates of local populations, to assess the impact of fishing mortality on population viability?

- Can gear- or time-specific mortality on separate stocks within the mixed-stock stream fisheries be measured?
- Can gear- or time-specific mortality on separate stocks within the mixed-stock ocean fisheries be measured?

ECOLOGICAL INTERACTIONS OF AYK SALMON

Because of their life history, salmon are enmeshed in food webs across multiple habitats, from freshwater streams to the open ocean of the North Pacific and back again. This section, organized by habitat, summarizes ecological interactions that impinge on salmon and emphasizes ongoing research on AYK populations. Direct effects of humans, such as fishing and boat traffic, are not included in this section, but several indirect effects are considered, including changes in populations of exploited species that interact with salmon. Direct effects of humans are covered in the next section. Much of the research on salmon emphasizes single-species questions. How many individuals are present? Where are they going? What are their survival and fecundity rates? In contrast, a community/ecosystem perspective addresses the interactions of salmon with their food, consumers, and organisms that structure their habitat. This perspective may contribute to understanding why numbers of salmon have changed and help project their future numbers.

Ecological Interactions in Freshwater

Habitat

In-stream habitat concerns the places where salmon return to spawn. *Oncorhynchus* spp. in general use gravel as a spawning sub strate, after digging a shallow depression that exceeds adult body length in diameter. Eggs develop successfully where water is oxygenated, free of excessive silt, and within a low temperature range (0-14°C, but development proceeds slowly at <8°C). Pink and sockeye salmon tend to spawn in riffles. Sockeye select sites near lakes where the young rear, and occasionally sockeye spawn on beaches. Chum prefer to spawn above turbulent areas. Chinook are reported to spawn in streams and rivers of a variety of depths and flow characteristics. Coho appear to be even less particular.

In many areas within the range of Pacific salmon—for instance, Washington, Oregon, and California—salmon populations have declined after the loss of spawning habitat due to timber extraction and development and hydroelectric projects that block fish passage (NRC 1996). However, in the AYK region, freshwater habitat has not been markedly affected by human activities. Rivers are naturally dynamic, as witnessed by changes in channel boundaries that have left discernable patterns in the landscape. In the lower parts of many rivers, old spruce trees indicate where the channel has not traveled for at least 150 years. In the upper parts of many rivers, channel intrusions are defined by bedrock dating back to preglaciation eras. All diversions of channel or river perturbations have been from natural causes. In short, AYK rivers have not been dramatically affected by human activities, with some local exceptions. Habitat loss to date includes a few rivers around Fairbanks and Nome where placer or other mining activities took place. There is a dam at Whitehorse, Yukon Territory, on the main stem of the Yukon River, approximately 3,060 km from its mouth. Interestingly, those changes occurred primarily at the beginning of the twentieth century, well before the recent AYK salmon declines. Changes in habitat also may accompany shifts in climate—for instance, through accelerated erosion of banks that have lost permafrost. Fishing and boating activities may concurrently influence water quality, including the amount of silt and detritus. However, essentially no data on water quality exist, although efforts to begin watershed monitoring are under way at Unalakleet.

Members of local communities have made many observations that should be included in developing research plans. For example, the committee was told of ecological observations by Alaska Natives that included northerly shifts of vegetation patterns, affecting caribou migrations; and changes in the timing of natural indicators, such as emergence of black flies and the shedding of cottonwood seeds as indicators of the imminent arrival of Chinook salmon. These are exactly the kinds of observations and connections that should be integrated into the framing of hypotheses and the setting of research agendas. Many people who live along AYK rivers report a recent increase in beaver populations. Some Alaska Native elders are concerned about the increasing beaver populations and the resultant increase in beaver urine, which they feel is killing salmon eggs and fry. Beavers are well-known ecosystem engineers that have the capacity to alter freshwater habitat by flooding shallow streams (e.g., Collen and Gibson 2001). This change could reduce the amount of spawning habitat for some salmon species, while increasing it for others. It is unclear if beaver dams could impede fish passage—most salmon have the capacity to leap at least 1 m vertically. Coho rearing in cool spring-fed systems often cluster in the warm water flowing out of beaver dams, where temperatures improve their bioenergetic capacity for growth. Coho also use off-channel habitats provided by beaver dams, where they feed on the variety of aquatic invertebrates adapted to this environment (Sandercock 1991).

A critical change in habitat may be due to the loss of salmon themselves. Salmon deliver large amounts of marine-derived nutrients to freshwater areas of low productivity. On the basis of research elsewhere, it is likely that several years of low returns lead to lower productivity of algae and invertebrates, eventually influencing food supplies for young salmon as they develop in rivers (Zhang et al. 2003). Salmon also create a substantial disturbance in streams as they build redds (Hendry et al. 2004; J.W. Moore, Univ. of Washington, unpublished material, 2003).

One of the challenges in future decades will be the maintenance of habitat. Development projects such as power, roads, and large-scale mining are on the horizon. It will be necessary to maintain habitat during the process of identifying other factors that influence salmon populations. Any recent variance in salmon populations is not likely the result of instream habitat loss or degradation.

Feeding Interactions

The feeding ecology of the five species of AYK salmon in freshwater and estuarine habitats influences the growth, survival, and abundance of salmon. Briefly, pink and chum salmon migrate almost immediately to sea and therefore have shorter periods of interaction in freshwater than do the other three species, although the amount of foraging in freshwater probably also depends on how far upriver a salmon is spawned. Sockeye spend more time rearing in and around lakes than do other species. The following paragraphs elaborate on the ecological interactions that occur in freshwater. The bottom line is that the ecology of Pacific salmon predisposes them to be influenced by changes in food, particularly for subpopulations that spend longer periods in freshwater. However, little specific information about freshwater residence and feeding exists for AYK salmon.

Pink and Chum Salmon

Pink and chum salmon in short coastal streams migrate rapidly from freshwater and do little feeding there. As with all salmonids, subpopulations in different locations vary in life history attributes. Smolts spawned far from the ocean certainly feed during out-migration, primarily on aquatic invertebrates. The most commonly documented prey in freshwater are larval and pupal dipterans, which is not surprising because they are abundant in most salmon streams and are small enough to be eaten by fry, which are only 25-35 mm long. Up to 100 chironomids have been found in the stomach of a single pink salmon (Salo 1991). Other common prey include mayfly and stonefly nymphs, copepods, cladocerans, water bugs (hemipterans), and terrestrial insects (Salo 1991). On the basis of this information, competition for food among smolts migrating downstream might influence growth and survival. Similarly, year-to-year variations in feeding conditions during the downstream migration might result in year-to-year variations in growth and survival.

Estuarine residence time can last for weeks or months (Salo 1991), but again, subpopulations show substantial variability. Chum salmon exiting the Yukon River move immediately out of the estuary, perhaps indicating that food supply is low there. Estuarine diets generally consist of copepods and terrestrial insects. Pink and chum salmon often form mixed-species schools early in the marine life history (Heard 1991) and presumably do so when they co-occur in estuaries. Although the information on the use of estuarine or brackish habitats in the AYK region is scant, what is known about the ecology of pink and chum salmon elsewhere suggests these habitats may provide an important feeding area. The spatial extent and physical characteristics of these habitats and per capita resource abundance can be expected to influence critical early marine growth and survival.

Sockeye Salmon

Sockeye differ from chum and pink salmon based on their longer freshwater residence and rearing in lakes. Upon emerging from the gravel, sockeye fry feed on small aquatic insects and, in lake outlet streams, zooplankton. Once they enter their nursery lakes, fry initially feed close to the shore on cladoceran and copepod zooplankton and terrestrial and aquatic insects. Larger fish move offshore and specialize to a greater extent on zooplankton. On a broad scale, smolt production from sockeye rearing lakes is linearly related to euphotic volume, strongly supporting a role for primary production in determining smolt production. Indeed, competition for food has been documented for some sockeye subpopulations: density-dependent growth occurs in some lakes but not in others (Burgner 1991). Additional evidence for food limitation comes from the observation that lake fertilization experiments typically boost salmon growth and survival. In Alaskan lakes, turbid tributaries from melting glaciers may reduce the compensation depth and decrease euphotic volume and smolt production. In other cases, smolt production may be limited by the availability of spawning habitat rather than per capita food availability. Lake Becharof, Alaska, and other lake systems where growth is density independent may be examples.

Competition from other species also may influence sockeye salmon dynamics. According to Burgner (1991), interspecific competition is most likely early in freshwater life, when fry feed in the littoral areas of lakes where potential competitors are most abundant. Once they move offshore, sockeye typically greatly outnumber potential competitors and intraspecific competition is likely to be more important than interspecific competition. However, some studies have demonstrated that interspecific competition in the pelagic habitat can reduce the growth of sockeye. O'Neill and Hyatt (1987) have shown convincingly that the presence of threespine stickleback may reduce the growth rate of sockeye. Also, in Siberian sockeye lakes, threespine stickleback can slow the growth of sockeye sufficiently to delay smolting and increase mortality (Burgner 1991). Such competition is likely only in those systems where per capita prey abundance is low enough to generate density-dependent growth of sockeye (Burgner 1991). When prey are sufficiently abundant, the presence of potential competitors actually may benefit sockeye by providing alternative prey for predators.

Sockeye growth in freshwater is influenced not simply by the amount of food but also by food quality (large herbivorous zooplankton) (Sweetman 2001) and by environmental temperatures (Brett 1995, Mueter et al. 2002). Farther north, or at higher elevations, low temperatures may limit growth when food is sufficiently abundant. This pattern is probably typical of Alaska sockeye lakes (Burgner 1991). On short time scales, diel migration by sockeye alters both the temperature and the food available, and therefore growth rates. On longer time scales, growth rates influence whether sockeye spend 1 or 2 years rearing in freshwater; in the 2-year case, they incur an extra year of competition and freshwater mortality.

Coho Salmon

Coho salmon rearing in streams are drift feeders, holding station in the stream and capturing terrestrial and aquatic invertebrates as they are swept downstream by the current. Coho are often territorial (Puckett and Dill 1985) and select faster, deeper water as they grow (Everest and Chapman 1972). They may also consume salmon eggs and, in their second summer, small fish, particularly salmon fry. Food supply likely is influenced by riparian vegetation, which supports terrestrial invertebrates that fall into the stream and provides inputs of leaves that support populations of detritivorous stream invertebrates, and by in-stream primary production of epilithic algae, which supports grazing stream invertebrates that are particularly available to drift feeders and also provide food for detritivores. Coho also depend on spawning adult salmon for eggs, benthic invertebrates dislodged by adults, decomposing flesh that is consumed directly, and nutrients that stimulate primary production and microbial processes (Wipfli et al. 2003). The salmon fry that emerge in spring are important prey for coho yearlings and smolts. The abundance of coastal coho is also closely correlated with the quantity of large wood in the stream channel (Fausch and Northcote 1992). This large wood serves a variety of functions. It retains spawning gravel, fosters the creation of pool habitat, which coho salmon favor for feeding, and provides cover from predators. Such habitats allow fish to obtain favorable tradeoffs between growth rate and predation risk.

Because of the long stream residence of coho, they are particularly sensitive to variation in water temperature and stream discharge. Stream temperatures in coho streams in the AYK region are typically cool, especially since coho spawn and rear in spring-fed systems in the interior, so warming is unlikely to be a concern for rearing fish. Both high and low flows may be detrimental to coho: low flows tend to reduce food supply and increase predation risk, whereas severe floods may scour eggs from the gravel or hamper early feeding. In some cool systems, low summer flows also may have a positive influence by increasing water temperature and promoting coho growth. Food and protection from predators are increasingly recognized as essential to successful overwintering in British Columbia, but it is unclear how much feeding occurs by overwintering coho in AYK streams.

Chinook Salmon

Chinook salmon share many aspects of foraging ecology with juvenile coho. Both species can be characterized as drift-feeding stream salmon, and many of the differences in juvenile ecology between the two species may be more a consequence of differences in the spawning habitats used by their parents than intrinsic differences in juvenile behavior. In the AYK region, both Chinook and coho do spawn in the same coastal streams, although coho spawn later than Chinook. In these systems, it would not be surprising to see the two species making similar use of rearing habitat. In interior streams, Chinook and coho segregate by stream types: Chinook spawn in the middle reaches of clearwater runoff rivers while coho spawn later in spring-fed systems. In clearwater runoff systems in the interior, juvenile Chinook are most abundant in the middle reaches of the river where they forage near woody debris on the outside of meander bends. However, juveniles will migrate upstream into small tributaries and downstream into larger rivers to find rearing habitat. Their affinity for woody debris mirrors that of coho and they are rarely found where it is absent (M. Bradford, Fisheries and Oceans Canada, personal communication, 2004), unless there is some other form of cover, such as surface ripple, cobble, or turbidity.

Impact of Disease

Ichthyophonus is a parasitic protist found in fishes around the world. However, in the AYK region, the disease it causes has been identified only in Chinook salmon. Chinook in the advanced stages of the disease are less valuable to subsistence and commercial fishers. The disease was first identified in 1985 but undoubtedly has been present longer, because symptoms of the disease have been observed over time by fishers along the river. Systematic studies have been carried out from 1999 to 2003 by R. Kocan and colleagues. Over this period, the incidence of

Ichthyophonus in Chinook salmon entering the Yukon River was 20-32%. Incidence of the disease on the spawning grounds is lower than at the mouth and midrange of the river, possibly indicating that diseased fish died before spawning, especially given that the incidence is higher in females than in males. No other disease has been identified as being as prevalent in the region.

Systematic studies of *Ichthyophonus* in Yukon salmon have not been under way long enough to observe the incidence of the disease over both high and low returns of salmon. Thus, the apparent impact of the disease on the variability of returns is difficult to assess. Likewise, the underlying factors of the disease are not understood. Salmon are believed to contract *Ichthyophonus* from ingested food. Limited sampling of herring in the Bering Sea reveals no *Ichthyophonus*, but sampling in the Gulf of Alaska has shown the disease to be present in herring there. Environmental and other forcing factors causing changes in the incidence of the disease in North Pacific fish are not understood.

Impact of Freshwater Predation

Anadromy may have evolved as a consequence of differences in size-dependent predation rates and foraging opportunities between the marine and freshwater environments (Gross 1987). Freshwater habitats are relatively safe for small fish. From this perspective, the anadromous life histories of salmon reflect the result of evolutionary adaptations that optimize the temporal sequence in which these fish exploit the suite of foraging and predation-risk trade-offs provided by freshwater and marine habitats. The nature of the trade-offs that these habitats make available may provide the ultimate explanation for the abundance of salmon and their migratory lifestyle.

Nevertheless, predation in freshwater habitats can be substantial enough to influence population dynamics. Existing studies show that predation can reduce abundance, contribute toward year-to-year variability in abundance, and regulate population size. In addition, indirect effects of predation, such as predator avoidance behavior, might influence population size. To support these conclusions, it is necessary to piece together insights from a range of different studies because we lack the general insights that might be provided by in-depth long-term studies of the role of predation in the dynamics of single populations. The lack of such in-depth, long-term work is not surprising, because studies of population dynamics are very demanding, even in small stream systems, and predation rates can be very hard to measure. It is sobering that the two most comprehensive studies of salmonid population dynamics, a study of brown trout (*Salmo trutta*) (Elliott 1994) and a study of steelhead (*Oncorhynchus mykiss*) (Ward 1996), made no effort to determine the contribution of predation to the total mortality rate. Predation in freshwater can reduce the abundance of Pacific salmon at every life history stage. However, the intensity of predation can vary greatly from place to place and from year to year, as can the species of predator involved. A species that is an important predator in one system may consume very few salmon in another.

In freshwater, the main predators on adults are bears (*ursus arctos*). Predators on eggs include sculpin (*Cottus* spp.), rainbow trout, coho salmon, Chinook salmon, Arctic char (*Salvelinus alpinus*), Dolly Varden char (*S. malma*), Arctic grayling (*Thymallus arcticus*), and a diving bird called the water ouzel (*Cinclus mexicanus*). Possibly, most egg predators simply eat dislodged eggs that would have died anyway. Predators on alevins (still in gravel) include leeches (*Piscicola salmositica*) and brown bears. Fry are eaten by coho yearlings, cutthroat trout (*Oncorhynchus clarki*), Dolly Varden char, and sculpins. Migrating smolts are a profitable prey, small enough to be vulnerable to most piscivorous fish and birds and often abundant enough to attract concentrations of predators. Predators include Bonaparte's gulls (*Larus philadelphia*), Arctic terns (*Sterna paradisaea*), glaucous-winged gulls (*Larus glaucescens*), short-billed gulls (*Larus canus*), Arctic char, and lake trout (*Salvelinus namaycush*) (Nelson 1966, Hartman and Burgner 1972, Moriarity 1977, Meacham and Clark 1979). Estimating mortality rates of salmon is extremely difficult, but large proportions (50-95%) of annual production must be lost to predators each year (Semko 1954; but see Volovik and Gritsenko 1970, Hunter 1959, Major and Mighell 1969, Rogers et al. 1972).

Mechanisms responsible for annual variability in predation include risk dilution by alternative prey—for example, predation rates on chum salmon fry may be reduced when pink salmon fry are abundant (Salo 1991). Annual fluctuations in predator abundance are another possible cause of variable predation rates—for example, fluctuations in the abundance of juvenile coho salmon, often an important predator in freshwater, would result in varying predation rates on their prey. Annual variability in environmental conditions also may affect predation rates—for example, high turbidity and high flows may reduce the travel time of migrating smolts and make them less vulnerable to predators. This process might explain the positive relationship between stream discharge survival rates of Chinook salmon migrating through the Sacramento River delta in California (Healey 1991). Annual variability in temperature may be important because warmer water may accelerate the metabolic rates of predators and increase their food consumption rates. Warmer temperaures also may allow predators adapted to warm water to penetrate into the normally cooler habitats occupied by salmon.

Clearly, many salmon are eaten in freshwater. However, no population level study has been able to measure the contribution of freshwater predation to population dynamics. Theory provides the only guide to the role of predation. Theoretical studies show that predators can regulate the size of salmon populations, and as a result there can be more than one stable population size (Peterman 1987). Predators regulate the population at the lower equilibrium while some other density-dependent factor regulates population size at the higher equilibrium. In the terminology of population ecology, populations at this lower predator-regulated equilibrium are said to be in a “predator pit.” This predator pit can exist only where there is a positive relationship between the proportion of the prey population killed by predators and prey abundance, and where the predation rate is sufficiently high to prevent an increase in population size to some higher level. Peterman (1987) used circumstantial evidence to make a convincing case that pink salmon populations in British Columbia have been caught in predator pits and Burgner (1991) used data from the little Togiak River in Bristol Bay (Ruggerone and Rogers 1984) to argue that some sockeye salmon stocks also may be regulated at low abundance by predators. Density-dependent predation also may generate annual variability in abundance. For example, a number of authors have suggested that the pronounced 4-year cycle in the abundance of sockeye salmon returning to the Adams River, British Columbia, is the consequence of predation taking a higher proportion of fish in years with weak runs (Ricker 1950, Ward and Larkin 1964, Larkin 1971).

Until now, one implicit assumption of this review has been that predation will reduce the number of salmon. This is true in the immediate sense that predation on returning adults will reduce the abundance of returning adults, but this assumption does not always hold when considering the effect that predation at one life stage will have on the abundance of fish at another life stage or at the same life stage in the next generation. In fact, as every fisheries ecologist knows, density-dependent mortality may result in a situation whereby a reduction in the abundance of salmon at one life stage will increase abundance in the next generation. This concept is reflected in the term "overescapement," which recognizes the possibility that large escapements of spawning adults may produce fewer progeny than smaller escapements. The concept of overescapement is associated with human harvest but also could be used to consider the impacts of other predators. Thinking along these lines shows that it would be possible for predation not to decrease abundance during at least part of the life cycle.

This brings us to the effect of predator removal on population dynamics. Predator removal programs dot the history of salmon management, and their goal invariably has been to increase the abundance of salmon by reducing losses to predators. During the first half of the nineteenth century, bounty programs were established in Alaska to increase salmon abundance by reducing the abundance of eagles, hair seals (harbor seals, ringed seals, ribbon seals, and bearded seals), and char (Meacham and Clark 1979). For a period, the Bureau of Fisheries also provided ammunition to its agents and the public to shoot gulls and terns; eggs in tern colonies also were destroyed (Hubbs 1940). In general, the effectiveness of these programs has not been evaluated. For example, although the federal bounty program on char in Bristol Bay between 1920 and 1940 is thought to have resulted in the removal of millions of char (as well as nontarget species such as rainbow trout and salmon), there was no evaluation of the effects of this removal, and the program ended when its value was questioned (Hubbs 1940, DeLacy and Morton 1943). There are a few interesting studies in which the effects of predator removal were better documented. One such study is ADF&G's capture and confinement project to reduce Arctic char predation on sockeye salmon smolts in the Wood River Lakes, Bristol Bay, Alaska (Meacham and Clark 1979). During 1977, Fish and Game biologists confined 5,588 char during the smolt migration and estimated that this "saved" about 900,000 sockeye salmon smolt from predation. There was another well-documented predator removal program in Cultis Lake, British Columbia (Foerster 1968). In this study, researchers removed a total of 10,000 northern pikeminnow (*Ptychocheilus oregonensis*), 2,300 cutthroat trout (*Oncorhynchus clarkii*), 935 Dolly Varden char, and 730 juvenile coho salmon over a 4-year period. They estimated that this removal reduced northern pikeminnow and char to a tenth of their former abundance.

During this period of predator removal, there was a marked increase in smolt production, with freshwater survival increasing by approximately 300% and also an increase in the size of the smolts compared with pre-predator removal years with smolt runs of similar size. Predator removal still plays an important part in salmon management—for example, in the Columbia River there is a predator control program for northern pikeminnow aimed at reducing predation on salmon smolts. In 2004, the Bonneville Power Authority funded Northern Pikeminnow Management Sport Reward Program is offering $4-6 dollars for each fish over 9 inches long, and since 1990 this program has resulted in the removal of more than 2 million fish from the Columbia River system. It has been estimated that this removal has reduced predation on salmon smolts by 25% (Northern Pikeminnow Management Program 2004). Predator removal programs should be viewed with caution, because food web interactions may render them ineffective or actually reverse the intended effect.

Some residents of the AYK region have suggested that changes in predator abundance might have contributed to recent declines in salmon or, even after human fishing pressure was relaxed, could prevent recovery of populations. Explicit examples include beluga whales at river mouths and piscivorous fish and birds that experience less hunting than before.

The direct effects of predation play an important role in population dynamics, but the indirect effects of predation are also important. The way that predation risk interacts with foraging opportunities to influence an animal's behavior is known to have profound consequences for growth and mortality. For instance, lake-rearing sockeye tend to reduce foraging in the presence of predators. Then, reduced growth rates probably result in increased duration of freshwater residence, increased inter-cohort competition, and a reduction in smolt production. Thus, predators may reduce smolt production both by consuming rearing fish and by altering prey behavior in a way that reduces their growth rate and intensifies competition for food.

Ecological Interactions in the Ocean

During their marine life-history phase, salmon are critically dependent on the magnitude and distribution of ocean productivity, particularly relative to how much food is needed by all organisms at their trophic level. The picture is complicated because trophic level varies with size, given that salmon can capture and consume larger prey as they grow. Consequently, foraging success may vary with events that alter ocean productivity as well as through exploitation competition.

One hypothesis for the decline of western Alaskan (AYK and Bristol Bay) salmon runs in the late 1990s is that climate negatively affected the ocean survival of salmon through changes in benthic and pelagic food webs (Kruse 1998). (See the section Restoration in this chapter for a discussion of potential impacts of hatchery salmon.) In 1997-1998, unusual changes in marine nutrients, primary production (coccolithophore blooms), and energy transfer through eastern Bering Sea food chains may have resulted in poor feeding conditions that reduced the growth and survival of juvenile salmon. Late runs and smaller than average body sizes of salmon returning to western Alaska in 1997-1998 indicated that adult salmon also may have been affected by these unusual conditions. Perhaps high sea temperatures along adult migration routes in the eastern Bering Sea or other factors, such as increased parasitism, predation, competition, and disease, caused the death of many adult salmon. Kruse (1998) suggested that analyses of relations between climate indices and return-per-spawner data, as well as process-oriented field studies of plankton dynamics and early ocean life history of salmon, were needed to understand which salmon life history stage was affected.

Brodeur et al. (2003) reviewed U.S. research on the food habits, feeding selectivity, daily ration, and food consumption studies of juvenile salmon during their first year at sea. Juvenile salmon are visual feeders and tend to select relatively large, pigmented (visually obvious) prey. The feeding habits of juvenile salmon are highly opportunistic, which means that they can eat almost anything that is readily available. For example, finding visually appealing pieces of plastic or other foreign objects in juvenile salmon stomachs is not unusual. Diel food consumption studies show that juvenile salmon in marine waters feed during daylight hours, often with peak feeding at dawn and dusk. Juvenile salmon often consume prey found only in the near-surface (neustonic) layer, and they aggregate in areas where water currents (for example, tide rips) concentrate neustonic prey. In turbid nearshore waters where visibility is limited, they may consume terrestrial insects or other items drifting on the surface. There are inter- and intraspecific differences in type and size of prey consumed by juvenile salmon. For example, coho and Chinook salmon tend to eat larger prey (crab megalopae and juvenile fish) than pink, chum, and sockeye salmon, which seem to prefer copepods, euphausids, and larval fish. As juvenile salmon grow, all species tend to eat larger and more evasive prey.

Interannual, seasonal, and spatial differences in prey availability can lead to major differences in diet composition and amount of food consumed by juvenile salmon. Food limitations for juvenile salmon are more likely to occur in nearshore (littoral) habitats, where space is limited and fish are more concentrated than in offshore (neritic) habitats. In the eastern Bering Sea, the initial growth of juvenile salmon may be poor because of limited food and visibility in turbid river plumes and nearshore waters (Straty and Jaenicke 1980). The influence of food abundance on juvenile salmon growth and survival varies depending on the size and age structure of the juvenile salmon population and the dynamics of the zooplankton population (Straty 1974). Marine field and computer modeling research in other regions has indicated that juvenile salmon are not food limited in neritic habitats—for example, they may consume less than 1% of the total production of available prey. Better information on consumption rates relative to available food resources is needed to estimate the carrying capacity of juvenile salmon in littoral and neritic habitats (Cooney 1984, Cooney and Brodeur 1998, Brodeur et al. 2003).

Broad syntheses of information on the ocean food and feeding habits of immature and maturing salmon in offshore waters of the North Pacific Ocean and Bering Sea are reported by species in the International North Pacific Fisheries Commission (INPFC) Bulletin series (coho salmon, Godfrey et al. 1975; sockeye salmon, French et al. 1976; chum salmon, Neave et al. 1976; Chinook salmon, Major et al. 1978; pink salmon, Takagi et al. 1981). This information was reviewed and updated by Burgner (1991) for sockeye salmon, by Healey (1991) for Chinook salmon, by Heard (1991) for pink salmon, by Salo (1991) for chum salmon, and by Sandercock (1991) for coho salmon. The results of field-oriented process studies and computer modeling research over the past decade indicate that food and nutrients are a major link between climate and the growth and survival of immature and maturing salmon in the Bering Sea and North Pacific Ocean. Maturing salmon in the Bering Sea in summer feed at rates close to their physiological maxima, and any reduction in daily ration can cause a significant decrease in growth over a time period as short as 2 months (Davis et al. 1998). When prey are abundant, salmon growth is limited by metabolic rates at high temperatures and by consumption rates at low temperatures. In summer, salmon may be able to regulate metabolic rates by making vertical descents from the surface to cooler subsurface waters (Walker et al. 2000). In winter, low lipid levels measured in immature salmon caught in the North Pacific Ocean suggest that fish are close to starvation (Nomura et al. 2000). When maturing pink salmon are abundant, immature salmon may switch their diets from high- to low-energy prey (Tadokoro et al. 1996). Reductions in summer growth of immature salmon in offshore waters and decreased survival are correlated with pink salmon abundance (Ruggerone et al. 2003). Increases in production of hatchery fish (next section) at a time when ocean productivity is decreasing may magnify the effect of food competition on salmon growth and fertility (Volobuev 2000).

Impacts of Hatcheries

Oceanic interactions among salmon in the Bering Sea and the Gulf of Alaska are complicated by the release of billions of hatchery fish that probably compete for food with wild salmon. In 2003, for example, nearly 1.5 billion salmon were released by two state, 29 private nonprofit corporations, and two federal hatcheries in Alaska (Farrington 2004). All of the hatcheries were in the Gulf of Alaska, southeast Alaska, or on rivers that flowed into one of those areas. The releases included 962,470,000 pink, 435,570,000 chum, 23,100,000 coho, and 9,300,000 Chinook salmon. Of the 173,344,000 salmon taken in Alaska in 2003, 42% (73,000,000) were of hatchery origin. In addition, many millions of salmon are released into the ocean by hatcheries in British Columbia, Washington, Oregon, and California as well as in Japan and probably elsewhere in Asia. An unknown number of those fish feed in the same areas that salmon of AYK origin feed in, and there is increasing evidence of competition among them for food (Volobuev 2000).

Impacts of Predation

Predation by marine mammals, fish, and seabirds is a major cause of early ocean mortality of juvenile salmon. Research on marine predators of juvenile salmon in North America and Asia was reviewed by the

North Pacific Anadromous Fish Commission (Beamish et al. 2003, Brodeur et al. 2003, Karpenko 2003, Mayama and Ishida 2003). Pearcy (1992) reviewed information on predation during estuarine, coastal, and oceanic life history phases of salmon in the subarctic Pacific; identified the early ocean stage as the most "critical" period; and concluded that future research to evaluate "important predators in the ocean, how their predation rates vary in time and space, and how they are related to size, duration of ocean life, and behavior of juvenile salmonids" should be given a high priority.

Meacham and Clark (1979) identified many important predators of juvenile salmon in Alaska—several seals, beluga whales (*Delphinapterus leucas*), eagles (*Haliaeetus leucocephalus*), gulls, and terns. Despite large populations of fish-eating sea birds in the eastern Bering Sea region, stomach content analyses of the birds have not shown significant predation on juvenile salmon (J. Sanger, Fish and Wildlife Service, personal communication, as cited by Rogers 1988). Fiscus (1980) reviewed information on 34 potential marine mammal predators of salmon in the North Pacific and contiguous seas, including 15 species known to prey on salmon. Predation on free-swimming salmon (when they are not caught in nets or other fishing gear) by six marine mammal species—harbor seal (*Phoca vitulina*), Steller sea lion (*Eumatopias jubatus*), California sea lion (*Zalophus californianus*), beluga whale, harbor porpoise (*Phocoena phocoena*), northern fur seal (*Callorhinus ursinus*), and killer whale (*Orcinus orca*)—is well known (Fiscus 1980, Pitcher 1981). Of these, beluga whales may be the major marine-mammal predator of juvenile and adult salmon in the eastern Bering Sea. In Bristol Bay, beluga whales congregate in some inner bays and use their sonar capabilities to feed on sockeye salmon smolts, until they begin to feed on adult sockeye returns in late June (Frost et al. 1984). Beluga whales are also distributed in the Norton Sound/Yukon Delta region (Lowry et al. 1999), but to our knowledge beluga predation on salmon in this region has not been investigated. Observations of predation by other species of marine mammals may occur primarily when salmon are caught in nets or other types of fishing gear. Sinclair and Zeppelin (2002) identified older (immature or adult) salmon as one of the more frequent prey of Steller sea lions in summer and winter.

At least 50 species of juvenile and small (<20 cm long) fish, but few large fish, are associated with juvenile salmon in coastal surface waters of the southeastern Bering Sea (Isakson et al. 1986). Salmon are cannibalistic, and many studies have documented adult salmon feeding on juvenile salmon in marine areas where their distribution, migratory routes, and run timing overlap. Spatial and temporal differences in the habitat preferences, ocean distributions, and migration routes of salmon at different maturity stages may serve to reduce cannibalism as well as size-selective predation by other predators. In the marine waters of southeastern Alaska (May-October), Orsi et al. (2000) observed predation on juvenile salmon by only 4 of 19 species of potential fish predators—none of the adult walleye pollock (*Theragra chalcogramma*) or adult herring (*Clupea pallasii*)—identified as major juvenile salmon predators in Prince William Sound (PWS), Alaska (Willette et al. 1999). The primary predators of juvenile salmon in this region were age 1+ sablefish (*Anoplopoma fimbria*) and adult coho salmon (Orsi et al. 2000).

Predation by salmon sharks (*Lamna ditropis*) on milling adult salmon in coastal marine waters, bays, and estuaries is commonly observed. Studies of diets and movements of salmon sharks in Alaska's PWS by Auke Bay Laboratory scientists in 1998-2001 indicated that salmon sharks are attracted to adult salmon returning to hatcheries and rivers in PWS, consuming 12% of pink salmon runs and 29% of chum salmon runs to Port Gravina in 2000 (L. Hulbert, Auke Bay Laboratory, personal communication, 2004). Salmon sharks are also well-known predators of immature, maturing, and adult salmon migrating in offshore waters of the Bering Sea and North Pacific Ocean, including the Gulf of Alaska (Nagasawa 1998). Japanese high-seas driftnet catch data indicate that salmon sharks migrate to offshore areas where salmon are most abundant—for example, salmon sharks are abundant in North Pacific waters south of 48°N in late April and May, when salmon are also abundant in these waters. Nagasawa estimated that salmon sharks (age ≥5; 595,000 fish in 1989) in the subarctic North Pacific consume 73-146 million salmon (113-226 thousand metric tons [t]) per year, which is equivalent to 12.6-25.2% of the total annual run of Asian and North American salmon in 1989. Some other well-known fish predators of immature, maturing, and adult salmon in the Bering Sea and North Pacific Ocean are Arctic lamprey (*Lampetra japonica*), Pacific lamprey (*Lampetra tridentata*), spiny dogfish (*Squalus acanthias*), lancetfish (*Alepisaurus ferox*), and daggertooth (*Anotopterus* spp.). Although wounds inflicted by lampreys and daggertooths are not always fatal, they may reduce the reproductive potential of salmon (Savinykh and Glebov 2003).

Many marine predators of juvenile salmon have been identified in other regions (Fresh 1996); however, relatively few studies have attempted to quantify the effects of marine predation on juvenile salmon survival (Brodeur et al. 2003). Parker (1965, 1968) is often cited as the standard (quantitative) reference to support the hypothesis that brood year strength of salmon is established by marine predation soon after ocean entry (Beamish et al. 2003). Parker estimated that 55-77% of pink salmon fry died during their first 40 days in the ocean (mortality, 2-4% per day), and mortality was 0.4-0.8% per day during their remaining sea life (approximately 144 days). Early ocean predation may be higher on pink salmon than on chum salmon, because pink fry are smaller than chum fry at ocean entry (Parker 1971). However, Pearcy (1992) estimated similar mortality for Oregon coho salmon smolts, which are much larger than pink salmon fry (2-8% per day, first 30-40 days at sea; 0.2-1.0% per day, remaining 450 days at sea). During years when climate change (for example, El Niño) causes a shift in the distribution of marine predators or a decline in the abundance of their nonsalmonid prey, these rates can be much higher at both juvenile and adult stages. In PWS, herring and walleye pollock are the dominant fish predators of juvenile pink salmon; the estimated consumption by nine fish and avian predator groups was approximately 50% of the annual PWS juvenile pink salmon production; and predation pressure was less in littoral than in neritic habitats (Willette et al. 2001). Scheel and Hough (1997) estimated that seabirds foraging near a hatchery in PWS ate 1-2% of hatchery releases of juvenile pink salmon. Beamish and Neville (2001) estimated an annual variation of 1.4-100% in predation mortality by spiny dogfish on juvenile coho and Chinook salmon hatchery releases in the Strait of Georgia. Piscivorous birds (primarily Caspian terns, *Sterna caspia*) nesting on islands in the Columbia River estuary annually consume large numbers of outmigrating juvenile salmonids (Roby et al. 2002).

To our knowledge, no ongoing research in the AYK directly focuses on quantifying marine predation of AYK salmon. Data from ongoing marine field research on salmon (for example, the Bering-Aleutian Salmon International Survey [BASIS] and the National Marine Fisheries Service [NMFS], Auke Bay Laboratory, Ocean Carrying Capacity [OCC] Program), invertebrates (especially squid), seabirds, marine mammals, and other species of fish could be used to fill some information gaps. A thorough investigation of marine predation mortality of AYK salmon will require coordinated ecosystem research and monitoring that is beyond the scope of any current marine salmon research programs. Research on other (nonsalmon) species and marine ecosystem research supported by the North Pacific Research Board, National Oceanographic and Atmospheric Administration (NOAA), and other agencies and organizations may serve to fill at least some information gaps.

Biological and Physical Challenges During Migration

Adults

For salmon that spawn in coastal areas, the upriver spawning migration is unlikely to be particularly demanding; however, fish that spawn in the upstream areas of the Yukon and the Kuskokwim Rivers must swim long distances. Little or no food is taken in freshwater, so the energy costs of migration may make up a considerable fraction of their total energy budget. In this situation, factors that increase the energetic cost of migration may have significant impacts on mortality during the upstream migration and also on spawning success. Factors that will influence the cost of the upriver migration include stream discharge and its effect on water depth and water velocity, water temperature, and the availability of structures that influence water velocity and turbulence, such as the roughness of the stream bed, large wood, and the structure of the stream bank.

High flows might increase migratory costs of chum, coho, and Chinook salmon spawning in the upper Yukon River by increasing the velocity of water they have to swim against. However, upstream migrants take advantage of the slower water near the stream bed and banks; as a result, the relationship between stream discharge and the velocity against which fish swim will depend on the bathymetry of the channel. Increased flow is most likely to increase migratory costs where the channel is confined, as at Hell's Gate Canyon on the Fraser River, British Columbia.

The effect of stream temperature on migratory costs is likely to be more important than the effects of stream discharge, because migrating fish can do nothing to avoid the higher metabolic costs of swimming at higher temperatures. In fact, the influence of stream discharge on stream temperature may have a greater impact on the energetics of migration than the influence of discharge on swimming speed. Given the large effects of changing temperatures on metabolic rate and swimming costs, it may be well worth investigating the possibility that annual variability in stream temperature affects the mortality rates of adult migrants in AYK. Research on the Fraser River, British Columbia, suggests high stream temperatures can lead to high mortality rates of adult migrants (Clarke et al. 1995), and the Yukon River and its major tributaries, though glacial in origin, can approach 20°C during the summer months.

These considerations of migratory energetics also focus attention on the role of large wood on channel morphology and current velocity. The abundance of large wood in the Yukon River and its major tributaries undoubtedly influences channel morphology and the depth and velocity characteristics of the reaches through which salmon migrate. The way this affects the energy expenditure of upstream migrants is unknown but may be worth investigating. Increased logging in the AYK region can be expected to change the pattern of large wood recruitment to these rivers in the future. Salmon make use of resting areas on the upstream migration and large wood may help form such areas. The influence of riparian vegetation on bank stabilization and channel morphology is a closely related issue. The wave drag hypothesis (Hughes 2004) suggests that large salmon like Chinook need water that is both slow and deep to minimize migratory costs; these areas occur along complex cut banks where friction slows flow. Complex banks also generate turbulence, which creates small-scale flow reductions and reversals, areas that fish can exploit to reduce migratory costs (Hinch and Rand 2000, Liao et al. 2003).

Smolts

The influence of stream discharge on the energetics of smolt migration is likely to be important for long-distance migrants. For these fish, high flows will provide more rapid transport to the marine environment because, in large rivers, traveling smolts position themselves in the middle of the river and near the surface, where water velocity is highest.

Water temperature during smolt migration is also likely to be important. Low temperatures are likely to be advantageous when prey availability is low, because this reduces metabolic costs and increases energy reserves at migration's end. During periods of migration when feeding and growth are more important, higher temperatures may be an advantage.

In all systems, stream discharge, water temperature, and turbidity are likely to have major implications for predation risk. In general, low flows, high temperatures, and clear water are likely to increase the risk of predation by making it easier for aquatic and avian predators to see smolts and by increasing the metabolic rate of aquatic predators. The Yukon River and its major tributaries are turbid systems; however, it is possible that reductions in the input of glacial silt in the future will reduce turbidity and make outmigrating smolts more vulnerable to predation.

Research Questions

The broad research question deals with partitioning the effects of environmental variability on salmon populations into marine and freshwater areas. In other words, are the fluctuations in salmon populations related more closely to changes in the marine environment, in the freshwater environment, sometimes one and sometimes the other, or both most of the time?

Habitat

- Has the loss of marine-derived nutrients due to recent low salmon returns reduced the productive capacity of salmon habitat?
- What are the cumulative impacts of small changes in habitat from mining, motorized boat disturbance, or changes in water level due to climate change (subsidence from higher temperatures, increased precipitation)?
- What proportion of habitat has been modified by beavers and how do salmon respond?

Disease

- Given the significant incidence of *Ichthyophonus* in Chinook salmon, and the possible impact of the parasite on migrating/spawning populations, how have the incidence and impact of the parasite played a role in the variability of returns? Annually monitoring the incidence of the parasite would be valuable in assessing variability of occurrence. If there is considerable variability, then a further assessment of its impact on spawning populations would be valuable. Because Chinook in the advanced stages of *Ichthyophonus* infestation are less valuable to subsistence and commercial fishers, other species might be taken as substitutes for them. These same data on disease would suggest how many harvested fish might be replaced with other fish.

Competition

- How common is density-dependent growth and survival in freshwater?
- In the ocean, do hatchery fish reduce food availability (and therefore growth and survival) of AYK salmon?

Predation

- What is the role of predation in the population dynamics of Pacific salmon in the AYK region? For any particular stock, such an understanding probably would provide much deeper insights into the factors regulating abundance and determining year-to-year variability in abundance. In cases in which predators regulate abundance, these insights also might provide the basis for scientifically based manipulations of predation risk to restore abundance to a higher equilibrium level. Existing studies demonstrate that it is possible to estimate predation rates for various life history stages, although it is more difficult in some cases than in others. For example, it might be relatively straightforward to estimate predation rates on pink salmon fry in the Nome River, but it would be vastly harder to estimate the mortality of smolts from a stock of Chinook in the Yukon River drainage during their migration to the ocean. Incorporating measurements on life history stage-specific mortality rates to determine the role of predation in population and dynamics is likely to be much harder than simply measuring mortality rates for a single stage and a single year. Such studies would need to cover multiple years to get a picture of the way predation rates varied with population size.

Such studies not only should have a sound theoretical basis, they also should aim to strengthen and extend current theory. To do this they need to be extremely well planned and executed and should involve leading researchers. These studies could be conducted on key stocks that represent the important species, life history types, and habitats. The backbone of these studies might be a program to provide accurate long-term data on the abundance, size, age composition, and sex ratio of adults returning to spawn as well as data on the abundance, size, and age composition of smolts leaving the system. More detailed projects on the sources of marine and freshwater mortality in these systems, including predation, could then be built into these projects. Selection of systems for these long-term studies will require thought, but criteria such as importance of the stock for human use, accessibility, and tractability are likely to be key elements to success. Partnerships involving local communities, ADF&G, federal agencies, and universities are likely to be required, paying special attention to how to maintain long-term support for the project in a world where short-term funding is the rule.

- What are the roles of particular predators in regulating the abundance of particular stocks? For example, there is some thought that predation by beluga whales on sockeye smolts is responsible for currently low production in the Kvichak River, once the most productive sockeye salmon system in the world. ADF&G estimates adult returns and smolt emigration from that system, which simplifies the collection of the data needed to determine the proportion of the run taken by beluga whales. Together with theoretical modeling of population dynamics, such studies may serve to support or disprove the beluga hypothesis.
- When stocks of considerable local importance experience prolonged reduction in productivity, are predators regulating the population at a low equilibrium? For example, the depressed chum and pink stocks in the Nome River on the Seward Peninsula may warrant such an investigation. The Nome River is a small, accessible system relatively amenable to study, and it has historically provided abundant fish in an area where other salmon resources are relatively scarce. In situations like this, relatively short-term predator-impact-assessment projects coupled with modeling work could provide insight into what is responsible for the low abundance. Insights from these studies could provide the foundation for management by manipulation of predation risk.
- How do anthropogenic factors alter predation mortality of AYK salmon (for example, climate change, hatchery releases, and large-scale marine fisheries)? Some specific examples follow.

- Were declines in AYK salmon runs in the late 1990s due to climate-induced changes in distribution, abundance, forage base, and feeding behavior of any major marine predators of juvenile salmon in the Bering Sea (for example, beluga whales feeding on juvenile salmon within or near coccolithophore blooms)?
- Did changes in predator removals by marine fisheries in the 1990s result in an increase in the abundance of coastal and offshore marine salmon predators of AYK salmon (for example, reduction in predator removals by large-scale Asian high-seas driftnet fisheries after the U.N. moratorium on large-scale high-seas driftnet fishing, effective after December 1992)?
- Were declines in AYK salmon runs in the late 1990s due to large-scale releases of hatchery salmon that attracted more apex predators (for example, salmon sharks attracted to maturing Japanese hatchery chum or PWS pink salmon) to the oceanic regions where AYK salmon migrate?

To adequately address these and other questions about predation mortality of AYK salmon, better information is needed on the distribution, life history, ecology, and population dynamics of the major marine predators of salmon and their trophic community structure in the Bering Sea and North Pacific Ocean. A thorough review of the food habits literature and ongoing research on potential marine predators of AYK salmon in the oceanic regions where they migrate would be useful and could be used by AYK SSI to develop a database of information on potential predation mortality of AYK salmon at various life history stages. To estimate predation mortality, information is needed on predator abundance, distribution, size and number of individuals, condition or health of predators, and environmental variables that may affect predation. Essential components of a successful research program include both field and computer modeling research. Willette et al. (2001) suggested that future research to understand the mechanisms influencing the mortality of salmon should emphasize the following: (1) field studies to develop better methods of measuring salmon (and predator) densities at sea, (2) partitioning estimates of salmon survival between juvenile and oceanic life history stages, (3) the use of releases of marked or tagged fish to validate computer models, and (4) using computer models to understand mortality processes.

HUMAN DIMENSIONS

Commercial and Subsistence Fishing Gear Across the AYK Region

Norton Sound

In the Norton Sound region, types of gear used for subsistence salmon fishing include beach seines, drift and set gill nets, and rod and reel, although seines and short-set gill nets were used historically as well (Thomas 1982, Magdanz and Ollana 1984, Georgette and Utermohle 2000). The type of gear used varies depending on species harvested, location, and river conditions when salmon are available. Fishing gear for subsistence salmon fishing is regulated in terms of type of gear and its length, where the gear can be deployed, and duration of use.

Yukon

Historically, fishing gear used for subsistence salmon fishing in the lower Yukon River drainage included dip nets, traps with fences, and drift and set gill nets made of willow or spruce root, sinew, baleen, or seal skin (Pete 1991). Seining with nets also was practiced in shallow streams. Fish wheels came into use in the early nineteenth century, along the middle and upper reaches of the Yukon River. Through time, the type of gear used and fishing method varied by species, season, water level, dispersion of salmon, density of the run, and river current (Wolfe 1979).

Imported manufactured materials, such as linen, were introduced in the late 1890s and used for making gill nets, and by 1920 were the predominant materials used for nets. By the early 1960s, net webbing made with nylon or nylon-based filament began to replace linen, and net length and depth increased, making them more versatile for fishing in deeper and swifter water and during high water conditions (Pete 1991).

Drift and set gill nets used are used for both Chinook and small salmon subsistence fishing. The length of the net varies, depending on species targeted, fishing area, season, and river conditions, with drift nets 120-600 ft long and set nets typically shorter (Pete 1991). The allowable gear (length, depth, mesh size, number of units) used in salmon fishing is set by regulation, which has become increasingly restrictive since the early 1960s. The amount of time gear may be fished has been regulated as well, although this varies throughout the drainage (Andrews et al. 2002).

Along the middle Yukon River from about Holy Cross to Galena, three types of gear are used—drift gill net, set gill net, and fish wheel—with each gear type used under particular river conditions. Farther upriver, from Ruby to the U.S.-Canada border, and along the Koyukuk, Tanana, and Porcupine Rivers, fish wheels and set gill nets are the primary gear, since the use of drift gill nets is ineffective in most areas. In some areas of the drainage, families sometimes use rod and reel for tak ing salmon, particularly Chinook salmon, when large quantities are not sought and fresh food is desired.

Salmon are caught in set gill nets and fish wheels with the use of one gear type or another depending on the quantity sought, range of species desired, availability of good eddy sites, and ability to check nets or wheels (Wheeler 1987, Case and Halpin 1990). Some fishing families used both set gill nets and fish wheels for Chinook salmon. Roughly one-half of the Chinook salmon caught in 1987 were taken in fish wheels and the other half were taken in nets. In contrast, more than 90% of chum and coho salmon were taken in fish wheels (Case and Halpin 1990).

Subsistence salmon fishing regulations restrict harvest activities in terms of eligibility, gear, and fishing times. Quantity is not limited and individual permits and licenses have not been required. In general, subsistence salmon fishing is least restricted before and after the commercial salmon fishing season. However, once the commercial salmon fishing season begins, subsistence salmon fishing is further restricted in terms of fishing times (Andrews et al. 2002). Actual fishing times vary among fishing districts and fluctuate based on salmon abundance, projected salmon returns, and commercial fishing quotas. In areas where no commercial fisheries exist, subsistence salmon fishing is allowed either 5 or 7 days per week.

Kuskokwim River

Historically, fishing gear used for subsistence salmon fishing in the Kuskokwim River drainage included spears, dip nets, gill nets, weirs, and traps (Oswalt 1980, Charnley 1984, Stokes 1985, Coffing 1991). Spears and harpoon darts were used in swift clear water tributaries of the Kuskokwim; traps and weirs were placed in clear water tributaries, such as the South Fork of the upper Kuskokwim drainage, and also in the main river, where large dip nets were sometimes used. Fish-wheels came into use in the early nineteenth century, along the middle and upper reaches of the Kuskokwim River.

Traditionally, gill nets were constructed of a coarse fiber twine made from willow bark (Coffing 1991) and other materials, such as seal skin (as reported in 1844 by Zagoskin [Michael 1967]), and moose or caribou sinew (Oswalt 1980, Stokes 1985). Linen twine was used for making gill nets beginning in the 1920s, when residents along the lower Kuskokwim River were able to obtain commercially made linen webbing from local stores in Bethel (Coffing 1991). Kuskokwim residents working in Bristol Bay canneries sometimes brought back 4.5- to 5.5-inch stretch mesh nets used in the Bristol Bay fishery and modified them for use in the Kuskokwim River (Coffing 1991). Gill nets were used both for set net and drift net fishing. Along the main stem of the middle and upper Kuskokwim River, fish wheels were introduced and were commonplace in the early 1920s, continuing to the present day. In the 1960s, nets made from synthetic fibers, such as nylon, came into use along the lower Kuskokwim. Most nets were 25 fathoms or less in length until the 1980s.

Since the 1980s, typical subsistence salmon fishing gear has included the use of drift gill nets, set gill nets, fish wheels, and rod and reel in the Kuskokwim drainage. In the lower Kuskokwim River and Kuskokwim Bay, fishing with drift gill nets is the predominant method for salmon fishing; however, some families use set nets. Gill nets, used for subsistence salmon fishing, vary in length and mesh size depending on fishing location, species harvested, and river conditions during the run (Coffing 1991).

In the middle reaches of the Kuskokwim, three types of gear are used—drift gill net, set gill net, and fish wheel—owing to the feasibility of using each type of gear under particular river conditions. In the farthest upriver areas, fish wheels and set gill nets are the primary gear, as the use of drift gill nets is not effective. In one area of the upper Kuskokwim drainage, rod and reel are used also for taking Chinook salmon, because other gear is not effective. Throughout the drainage, families sometimes use rod and reel for taking salmon, particularly Chinook salmon, when large quantities are not sought and fresh food is desired.

Along the lower Kuskokwim, salmon are caught in set gill nets ranging from 10 to 270 ft long, with the length depending on the specific characteristics of the river channel, sandbar, or riverbank where it was placed (Coffing 1991). Drift gill nets, usually 300 ft long, were used in the main stem of the Kuskokwim River. Most fishing families used both types of gear for Chinook salmon fishing. Other salmon species were taken with the same type of gear, although with a reduced mesh size. Along the middle Kuskokwim, residents fish for salmon with fish wheels as well as with drift and set gill nets. Nets are generally 150-200 ft long, with mesh size varying depending on the salmon species targeted (Charnley 1984).

For subsistence salmon fishing regulations on the Kuskokwim, see the previous section on the Yukon River.

Changes in Commercial Fishing Gear and Catch[2]

Throughout the AYK salmon management region south of Kotzebue Sound—composed of the Kuskokwim, Lower Yukon, Upper Yukon, and Norton Sound River systems—fishing gear has become more efficient since the late 1970s. Wooden boats have been replaced by aluminum boats with greater horsepower; lighter nylon netting (which is easier for fishermen to manage) is now used throughout the region; and set nets have been replaced in some locations by drift nets. There is a ripple effect to subsistence fisheries—boats, motors, and nets from commercial fishing are also used for subsistence fishing, and cash earned from commercial fishing helps to pay for gas and boat repairs for both commercial and subsistence activities (Buklis 1999). Between 1980 and 1996, the herring fishery also influenced incomes and gear used in the salmon fishery, particularly in the Kuskokwim Bay, the Lower Kuskokwim, and Norton Sound. Income from herring helped support salmon fishing. Some boats used for herring were also used for salmon, and larger herring fishing boats were sometimes used as salmon tenders (tenders are large boats contracted by processors to collect fish from commercial boats in open-water fishing areas as opposed to off-loading directly on the docks). Openings for commercial salmon fishing have been shortened in some areas as a result of increased efficiency and reduced run size. This section describes gear changes for each region and changes in fish catch and value for the region as a whole. The overlap in gear and personnel engaged in commercial and subsistence fishing can make ob-

[2]Much of the information in this section is based on personal communications with John Hilsinger, Dan Bergstrom, and Jim Menard, Regional Management Supervisors for ADF&G, April-May 2004.

taining unambiguous information about commercial and subsistence landings more difficult.

Yukon River Commercial Fishery

In the 1970s, many commercial fishing boats in the Yukon River were wooden and 18-20 ft long, with limited capacity for holding fish. At that time, outboards were generally 35-50 horsepower. During the1980s, the fleet changed to mostly aluminum boats, 20-26 ft long and with greater capacity, and the size of outboards increased to 70-200 horsepower. While cotton twine gill nets were used through the 1970s, use of multifilament gill net web increased during the 1980s. In addition, commercial fishermen in the lower Yukon River switched from using predominantly set net gear to drift gill net gear in the early 1980s, which is believed to be more efficient at capturing salmon. The length of net gear has remained constant since statehood at 150 fathoms (900 ft) for set gill nets and at 50 fathoms for drift gill net gear. Even upriver fish wheel gear changed in the 1980s from the smaller wheels and less effective gear to the use of larger and more easily adjustable wheels that could capture more fish and raise and lower baskets to match changes in water level. Higher prices paid across the board for salmon provided much of the funds to upgrade gear in the 1980s.

Greater efficiency in the fleet caused Yukon River commercial catch per unit effort (CPUE) to increase from the 1970s to the 1980s. With increased efficiency and CPUE, management of the fishery began to regulate mesh size (for targeting specific species at specific times) and to reduce the length of commercial fishing time (also referred to as commercial openings). Fishing time in the Lower Yukon changed from two 48-hour periods per week during most of the 1970s; to two 36-hour periods per week starting in the late 1970s; to two 24-hour periods in 1983; to generally two 12-hour periods beginning in 1987; to generally two 6-, 9-, or 12-hour periods in the 1990s. Fishing time was eventually decreased in the Upper Yukon (Subdistricts 4-A, 5-B and 5-C) as a result of increased fishing effort beginning in 1990. Openings were reduced from two 48-hour periods per week since 1974 to two or three 12- or 18-hour periods per week through the 1990s. Some upriver districts (Subdistricts 4-B and 4-C and District 6) with very low commercial fishing effort were not required to reduce openings.

At present, there is only a small market for salmon in the Upper Yukon and very low fishing effort. Overall, commercial fishing time since 1998 has substantially decreased in the Yukon River primarily because of lower run sizes as well as declining salmon markets. The number of tenders collecting fish from commercial fishermen has also changed. From the early 1980s to mid-1990s, the number of tenders (particularly in the Lower Yukon) increased, which increased efficiency in offloading catches. With declining markets, the number of tenders since1998 has decreased substantially.

Kuskokwim River

Similar to the Yukon, commercial gear used by Kuskokwim fishermen changed in the 1980s from wood to aluminum boats with greater horsepower. These boats are safer in rough weather, and they can hold all the fish that fishermen can catch in one fishing period. In the current century (from 2000 on), fishing periods have become shorter, catch per period has declined, and value per pound has dropped. As a result, many fishers have shifted back to smaller boats (primarily riveted aluminum) as they are more economical to operate.

Commercial fishing is allowed with set or drift gill nets. The use of set gill nets is insignificant in the commercial fishery. Mesh sizes for the commercial fishery in Districts 1 and 2 were reduced to 6 inches after June 25 each season from 1971 to 1984. Since 1985, commercial regulations have limited gill net length to 50 fathoms (300 ft), mesh size to 6 inches, and depth to 45 meshes for all districts. The directed commercial king (Chinook) salmon fishery in the Kuskokwim River was discontinued in 1987. Most of the king salmon harvested in recent years are taken by subsistence fishers.

There are enough boats and nets in the commercial fishery that the fleet would have exceeded the allowable harvest in the river on any given day from the mid-1980s through the mid-1990s provided unrestricted fishing time. Since the late1970s, fishing time slightly decreased from two or three 8-hour periods per week to two or three 6-hour periods per week. The number of periods per week was based on run assessment. During the 1990s, later openings of the fishery further reduced targeted fishing for king salmon and management was restricted to chum salmon. Since the mid-1990s, the commercial salmon fishery has been characterized by generally weak returns, low effort, low harvest, poor prices, and collapsing markets.

The number of tenders also increased during the 1980s, but because of a substantial weakening of market conditions (Naylor et al. 2003), tenders have been almost nonexistent in the Kuskokwim River since 2001. During the 2003 season, two companies without buying stations in the river sent tenders into the river to buy fish during several periods of the season. These fish were then transported out of the district for processing. During the past 2 years, there has been no commercial chum fishery in the Kuskokwim River during June and July, mainly because there is no buyer. During the coho salmon fishing period, fishers have primarily offloaded at one dock location in Bethel or at one or two large tenders operated as dock-type stations. Fishing effort has substantially decreased due to reduced processing capacity and lower prices. Management has changed to a market-driven approach in an attempt to match processing capacity with lower fishing effort. Generally, fishing periods have been more numerous but shorter than they were historically.

Board of Fisheries (BOF) action before the 2000 season divided District 1 into two subdistricts. Fishers were primarily restricted to fishing in one of the two subdistricts. These regulations provided for the implementation of more frequent fishing periods of lower harvest potential. Processor capacity has been a significant factor in setting the duration of commercial fishing periods. BOF action during the 2003 season provided ADF&G authority to establish closed periods before, during, and after commercial fishing periods to ensure that subsistence fishers had reasonable fishing opportunities.

Norton Sound and the Nome Subdistrict

In the 1960s, when commercial salmon fishing started in Norton Sound, boats were wooden and 15-20 ft long. Now boats are aluminum, 20-28 ft long, and powered by larger outboards. Although boats have gotten bigger, the commercial fishery is a set-net fishery, and therefore a larger boat with greater horsepower is needed so that fishermen can go out in rough weather. Nets typically are set at the 6 p.m. opening time and then often not checked again until morning. If runs are strong, fishermen check their nets several times during the day. Others have nonfishing jobs and do not check their nets until after work.

The net gear per permit holder has stayed at 100 fathoms. (In 1985, regulations changed to allow a total of 200 fathoms [1,200 ft] per boat in aggregate if two permit holders were fishing together). Nets have become easier to manage with the lighter nylon netting. Mesh restrictions were introduced in the 1980s to target specific species at specific times. In 1980, for example, gillnets of 4.5-inch mesh (or smaller) were mandated in certain locations and periods by emergency order. In 1986, ADF&G began restricting mesh size to 6 inches or less between July 1 and July 15 to protect Chinook salmon and target the fishery on chum and coho salmon.

Until recently, the region has generally maintained two 48-hour commercial fishing periods per week, with the exception of the Nome subdistrict. In the 1960s, the season was open from June 15 through August 31; at this time, the fishery was largely self-regulated by a limited market. In the 1980s, the opening date was pushed back to sometime between June 8 and June 15, and the ending dates were August 31 and September 7 depending on the location (for example, Norton Bay, Shaktoolik, and Unalakleet [subdistricts 4, 5, and 6] could remain open until September 7, and Moses Point [subdistrict 3] would open and close by emergency order only). Often, buyers terminated their operations a week or two before the ending date. Reductions in fishing time in the 1990s were the result of weaker chum and Chinook runs. For Chinook salmon, commercial openings were reduced to 24 hours. (Chums often lacked a market so there was no regulation.) In recent years, weak Chinook and chum runs have necessitated keeping the commercial fishery closed.

The management situation is quite different in the Nome subdistrict.[3] In the 1960s commercial fishing was open 7 days a week. The market was limited to local sales. In the early 1970s, as outside buyers entered the area, commercial fishing time was restricted. There were increasing restrictions in the 1980s and 1990s. In 1999, the Nome subdistrict went to a Tier II chum fishery, which limits who can fish for subsistence.[4] A permit system for subsistence fishing first went into effect in 1974 to track subsistence catch more carefully. In 2001, BOF closed commercial chum fishing in the Nome subdistrict, with the stipulation

[3]See ADF&G 2003 Annual Management Report for further details on regulation in the Nome subdistrict.

[4]Tier II fishery status for chum is defined by the Alaska Board of Fisheries (section 5 AAC 01.182) to limit subsistence uses after nonsubsistence consumptive uses have been eliminated. Tier II permits are issued on a point system (established in section 5 AAC 01.184) to the highest ranking applicants, then to the next highest ranking, etc., until the permits authorized by ADF&G according to run size have been exhausted. Permits are generally issued for a 1-month period.

that the fishery may not reopen until the abundance of chum salmon has reached a harvestable surplus large enough to meet subsistence needs for 4 consecutive years. (It is worth noting, however, that there has not been a chum-directed commercial fishery open in the Nome subdistrict since the 1980s.) Some of the subsistence fisheries for chum were also closed in 2001 (Cripple and Penny rivers).

Commercial Catch and Value for the Region

Until the mid-1990s, commercial fishing effort in the AYK region was relatively stable. During the past 5 years, however, fishing effort (number of permits fished and average pounds landed) has declined for most fisheries (Table 3-2). Salmon prices have declined for all species except Yukon Chinooks, and average gross earnings have declined precipitously in all commercial fishing areas. Without a viable commercial market for salmon in the AYK region, it is unlikely that commercial fishing effort will rebound to the level experienced in the 1980s and early 1990s anytime soon. However, commercial fishing gear still will be used for subsistence fishing within regulatory limits (mesh size, opening times), provided that subsistence fishermen have the cash to fuel and repair their boats.

Sportfishing

Sportfishing or recreational angling is "fishing primarily for recreation or enjoyment as opposed to fishing whose main purpose is the production of food or other products" (Policansky 2002). Sportfishing is defined in Alaska statutes as follows: "'sport fishing' means the taking of or attempting to take for personal use, and not for sale or barter, any freshwater, marine, or anadromous fish by hook and line held in the hand or by hook and line with the line attached to a pole or rod which is held in the hand or closely attended, or by other means defined by the Board of Fisheries" (Alaska Statute 16.05.940 [29]). State regulations allow the use of a hook and line attached to a rod or pole for taking salmon in the subsistence fishery in the Kuskokwim drainage downriver of and including the Tatlawiksuk River drainage (near Stony River) (5 AAC 01.270).

People often enjoy subsistence or commercial fishing, and recreational anglers often eat their catch, which makes it somewhat difficult to

TABLE 3-2 Arctic, Yukon, Kuskokwim Salmon Fisheries. Permits Issued, Permits Fished, Pounds Landed, and Estimated Gross Earnings Averaged for the 1987-1997 and the 1998-2002 Periods

Fishery	Time Period	Ave. Permits Issued	Ave. Permits Fished	Ave. Gross Earnings	Ave. Pounds Landed	Price on Board ($/lb)
Kuskokwim	'87-'97	832	789	$5,382,961	10,119,733	$0.53
Gill Net	'98-'02	823	571	$951,159	3,035,801	$0.31
Norton Sound	'87-'97	201	121	$468,017	1,350,003	$0.35
Gill Net	'98-'02	192	58	$130,894	591,314	$0.22
Kotzebue	'87-'97	217	126	$613,147	1,628,051	$0.38
Gill Net	'98-'02	193	47	$164,720	967,519	$0.17
Lower Yukon	'87-'97	707	665	$7,043,806	5,343,975	$1.32
Gill Net	'98-'02	703	475	$1,839,551	666,689	$2.76
Upper Yukon	'87-'97	72	34	$162,349	104,810	$1.55
Gill Net	'98-'02	72	6	$6,609	6,537	$1.01
Upper Yukon	'87-'97	162	103	$731,663	664,282	$1.10
Fish Wheel	'98-'02	160	12	$18,384	22,941	$0.80

Source: CFEC 1998, 2003.

classify an activity unambiguously as recreational fishing. For the purposes of this report, we define it as fishing by people who have bought an Alaska sportfishing license. In the AYK region, sportfishing usually is conducted with rod and reel. Known and potential effects of sportfishing include fishing mortality caused by taking fish (including mortalities following catch-and-release angling), disturbance of the habitat, and pollulution of the habitat. Information on the significance of those effects in the AYK region is sparse. For example, the committee heard anecdotes that boats can disturb redds in shallow water, although no data are available. Also, some burned and unburned petroleum hydrocarbons, as well as other compounds, enter the water as a result of boat transport of anglers, although the amounts and their effects are unknown.

Alaska sportfishing regulations are complex and diverse; often, they vary by species and by stream. For example, in the Yukon River, 2003 regulations included a limit of three Chinook salmon over 20 inches per day, of which only two could be over 28 inches, with a limit of 10 per day for fish smaller than 20 inches. For “other salmon,” the daily limit was 10 fish with no size limit. Regulations were similar for the northwestern region, which includes Norton Sound, but the limit for chum salmon was three per day, except in an area around Nome, which was closed to fishing for chum salmon. Regulations were similar for the Kuskokwim drainage (except that the limit of "other salmon" was five per day) and on the Aniak River. There, the limit for all salmon was three per day, of which no more than two could be Chinook salmon. The limit for Chinook salmon was two fish more than 20 inches per day *and per year*, and such fish, but no others, are required to be recorded and reported. The limit for sockeye, pink, and coho salmon was three fish per day but subject to the aggregate limit of three salmon of any type per day. The retention or possession of chum salmon was prohibited. In addition, above Doestock Creek, only unbaited, single-hook artificial lures may be used in the Aniak River. (Current Alaska sportfishing regulations can be accessed at the ADF&G web site.[5])

Alaska sportfishing regulations also specify *possession limits*, "the maximum number of unpreserved fish a person may have in his possession" [5 AAC 75.995 (20)]. *Preserved fish* is fish "prepared in such a manner, and in an existing state of preservation, as to be fit for human consumption after a 15-day period, and does not include unfrozen fish temporarily stored in coolers that contain dry ice or fish that are lightly salted" [5 AAC 75.995 (21)]. Thus, if a sport angler had a generator and a freezer at a field camp, the possession limit could be legally increased.

The complexity of the ADF&G sportfishing regulations makes them difficult for anglers to understand and obey. Indeed, complex regulations also are difficult to enforce. The degree of compliance with and enforcement of sportfishing regulations in general and in the AYK region in particular is not well known. Anecdotal evidence suggests that guides in the AYK region help enforce regulations, which makes sense because it is in their interest to conserve their fisheries. In general, better management information exists about guided anglers than about nonguided ones, because Alaska law requires guides to register with ADF&G, and they must work for a registered fishing-service business, although the degree of compliance with and enforcement of this law also is not well known.

The above sample of Alaska sportfishing regulations information is provided to show that information on the aggregate effect of sportfishing on salmon populations in the AYK region is neither well known nor easy

[5]See http://www.adfg.state.ak.us for more information.

to obtain. Although the number of people who buy Alaska sportfishing licenses each year is known, it is not known where each angler fished. Consequently, distribution of fishing effort across the region is currently impossible to estimate accurately. Better information (reporting) on sportfishing catches would help address this knowledge gap.

We have considered that commercial and subsistence fishing influence each other; in other words, they compete for the same fish. Sportfishing should be considered similarly. Clearly, if sport-caught fish are retained, then those fish are not available to commercial or subsistence fishers. However, if sport-fish are released alive, then how are subsistence and commercial fishing affected?

In most (although not all) cases, sportfishing occurs after commercial fishing and therefore has no direct influence on commercial catch. Also, sportfishers do not take many fish in the AYK region. Even if all anglers took their limits, the number would be small compared with the commercial catch. Although hard information is lacking, most anglers keep fewer salmon than allowed, and the retention of other species either is prohibited (for example, rainbow trout) or probably is inconsequential (for example, grayling).

How then does catch and release (C&R) influence AYK fishers? One difficulty with C&R is that it runs counter to many Alaska Natives' view of appropriate treatment of food (Wolfe 1988, Lyman 2002). In addition, not all fish survive C&R, and, even if they do, reproductive success could be impaired (Policansky 2002). However, in the cold waters of the AYK region, survival after C&R is likely to be high—greater than 90%—and because these salmon usually are caught close to their spawning grounds, where they soon will die anyway, C&R probably does not have a measurable effect on the population unless the population affected is small. As an example of concern about the effects of C&R on a small and dwindling population, in 2000, Maine prohibited all angling for Atlantic salmon (*Salmo salar*), specifically including C&R (Maine Atlantic Salmon Commission 2001). However, C&R can have other effects. During C&R angling, anglers step on or boat over redds and thus disturb and kill eggs. In addition, allowing C&R for salmon while restricting or prohibiting commercial and subsistence fishing can create a perception of unfairness. People who observe anglers engaging in C&R might be more confident about engaging in subsistence fishing, despite regulations. Although a considerable literature has developed on C&R fishing in North America and elsewhere (Pitcher and Hollingworth 2002, Lucy and Studholme 2002), many aspects of its direct and indirect effects remain unstudied, especially in remote areas where subsistence fishing is important, as in western Alaska.

Influence of Ocean Fishing

Ocean mortality has both natural and anthropogenic causes, with fishing being the most observable cause of anthropogenic mortality. The effects of ocean harvests by directed salmon fisheries or incidental catches by fisheries targeting other marine species (bycatch) occur directly on immature and maturing salmon, but the removal of salmon can have other indirect effects on salmon populations and on their ecosystem through a variety of ecological interactions.

Historical Trends in Ocean Fishing and Interceptions of AYK Salmon

Brodeur et al. (2003) briefly reviewed the history of salmon fishing and trends in commercial salmon catches in Alaska. Pacific salmon have been fished by Alaska Natives for millennia in streams and along a coastal band that was accessible from small vessels. Fishing in more oceanic waters required sturdier vessels. Ocean fishing for salmon increased after development of the gasoline engine and refrigeration in the early 1900s. The federal government managed the coastal Alaskan salmon fisheries from 1867 through 1959, although they were virtually unregulated (Cooley 1963). Since the establishment of the U.S. 200-mile zone, ocean fisheries within 3 miles of shore have been managed by the state of Alaska, and fisheries from 3 to 200 miles offshore are managed by the federal government (NMFS). Commercial gears for catching salmon in the ocean have included traps, beach seines, purse seines, drag seines, drift gill nets, and set gill nets, among others. Commercial fishing for salmon in Alaska began in the 1880s, and catches peaked in 1936 at 290,000 t. The decline from that peak to a level below 100,000 t in the 1950s through the early 1970s was largely due to overfishing and unfavorable climate conditions (Brodeur et al. 2003). Conservation measures, favorable climate conditions, and reductions in the Japanese high-seas salmon driftnet fisheries, among other factors, resulted in an increasing trend in commercial salmon catches that continued from the late 1970s through the mid-1990s (peak in 1995 at 412,000 t). Since the late

1990s, poor runs of salmon in many areas of western Alaska combined with low prices due to the glut of farmed salmon on world markets have resulted in an economic disaster for commercial salmon fisheries in western Alaska. There was some improvement in 2003. For example, the 2003 Yukon River Chinook salmon and fall chum salmon runs were the strongest in recent years and supported small commercial harvests (NPAFC 2003). In Norton Sound, however, the combination of poor salmon runs and lack of fish buyers in 2003 resulted in the second lowest commercial harvest on record. Runs of chum salmon to eastern Siberia (Anadyr River) have also experienced unexpected and dramatic declines, resulting in a decrease in commercial harvests from an average of 2,000-3,000 t to 72 t in 2002 and to 349.5 t in 2003 (NPAFC 2003).

Interceptions of AYK salmon by commercial salmon fisheries in other regions of Alaska have been a longstanding concern, particularly interceptions by the South Unimak Island (False Pass) and Shumagin Island fisheries (also called South Peninsula June fisheries) and in non-terminal areas by the South Alaska Peninsula Post-June fisheries (Eggers et al. 1991; Shaul et al. 2004a,b). These fisheries are collectively called the Area M fisheries. Shaul (2003) reviewed the history of the South Peninsula June fisheries, which began in 1911. These fisheries target maturing sockeye salmon but also have a large incidental harvest of chum salmon, which are caught along their migration routes from the Gulf of Alaska to the Bering Sea in June. Harvests of chum salmon by the June fishery averaged 186,000 fish in 1960 to 1969, 306,000 fish in 1970 to 1979, and 566,000 fish in 1980 to 1987, including a record harvest of 1.1 million fish in 1982 (Eggers et al. 1991). From 1994-2003, harvests by the June fishery have averaged 4,370 Chinook, 1,133,297 sockeye, 2,234 coho, 485,308 pink, and 324,163 chum salmon (Shaul et al. 2004a). To protect AYK chum salmon stocks, harvest caps were the primary method used by ADF&G during the June fisheries (400,000 fish in 1986, 500,000 fish in 1988 to 1989, 600,000 fish in 1990 to 1991, 700,000 fish in 1992 to 1997, and a "floating cap" of 350,000 to 650,000 fish in 1998 to 2000) (Shaul 2003). Since 2001, when BOF designated Kvichak (Bristol Bay) sockeye salmon and several AYK chum stocks as stocks of concern, the South Peninsula June fisheries were limited to no more than nine fishing days for seine and drift gill net gear (with no harvest limits). In nonterminal areas the Post-June (July-October) South Alaska Peninsula fishery also intercepts adult salmon returning to other regions and, at times, large numbers of immature salmon (Chinook, sockeye, coho, and chum salmon that become gilled in purse seine web) (Shaul et al. 2004b). From 1994 to 2003, annual harvests by the South Peninsula Post-June fishery have averaged 1,847 Chinook, 535,073 sockeye, 200,058 coho, 5,486,201 pink, and 679,770 chum salmon (Shaul et al. 2004b). In 2004, the BOF rescinded a 60,000 cap on coho salmon that had been in effect since 1998 to limit interceptions of AYK salmon by the Post-June fisheries in late July. Tagging studies have shown that chum salmon from many populations in Asia and North America, including AYK, are intercepted by the June fisheries (Eggers et al. 1991). Recent genetic studies of chum salmon in the Shumagin Islands fisheries indicate that AYK stocks are the largest contributors in early June (as high as 69% in early June test fisheries) and decline through June and July to about 5% (Seeb et al. 2004).

Historically, the ocean fisheries of greatest concern to AYK stakeholders were the Japanese high-seas salmon driftnet fisheries. Harris (1987) reviewed the history of these fisheries and the international agreements that regulated them. The high-seas driftnet fishery for salmon started when the Soviet Union began restricting access to salmon along the Kamchatka Peninsula in the early 1930s, forcing the Japanese to fish elsewhere, including the Bering Sea. World War II curtailed these activities, but after the war's end, the Japanese began anew to expand the activities of their fishing fleet. Both Canada and the United States were concerned that the Japanese were taking North American salmon in this ocean-intercept fishery. This concern led to the 1952 International Convention for the High Seas Fisheries of the North Pacific Ocean, which established the INPFC and restricted the Japanese to fishing west of 175°W in the North Pacific Ocean and Bering Sea (Jackson and Royce 1986). This restriction and others imposed by the Soviet Union led to a contentious situation as the Japanese continued to expand their high-seas intercept fishery for salmon. The Japanese high-seas driftnet fishery was contentious, in part because it caught immature and maturing salmon of unknown origin. The major goal of INPFC research was to determine the origin of fish taken on the high seas.

Estimates of interceptions of western Alaska salmon by the Japanese salmon driftnet (mothership) fisheries (1956-1975) were reviewed by Fredin et al. (1977). The major North American salmon stocks intercepted by these fisheries were from western Alaska. The effect of these fisheries on returns of salmon to the AYK region was substantial. For example, Yukon River (immature age 1.2 fish) was estimated to be the major stock contributing to Chinook salmon catches by the Japanese mothership fishery in the Bering Sea (Myers et al. 1987), averaging 36% of the total catch during 1975-1977 and 42% during 1978-1981 (Rogers 1987).

In 1976, the Magnuson Fishery Conservation and Management Act extended U.S. jurisdiction offshore to 200 miles and exerted limitations on ocean fisheries with the implicit goal of excluding all non-U.S. vessels from the fisheries. Following the lead of the United States, the Soviet Union declared a 200-mile fishery conservation zone in 1977 that further restricted the Japanese fishery. New agreements by INPFC in 1978 eliminated the fishing sector southeast of 56°N 175°E, and research emphasis in the North Pacific Anadromous Fish Commission (NPAFC) shifted to estimating interceptions of North American salmon by the land-based driftnet fisheries operating southwest of 46°N 175°W (Myers et al. 1993). An exceptionally large catch of 864,000 Chinook salmon by the Japanese mothership and land-based driftnet salmon fisheries in the Bering Sea and North Pacific Ocean in 1980 included an estimated 229,000 Yukon and 196,000 Kuskokwim Chinook salmon (Rogers 1987). By the late 1980s, further restrictions by USSR-Japan and INPFC agreements had led to substantial reductions in the Japanese high-seas salmon fisheries.

As the Japanese high-seas salmon driftnet fisheries were further reduced, new Asian pelagic squid driftnet fisheries developed rapidly in the North Pacific Ocean in the early 1980s. The squid driftnet fisheries legally intercepted salmon as part of their bycatch, but substantial illegal directed salmon fishing also occurred. Estimates of legal catches by the 1990 Japanese squid driftnet fishery calculated by two methods were 210,000 fish (plus 21,000 fish that dropped out of the driftnets during retrieval) and 164,000 fish (17,000 dropouts) (Pella et al. 1993). Illegal high-seas catches by non-salmon-producing (Asian) nations in 1988 were estimated to be at least 10,000 t (5.5 million salmon) (Pella et al. 1993). In 1989, the United Nations' General Assembly adopted a resolution that called for a ban on all large-scale high-seas driftnet fishing unless effective conservation and management measures were taken. In 1991, the high-seas driftnet fishing nations and other nations agreed to a global moratorium on all large-scale pelagic high-seas driftnet fishing, effective at the end of 1992. The last year of operation of the legal high-seas salmon driftnet fisheries was 1991, and the last year of operation of the legal high-seas squid driftnet fisheries was 1992.

In 1993, a new international treaty—Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean—established NPAFC[6]. This treaty established the world's largest marine conservation area for salmon (all international waters north of 33°N in the North Pacific Ocean and Bering Sea). Throughout this vast area, all directed fishing for six species of Pacific salmon, as well as steelhead trout, is prohibited, and incidental catches of salmon by fisheries targeting other species must be minimized. These conservation measures and fishery regulations are strictly practiced and enforced by the governments that have signed the treaty (Canada, Japan, Russia, Republic of Korea, and the United States). The salmon conservation and management authority of NPAFC does not extend into the 200-mile zones of member nations. For example, within the Russian 200-mile zone, a large-scale Japanese salmon driftnet fishery still operates legally as well as a Russian salmon driftnet fishery that developed during the 1990s. And within the U.S. 200-mile zone, U.S. groundfish trawl and mixed-stock salmon fisheries are known to intercept Canadian, Russian, and Japanese salmon as well as fish from all salmon-producing regions of North America (Seeb et al. 2004). Illegal high-seas driftnet fishing and enforcement activities are reported annually to NPAFC, and these reports indicate that illegal high-seas driftnet fishing for salmon is currently at an all-time low. With respect to other types of high-seas fishing gear and fisheries, information on salmon bycatch and illegal directed fishing for salmon is largely anecdotal.

The effect of groundfish trawl fisheries operating in the Bering Sea and Gulf of Alaska on returns of Chinook and chum salmon to the AYK region has been a major concern since 1977, when the NMFS scientific observer program began to provide estimates of salmon bycatch by foreign vessels operating in the U.S. 200-mile zone (French et al. 1982). Compared with interceptions by the former Japanese high-seas salmon driftnet fisheries, however, the estimated interceptions of Yukon River and Kuskokwim River Chinook salmon by foreign and joint-venture groundfish trawl fisheries in the Bering Sea and Aleutian Islands region of the U.S. 200-mile zone in 1977-1985 were relatively low (15,200 fish in 1977, 13,600 fish in 1978, 43,500 fish in 1979, 40,000 fish in 1980, 11,200 fish in 1981, 5,300 fish in 1982, 3,600 fish in 1983, 3,900 fish in 1984, 3,400 fish in 1985, and 2,000 fish in 1986) (Myers and Rogers 1988). The foreign and joint-venture fisheries in the U.S. 200-mile zone

[6]See http://www.npafc.org for more information.

were rapidly phased out as the U.S. groundfish fishing industry reached full capacity. Since then, there have been only a few attempts to quantify the stock composition of salmon bycatch, which is largely chum and Chinook salmon (Berger 2003). Estimates of the stock composition of chum salmon in incidental catches by U.S. trawl fisheries in the Bering Sea in 1994 indicated that 39-55% originated in Asia; 20-35% originated in western Alaska; and 21-23% originated in southeastern Alaska, British Columbia, or Washington (Wilmot et al. 1998). In 1995, 11% of the chum bycatch by the U.S. Bering Sea trawl fishery was sampled, and an estimated 13-51% originated in Asia; 33-53% originated in western Alaska; and 9-46% originated in southeastern Alaska, British Columbia, or Washington (Wilmot et al. 1998). A substantial bycatch of chum and Chinook salmon also occurs in U.S. trawl fisheries in the Gulf of Alaska (Berger 2003), although there are no estimates of the stock composition of the salmon bycatch in this region. Witherell et al. (2002) reviewed available information on salmon bycatch in U.S. groundfish fisheries from 1990 to 2001 and estimated that an annual bycatch of 30,000 immature Chinook salmon in the Bering Sea groundfish fisheries equates to an adult equivalent bycatch (fish that would have returned to spawn had they not been intercepted) of 14,581 western Alaska Chinook salmon or a 2.7% reduction in western Alaska Chinook salmon runs (catch and escapement). Witherell et al. (2002) discussed problems with estimating salmon bycatch in the U.S. groundfish trawl fisheries, including the lack of recent estimates of stock composition, and recommended that a high priority be given to salmon stock composition research.

There are also commercial trawl fishing fleets operating inside the Russian 200-mile zone in the Bering Sea, Commander Islands, and western North Pacific Ocean that may intercept at least some AYK salmon. Russia does not have a scientific observer program to quantify salmon bycatch by these fleets. Russian estimates based on research trawl data have indicated that salmon bycatch by these trawl fisheries is low (Radchenko and Glebov 1998).

Effects of Ocean Fishing on Salmon Populations and on Their Ecosystem

It is difficult to determine the historic effects of ocean fishing on ecosystem functioning. Catches were used as a surrogate for abundance and this “is a poor substitute for total biomass,” especially when used to assess carrying capacity (Myers et al. 2000). Were this not true, we also would face the constraint that the historical catch records are too short to distinguish between climate effects and overfishing. Finney et al. (2000, 2002) used lake-sediment cores as a proxy for salmon production. Their results show that climate change and fishing have contributed to decadal-scale fluctuations in Alaskan salmon populations. These cores contained measurable amounts of marine-derived nitrogen whose abundance indicated the long-term changes in salmon populations over 2,000 years or more. Over the past decade there has been an increasing awareness of the importance to freshwater and terrestrial ecosystems of marine-derived nutrients from the carcasses of spawned-out salmon (Willson et al. 1998, Bilby et al. 2001, Naiman et al. 2002). Although there were historic variations in salmon abundance that could be attributed to climate variability, recent declines demonstrate the effects of fishing and subsequent feedback loop where the loss of marine-derived nitrogen further limits stream productivity.

Fisheries effects are compounded by historic environmental fluctuations that occur with interannual, decadal, and longer-term effects on growth and production (Myers et al. 2000). The Bering Sea ecosystem has experienced dramatic change, especially since 1997 (Loughlin and Ohtani 1999 as cited by Seeb et al. 2004). Canadian researchers hypothesized that changes in climate, called regime shifts, affected the abundance of salmon in synchrony over large areas. Regime shifts are reported in 1977, 1989, and 1998 (Beamish et al. 2003, see section Influence and Consequences of Changes in the Physical Environment in this chapter). Regime shifts are characterized by changes in ocean temperature, sea level heights, river flows, and temperatures. The Pacific Northwest region and Alaska appear to have production regimes that are inverse and potentially linked to wind stress (Hare et al. 1999, Brodeur et al. 2003). Fishing also decreases the total abundance (biomass) of the harvested stocks, affecting community structure (Pauly et al. 1998, 2002). As fish are removed, the forage for piscivores is diminished and higher trophic levels are affected. For example, Beamish et al. (2003) state that coho are predators of pink salmon and they prefer pink over chum. Coho and Chinook are largely piscivores even as juveniles (Healy 1991, Sandercock 1991). Although trophic structure is altered directly in this way, it is also altered indirectly through the change in competitive interactions. There are few published studies of competitive interactions among salmon species, particularly for the AYK region. One study by Ruggerone and his colleagues (2003) evaluated the interactions between

Asian pink salmon and Bristol Bay sockeye. A high abundance of adult Asian pink salmon in odd-numbered years was correlated with decreased growth of immature sockeye salmon during their second and third years at sea. Adult returns from sockeye salmon smolts migrating to sea in even-numbered years were 22% less abundant than smolts migrating in odd-numbered years (Ruggerone et al. 2003).

The vulnerability of salmon species to harvest in the ocean varies by the length of their residency in marine waters, and this varies by the life history (see Chapter 2). For example, marine residency is shortest for pink salmon and longest for Chinook salmon. Vulnerability to harvest also depends on the ocean distribution and migration route of each species. As discussed in Chapter 2, ocean distribution and migration routes are specific to the species and to each local population, and they also depend on sexual maturity, age, and size among other factors.

Salmon species abundance varies spatially and temporally in oceanic waters. Although species abundance is documented in landings, the data on abundance from catch statistics can be misleading. Fisheries tend to concentrate on large populations and ignore smaller ones (NRC 1996). This leads to inflated and misleading statistics on CPUE as fisheries fall back to concentrate on abundant populations when species are in decline. When species decline, they do not do so uniformly. The species are formed from local populations whose vital rates vary temporally and spatially from each other. As salmon species expand and contract, they do so by forming and losing local populations. Because the vital rates vary within a species according to the nature of their local populations, fishing affects these local populations differentially depending on the mixture of species and the local populations within them. Fishing of mixed stocks has detrimental effects on those local populations that can least resist fishing mortality. Without the ability to identify these vulnerable local populations, they can be extirpated with fishing mortalities that cause no harm to other local populations within the mixed group.

Accurate stock identification is essential to managing mixed-stock fisheries. Despite its importance, we have limited information about AYK salmon stock structure, and our knowledge of population structure in other regions of North America is likewise limited (Utter and Allendorf 2003, see section Fishing and Genetics of AYK Salmon in this chapter). Research using genetics began in the mid-1980s to determine the origins of chum salmon caught in the high-seas driftnet fishery for flying squid. Further study with genetic markers shows that the Bering Sea is an important rearing area for immature chum salmon from North America (Seeb et al. 2004). This recent study revealed that the migration routes are more widespread than previously thought. Using genetic baselines from 356 stocks of chum salmon, scientists found that Alaskan chum salmon were using migration corridors along the Kamchatka coast. Hence, Alaskan salmon are vulnerable to fisheries and bycatch from a greater spatial area than previously considered. Such bycatch is a concern because of the low returning abundance of chum salmon to the Yukon/Kuskokwim Rivers since 1997 (Shotwell et al. in press). Harvest in both rivers combined dropped from 1.94 million fish to 0.32 million fish from 1997 to 2001.

Little has been known about population structure for coho salmon throughout western Alaskan waters (NRC 1996). A recent study in the Yukon River (Olsen et al. 2004) has shown that there is little population structure for chum salmon originating from the Yukon River, while there is substantial evidence of small-scale population structure in coho salmon. These results are supported by other studies showing that chum salmon organize at a greater spatial scale than do coho salmon (Myers et al. 2000). In a test fishery on the high seas, chum salmon were taken and compared by using genetic stock identification (Winans et al. 1998). In the Bering Sea, 45% of the chum salmon were of Japanese origin, 38% Russian, and 15% Alaskan, while in the North Pacific Ocean the mixture was 15% Japanese, 62% Russian, and 22% Alaskan. Regional markers also have been demonstrated in chum for Canada and U.S. sourced fish. However, without the ability to distinguish local populations (or ecologically significant units), fishery managers cannot correctly regulate the impacts of fishing mortality or the persistence of local populations. This is a fundamental problem in the current management of AYK salmon.

Within the problem of mixed-stock fisheries also exists the issue of wild and hatchery mixtures within a species (see section High-Seas Competition in this chapter). This is an especially acute problem with the potential loss of wild stocks and their replacement by hatchery-reared fish (Myers et al. 2004). Hatchery-reared fish may have a different response to harvest and fishing mortality that can have unintended consequences for the survival of wild stocks if the mixing of these two contingents is unknown. Brodeur and colleagues (2003) reviewed briefly the methods used to distinguish hatchery and wild stocks of juvenile salmon during their first marine year and stated there is considerable overlap in the spatial distribution between them.

Among the direct effects of fishing, scientists have observed long-term declines in size and age at first maturity as well as in overall size at age (Helle and Hoffmann 1995, 1998; see section High-Seas Competition in this chapter). This is due both to climate change and to selective effects of fishing (see section Fishing and Genetics of AYK Salmon in this chapter). Ricker and Wickett (1980) explained the decades-long decrease in size at age as a result of increased fishing mortality of faster-growing fish with sufficient intensity to sustain directional natural selection. Of further consequence is the fact that slower growing smaller fish have lower fecundity when fecundity is a function of body length.

Ongoing Research in the Region

Ongoing research in the region is aimed largely at the development of methods for accurate identification of salmon stocks in mixed-stock ocean catches. This involves collaborative efforts among government and university scientists in Alaska (for example, NMFS, ADF&G, and University of Alaska Fairbanks), as well with Canadian, Japanese, Russian, and Korean scientists, coordinated in part by the NPAFC. The NPAFC/BASIS research program with some financial support from the North Pacific Research Board (NPRB) is conducting genetic and salmon-tagging studies to learn more about stock-specific migration patterns and run timing of salmon in the Bering Sea and North Pacific Ocean. In addition, NMFS/Auke Bay Laboratory scientists have used genetic baselines to estimate the stock composition of salmon in illegal high-seas salmon catches.

There is also ongoing NMFS, Alaska Fisheries Science Center (Resource Assessment and Conservation Engineering Division), and industry research to develop a salmon-excluder device that would reduce salmon bycatch in pollock trawls. The NPRB has funded some of this research (NPRB 2004). Initial tests of a device to allow escapement of salmon resulted in a salmon "escape rate of 12% with minimal (2%) pollock loss" (Rose 2004).

BASIS/NPAFC research is providing new information on ocean distribution of AYK salmon. Genetic stock identification research, funded in part by NPRB, will provide information on the stock composition of salmon in the Russian 200-mile zone. Russia (KamchatNIRO) has ongoing scale-pattern analysis research to estimate stock composition of salmon in the Russian 200-mile zone.

Questions of Greatest Concern to Stakeholders

The issue of greatest concern to the region's stakeholders is whether ocean-intercept fisheries are contributing to the decline of AYK salmon runs, although some participants in the committee's site visits expressed the view that high-seas fisheries and habitat issues were beyond their immediate reach and first wanted to look for local solutions. A few stakeholders presented testimony on problems of ocean interceptions by AYK commercial fisheries (for example, interceptions of Yukon River Chinook salmon in Norton Sound commercial fisheries and interceptions of Kuskokwim River salmon in Kuskokwim and Goodnews Bays). Stakeholders most often identified interceptions by Area M and groundfish trawls in the U.S. 200-mile zone as a problem. Few stakeholders identified the ocean-intercept fisheries in distant waters (for example, inside the Russian 200-mile zone) as a problem. However, new knowledge that brings to light extensive migrations of AYK salmon underscores the potential impact of these fisheries on AYK stock survival (Seeb et al. 2004).

Understanding the effects of high-seas and ocean fishing on salmon stocks of the AYK region requires accurately identifying these stocks. Several techniques exist that have been used to identify salmon with their natal region, including physical tags, natural tags (scale patterns, parasites, and otolith trace elements), and genetics. Among these techniques, genetics is fast becoming the technique of choice. Recent advances in genetic-identification techniques have led to a burgeoning growth of knowledge of salmon population structure in the Bering Sea and North Pacific Ocean. An extensive genetic baseline has been developed for chum salmon, and scientists are developing baselines for the other species.

Aside from genetics, some Norton Sound stakeholders suggested using physical tags in a mark-recapture experiment to estimate interceptions of AYK salmon by nonterminal fisheries by using releases of large numbers of marked salmon from a central incubation facility to estimate interceptions of North Sound salmon in local and distant-water commercial fisheries (T. Smith, P. Rob, and P. Velsko, unpublished proposal to the Fishery Disaster Relief Program for Norton Sound Alaska 2002). Smith et al. suggested that this type of information could provide a scientific basis for regulatory measures to reduce interceptions as well as for assessing bycatch-reduction methods for stocks of concern.

Natal tags such as otolith trace elements have not been used in the AYK region, but they would provide a finer-scale measure of movements and natal origins than do current genetic techniques elsewhere; see Dorval 2004 for fine-scale application in Chesapeake Bay. They are an especially valued tag when there is gene flow sufficient to overwhelm genetic isolation but insufficient to negate selective pressures from adaptation to local streams.

Research Questions

- What are the genetic baselines for all five species?
- How can the baselines, when completed, be used to identify the stock composition of bycatch in the Bering Sea trawl fisheries?
- What are the stock mixtures in the Area M intercept fishery? What is the relationship between run timing and stocks of different natal origins? Those questions can be addressed through the use of genetic markers.
- How do salmon of different stocks and origins move, and how are they intercepted by non-terminal fisheries? To what degree can natural tags supplement genetic studies?

Along with the development of genetic tools and their applications to various ocean fisheries, a comprehensive plan to reduce ocean interceptions of AYK salmon could be developed. Past experience indicates that successful bycatch-reduction plans involve partnerships among scientists, fishing industry representatives, resource managers, subsistence user groups, and policy makers (National Fisheries Conservation Center 1994). The plan should be based on sound scientific methods, and research should include iterative processes of experimental design, field applications, and statistical data analyses. An important final step, which often fails to occur, is the integration of research results into resource management and regulatory processes.

A plan to reduce AYK salmon interceptions by ocean fisheries could include (but should not be limited to) the following objectives:

1. Identify ocean fisheries with significant interceptions of AYK salmon.
2. Develop observer programs, if necessary, to count the bycatch and collect associated data and biological samples.
3. Determine age, maturity, and stock composition of salmon in ocean-intercept fisheries, estimate interceptions, and evaluate how interceptions may affect returns (catch and escapement) in current and subsequent years.
4. Estimate and evaluate non-catch mortality (for example, dropouts from gill nets).

5. Characterize temporal and spatial variation in ocean interceptions of AYK salmon stocks.
6. Improve assessments of status and condition of AYK stocks affected by ocean-intercept fisheries.
7. Develop and evaluate gear and gear modifications to reduce AYK salmon bycatch.
8. Identify and evaluate non-gear (for example, fish behavior) and fishing (for example, tow trawl gear at less than 5 knots) methods to reduce interceptions.
9. Evaluate biological, sociological, and economic impacts of management options to reduce interceptions of AYK salmon.
10. Develop educational outreach programs on bycatch reduction for fishing industry and AYK stakeholders.
11. Identify and evaluate new or developing fisheries that may cause significant ocean fishing mortality of AYK salmon.
12. Evaluate the indirect effects of ocean interceptions on salmon populations and the ecosystem (for example, effects on size and age at return; effects on marine-derived nutrients in AYK rivers)

Human Demography in the AYK Region

Salmon have been a major food source to indigenous and rural residents of the AYK region throughout history. In addition, the commercial value of salmon has been an important component of the economy for many communities in the region, particularly in the latter twentieth century, although it has waned in the past decade. Salmon also were an important source of food for nonindigenous peoples, as populations swelled in communities such as Nome and Fairbanks during the early twentieth century associated with gold exploration and mining. Salmon, too, provided sustenance for thousands of dogs used for transporting mail, freight, and passengers throughout the region during the first third of the twentieth century.

Understanding the fluctuation of the human population within the AYK region should provide insight into the variability in salmon populations. Changes in human population and its distribution within the region, as well as variability in salmon harvest and use by the human population, serve in examining the human population during the past 100 years.

Human Population and Its Distribution

The AYK regions from Nome along the eastern Bering Sea coast in the north to Kuskokwim Bay in the south, including the drainages of the Yukon and Kuskokwim Rivers, have been described in numerous historical records beginning with Russian exploration in the late eighteenth century. Subsequently, in the nineteenth century, Russian traders and explorers continued to document the indigenous people and their distribution in the region within which the Russians engaged in commerce, primarily associated with the trading of fur pelts (Michael 1967). Later in the nineteenth century, after the United States purchased Alaska, descriptions of the indigenous and immigrant populations are primarily in government reports of military and scientific expeditions and in U.S. census reports, with the populations of settlements in Alaska recorded officially for the first time for the 1880 U.S. census (Petroff 1884). Since that time, the decennial census of the United States has been the primary source for human population estimates of communities in Alaska. Since about 1980, Alaska often has provided annual estimates for many communities between the decennial censuses (ADLWD 2004, ADCED 2004).

Historical records from the eighteenth, nineteenth, and early twentieth centuries are important for the information they provide about critical events affecting the indigenous population, migration of people into the region, and distribution of the indigenous and nonindigenous populations. For example, while the influx of Russians was relatively small and associated with the early fur trade, their report of the 1838 smallpox epidemic in the AYK region describes the devastation to and reduction of the indigenous population extending from Fort St. Michael (near present-day St. Michael along Norton Sound south of Nome) to areas south of Kuskokwim Bay, specifically, Nushagak along Bristol Bay (Michael 1967). The widespread influenza and measles epidemic of 1900 is reported to have affected the people of the Yukon and Kuskokwim drainage the most severely (Wolfe 1982). Again, in 1918, a flu epidemic hit the region. Each of these epidemics resulted in a redistribution of the human population as survivors of communities often joined others and remnant communities coalesced into larger settlements (Pete 1984, Andrews 1989). Thus, the indigenous population of the Yukon and Kuskokwim changed little between 1880 and 1940, largely due to these disease outbreaks (Andrews 1989). Some sources estimate the indigenous population did not reach precontact levels until about 1960. After this time, rapid and major growth occurred in many communities as improved health care, village settlement, and reduced mobility all contributed to reduced mortality.

Before 1940, the decennial U.S. census was relatively incomplete, although it did provide a snapshot of the indigenous population and of its distribution throughout the region. Many settlements existed that were not recorded. In turn, lack of consistency existed in documenting the number of people in the same community from one census to the next (Nelson 1882, Ray 1975, Burch 1980, Pete 1984, Pierce 1984, Andrews 1989).

Overall, the village population in the regions tripled from 1950 to 2000 in the Yukon and Kuskokwim drainages and doubled in the Norton Sound area, while the urban, Greater Fairbanks area increased fourfold (Wolfe 2003, ADCED 2004), primarily from in-migration from outside Alaska but also from communities within the Yukon drainage. While the rural AYK population was 66% of the Greater Fairbanks population in 1950, it fell to 45% of the urban area by the year 2000.

Population Changes Across the AYK Region

Every 10 years, the federal government estimates the human population of communities in the AYK region. During the intervening years, the state of Alaska estimates population and other key socioeconomic indicators through its Census and Geographic Information Network (ADCED 2004, ADLWD 2004). The Institute of Social and Economic Research (ISER 2004) has conducted analyses of the Alaska Native population based on the 1980, 1990, and 2000 federal censuses as part of their Special Economics Studies Program; the Alaska Department of Labor and Workforce Development (2004) has also conducted population analyses based on the same census data. These analyses have used federal census divisions for analytical units, and while these delineations do not match the AYK region, they do point to important trends in distribution of the village population in terms of changes in annual regional growth rates, net migration, growth rates by age, mortality and fertility, infant mortality, and projected population changes by 2010 (Goldsmith and Howe 2003) and 2018 (ADLWD 2004).

In addition, ISER has several studies under way pertinent to human population distribution and economy in rural areas of Alaska, including studies to track rural settlement patterns, describe the rural economy and urban-rural relations, and on modeling the structure of Alaska's economy (ISER 2004).

Norton Sound

The population of the Norton Sound region from Wales to Stebbins, at roughly 7,000 in the 2000 census, was nearly two-thirds less than reported 100 years earlier in the 1900 census. While Nome remains the largest community in the region, it too has only one-third of its 1900 population. Since 1940, it has accounted for about one-half of the regional population in each 10-year census (ADCED 2004).

During 1950-2000, the population of the Norton Sound region doubled from about 3,600 people to more than 7,000; both the regional center of Nome and the village populations doubled (ADCED 2004, Wolfe 2003). While most of this growth occurred in the regional center of Nome from 1950 to 1990, Nome's population remained virtually unchanged during the next 10 years. In contrast, most population growth (in overall numbers and percentage) in the region occurred from 1970 to 2000 in three communities: St. Michael, Stebbins, and Unalakleet—all situated along southern Norton Sound (ADCED 2004). The population of these communities has nearly doubled in 30 years; the remainder of the region grew by a factor of about 1.5.

Yukon

The human population in the Yukon drainage has increased fourfold since 1950. Most of this increase is accounted for in numbers by the Greater Fairbanks area, with a population of 82,840 in 2000, accounting for about 85% of the Yukon drainage population (ADCED 2004). While the overall village population has tripled during this period, the population was less than 15,000 in 2000.

However, not all village populations tripled during 1950-2000. For example, many village populations declined during 1960-1970, particularly those in the upper portions of the drainage (such as Alatna, Beaver, Bettles, Birch Creek, Chalykyitsik, Koyukuk, Holy Cross, Shageluk, and Tanana); others have declined since 1980 (such as Fort Yukon, Galena, and Rampart).

In contrast, most of the increase in village population has occurred in communities now exceeding 500 people, which have doubled in size since 1960. These communities are situated primarily along the lower Yukon River and sea coast near the mouth of the Yukon (including Alakanuk, Chevak, Emmonak, Hooper Bay, Mountain Village, Pilot Station, and St. Marys). Collectively, these communities accounted for roughly 40% of the village population of the Yukon drainage in Alaska in 2000 (ADCED 2004).

Kuskokwim

The total population of communities in the Kuskokwim drainage also has increased fourfold since 1950. Much of this increase is accounted for by Bethel, which increased eightfold from 651 people to 5,471 by the year 2000. In 1950, Bethel accounted for 15% of the population of the Kuskokwim drainage, whereas in 2000 it accounted for 33% of the population (ADCED 2004). As with the Yukon drainage, the overall village population of the Kuskokwim drainage tripled from 1950 to 2000, with a population of 11,086 in 39 communities compared with Bethel's population of 5,471.

Again, not all village populations have tripled during 1950-2000. For example, many villages have decreased in population since 1990 (such as Goodnews Bay, Lower Kalskag, Mekoryuk, and McGrath). Most communities in the middle and upper portion of the Kuskokwim drainage have remained about the same size since 1970 or 1980.

As with the Yukon drainage, most of the increase in the population of the Kuskokwim drainage occurred in communities now exceeding 500 people, which have doubled in size since 1960 or 1970. Similarly, most communities are situated primarily along the lower river and sea coast along or near Kuskokwim Bay (including Akiachak, Kasigluk, Kipnuk, Kwethluk, Toksook Bay, and Quinhagak). Collectively, these communities accounted for roughly one-third of the village population of the Kuskokwim drainage in Alaska, excluding the town of Bethel.

Uses of Salmon

ADF&G continues to monitor the harvest of salmon for subsistence, commercial, and sport uses in the AYK region. These monitoring efforts continue to provide information that can be compiled for showing overall harvest and harvest by community, permit holder or licensee, and household, in the case of subsistence harvests. This information is added annually to the databases the agency developed in the 1990s.

Both ADF&G and the federal Office of Subsistence Management of the Fish and Wildlife Service (FWS 2004) conduct or contract for studies of subsistence harvest patterns, including salmon fishing, by residents of the AYK region. These studies often supplement the more ethnographic baseline studies conducted in many communities during the 1980s and 1990s in that they address specific topics related to wild resource use in more depth.

Studies such as these provide much of the data useful for analyzing changes in population and distribution and the impact of humans on salmon abundance in the AYK. Numerous studies since 1980 have demonstrated the level and significance of wild food, including salmon, to the economy and culture of the communities in the AYK region (Oswalt 1967, Wolfe 1981, Wolfe and Walker 1987, Wolfe and Utermohle 2000, Scott et al. 2001, ADF&G 2004). Alaska Natives of Athabaskan, Yup'ik, and Inupiat ancestry are the indigenous occupants of the region, and they accounted for roughly 90% of the village population in the AYK region in 2000 (ADCED 2004). In contrast, Alaska Natives in the urban Greater Fairbanks area made up about 10% of the population. Similarly, the pattern of use of salmon and other wild food for domestic purposes has been directly related to the cultural composition of communities (Wolfe and Walker 1987, Wolfe 2003). For example, wild food harvests in AYK villages were about 2 lb per person per day, based on surveys during the 1980s and 1990s, more than 25 times the estimate for Fairbanks (21 lb per capita per year), where residents rely on imported foods (Wolfe and Utermohle 2000, Wolfe 2003).

The subsistence salmon fishery of the Yukon and Kuskokwim drainages is one of the largest in the state, both in magnitude and on a per capita basis. In 1999, the combined and Yukon salmon fisheries accounted for 45% of all salmon taken in the state for subsistence (Andrews et al. 2002). In some villages of the Yukon, the harvest of salmon itself has ranged from as much as 2/3 lb per person per day to 11/4 lb in the early 1980s, although declining to 1/2 to 2/3 lb in the same communities by 1999 (Andrews et al. 2002, ADF&G 2002).

Similarly, the mixed subsistence-cash economy of villages in the AYK region has a strong cultural and historical basis but also is related to the higher costs of imported goods in remote communities and limited cash income opportunities. Mean per capita incomes in the AYK villages were about one-half those in Fairbanks (about $10,000 per person compared with about $20,000 per person) based on the 2000 U.S. census (Wolfe 2003). Subsistence salmon harvests and commercial fishing have been a major component of the economy for families in many communities in the region. The relationship between subsistence and commercial fisheries is strong (Wolfe 1984, 1998; Wheeler 1987; Andrews 1989; Coffing 1991). In many communities of both the lower Yukon drainage and lower Kuskokwim drainage, at least one household member held a limited-entry permit for commercial salmon fishing during the 1980s (Wolfe 1981, Coffing 1991). The commercial fisheries have neither displaced nor replaced subsistence fisheries within communities with commercial fisheries. Subsistence salmon fisheries continue to be of major importance to villages, not only as a source of food and livelihood, but also for cultural continuity and maintaining strong family relationships.

The significance of salmon fishing in AYK communities is evident also in the level of participation by households and the extent of sharing regardless of the amount of salmon caught (ADF&G 2002). Since the late 1980s, for example, more than 2,100 households within the Yukon and Kuskokwim drainages harvested salmon for subsistence in 1999 (ADF&G 2001).

Salmon harvests for subsistence and commercial uses have been documented since the early twentieth century. Many reports include the species harvested, locations, and variability in the salmon run over many years. The method of documenting the harvest, the frequency of documentation, and the extent of coverage throughout the region are not always consistent. However, general trends can be elicited, providing a longer-term perspective on salmon fishing patterns and harvests than official ADF&G records.

Beginning in 1918 and intermittently into the 1930s, estimates of salmon harvests by villages in the Yukon and Kuskokwim drainages were obtained by government scientists who traveled in the region to ascertain the status of the fisheries (Bower 1919-1946, Gilbert and O'Malley 1921). These estimates included salmon taken for use as dog food and for trade (for both human consumption and dog food). Salmon harvests for the few commercial operations near the mouth of the Yukon and Kuskokwim Rivers were reported also, although these operations were intermittent. Later, in the 1940s and 1950s, documentation by the federal government of salmon harvests in the region was sporadic. In 1961, the state of Alaska began to document subsistence salmon harvests in the AYK region. Still, the methodology varied from year to year; not all communities were surveyed, and estimates were not always generated for each species of salmon harvested (Walker et al. 1989). By the late 1980s, the state revised and improved the methodologies for estimating salmon harvests in the AYK region (Walker et al. 1989, Georgette and Utermohle 2000, Borba and Hamner 2001, ADF&G 2002).

Trends in the salmon fisheries are most precise since 1989 when the method for recording subsistence salmon catches in the AYK region reached a point that recording and estimating harvests became consistent, statistically sound, and comprehensive (at most, all communities were surveyed). In addition, the method for estimating the number of salmon taken in the sport fishery was also improved during this time (ADF&G sources). These harvest estimates, combined with the commercial harvest data recorded on tickets for all fish sales/purchases, produced the most comprehensive and accurate report of harvest to date (CFEC and ADF&G sources).

Before 1990, the most precise harvest information is that reported for the commercial salmon fisheries in the early twentieth century and after the onset of limited-entry salmon fishing in the mid-1970s. Subsistence salmon harvests, while reported, remain to be evaluated and analyzed for the purpose of generating a reliable estimate of total harvest by species and by weight. In this way, a more reliable estimate of total salmon taken annually could be generated and analyzed. It remains uncertain whether the annual and per capita harvests for subsistence purposes since the late 1980s exceed those of the early twentieth century, and if so, to what degree.

Research Questions

In meetings and workshops in the AYK region as part of this review, residents stated that the continued harvest and use of salmon was of paramount importance for sustenance, livelihood, community sustainability, and cultural continuity. Research that would be most beneficial to these communities would address the following questions:

- What level of harvest can be sustained during the short term (5, 10, 15 years)? Recognizing that salmon populations generally have been declining in the past decade or more and that harvests have been restricted and curtailed in many instances, what amount of harvest, if any, can be expected in each region, for each species, during the rebuilding of salmon stocks?

- What level of harvest can be sustained over the long term (20 to 40 years)? What role can salmon play in the livelihood of families and communities during the next two generations? Salmon have been a major contributor to the economic and cultural continuity of many communities in the AYK region during the past 100 years. Major changes in community economies have become necessary with continued declines in salmon abundance. However, estimated future salmon abundance is important for community self-determination.
- What are the upper- versus lower-drainage issues given differences in human population growth and movement of fish through the life cycle?
- What changes have occurred in the number, distribution, and way of life of the human population of the AYK region in the past 100 years?
- What changes have occurred in the harvest and use of salmon by the human population in the AYK region?
- What geographic variability, if any, is evident in these changes?
- Is there any relationship between the reduction/increase in subsistence salmon harvests with commercial salmon harvests over time?
- What are the predicted increases in human population and its distribution in the AYK region in the next 20 and 40 years, and what are some predictable outcomes of salmon harvest and use?

Answering these questions requires analyzing existing information from human population censuses and salmon harvest estimates. A retrospective analysis, for example, of the per capita harvest (number and dressed weight in pounds) of different salmon species will help indicate the nature of change in harvest and use of salmon in the AYK region. Existing information on population and harvests will serve as the basis for generating one or more drainage-wide population and harvest estimates for a retrospective analysis.

We are not aware of any syntheses of ethnographic information, traditional knowledge, and other descriptions of distribution of the human population before 1940 relative to salmon fisheries in the Yukon, Kuskokwim, and Norton Sound areas. Salmon was not a key food source for all communities in the AYK region, and not all communities historically used all species of salmon. In other cases, there were communities that harvested salmon from areas where salmon are no longer taken. A complete picture of the geographic distribution of historically used harvest areas, the seasons they were used, and the species harvested will help reveal changes in the impact of human populations on salmon.

Modeling the projected growth of the human population and its distribution in the AYK region is likely to provide insight on some issues that may emerge relative to salmon harvest and use. These models can aid communities in evaluating the reliability of salmon as a source of food and livelihood in generations to come.

- Another question that needs to be addressed is, what are the impacts of subsistence, commercial, and recreational fishing on salmon? These impacts may be in terms of population dynamics, but also they could be extended to consider, for instance, the role of mesh sizes and fishing seasons in altering the genetic structure of populations or the role of motorized boats in reducing the survival of eggs on spawning grounds.

LEGAL AND POLICY CONSIDERATIONS

The committee heard in testimony widespread concern for protecting salmon habitat and salmon stocks. Some villages had made consistent efforts over decades to protect the regions they use for subsistence, having claimed land under the federal Alaska National Interest Lands Conservation Act (ANILCA), written protective measures into coastal zone management plans, purchased inholdings, and established restrictive use policies of regional lands, all for the expressed purpose of protecting subsistence resources.

The committee also heard from agency personnel that ensuring long-term protection of salmon stocks was the top priority in fisheries management for the region. The committee heard several times that the first priority of the agencies is to get sufficient salmon up the river for conservation needs; the second priority is to meet customary and traditional uses of fish for subsistence purposes; and the third priority is to provide for commercial and sports fishers. There appears to be a confluence of state and federal agency priorities with those of the AYK regional community users.

Under state law (Alaska Statute Sec. 16.05.258), subsistence uses are priority uses. All other “consumptive” uses of a fisheries stock or wildlife population must be eliminated before subsistence fishing or hunting of that stock or population is closed. This statute does not imply that subsistence fisheries or hunting resources cannot be regulated (for example, by season, by gear type) while all other uses are allowed, but it does mean that the subsistence resource cannot be closed before nonsubsistence activities or limited to a restricted set of Alaska residents. A variety of state and federal subsistence laws apply to Alaska's fishery resources. The Yukon River, for example, runs through both state and federal lands and therefore is subject to dual management by the U.S. Fish and Wildlife Service and by ADF&G. Such dual management can create difficulties in the balance of conservation, subsistence, and commercial or sport fish agendas. Only Alaska residents qualify for subsistence resource use according to state law (FWS 2003b).

ANILCA applies to federally managed land and waters (rivers adjacent to federal land) and protects a rural subsistence priority in times of shortage. The Federal Subsistence Board does not directly manage commercial fisheries or sport fisheries, but it can close federal or state waters to these fisheries to protect subsistence opportunities. It can also adopt regulations closing federal waters to everyone except eligible rural Alaska residents (FWS 2003b). Thus, unlike the state law that provides subsistence opportunities to all Alaskans, ANILCA provides subsistence preference to rural Alaskans. This subsistence preference was deemed inconsistent with state law (Shapiro 1997). A chronology of Alaska subsistence laws is presented in Appendix A.

Dual state and federal management of subsistence salmon fisheries is complicated further by forces external to the AYK region. For example, the lack of information about the spawning destination of fish taken in intercept fisheries (such as in Area M) and in the lower sections of the Yukon and Kuskokwim Rivers makes for a challenging management environment. For instance, at the same time that this committee was deliberating the information needs to address the decline of salmon in the AYK region, the Alaska Board of Fisheries took action to expand the intercept salmon fisheries in Area M. This decision, of course, raises local concerns within the AYK region that expansion of the intercept fishery will influence stocks in the AYK region, including salmon identified as stocks of concern.

Other federal laws, such as the Endangered Species Act, are not applicable in this region because no salmon species are listed or have been proposed for listing there.

Some of the information needed to address these issues is biological in nature. A research strategy to address these information needs appears elsewhere in this report. However, the committee also concludes that a need exists for clarifying the confluence of law, policy, and regulation in addressing stock conservation, addressing customary and traditional subsistence harvest, and protecting habitat. Given the interjurisdictional nature of the law and of responsibilities, independent research such as that by Bader (1998) would be helpful in identifying legal and policy alternatives for the region's populace, for the resource managers of the region, and for the managers beyond the geographic region whose policies affect AYK regional stocks. With respect to the changing policy and regulation vis a vis subsistence, the database constructed by Andrews et al. (2002) provides a useful beginning for expanded legal research/analysis on state and federal responsibilities for protecting subsistence priority.

The committee judges that successful rebuilding of salmon stocks in the region and protecting them for the long term requires a stronger base of scientific information than now exists as well as, and especially in the interim, a thoughtful and conservative policy and regulatory approach. Quality research and analysis of legal, policy, and regulatory alternative approaches and the clarification of responsibilities could be helpful in reaching those mutual goals.

Research Questions

- How are laws translated into regulatory policy, and to what degree do those policies achieve the stated purposes of those laws, with respect to protecting subsistence use, conserving salmon populations, and protecting habitat?
- How do state and federal responsibilities interact? Under what circumstances do those interactions enhance or hinder achieving policy goals?
- Are there politically acceptable alternatives that could achieve those legal goals more effectively?

RESTORATION

Background on Fish Restoration Successes and Failures

The committee is reluctant to recommend specific restoration options, except at small scales and locally, because it remains uncertain what the major factors affecting salmon populations are. It is not even certain that the low runs of AYK salmon in the 1990s and early 2000s represent a long-term decline; it seems equally likely that they reflect regional fluctuations in abundance, perhaps related to environmental fluctuations. Salmon runs in many other parts of Alaska have been high during the period.

For example, if a change in ocean carrying capacity has led to a decline in ocean productivity for salmon and hence smaller salmon runs, then restoration activities in streams or reduction in fishing effort are unlikely to be effective. On the other hand, if excess fishing or habitat degradation in freshwater areas have depleted spawning populations or decreased the productivity of streams as rearing areas for salmon, then stream-based restoration activities or a reduction of fishing effort would be more likely to succeed.

For this reason, the committee urges that the AYK SSI's main focus, at least initially, be on funding, conducting, and coordinating research and analyses that can help to better identify the role of major factors affecting salmon abundance in the AYK region and on partitioning their effects into the marine and freshwater environments.

Much of the knowledge about salmon developed for Canada, Europe, and the Lower 48 of the United States (NRC 1996, 2004a) is not applicable directly to restoring AYK salmon. Indeed, despite that knowledge, the degree of success that restoration efforts in those places have had is not enormously encouraging, and the most successful efforts have involved habitat restoration, which is not obviously a major issue in the AYK region. Below we discuss some issues that seem relevant to restoration efforts.

Hatchery Production Within the AYK Region

Within the AYK region, no large hatcheries exist. In Canada's Yukon Territory, a small mitigation hatchery was built when the Yukon River was dammed at Whitehorse for electrical production. Chinook salmon are collected at the dam and used for broodstock in the hatchery located above the dam. All fish produced (about 250,000 per year) are released into the Yukon system above the hydroelectric dam—at Wolf Creek, Michie Creek, McClintock River, and Byng Creek. Released fish are marked, and when they return to the fishway, they account for 33-50% of the Chinook returning to the fishway (less than 1,000 total return per year of the 30,000 crossing the U.S.-Canada border).

In addition to the hatchery in Whitehorse, in-stream incubation/rearing systems are used for Chinook in the Yukon Territory on the Klondike and Mayo rivers, and McIntyre Creek. In the U.S. section of the Yukon River drainage, periodic small-scale use of incubation boxes has occurred periodically, especially in conjunction with schools, but no substantial effort continues.

ADF&G, supported by the Yukon River Drainage Fisheries Association, has a policy to oppose large-scale enhancement hatcheries (designed to create new runs of fish) in the Yukon system. Projects to restore wild stocks and their habitat are supported.

In the late 1980s and through much of the 1990s, a small hatchery on the main stem of the Noatak River north of Kotzebue produced chum salmon. That hatchery is no longer in operation.

Production Beyond the AYK Region

Salmon from the AYK region face competition for food with hatchery fish in the Bering Sea and Gulf of Alaska, as do all wild salmon from both the North American and the Asian sides of the northern Pacific. Hatchery releases of all species of salmon from Alaska and Asia amount to several billion fish per year. Thus, biological competition between AYK salmon and hatchery salmon occurs primarily in the ocean and not within the AYK region. Among commercial salmon fishers, market competition exists. Most market competition covers pen-reared operations worldwide and sea ranching operations. Because subsistence fisheries are often subsidized by commercial fishing operations in the AYK region, this market competition is a concern to both subsistence and commercial fishers.

Because industrial scale gold mining occurred in the Yukon Territories for nearly all of the twentieth century, substantial salmon habitat was lost or significantly altered. Under their joint management efforts, both the United States and Canada supported the restoration of habitat for Yukon River salmon. The in-stream incubation and rearing boxes are part of that effort. Research should be undertaken to establish whether this effort is supportive of these joint goals or whether other cost-effective methods of restoration can be identified. Because one-half of all Chinook salmon harvested in the U.S. Yukon system are spawned in Canada, this is important to both partners.

High-Seas Competition

Competition between AYK salmon and hatchery salmon at the early ocean life stage appears minimal, because AYK salmon juveniles (ocean age .0) are distributed in waters over the eastern Bering Sea shelf, where they intermingle primarily with other wild stocks of western Alaskan origin. Stock identification research by a variety of methods (tags, fin clips, parasites, otolith marks, scale patterns, and genetics), however, reveals extensive overlap in the ocean distributions of immature (ocean age .1 and older) and maturing Asian and North American hatchery and wild salmon in areas east of 170°E longitude in the central and eastern Bering Sea, Aleutian Islands, and North Pacific Ocean (see INPFC and NPAFC bulletin, technical report, and document series). Because of broad seasonal changes in high-seas salmon distributions, the greatest potential for competition between AYK salmon and Asian hatchery salmon occurs in winter, spring, and early summer in the North Pacific Ocean and in summer and fall in the Bering Sea. The distributions of AYK salmon and North American hatchery salmon overlap most extensively in the Gulf of Alaska, which is a major feeding area throughout the year for all species of western, central, and southeastern Alaska salmon, as well as northward migrating stocks of U.S West Coast (Washington, Oregon, Idaho, and California) and British Columbia salmon.

Competition between AYK salmon and hatchery salmon most likely is intense when hatchery releases are large and variations in climate result in poor ocean rearing conditions (Francis and Hare 1994, Gargett 1997, Beamish et al. 1999, Hilborn and Eggers 2000, Volobuev 2000, Levin et al. 2001, Ruggerone et al. 2003). Considerable direct and indirect evidence exists for inter- and intraspecific food competition and density-dependent ocean growth and survival of immature and maturing salmon in the Bering Sea and North Pacific Ocean (Kaeriyama 1989, Ishida et al. 1993, Bigler et al. 1996, Tadokoro et al. 1996, Davis et al. 1998, Helle and Hoffman 1998, Azumaya and Ishida 2000, Walker et al. 2000, Watanabe 2000, Levin et al. 2001, Ruggerone et al. 2003). Direct field research on competition specifically between AYK salmon and hatchery salmon is complicated by the lack of adequate tools to identify the origin of individual fish in mixed-stock samples. Thermal otolith marks are a fast, easy, and relatively inexpensive way to identify hatchery fish (Hagen et al. 1995, Carlson et al. 2000). An increase in the number of duplicate marks released by Asian and North American hatcheries, however, has made it impossible to determine the origins of many otolith-marked hatchery fish in Gulf of Alaska samples. NPAFC is attempting to coordinate hatchery salmon otolith marking programs in Asia and North America to reduce or eliminate duplicate marks.

In-Stream Incubation Boxes and Small Hatcheries as an Aid to Enhancement

The committee heard much interest and concern about the use of either small hatcheries or in-stream incubation boxes to restore and enhance salmon stocks in the AYK region. Other studies, including those conducted by the NRC (1996, 2004a), have looked closely at hatcheries. The conclusions from those reports have been consistent, each noting that hatcheries produce fish that compete with, and often outcompete, wild salmon stocks, whose populations can experience adverse genetic effects. We agree that the risks of large-scale hatchery production, especially in the absence of information about the carrying capacity of the ocean to support the growth of additional young salmon, outweigh the benefits. However, carefully controlled studies of in-stream incubation boxes do not appear to entail significant risk. They could lead to valuable information, as well as perhaps enhancing salmon runs locally.

The committee recognizes that stocks in this region are near the northern extreme of the species. With limited data in hand, we believe that marine-derived nutrients are critically important to these streams. Ensuring that adequate fish reach the spawning beds is relevant not only for spawning but also for nutrient supply to other aquatic and terrestrial ecosystems. Research on selected streams, especially those of the northernmost coastal region and of the most upstream regions of the larger rivers, might show that temporary enhancement of those streams would improve the productivity of those streams by jump-starting the nutrient cycle. The committee cautions, however, against human intervention in the long-term selection of parents for the next generation, judging that natural selection of mating pairs on the spawning grounds is an important factor in maintaining both the genetic diversity and the genetic strength of the stocks. A research plan should be developed to investigate the roles of climate change and marine-derived nutrients on AYK salmon stocks and later to study the use of artificial enhancement intervention.

Research Questions

- How can information needs be prioritized to improve the likely effectiveness of restoration efforts? We have noted the difficulty of advising on a restoration plan for AYK salmon given the lack of confidence about why their numbers declined in the 1990s and early 2000s. If all the research questions in this report were answered, then a restoration plan could be suggested with greater confidence than we have now, but answering all of them would take enormous sums of money and a long time. That is why a prioritization exercise could be helpful. As mentioned earlier, one of the most important general things to do is to partition environmental and human effects on salmon population sizes into freshwater and marine components.
- At a more specific level, analysis of the existing hatchery and in-stream incubation boxes above Whitehorse on the Yukon and of the recent hatchery experience on the Noatak would provide an important start to this research. What do the data in these locations show? Do controls exist? Did the Noatak hatchery influence relative run strengths of salmon there? Did hatchery and stream boxes on the upper Yukon tributaries influence run strength?

INCORPORATING TRADITIONAL KNOWLEDGE AND COMMUNITY INPUT INTO RESEARCH

Traditional knowledge and indigenous researchers must be involved at all levels of research within their traditional homelands and on the resources they depend on. Because indigenous people have such an extensive, historical, and indivisible affinity to the land they call home and a fundamental interest in the outcome of all research, they have a much greater need to be involved.

Incorporating traditional knowledge into science to answer research questions has not been done to any large extent. However, methods for collecting traditional knowledge have been developed and much information has been collected.

As long as people and land continue to be inextricably linked, traditional knowledge will continue to expand. However, the state of experiential land-based traditional learning is in jeopardy in many parts of

Alaska because the linkage between aboriginal people, the environment, and ancestors is weakening. (The connection to the natural environment and land-based traditional learning and retention of the Native language—especially Yup'ik—and culture are currently stronger in the downriver parts of the AYK region than in most other Alaska communities, but the factors that have affected these features operate there as well as elsewhere in Alaska.) Multiple causes have driven these changes, which probably began with the forced removal of indigenous people from the land by mandatory attendance in school and the reduction in size and contiguity of aboriginal homeland through state and federal actions such as statehood, the Alaska Native Claims Settlement Act, and ANILCA. Regulatory management regimes also might have had an effect. These acts of state and federal sovereignty served to assert their claim of ownership of Alaska's land, reduce tribal members' status as members of sovereign nations to state-chartered corporate stockholders, and divide the landscape into small checkerboard plots with every other plot owned by different individuals. Finally, these governmental moves served to remove or restrict access to the resources on the land. The primary reason for declining traditional knowledge, closely linked to the land and tribal status changes, is a rapid change from a traditional, land-based lifestyle to a lifestyle detached from the natural environment more dependent on others—for example, grocery stores and governmental programs.

Indigenous people have shared traditional knowledge within their own societies and with explorers (new arrivals also) since "the beginning of time." In North America, this behavior was demonstrated when the American Indians helped the Europeans survive in the new continent. This attitude of cooperation continues today where Alaska Natives provide valuable information to researchers on weather, habitat, and ecological changes and wildlife extinctions.

One problem with the current state of knowledge is that most research conducted regarding or including traditional knowledge has been collected, interpreted, and written down from the perspectives of researchers who are not familiar with traditional knowledge. The research techniques might be the current approach for conducting laboratory type research but do not work well with subject matter that is often implicit in nature and contained in people.

Anthropologists have long been involved in the collection and interpretation of traditional knowledge. Although traditional knowledge has been incorporated into nearly all fields of research, it is through anthropology that we find the most in-depth discussions, study, and acceptance of this concept.

ADF&G has been involved in compiling traditional knowledge since the 1980s. Most studies have been conducted through the ADF&G Subsistence Division, focusing primarily on human use of harvested wild resources.

To some extent ADF&G has studied community and individual use of salmon in every village on the Yukon River. From the lower Yukon to the Alaska/Canada border, they have documented the use of salmon for dog and human food and identified current usage patterns as well as traditional and changing harvest methods. Additionally, many theses and dissertations have been written, including a variety of salmon traditional knowledge topics.

Wildlife researchers have been less inclined to bridge the gap between traditional knowledge and traditional science. They find it difficult to incorporate intergenerational information that has been passed down in a verbally implicit format, because their research system originates from a university-based, scientific-method approach.

While numerous traditional knowledge projects are conducted each year, a key thematic problem with the process is that it is difficult for people educated in traditional knowledge to convey their knowledge to those desiring it in a short period of time or within a few lines of text (NRC 2002). Those organizations that require this information should hire permanent staff capable of bridging the gap between the traditional and their specific field of interest. Often, individuals who have not learned ecological or anthropological information in an experiential and verbal manner but have gained their knowledge from institutions are ill-equipped to translate or relate the various fields.

Traditional knowledge can provide valuable insight into nearly all fields of scientific endeavor. Clearly, it is an invaluable tool that contributes to the success of scientific research. Traditional knowledge opens a window on a time before the Industrial Revolution became part of everyday life in Alaska. Unfortunately, we continue to lose the eyes (and minds) and knowledge of elders who experienced life before a new lifestyle (post-Industrial Revolution) so radically changed their lives. At present, few remaining elders exist in Alaska who can remember a time when they depended entirely on (and were an integral part of) their natural environment. Therefore, in many cases we are collecting secondhand information, as documented by less vividly detailed results of current traditional knowledge research projects. While scientists have been standing behind podiums debating the validity and merits of plaiting traditional ecological and traditional scientific knowledge, thousands of volumes of irreplaceable data are forever lost to the grave. This should instill a sense of urgency for the collection and integration of these data before they slip forever into an undocumented past. Most scientific investigations already have limited historical data. The problem of focusing on a single species is illustrated in discussions in this chapter of predator-prey relationships in the AYK region.

The most promising development for incorporating traditional knowledge into traditional science has been occurring within the indigenous community. Each year more indigenous researchers graduate college and work in various fields that incorporate their traditional knowledge and their ability to translate it into terms that others can easily understand. Many professional indigenous people working in research-based fields have pursued higher education and research positions because of the appeals of their elders and community leaders who want more informed decision making in areas that affect their lives. The elders' experiences with academic and government researchers have usually left them feeling uninvolved. Often their information is collected, translated, and placed in a report or book. However, the reasons they participated and the results they hoped for often are not forthcoming.

Just as a wildlife biologist, cultural anthropologist, or other scientist would not trust the results of someone not in their field, it is equally troubling to a traditional knowledge holder to have someone seen as an outsider conduct interviews, make conclusions, and write reports that suggest they are a traditional ecological knowledge expert.

To generate the best results in any research project one must begin with the most capable researchers. In the area of weaving traditional knowledge and traditional science, one must find a researcher capable of understanding the dynamics of both sides and incorporating the most applicable and useful components of each to answer the question at hand. Finding researchers with these qualifications is not an easy task. However, we must nurture the concept and make it as easy as possible for these types of researchers to become involved. Most of the few researchers who fit this description find themselves in a difficult situation. It is difficult to find work within the indigenous community, but that is where they are needed the most. Traditional knowledge is the very essence of the people who hold that knowledge, and it is often critical to resolving agency questions and problems.

The AYK SSI is itself an excellent example of integrating local communities and Western science. As described in Chapter 1, the SSI is composed of Alaska Native organizations as well as others. Members of those Native organizations, often members of local communities, are playing a major role in developing research questions, making funding recommendations, and engaging Western scientists. They were part of the decision to request help from the National Research Council. Thus, the motivation for the development of the AYK SSI's Research and Restoration plan is tied to Native culture and the sustainability of salmon. It differs from programs that are generated in the science community and presented to (or even imposed on) local communities. By the same token, the research that the SSI funds will share some of those features.

Research Questions

- How can the loss of vanishing and valuable information be prevented? Organizations like the Arctic Council, Council of Athabascan Tribal Governments, the Alaska Native Knowledge Network, and many others having been striving to conserve traditional knowledge for years. However, while those projects are important, their value and effect will not be completely realized until they are fully integrated into the relevant fields.
- How can traditional knowledge and traditional science be integrated? Traditional knowledge and Western science are woven together best by someone who has grown up with a traditional indigenous upbringing and then gained an understanding of the scientific method through formal training. This method is better than relying on an outsider to meet, learn about, and build relationships with an indigenous community or to have someone raised within an indigenous community attempting to apply the scientific method without the proper training. It is much easier—challenging though it might be—for a nonscientist to learn the methods of science than it is for someone from outside the Alaska Native culture to learn the Natives' way of knowing. It is necessary to identify and encourage indigenous and collaborative research projects that weave traditional science and traditional knowledge with Western science, including the consolidation of salmon research into a library, including geographic information system data.
- How can local communities be involved in scientific research? Information should flow bi-directionally. The entire population

from elders to schoolchildren should be represented where appropriate. One possibility would be the involvement of school students in marine science activities, as for example is being done at Little Diomede, Alaska (K. Frost, ADF&G, personal communication, August 2001). The committee was impressed by the enthusiasm shown about being involved by students at places it visited, in particular at Unalakleet, where it met in the school's facilities. In addition, asking this question leads to additional more detailed questions, such as the following: What communities are associated with which spawning and rearing areas for AYK Chinook stocks? What communities are associated with which spawning and rearing areas for AYK summer chum stocks? What communities are associated with spawning and rearing areas for AYK fall chum stocks? This last question also requires a list of spawning and rearing areas and communities, which also are basic research questions. What types of local habitat manipulation by communities would improve the survival of eggs, fry, and smolts in their associated spawning and rearing areas (such as live boxes, beaver dam management, woody debris, and predator fish management)? What monitoring program can be implemented to measure the success of egg, fry, and smolt survival at this local level? What types of genetic or biological markers can be used to identify fish from these local stocks?

4

Foundations for a Restoration and Research Plan

ESSENTIAL COMPONENTS FOR THE AYK SSI SCIENCE PLAN

- A mission and/or vision statement: the mission is an intellectual statement that defines the Arctic-Yukon-Kuskokwim (AYK) Sustainable Salmon Initiative's (SSI's) role, and the vision statement comes from informed imagination.
- Background information: this includes a brief regional description, present state of knowledge, and other relevant science plans.
- Research and restoration issues and needs the plan will address these include fishery management and ecosystem concerns along with other scientific issues.
- An overarching theme: the theme is the thread that binds the individual research topics together.
- A set of research themes and approaches to accomplish the needed research: this set often includes topics such as processes and variability in the physical environment, species responses to perturbations, food web dynamics, contaminants, essential habitat, monitoring, modeling, process-oriented studies, and retrospective studies.
- Implementation and protocol issues: these include topics such as policies for cooperation, identifying and addressing user needs, data quality, management and dissemination, logistics, outreach and education, and community involvement.

DEVELOPMENT OF RESEARCH FRAMEWORKS

The elements of a restoration and scientific research plan include a focus of the program, methods to develop research themes, assessment of prior research and restoration efforts, and integration of the study plan with ongoing research programs. In Chapter 3, we reviewed the current knowledge of factors that affect salmon abundance in the Arctic-Yukon-Kuskokwim region, and we identified knowledge gaps and areas of concern for further research. However, just identifying knowledge gaps and areas of further research does not constitute a research plan. Which knowledge gaps should receive priority? Should the most expensive projects be funded initially? Should less expensive projects receive high priorities so that more research can be funded? Even if we had easily identified priorities, how could important research be accomplished to build knowledge synergistically?

To accomplish this goal of building knowledge in a systematic fashion, a framework is needed that guides the integration of research into a larger picture than would be available from individual projects by themselves. The research framework presents a vantage point that integrates current knowledge and gaps into a broad vision of the world.

For a problem as complex as the decline in salmon abundance in the AYK region, no single framework seems likely to encompass all research gaps into a unified body of knowledge. For this reason, we adopted three frameworks with different vantage points to address the problem; they should be viewed as examples that could be used in developing a detailed research plan. The three frameworks are based on a fish-centric view, a human-centric view, and a retrospective human view. They lead to research questions. There is some overlap with the questions in the previous chapter, but only partial. Because these questions were developed through a different pathway, they are listed in this chapter. The final chapter provides a broad approach to prioritizing all the questions.

Framework 1: Understanding Salmon Life History and Population Dynamics

The focus of a fish-centric research program developed within this framework would be to explain annual and longer-term variations in the abundance of salmon in terms of the processes that affect their reproductive ecology and their growth and mortality during each life history stage. One challenge of this approach is that salmon make use of a sequence of freshwater and marine habitats during their life cycle (Figure 4-1). As a result, a research program developed within this framework needs to integrate and prioritize studies that cover the full range of habitats used by the salmon and the full range of important processes that operate in these habitats. Fortunately, this approach can draw on the tremendous amount of information and knowledge that exists on the ecology of the five species of salmon described in Chapters 2 and 3. This knowledge provides an excellent background against which to identify the important knowledge gaps, many of which are described in Chapter 3; it also provides considerable guidance on how to structure a research program. Some of the research themes, questions, and approaches identified in earlier chapters that might be considered when developing a science plan within this framework are as follows.

1. How are the reproductive ecology, survival, and growth of salmon influenced by changes in the physical and biological characteristics of their freshwater and marine habitats?

- What determines variability in egg-fry survival?
- What determines growth and survival during freshwater residence?
- What determines survival during the smolt outmigration?
- What determines growth and survival during the first summer at sea?
- What determines growth and survival during the first winter at sea?
- What determines the growth and survival of .1 and older fish at sea?
- What determines survival during the spawning migration?
- What determines the fecundity and spawning success of mature adults?

2. How do human activities affect the survival and growth of salmon in freshwater and marine environments?

- How do activities that affect freshwater habitats (jet boating, placer mining) affect reproduction, survival, and growth in freshwater?

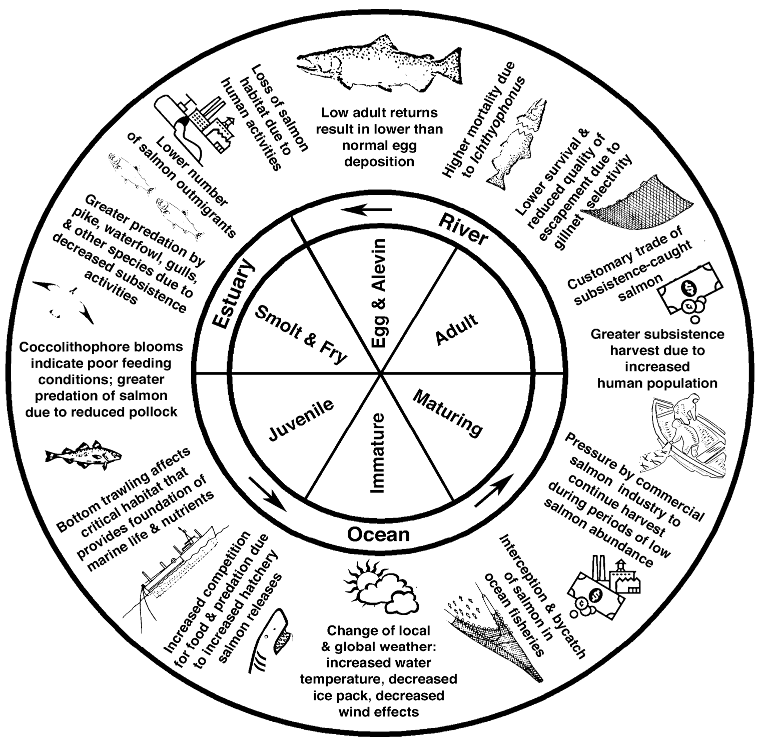


FIGURE 4-1 Salmon life cycle and factors that could influence population variability. This conceptual model is based on the salmon life cycle and can be shared across a wide range of holders of ecological knowledge and provides hypotheses for salmon declines. Modified from an original drawing by Andy Bassich (Eagle, Alaska).

- How does the bycatch of salmon affect marine survival?
- How do interception fisheries in U.S. and Russian waters affect marine survival?
- How does competition with ranched salmon affect growth and survival?
- How do human-induced changes in climate affect ocean growth and survival?
- How do fisheries-induced changes in marine food webs affect growth and survival?

- How do terminal fisheries affect survival?
- How does the selection imposed by human-induced mortality affect life history evolution?
- How does human-induced mortality affect stock structure in stock complexes?

3. Improved techniques for stock identification would greatly facilitate research on questions relating to population dynamics. It would be very valuable to have the capability to assign fish caught at sea to their natal drainage. The higher the resolution of this assignment, the more questions become accessible to researchers. Technological developments might include the following:

- Better genetic techniques for finer-scale stock identification.
- Development of other techniques, such as otolith microchemistry, for stock identification.

4. Research on the influence of physical, biological, and anthropogenic processes on AYK salmon in the marine environment would be facilitated by knowledge of their movements and distribution while at sea. Important research to provide relevant data is currently under way as part of the Bering-Aleutian Salmon International Survey (BASIS) program. Efforts to increase the value of the information gathered by this effort to accomplish the goals of the SSI might include the following:

- Development and application of finer-scale stock identification techniques to identify AYK salmon stocks in BASIS samples.
- Ensuring that tissue samples from salmon sampled by the BASIS program are preserved to allow later fine-scale stock identification.
- Studies of salmon movement at sea with archival tags and pop-off tags that transmit data via satellite.

5. Experience shows that a multipronged approach to research problems can often be effective. Any research plan should recognize that research into the questions described above could be addressed by at least four types of studies. These four types apply in varying degree to all the frameworks; here we apply them specifically to this one. A more general discussion is in the section on implementation, below.

- Process-based studies: These investigate how processes operate that affect salmon abundance. For example, how much does predation by salmon sharks increase the mortality of salmon at sea? This kind of study might involve cruises to estimate the abundance, distribution, and diet of salmon sharks (Nagasawa 1998). They are often expensive but can provide important new information.
- Retrospective studies: These studies use existing data to test hypotheses. For example, how does the abundance of Asian pink salmon affect the growth and survival of salmon from western Alaska? When well done, this kind of study can give excellent value for money (Ruggerone et al. 2003). The use and interpretation of traditional ecological knowledge fits naturally into this category. Such studies might test hypotheses about the mechanisms responsible for low returns of salmon in 1997 and 1998 (Kruse 1998).
- Theoretical studies, perhaps more accurately defined as studies that describe hypotheses using mathematical models: Such models are often implemented on a computer. An example of this kind of study is the model of foraging and predation risk trade-offs developed by Gross (1987) to explain the evolution of anadromy. These kinds of studies are essential in ecology because hypotheses are often complex—for example, hypotheses concerning the way food webs operate. Models are useful tools in process and retrospective studies as well.
- Monitoring studies: For example, how does the abundance, age structure, body size, and fecundity of spawning adults entering a river to spawn change from one year to the next? These studies are essential for understanding population dynamics; they are the bread-and-butter work of salmon biologists at the Alaska Department of Fish and Game (ADF&G) because they provide the data needed to fit a stock-recruitment curve (Ward 1996). They can also provide the raw data for retrospective studies and useful background information for process-based and modeling studies. The danger is to view these studies as an end in themselves. By themselves, they provide little insight into the processes that influence salmon abundance and can demand a considerable investment of resources. When monitoring is costly, it may be better to focus effort on a few tractable key systems than to attempt extensive coverage. These systems should be selected so the results they provide are applicable to other systems of interest.

Framework 2: A Conceptual Framework for Sustainable Salmon, Emphasizing Human Social, Economic, and Political Linkages

This conceptual framework emphasizes the human system in which salmon fisheries occur (Figure 4-2). Fishing regulations and escapement objectives result from local applications of state and federal laws. International fishing agreements influence high-seas catch and bycatch of salmon. In-stream management and ocean fisheries achieve management objectives to various degrees, but this fishing undoubtedly influences salmon population dynamics. Feedback from the human community underscores the idea that changes in economic and social organization as well as in regulations influence human effects on salmon. Finally, while it is clear from our site visits and from many published sources that salmon have immense cultural and economic value, these values have not yet been broadly quantified. Some evidence exists that local human communities have felt left out of the processes involved in establishing top-down regulatory policies.

This framework results in the following research themes becoming apparent. The research themes correspond to the numbered parts of Figure 4-2.

1. Legal oversight: Specific laws govern some aspects of the determination of total salmon catch and allocation. Because salmon range widely in the ocean, well outside of the U.S. exclusive economic zone, international fishery agreements also contribute to the distribution of salmon among human users. It is not clear to this committee how the variety of state, federal, and international laws are translated into fishing regulations, the setting of escapement objectives, and other socioeconomic factors. One research theme explores the legal context for salmon management and how it is translated into regulations and escapement objectives.
2. Population modeling and implementation: The committee was unable to discern how much, if at all, traditional fishing axioms (for example, if you don't use the fish, they will disappear; when there are fewer fish, you should catch fewer fish; catch what you can now, because there may be short times ahead) are incorporated into ADF&G's management strategy, which is roughly to set and meet escapement goals. It also was not obvious how best to effect such an integration.

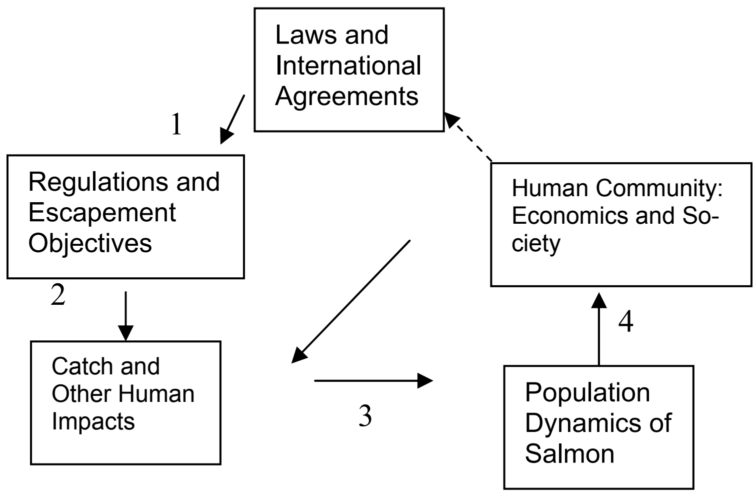


FIGURE 4-2 Diagram of the human system influencing salmon fisheries.

3. Effects of salmon on society: Why do salmon matter to people? This question sits at the heart of the existence of the SSI. It is severely complicated by regional differences in economies, values, demographics, and cost-benefit assessments.

4. Effects of management and society on fishing (effort, fisheries, fish): Fishing and other anthropogenic effects on salmon, both in streams and in the ocean, are a complex function of human activities, often constrained by (or pursued despite) management. There is little quantitative understanding of these relationships. Human impacts on salmon are obvious factors that might be altered to restore salmon.

Questions that can be derived from this framework include the following:

- What do we know about the historical evolution of gear types and catch-per-unit effort?
- How can we relate human demographic information to the history of salmon abundances?
- How have people in the region adapted to fluctuations in salmon abundances?
- How have people and their activities affected spawning beds?
- How have commercial, subsistence, and recreational fishing affected salmon in rivers and at sea?

- How have management and policies at local, regional, national, and international scales affected population fluctuations in AYK salmon?
- How have social and cultural changes affected fishing in the AYK region? What impacts has run-size variability had on ecosystems, human communities, and commerce of salmon?
- What have been the socioeconomic consequences of a variety of management actions—for example, actions by the Board of Fisheries, commercial buyouts, and fishing cooperatives?
- How do human activities (harvest, hatcheries, pollution) influence variation in ocean food and feeding conditions of AYK salmon?
- Were declines in AYK salmon runs in the late 1990s due to large-scale releases of hatchery salmon that attracted more apex predators (for example, salmon sharks attracted to maturing Japanese hatchery chum or Prince William Sound pink salmon) to the oceanic regions where AYK salmon migrate?

Framework 3: Resilience of the AYK Salmon-Human System

This framework highlights the dynamic nature of the AYK salmon system (human and biophysical) over multiple generations. The idea behind the framework is that ecosystems experience natural variability due to biotic and abiotic shocks (disease epidemics, human activities, and climate shifts) and that ecosystem functioning and services to humans can remain intact in the face of such shocks as long as they are not too great. Resilience is defined as the amount of disturbance a system can absorb and still remain in the same state or socioecological balance (Holling 1973, 1996). The definition also encompasses the ability of a coupled human-ecological system to learn and adapt to change so that the fundamental ecosystem functions and services are not degraded in an irreversible fashion (Carpenter et al. 2001, Berkes et al. 2003, Folke 2003). The concept of resilience is particularly important for complex systems that face significant uncertainty like the AYK salmon system.

Ecological research has shown that ecosystems with reduced resilience can still function and generate services (fishing incomes and subsistence) and that they therefore may appear to be functioning normally (Folke 2003). However, when systems faced with diminished resilience (due to excessive human pressure on the resource) are subject to a sudden event (a shift in climate), a critical threshold may be reached. At this threshold, the ecosystem moves into a new, less desirable state with a reduced capacity for life-supporting services for society (Scheffer et al. 2001). In a resilient system, disturbance events can create opportunities for innovation and reorganization of human behavior. In a nonresilient system, even a small shock may threaten the persistence of the system (Folke 2003). A critical question for the AYK SSI is how resilient the AYK salmon system is.

The concept of resilience for the AYK salmon system is illustrated in Figure 4-3. In this figure, hypothetical salmon metapopulations[1] are shown over a long period, dating back to times when commercial and sport fishing for salmon did not occur in the AYK region, and when commercial fish catch in the Bering Sea and the Gulf of Alaska (for example, sockeye salmon, pollock) did not occur and thus did not affect AYK salmon populations via bycatch or intercept fishing. As commercial and sportfishing became more prevalent in the region, greater pressure was placed on salmon metapopulations in the AYK. The hypothesis shown in Figure 4-3 is that human fishing pressure is eroding the resilience of the AYK salmon system, drawing it close to population levels where continued survival is at serious risk (dashed line) for some metapopulations. (An alternative hypothesis is that global warming is creating irreversible damage to the salmon ecosystem that may be independent of the level of fishing pressure and direct human activity in the region. Yet another hypothesis is that current low populations of AYK salmon reflect only a temporary fluctuation rather than a long-term trend.)

Three different scenarios are shown in Figure 4-3. The fluctuating lines represent variability in salmon metapopulations under different degrees of human fishing pressure. The smooth lines represent the 5-year moving average (trend) in each fluctuating line. Variability in the metapopulations reflects climate change, disease outbreaks, change in ocean predation, and ecological change in freshwater systems.[2]

Figure 4-3 (a) represents subsistence fishing with no commercial or sports catch. The subsistence philosophy in many AYK communities

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[1]The concept of metapopulations is applied to the arrangement of local populations of salmon of a certain species in river systems (Kuskokwim chum or Yukon Chinook) (NRC 1996). A metapopulation is composed of several locally adapted populations that have different spawning grounds in different tributaries of the river system. Genetic diversity is maintained by the straying of fish among different tributaries. A metapopulation thus may contain significant genetic diversity, which is important to its long-run survival.

[2]In the figure, the pattern of population variability has been determined by using a random number generator for illustrative purposes.

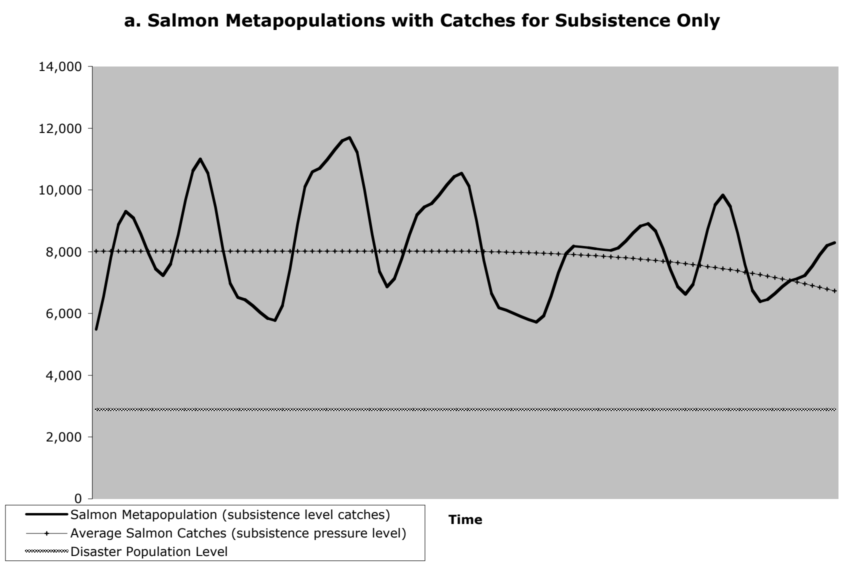

FIGURE 4-3a Hypothetical salmon populations under subsistence conditions only.

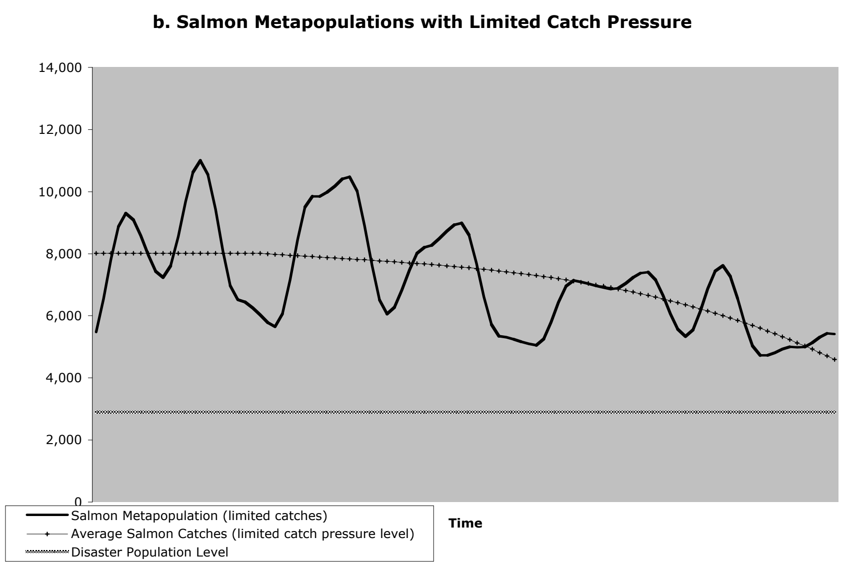

FIGURE 4-3b Hypothetical salmon populations with limited catches.

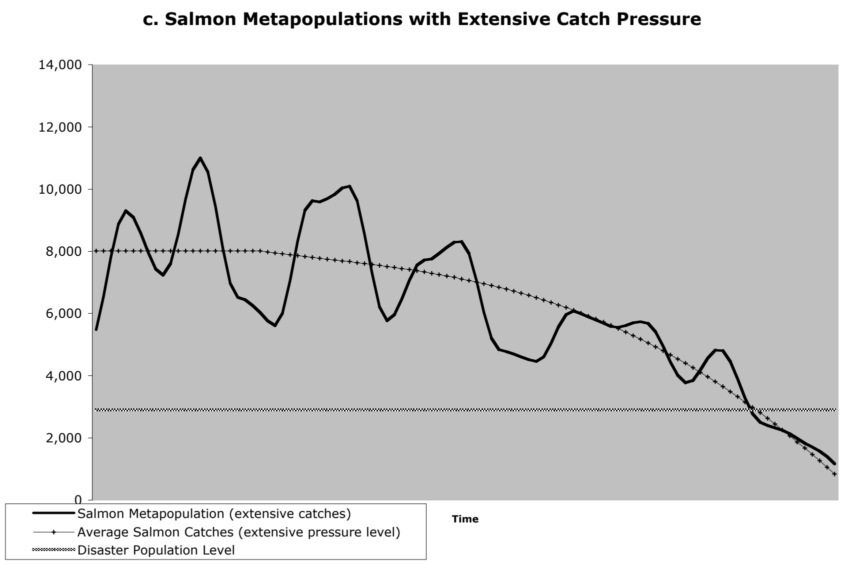

FIGURE 4-3c Hypothetical salmon populations with extensive catches.

has been to catch a lot of fish when the runs are good and to catch fewer fish when the runs are poor. Over time, the trend is slightly downward, reflecting human population growth and greater subsistence needs of the AYK communities. This degree of fishing represents the most resilient of the three scenarios shown. Figure 4-3 (b) shows limited commercial and sports catch, and Figure 4-3 (c) shows extensive or unlimited commercial and sports catch. The latter, in particular, may have little adaptive response to metapopulation levels—particularly if it is not being managed to protect long-term ecosystem and subsistence needs—and thus may be nonresilient.

This framework essentially organizes the recommended research themes into anthropogenic and biophysical categories. The anthropogenic research questions help to clarify which of the three scenarios or trends is likely occurring in terms of fishing pressure. All questions related to subsistence catch (for example, human population needs, gear type, fishing pressure, and habitat effects of motorized equipment on spawning beds), commercial catch in the AYK region (for example, gear type, management, down- and up-river issues, impact of motorized equipment), and sports catch in the AYK region (for example, the mortality, morbidity, fecundity of fish caught and released; number of operations; effects on spawning habitat) are included in this analysis. Restoration-related research questions also fall into this category.

Anthropogenic research includes studies on the impact of bycatch and intercept fishing activities in the Gulf of Alaska and the Bering Sea on AYK salmon metapopulations. Biophysical research questions help describe the variability in the system for all scenarios over time. These questions encompass research on climate change and ecological change in factors such as predation, disease, and habitat within rivers.

This model does not distinguish specific freshwater and ocean segments of the salmon lifecycle. However, it is of great importance to try to partition environmental and human effects on salmon into freshwater and marine influences so that management and restoration plans can be better informed. The model is anthropocentric, as is framework 2, focus sing mainly on humans' role in the resilience of the system. It specifically addresses the impacts and interests of various stakeholders (subsistence, commercial, and sportfishing groups). The ultimate goal in terms of improving resilience in the system is to widen the buffer zone between the at-risk population level and trends in salmon metapopulations.
Research on resilience represents one of the frontiers for addressing interdisciplinary social/ecological/physical questions. As Folke (2003) summarizes, "It requires a shift in thinking from focusing on controlling change in an engineering fashion for optimal solutions to accepting that change is the rule rather than the exception (Holling and Meffe 1996, Van der Leeuw and ARCHAEOMEDES Research Team 2000). The old way of thinking implicitly assumes a stable and infinitely resilient environment. The new perspective recognizes that resilience can and has been eroded and that the challenge facing humanity is to try to sustain desirable pathways for development in the face of change (Carpenter et al. 2001, Folke et al. 2002)."

Some of the questions this framework generates overlap with those of framework 2, but other important ones do not.

Questions about Anthropogenic Effects

- How many AYK salmon are caught as bycatch in offshore fishing? What is the distribution of that fishing effort and the distribution of those catches?
- How many salmon that do or could compete with AYK salmon are produced by hatcheries elsewhere in Alaska, in North America, and in Asia?

- How have commercial landings inside the AYK region varied over time? What is their relationship to run sizes?
- How have subsistence catches varied over space and time? How do subsistence fishers respond to changes in run sizes and the species composition of runs in terms of total fishing effort and the spatial and temporal distribution of fishing effort?
- How many fish do recreational anglers catch in the AYK region? Are there measurable effects on fish populations of catch-and-release fishing? As described in the previous chapter, better information is needed on recreational catches.
- In general, how do the kinds and distribution of fishing effort inside the AYK region and offshore vary in space and time as a function of changes in market prices of wild-caught Alaska salmon?

Questions About Biophysical Effects: Climate, Habitat, and Biology

- How do climate changes affect AYK salmon, and how should those changes be incorporated into management?
- How should traditional knowledge and weather records be compiled to (reconstruct a long-term weather (climate) record, including floods, ice cover, droughts, and so on? Could these variables be helpful in predicting salmon population sizes if they are correlated?
- How do variations in large-scale atmospheric patterns such as Pacific decadal oscillation (PDO), El Niño-southern oscillation (ENSO), and sea ice manifest themselves locally?
- Where and when do smolts enter the marine environment; what factors dictate when smolts arrive; what is the form of their outmigration (en masse or more extended through time); how sensitive is the outmigration to changes in the environment (temperature, salinity, ice)?
- How does their initial distribution change with time; what role do currents play; where in the water column are the smolts and how does this vary through light/dark periods and as they mature; does turbulence generated by storms affect predator/prey relations?
- How are the variations in the large atmospheric patterns such as the Arctic oscillation (AO) and the Pacific Decadal Oscillation (PDO) manifest (wind speed, air temperature, moisture fluxes) in the time/space domains relevant to salmon survival, mainly of smolts and juveniles (summer/fall in the coastal waters from Kuskokwim Bay to Norton Sound), to a lesser degree to spawning/riverine life history stages (Kus-

kokwim/Yukon River basins over appropriate time span), and perhaps to adults (Bering Sea/North Pacific all seasons)?

- The food web developed by Aydin et al. (2002) was a static one. Given what we know about the role of environmental factors in populations, what could we learn about the variability of AYK salmon by incorporating food web change in response to environmental change (from year to year to decadal to long-term global climate change)?
- Were declines in AYK salmon runs in the late 1990s due to climate-induced changes in distribution, abundance, forage base, or feeding behavior of any major marine predators of juvenile salmon in the Bering Sea (for example, beluga whales feeding on juvenile salmon in coccolithophore blooms)?

SUMMARY OF RESEARCH QUESTIONS

The questions we have derived from the three frameworks are extensive, and some are quite detailed. In this respect, they are quite similar to the research questions this committee found to be important to the region's stakeholders, and some of them are the same questions. In developing a research and restoration plan, the AYK SSI will need to find a way to prioritize and organize the questions. The committee has the following advice.

Two pervasive themes in all the questions concern the kinds, numbers, and distribution of salmon and what people do and why they do those things. The first can be rephrased by saying that we need to have a much better accounting system for AYK salmon: we need to know how many there are, we need to know where they spend their time during all phases of their life history, and we need to understand how populations of salmon within each of the species are differentiated. There is a need for better assessments of the numbers of salmon of the five species in the various drainages. Information is needed on their numbers at all life history stages and in all the environments they inhabit. Better and more detailed information is needed on the genetic makeup of the salmon populations in the region and their distribution in time and space. Very basic information is missing on the genetic structure of populations of salmon in the AYK region. Without analysis of stock structure for most species, an analysis of fishing effects on separate stocks in a mixed stock fishery is impossible. To understand the effects of fishing on the genetics of a species, the first step is to distinguish the interbreeding units that constitute the local populations. The next step is to estimate the abundance, vital rates, and migration rates to distinguish source and sink groups and to establish the productivity of each of the local populations. Not only is this theme pervasive, but the knowledge it embodies also is a prerequisite for answering many of the more detailed questions described above.

The second theme can be rephrased by saying that we need to understand much better what people in the region are doing with respect to salmon and why they are doing those things. To some degree, that applies also to people outside the region. We need to know how many people are fishing, when they fish, how many fish they take, and what factors affect those behaviors. Better information is needed on the numbers and kinds of fish taken by human activities in the region and in other areas where AYK salmon can be caught during their oceanic migrations. We need to understand what factors influence the development, promulgation, and enforcement of fishing regulations, including how federal and state laws concerning conservation of biological diversity and protection of subsistence rights are translated into management regulations. We also need to understand what factors influence people's compliance with those regulations. This theme, like the first, is not only pervasive; but it also is a prerequisite for answering many of the more detailed questions described above.

RESTORATION

This committee's charge included restoration as well as research. However, given the currently poor understanding of variability in the abundance of salmon and in fishery landings in the AYK region, it is premature to recommend a detailed and extensive restoration plan. This judgment does not extend to the potential benefits of management actions to reduce fishing mortality or competition with hatchery fish at sea if such actions are supported by available information. The following possibilities might be worth considering.

- The AYK SSI should consider controlled-design experiments to assess the effects of existing hatcheries, if any are re-opened; incubation boxes; and other enhancement techniques in the region on salmon populations in small streams.

- There is a lack of readily available information on earlier hatchery or incubator systems in the Kotzebue area (for example, on the Noatak River). That information should be made available so that lessons can be learned from it, or at least so the design of the project can be improved to facilitate learning if necessary. Are there lessons to be learned from hatcheries in eastern Kamchatka and elsewhere?

IMPLEMENTATION

To understand the causes of AYK salmon variability, several approaches could be used, including monitoring, process studies, retrospective analyses, and modeling. The resources required to address salmon variability here are significant because the problem has a variety of geographical scales, and it has interdisciplinary aspects. Salmon variability could depend on factors that can act at very small scales, such as stream temperature and flow. It also might depend on oceanic conditions affecting the ocean carrying capacity of the Bering Sea and North Pacific. Physical, biological, and chemical variations in the ocean, atmosphere, and terrestrial environment could play important roles. This is a large, complex problem, and the ecosystem will be continually changing. This daunting task is made easier through interactions with ongoing and future science programs in the region. The AYK SSI would benefit from coordinating with, perhaps to the extent of the joint funding of, research projects. In addition, prioritization of possible research projects is an essential part of any research plan. Trade-offs will have to be made, and we suggest the following:

1. A clear understanding of the goals of the research plan.
2. An assessment of the financial and intellectual resources available.
3. The development of a process to bring these resources to bear in a way that will make cost effective progress towards the goals of the plan.

Monitoring

Monitoring always ensures some success, because valuable observations are being collected that can serve to answer more than just the questions above. It also can provide background for process-oriented studies and eventually provide input to modeling efforts. The lack of monitoring information is detrimental to other types of research. The data gaps that exist in many time series and the entire lack of some time histories limit the value of retrospective studies. In such studies, tantalizing suggestions can be made, but time series of vital parameters often simply do not exist.

One of the greatest payoffs will come from monitoring efforts. A focus on physical and biological aspects of the ecosystem where AYK salmon spend their first several months at sea would be a critical element. Importantly, monitoring provides a vehicle for local people, including the subsistence stakeholders, to become directly involved in the AYK SSI program's challenge of restoring the abundances of AYK salmon.

An excellent example of the application of environmental time series to examine the potential causes for changes in salmon survival rates is provided by the results of Shotwell et al. (in press). They found that the "best" models for the Kuskokwim and Yukon Rivers explained 89% and 81% of the variability in survival rates, respectively. The best predictors for Kuskokwim chum salmon were springtime air temperature during the freshwater life stage, along-peninsula wind stress (nutrient transport and the ensuing nutrient-phytoplankton-zooplankton [n-p-z] sequence providing prey) during early marine residence, and Kuskokwim coho adult predation during early marine life stage. The best Yukon predictors were springtime precipitation in freshwater areas, strong winds (turbulence providing mixing to drive n-p-z sequence and hence prey) at station M2 in the Bering Sea, and the summertime AO index. All these predictors have their greatest effects in the first year of a salmon's life.

As an ancillary program of the monitoring effort, it will be useful to pursue retrospective studies of how climate patterns (for example, AO, PDO) manifested on time/space scales relevant to AYK salmon in their first few months in the marine environment are important to establish a baseline spanning all possible observations. Because there is a 40-year long time series of daily data from the National Center for Environmental Protection (NCEP), National Center for Atmospheric Research (NCAR), reanalysis, a 30+-year accurate history of sea ice concentrations, and a 9-year record of oceanic conditions at mooring M2 on the southeastern Bering Sea shelf (Stabeno et al. 2001), retrospective studies could provide a solid foundation for examining interannual variability and perhaps the impact of ENSO events. The potential value of retrospective studies of atmospheric parameters and sea ice behavior is evident in the development of the oscillating control hypothesis (OCH) for energy flow over the shelf of the southeastern Bering Sea (Hunt et al. 2002). A more recent presentation (McNutt et al. 2004) examined sea ice observations for 1972-2003 and found that there have been five distinct patterns of ice retreat in May. What would the patterns in June look like? The potential relation of these patterns to biophysical conditions that alter the survival of smolts first entering the marine ecosystem would be a valuable product to examine pathways the abiotic environment affects, especially biota and salmon survival. The atmospheric and sea ice time series are too short, however, to reliably examine any of the longer-period atmospheric and oceanic climate signals such as the regime shifts.

Process Studies

Process-oriented studies also are needed to learn what mechanisms are crucial to smolt and juvenile survival. In accord with the results presented by Logerwell et al. (2003), S. K. Shotwell (University of Alaska Fairbanks, workshop presentation, November 19, 2003), and suggested by others (Helle et al. 2003), specific mechanisms contribute to the variability of survival of salmon smolts/juveniles. Process-oriented field studies are needed to establish what these mechanisms are; how they function; and whether there are direct links between oceanography, marine habitat, food availability, and survival and/or whether predator dynamics interact with the ocean processes (Logerwell et al. 2003). As we noted earlier, both of these pathways (top-down and bottom-up) can coexist and have been suggested as operative in the southeastern Bering Sea (Hunt et al. 2002). Any experiment designed to examine mechanisms must include the possibility of either pathway's existence.

Model Development

A measure of the success of the SSI's science and restoration program is that results from research will lead to the ability to predict changes to the ecosystem, including changes in abundance of returning adult salmon. These predictions are essential for fisheries management and for protecting Alaska's ecosystems, including its people. This goal requires developing ecosystem models (Walsh and McRoy 1986) that capture the essential abiotic and biotic phenomenon within the salmon's essential habitat, that account for the crucial mechanisms that dictate energy flow through the ecosystem, and that have an adequate monitoring system to supply information for future forecasts.

Adaptive Management

By adaptive management, the committee means the design of management actions as experiments. This means that in planning management actions, the need for obtaining data from them as well as from controls should be taken into account. In some cases, there might be a perception of risk. For example, if a population is severely depleted, then having a control for a management action that restricts fishing might be seen as reckless. Absent such extreme considerations, however, most management actions can be designed with experimental controls to collect new information. In the AYK region, this will imply coordination and cooperation of researchers with management agencies, such as ADF&G.

Coordination and Partnership with Other Programs

Among the ongoing and/or planned programs are the following: the North Pacific Research Board (NPRB), the Gulf of Alaska Ecosystem Monitoring (GEM) program, Alaska Ocean Observing System (AOOS), Ecosystem Fisheries Oceanography Coordinated Investigations (EFOCI), the Bering Sea Ecosystem Study (BEST), the Bering-Aleutian Salmon International Survey (BASIS), the Norton Sound Sustainable Salmon Initiative (NS SSI), the U.S./Canada Yukon River Joint Technical Committee program (JTC), the World Wildlife Fund/National Science Foundation program (WWF), the Fisheries Resource Monitoring Program (FRMP), and the National Oceanic and Atmospheric Administration's (NOAA's) Arctic Program. We envision coordination will occur through at least three pathways: researcher interaction or bottom-up, executive director to executive director or top-down, and cross-fertilization among scientific and technical committees or panels. For the first pathway, we suggest that the AYK SSI have an annual meeting for principal investigators to present research results in conjunction with the NPRB and

GEM symposium held each January. The top-down approach would have directors of the aforementioned programs attend an annual meeting to ensure integration among the various projects. This would occur before the annual requests for proposals so that decisions made at the meeting could be integrated into their respective requests for proposal processes, including considering joint funding where appropriate. The final element of the coordination strategy suggests that there be some individuals who sit on more than one scientific and technical committee or science panel, and ensuring that at least a few members of these bodies have knowledge of other relevant programs. Brief descriptions of the potential science programs that might be coordinated with the AYK SSI restoration and research efforts follow. As mentioned previously, the AYK SSI is composed of several Alaska Native organizations as well as others, including ADF&G, the National Marine Fisheries Service (NMFS), and the Fish and Wildlife Service, and that structure should automatically enhance coordination with other programs. The partnerships that led to the formation of the AYK SSI are a good example of the effectiveness of the approach.

NPRB

An overarching research program is the NPRB (NPRB 2004, NRC 2004b), which has been funded to carry out marine science studies in the North Pacific, Bering Sea, and Arctic Ocean. The work is supported by a federal endowment and should continue indefinitely. A goal is to understand the marine ecosystem and to improve "the ability to manage and protect the healthy, sustainable fish and wildlife populations…and provide long term sustained benefits to local communities." To carry out its mission, the NPRB has adopted the following supporting goals: improve understanding of North Pacific marine ecosystem dynamics and use of the resources; improve the ability to manage and protect the healthy, sustainable fish and wildlife populations that comprise the ecologically diverse marine ecosystems of the North Pacific and provide long-term, sustained benefits to local communities and the nation; improve the ability to forecast and respond to the effects of changes, through integration of various research activities, including long-term monitoring; foster cooperation with other entities conducting research and management in the North Pacific and work toward common goals for North Pacific marine ecosystems; and support high-quality projects that promise long-term results as well as those with more immediate applicability.

The AYK SSI would greatly benefit from establishing a working relationship with the NPRB, which is currently funding ~$1.8 M (projects in 2002 and 2003) of research on salmon in the Bering Sea and has selected the Bering Sea region to focus ecosystem research over the next 5-7 years.

An example of an ongoing, relevant NPRB study is that of Hillgruber and Zimmerman (NPRB Project: R0327), who are examining the early marine ecology of chum salmon (*Oncorhynchus keta*) in Kuskokwim Bay. The following identifies objectives of this process-oriented study as presented in the semiannual report (Hillgruber et al. 2003). The overall goal is to assess the effects of physical, biological, and environmental factors on the distribution, feeding, condition, and growth of juvenile chum salmon during their estuary residence. Using a bioenergetics-based food web model based on directed sampling for prey, diet composition, growth, size structure, and energy content will help us to understand patterns observed in the feeding, growth, and condition of chum salmon juveniles. Specifically, our objectives include the following: (1) determining the spatial and seasonal distribution of chum salmon juveniles throughout Kuskokwim Bay, (2) assessing the spatial and seasonal patterns of environmental variables, and (3) describing the relationship between juvenile distribution patterns and these variables.

Another relevant example of NPRB-funded projects is one entitled Nearshore Circulation in the Bering Sea: Towards Community-Based Oceanographic Research, which was led by Larson King (Nunivak Island Native), and Tom Weingartner and Seth Danielson of the University of Alaska Fairbanks. The goal was to determine the feasibility of monitoring nearshore circulation and then conduct operations during outmigration of salmon smolts in Kuskokwim. This project was successful in collecting important observations of coastal currents (King et al. 2004).

GEM Program

Another planned long-term science effort in this region is the GEM program (EVOS 2004), which is an outgrowth of the science studies of the Exxon Valdez Oil Spill (EVOS) program (NRC 2002). GEM has developed a science plan to address ecosystem changes in the northern Gulf of Alaska in the region affected by the oil spill. Its efforts are focused on the northern Gulf of Alaska, which was affected by the 1989

EVOS, with particular emphasis on long-term monitoring. Time series for the northern Gulf of Alaska might provide evidence for long-term changes in the Bering Sea ecosystem that is generally downstream. Coordination with data management within this program is suggested also.

AOOS

An international initiative to make long-term observations of the ocean, Global Ocean Observing System, has prompted the development of a U.S. component that addresses coastal observations of which AOOS is part (AOOS 2004). AOOS has the goal of conducting long-term ocean observations and is currently in the planning stages. It will have data management and public outreach components that could be important to AYK SSI studies.

EFOCI

EFOCI will undertake long-term monitoring, process studies, and numerical modeling to assess, understand, and forecast the Bering Sea and Gulf of Alaska climate and ecosystems. Although we understand that climate variability occurs and is reflected in marine populations, we do not know what processes translate physical variability into biological change. Currently, there is no basis for acquiring this knowledge, as no long-term, area-wide ocean research program documents productivity or tracks changes in the Bering Sea and Gulf of Alaska ecosystems. NOAA scientists at the Pacific Marine Environmental Laboratory, Geophysical Fluid Dynamic Laboratory, and the Alaska Fisheries Science Center will accomplish most of the work.

BEST

BEST (ARCUS 2004) is likely to be relevant to the efforts to develop a science plan for the AYK region. That study will focus on the influences of biological production as it is transferred into the upper trophic levels. BEST is a component of SEARCH (Study of Environmental Arctic Change) and ESSAS (Ecosystem Studies of Sub-Arctic Seas, which is expected to become a regional program under GLOBEC) and will interact with ASOF (Arctic/Subarctic Ocean Fluxes) and PICES

(North Pacific Marine Science Organization). The program goal is to develop an ability to predict the effects of climate change on the ecosystems of the eastern Bering Sea and their ability to support sustainable commercial and subsistence harvests. The overarching question that was developed to focus research is, How do changes in forcing functions affect the shelf ecosystem, including production, community composition, and trophic linkages? Other specific questions developed for and presented in the BEST Science Plan that are directly related to the goal of the AYK SSI program are as follows: Can we develop a predictive modeling capability, and How do changes in the ecosystem affect the quality, quantity, and availability of Bering Sea resources for commercial and subsistence harvests?

The BEST Science Plan (2003) acknowledges that the resources of the eastern Bering Sea are critical for the survival and social and economic well-being of people, particularly those living in western Alaska, and that there is a need to know how changes in eastern Bering Sea ecosystems will affect the abundance of salmon runs. Changes in the species composition, abundance, quality, or distribution of these fish and shellfish have major economic and social impacts, particularly in the coastal communities of western Alaska. The plan states (statements in brackets have been added by us for clarity):

> The ability to foresee how climate change will affect the availability of resources to them could be of great benefit in planning the responses to change. Whether it is the future availability of salmon to villagers on the Yukon/Kuskokwim Rivers [rivers flowing into Norton Sound], or the abundance of pollock available for commercial harvest [which affects local people through the community development quotas], knowledge of potential change in resource availability can improve planning decisions. An important goal of the BEST Program must be to contribute to our ability to manage and sustain the marine resources of the eastern Bering Sea, and to provide managers and planners with the knowledge of ecosystem response to climate change.

BASIS

The North Pacific Anadromous Fish Commission (NPAFC) has developed a plan to establish a program for long-term, large-scale ecosystem research on salmon in the Bering Sea called BASIS. Member countries are the United States, Canada, Japan, and Russia. The plan calls for seasonal (spring, summer, fall, winter) synoptic cruises of 1 month duration per year for 5 years. Their plans are outlined in the NPAFC Science Plan 2001-2005.

The focus of BASIS is on carrying capacity and ecology of resources. Scientific issues that provide necessary direction to the research include (but are not limited to) the following:

- Seasonal-specific migration patterns of salmon and their relation to the Bering Sea ecosystem.
- Key biological, climatic, and oceanic factors affecting long-term changes in Bering Sea food production and salmon growth rates.
- Similarities in production trends between salmon populations in the Bering Sea and common factors associated with their trends in survival.
- Overall limit or carrying capacity of the Bering Sea ecosystem to produce salmon.

NPAFC member countries—Canada, Japan, the Republic of Korea, Russia, and the United States—carry out the research. BASIS is in its third year of operation with a focus on field sampling covering the entire Bering Sea (Figure 4-4). The BASIS research area is complementary to that of AYK SSI, and it will be useful for the AYK SSI to partner with BASIS.

An example of an ongoing BASIS research program is the Ocean Carrying Capacity (OCC) Program, Auke Bay Laboratory, Alaska Fisheries Science Center/NMFS, that has been conducting surveys of juvenile salmon on the eastern Bering Sea shelf since 1999. Initially, the focus of the Bering Sea work was to monitor the effects of climate on growth, migration, and distribution of juvenile Bristol Bay sockeye salmon. In 2002, the work was expanded to include investigations of AYK juvenile salmon in coastal waters of the eastern Bering Sea and the Arctic Ocean through Kotzebue Sound as well as to offshore stations within the NPAFC/BASIS study area. Research activities specific to food and nutrition of AYK salmon include the following: (1) studies on diet overlap and prey selectivity among salmon and other fishes; (2) describing the trophic dynamics of juvenile salmon and their predators in coastal waters; (3) developing bioenergetic models of juvenile salmon growth; (4) identifying key biological, climatic, and oceanic factors affecting long-term changes in Bering Sea food production and salmon growth rates;

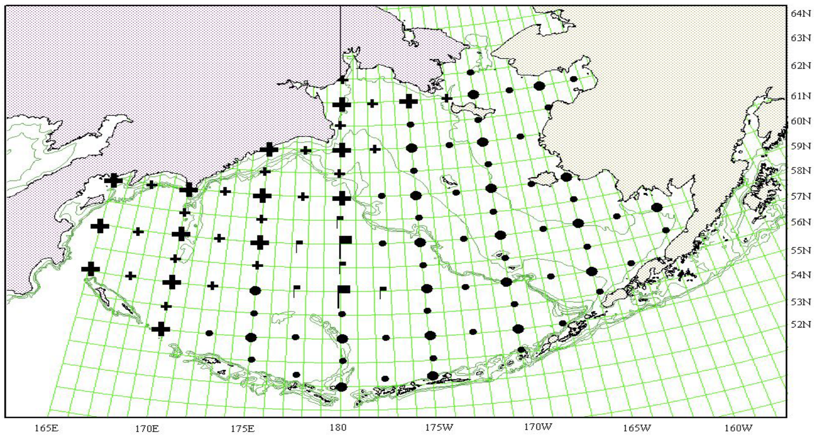

FIGURE 4-4 Map showing sampling stations in the Bering Sea. Dots show stations in U.S. waters, flags show stations in international waters, and pluses show stations in Russian waters. Source: NPAFC 2001.

and (5) evaluating the limit or carrying capacity of the Bering Sea to produce salmon and the effect of hatchery salmon on Bering Sea food supplies (principal investigators: Jack Helle, Ed Farley, and Jim Murphy, Auke Bay Laboratory, NMFS, Juneau, Alaska) (ABL 2004).

NS SSI

In response to sharp declines in Norton Sound salmon harvests, a Research and Restoration Plan for Norton Sound Sustainable Salmon Initiative (NS SSI) was drafted in 2002 to protect the wild salmon resources and habitats of Norton Sound, to support effective management of salmon in the region, to garner public support and involvement for sustained use and protection of salmon resources, and to study the potential use of artificial means to preserve salmon stocks. The overarching questions are, What controls the abundance of salmon in Norton Sound, and what can we (they) do about it? This plan could serve as a sub regional plan for the AYK SSI.

An example of a relevant, ongoing research program is Ecology of Juvenile Chum Salmon from Norton Sound: The Role of Estuarine Transition Zones and Implications for the Early Marine Life Stage, which involves field sampling (2003-2006) to compare stomach contents (relative fullness and prey) of chum salmon fry entering and leaving estuaries and in the nearshore marine waters of Norton Sound (principal investigators: S. Kinneen, Norton Sound Economic Development Corporation; M. Nemeth and B. Haley, LGL Alaska Research Associates, Inc., Anchorage; W. Griffiths, LGL Limited, Sidney, British Columbia) (NSEDC 2003) (funded by the federal Fishery Disaster Relief Program for Norton Sound). Additionally, since 1991, the High Seas Salmon Research Program, University of Washington, has conducted studies on the food habits, bioenergetics, and feeding ecology of immature and maturing salmon in the central North Pacific Ocean, Bering Sea, and Gulf of Alaska. Ongoing analyses of salmon food habit data time series with respect to AYK salmon are funded in part by the Yukon River Drainage Fisheries Association (co-investigators: K. Myers, N. Davis, R. Walker, and J. Armstrong, School of Aquatic and Fishery Sciences (SAFS), University of Washington, Seattle; funded by NOAA) (SAFS 2004).

JTC Plan

There is a U.S.-Canadian JTC Plan to "help management meet and protect escapements and maximize harvest." This work focuses on salmon projects on both the Canadian and the Alaskan portions of the Yukon River.

The six-page U.S. and Canada Yukon River JTC Plan was completed in late 2003 after a process lasting more than a year. It includes some background, a mission statement, and four goals with underlying objectives and research issues. The background suggests that optimal or maximal fishing yields are achievable. The mission statement emphasizes the roles of habitat and population dynamics for sustainable fishing and explicitly acknowledges the intersection of local, traditional, and scientific knowledge. The plan's four goals are to (1) assess and achieve fishery management objectives; (2) assess, conserve, and restore salmon habitats; (3) build and maintain public support of, and meaningful participation in, salmon resource management; and (4) improve understanding of salmon biology and ecology. According to the document we reviewed, specific research projects have been suggested or are now being carried out to address issues identified by the plan (but no research project can appear in more than three places!), but we did not see this distribution of projects.

The JTC plan does an unusually good job of encouraging public science; after all, it is one of the four goals. It suffers from the lack of a conceptual framework about how the system works, which makes it difficult to prioritize research to address the biggest uncertainties or to assess the magnitude of what are believed to be strong linkages. Apparently, research priorities are developed by gathering large groups of people together in workshops and essentially voting. It would be interesting to know if different priorities emerged if participants first had to discuss and agree on a conceptual framework.

WWF

WWF has developed the program Coastal Communities for Science: A Bering Sea Partnership. This offers the AYK SSI an opportunity to learn from and/or coordinate efforts with an ongoing program to develop specific elements for education, outreach, and community involvement activities. The WWF Program goals are to increase access of Alaska Native communities to Bering Sea research by creating opportunities for their participation in research, to increase the number of youth interested in and excited about science, and to inspire confidence within the future leaders of the Alaska Native Bering Sea coastal communities to consider science as a possible career direction and to feel comfortable communicating to scientists, posing questions, and even participating in the process of answering questions that are important to coastal communities. The target audience of the WWF program is Alaska Native coastal communities (Mekoryuk, Hooper Bay/Paimiut, Unalakleet, and the Pribilof Island communities of St. George and St. Paul), with a particular emphasis on community leaders, educators, and youth.

In consultation with community educators and participating scientists, WWF will coordinate community-scientific teams' efforts to conduct biotic surveys around participating communities. The focuses of these studies are fish, flora, and biodiversity/habitat surveys, topics that allow for practicable and affordable projects to be undertaken with youth participation. These topics also offer opportunities for skill building in other academic areas, particularly mathematics but also in art (through the design of exhibits) and language (communication of results through web sites, written reports, displays, and oral presentations at community meetings and conferences).

FRMP

The Fisheries Resource Monitoring Program (FRMP) was begun in 2000, after federal jurisdiction over subsistence fishing in Alaska was expanded to include about 60 percent of Alaska's freshwaters. The FRMP mission is to identify and provide information needed to sustain subsistence fisheries on federal lands for rural Alaskans through a multidisciplinary, collaborative program. A competitive process combining scientific and local review is used to select a package of projects each year which must be approved by a Federal Subsistence Board representing five agencies. Recent enhancements to the FRMP include the Partners for Fisheries Monitoring Program (Partners) and a Regional Strategic Planning Initiative (Strategic Planning). Partners develops capability and expertise in rural organizations by funding full-time, year-round fishery biologists and anthropologists, as well as summer student interns. These positions assist in planning and conducting FRMP projects; performing community outreach, education, and training; and coordinating subsistence fisheries monitoring activities. Strategic Planning ensures funded projects address the most important FRMP information needs. This is being accomplished through facilitated workshops attended by regional managers, scientists, Regional Advisory Council members, and stakeholders who develop goals, objectives, and information needs for Federal subsistence fisheries, identify knowledge gaps, and prioritize information needs.

Since its inception, the FRMP has funded nearly 170 projects, at a cost of $30 million, which provide more than 50% of total fisheries monitoring efforts in some regions. These projects provide information on fish populations, including species previously overlooked due to limited commercial and recreational importance; improve subsistence harvest documentation by implementing projects recommended by a statewide evaluation of existing efforts; and gather traditional knowledge from rural residents for use in management. Three databases have been developed to make information accessible to agencies and the public. Stakeholders have been integrated into subsistence fishery management through consultations, collaborations, and capacity building. By providing sound scientific data, building capacity in rural organizations, forging partnerships, and promoting local involvement, the FRMP has assisted federal and state agencies to manage fisheries resources and provide for subsistence uses.

NOAA's Arctic Program

NOAA's Arctic Program is currently funding research in the Bering Sea. The focus is on climate change and its various impacts throughout the Arctic. The Arctic Theme Page (NOAA 2004) provides access to widely distributed Arctic data and information. One project that is funded by NOAA's Arctic Program provides a natural candidate for co-operative research with AYK SSI. The Ecosystem Change in the Northern Bering Sea project investigates the hypothesis that recent anomalous spring and summer productivity on the northern Bering Sea shelf relates to decadal-scale atmospheric/sea-ice/oceanic processes, which reflect regime-induced climate changes in the western Arctic. Recent work (Grebmeier and Dunton 2000, Cooper et al. 2002) shows that there are hot spots of biological productivity southwest of Saint Lawrence Island and that this productivity has been decreasing over the past decade.

These results underscore the timeliness of increased focus on the ecosystem of the northern Bering Sea. A program has been defined to conduct process studies of the northern biological hot spots; establish a northwestern Bering Sea biophysical oceanographic mooring to document ongoing changes similar to the multiyear FOCI mooring, M2, on the southeastern Bering Sea shelf; and undertake a retrospective analysis of all northern Bering Sea data to put future changes into context and to provide an objective measure for change detection.

Long time series will play a critical role in assessing the ecosystem changes in the Bering Sea and the North Pacific. While the AYK SSI eventually should be contributing to these data sets with their own observations, they can take advantage of the GEM-sponsored GAK1 hydrographic time series near Seward in the Gulf of Alaska and the M2 biophysical mooring on the southeastern Bering Sea continental shelf that is sponsored by NPRB. Additional long time series atmospheric data are available from the National Weather Service's National Climate Center (NCC), while some stream flows are available from the U.S. Geological Survey archives.

In addition to the previously listed programs, the Arctic Monitoring and Assessment Program (AMAP) includes long-term monitoring for the Bering Sea and the Arctic Ocean, and the Arctic Research Initiative (ARI) supports work in the Bering Sea including field work. There is also a continuing program that is studying fluctuations in the populations of Steller sea lions in the Gulf of Alaska and Aleutian Islands, which could produce information relevant to assessing long-term changes in the marine ecosystem in those regions and the North Pacific. It also will be important to coordinate with NOAA studies of the Bering Sea eco systems and North Pacific (PMEL 2004a,b) and NOAA fisheries studies (AFSC 2004).

In summary, the AYK SSI will be a subset of these larger programs and should take advantage of these ongoing studies. In addition, PICES (2004) serves to coordinate and promote exchanges of information among the nations bordering the North Pacific.

Data Management

There is a great challenge to assemble, integrate, and make available the data that will be necessary and useful for scientific investigations of the AYK salmon. The data will range from estimates of human and salmon populations to deep ocean temperatures and salinities. Their geographic extent will range from freshwater environments to the entire Bering Sea and North Pacific. Fortunately, other data management groups such as the Data Management and Communications System of the Global Ocean Observing System (GOOS 2001) are dealing with similar data management issues. They have addressed the problems of data submission, quality control, long-term stability, data exchanges, data archiving, and access and delivery of real time data to resource managers.

Progress has been made at NOAA's Pacific Marine Environmental Laboratory (PMEL) on assembling the North Pacific Ecosystem Metadatabase (PMEL 2004b). This provides a catalogue of environmental data for the Bering Sea and the North Pacific and links to the custodians of those data sets. It will serve as an excellent source for national and international data for the AYK region.

5

Conclusions and Recommendations

CONCLUSIONS

The data show clearly that salmon returns in the AYK region in the 1990s and early 2000s were lower than previously. Those low returns have caused considerable social and economic hardship in the region. The committee concludes further that current scientific information is not sufficient to explain the reasons for the low returns with any confidence. It is at least possible that the low returns represent population fluctuations rather than a long-term declining trend.

Identifying the nature of the declines (or fluctuations) in salmon runs and their causes will take a great deal of research. Conducting that will require much time and money—much more money than the $13.5 million that has been appropriated and even than the total of $18.5 million whose appropriation is hoped for. However, at least some of that research will need to be completed before a fully developed restoration plan is undertaken, if indeed one proves to be needed. The committee judges that insufficient information is currently available to initiate a large-scale restoration program, although some small-scale local programs appear to be worth investigating.

An encouraging aspect of the research enterprise in the region is the degree to which it involves Alaska Native organizations and communities. Any increase in that involvement is likely to benefit the research and the communities themselves even more. In addition, the AYK SSI appears to recognize the need to coordinate and partner with other research programs in the region and elsewhere. Given the large spatial extent of the region (and hence the research problem) and the relatively modest amount of money available, such coordination is essential, as are partnerships.

The committee has not explicitly considered research into social and economic matters for their own sake. That is, the committee has considered social and economic research that is directly tied to the sustainability of salmon runs, but not if it is tied mainly to the sustainability of the communities in the region. The committee interpreted its charge as guiding it in that manner.

RECOMMENDATIONS

Research

This report has described a large number of research themes and questions. Those questions all have scientific interest and all have some potential to shed light on the relationship between human and environmental factors and fluctuations in runs of AYK salmon. However, if results that are useful to management are required in a reasonable amount of time, then prioritization is required. The committee suggests the following approaches to prioritizing research funding. We assume that the ultimate goal of the AYK SSI is management, that is, helping to ensure that salmon runs can be exploited sustainably, and our suggestions for research prioritization are made in that context. The committee judges that focusing the research effort on the topics below would be cost-effective and productive.

- The greatest research need appears to be better information on the numbers and distribution in space and time of the various species and stocks of AYK salmon. We need to know more about population sizes and productivity (how many fish there are) and more about the genetic makeup of species and populations. The latter information is a prerequisite for assessing the interaction of human and environmental factors with salmon populations, because different salmon populations have different growth rates, fecundity, productivity, and in general can respond differently to those factors. Better assessments are needed of the numbers of salmon of the five species originating in the various drainages at all life stages and in all the environments they inhabit. Without analyses of numbers and of genetic makeup, analyzing the effects of fishing, including fishing on mixed stocks, is not possible. This research theme is pervasive and the knowledge it embodies is a prerequisite for answering many of the more detailed questions we have described elsewhere.

- It would be of great value to be able to partition factors that affect AYK salmon runs into those that operate mainly in freshwater and the adjacent landscapes, and those that operate mainly in the marine environment. If such partitioning of factors can be achieved, it should be possible to learn whether the most important factors are marine or freshwater; or whether at certain times they are marine, and at other times freshwater; or whether both marine and freshwater factors are important most of the time. For freshwater, this requires a better understanding of habitat variations and their effects on AYK salmon than we now have.
- Better information is needed on the extent, nature, and distribution in time and space of human activities that affect salmon, and the degree to which they affect salmon. In the AYK region, those activities are mainly fishing. In particular, better information is needed on the amount and consequences of recreational fishing and the amount and effects of bycatch and directed fishing at sea. Better information on the spatial and temporal distribution and landings of subsistence and commercial fishing within and near the rivers of the AYK also would be helpful, as well as the dependence of that variation on the number and kinds of salmon available. We need to understand factors that influence the development, promulgation, and enforcement of fishing regulations and people's compliance with them. This research theme also is pervasive and a prerequisite for answering many more detailed questions.

Restoration

The committee does not recommend the initiation of a large-scale restoration plan until better information is produced by the research outlined above. However, small-scale local initiatives might hold promise. They include the following:

- Controlled-design experiments to assess the effects on salmon populations in small streams of existing hatcheries, if any are re-opened, and incubation boxes and other enhancement techniques.
- Retrospective analyses should be done on hatchery and incubator systems, both those currently in operation and those that have ceased operations. Such analyses should include North Pacific and Bering Sea hatcheries that seem likely to shed light on issues within the region.

Implementation

The implementation of this research program should use monitoring, process studies, retrospective analyses, and theoretical studies. Models are useful tools in many of these research activities. In addition, adaptive management has the potential to be effective and to contribute to knowledge that could help to form the basis of a restoration plan. In many if not all cases, this would require the cooperation and involvement of management agencies, especially ADF&G. Management actions should be designed to include the gathering of scientific data; in other words, they should be thought of as if they were controlled experiments. In truth, management actions often are experiments, but they usually have poor or no experimental controls.

The resources required to address salmon variability in the AYK region are significant because the problem has a variety of geographical scales, and it has interdisciplinary aspects. Salmon variability could depend on very small-scale influences such as stream temperature or flow. It also might depend on oceanic conditions that affect the ocean carrying capacity of the Bering Sea and the North Pacific Ocean. Physical, biological, and chemical variations in the ocean, atmosphere, and terrestrial environment could play important roles. This is a large, complex problem, and the ecosystem will be continually changing. This daunting task is made easier through interactions with ongoing and future science programs in the region. The AYK SSI would benefit from coordinating with them, perhaps to the extent of joint funding of research projects. Examples of such programs include the North Pacific Research Board, the *Exxon Valdez* Oil Spill Gulf Environmental Monitoring Program, the Alaska Ocean Observing System, Ecosystem Fisheries Oceanography Coordinated Investigations, the Bering Sea Ecosystem Study, the Bering-Aleutian Salmon International Survey, the Norton Sound Sustainable Salmon Initiative, the United States/Canada Yukon River Joint Technical Committee Program, the World Wildlife Fund/National Science Foundation Program, and the National Oceanic and Atmospheric Administration Arctic Program.

In addition, the committee recommends monitoring programs as being likely to provide useful information and having the potential to provide long-term data sets. Managing, coordinating, synthesizing, and making available the data collected by all these programs, including research funded by the AYK SSI, are important challenges that need careful consideration in any research plan.

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Appendix A

Chronology of State and Federal Subsistence Management

1978: ALASKA SUBSISTENCE LAW

The Alaska legislature passed the state's subsistence law in 1978. The law established subsistence as the highest priority use of the state's fish and game resources, directed the Boards of Fisheries and Game to develop regulations to allow for subsistence harvests whenever a biological surplus was available, and created the Division of Subsistence within the Alaska Department of Fish and Game. The 1978 law defined subsistence *uses* of fish and wildlife but not subsistence *users*.

1980: ALASKA NATIONAL INTERESTS LANDS CONSERVATION ACT

Congress passed the Alaska National Interest Lands Conservation Act (ANILCA) in 1980. Title VIII of ANILCA establishes subsistence uses of fish and wildlife and other renewable resources as the priority consumptive use of all resources on public lands. Subsistence uses are customary and traditional uses by rural Alaska residents of wild, renewable resources for personal or family consumption, for the making and selling of handicrafts, for barter or sharing for personal or family consumption, and for customary trade. Title VIII provides that the Secretaries of Interior and Agriculture shall not implement its provisions if the state enacts laws consistent with the priority. In 1980, state law was consistent with Title VIII, and the state managed subsistence uses on all lands in Alaska.

1982: JOINT BOARDS RURAL REGULATION

Alaska's subsistence statute originally did not include a preference for rural residents. Nonetheless, in 1982, the Joint Boards of Fisheries and Game adopted regulatory language establishing a subsistence priority for rural residents.

1985: MADISON DECISION

In 1985, the Alaska Supreme Court ruled in *Madison v. Alaska Department of Fish and Game*, 696 P.2d (Alaska 1985), that the Joint Boards' regulations were not consistent with the 1978 subsistence statute, because the statute did not provide a priority for rural residents. Therefore the regulations were invalid, and the state fell out of compliance with Title VIII.

1986: AMENDMENTS TO ALASKA'S SUBSISTENCE LAW

In 1986, the Alaska legislature substantially changed the state's 1978 subsistence law. It amended the definition of "subsistence uses" to require residency in a rural area and it defined "rural areas." The amended law required the state boards to identify which fish stocks and wildlife populations were customarily and traditionally taken by subsistence users and to adopt regulations providing subsistence users reasonable opportunity to harvest these resources. The Department of Interior again found the state to be in compliance with Title VIII of ANILCA.

1989: MCDOWELL DECISION

A group of nonrural residents filed a court challenge to the state's revised subsistence law. In 1989, the Alaska Supreme Court ruled in *McDowell v. State of Alaska*, 785 P.2d 1 (Alaska 1989), that the rural preference language of the state's subsistence statute violated the equal access clauses of the state constitution. Consequently, the state's subsistence program was no longer in compliance with Title VIII of ANILCA.

1990: FEDERAL MANAGEMENT BEGINS

Because state law no longer provided rural residents a priority for subsistence hunting and fishing on public lands, the secretaries of Interior and Agriculture assumed management authority over subsistence uses on public lands in Alaska on July 1, 1990. They created the Federal Subsistence Board (FSB), composed of one representative from each of the five federal land management agencies in Alaska (Bureau of Land Management, National Park Service, Bureau of Indian Affairs, U.S. Forest Service, and U.S. Fish and Wildlife Service). In addition, a member of the public serves as the FSB chair. Initially, the federal agencies interpreted "public lands" to include only lands and waters owned by the United States. Therefore, the agencies generally did not regulate subsistence uses in navigable waters.

1992: AMENDMENTS TO THE ALASKA SUBSISTENCE LAW

In 1992, the Alaska legislature further amended the state's subsistence law. These statutory changes did not bring the state's subsistence laws into compliance with Title VIII, however. The law continued to grant a subsistence priority over other consumptive uses but required the state boards to identify nonsubsistence areas where no subsistence priority exists. To comply with the 1992 law, the Boards of Fisheries and Game conducted a comprehensive review of existing subsistence regulations and developed new subsistence regulations, including those creating nonsubsistence areas.

1994: KATIE JOHN DECISION

After the secretaries assumed subsistence management authority on public lands, several rural residents filed suit against the state and the United States to include navigable waters in the federal subsistence program. In March 1994, the U.S. District Court in Anchorage ruled in *Katie John v. United States* that "public lands" to which Title VIII applies include all navigable waters in Alaska under the navigational servitude doctrine.

On appeal, the U.S. Court of Appeals for the Ninth Circuit ruled in April 1995 that the navigational servitude does not constitute "public lands" within the meaning of ANILCA. However, it found that "public lands" include navigable waters in which the United States has a reserved water right, and it ordered the federal agencies to identify the waters subject to that right. The U.S. Supreme Court denied the state's petition for certiorari review of the Ninth Circuit decision.

1994: BABBITT DECISION

In *Alaska v. Babbitt*, which was consolidated with the *Katie John* v. *United States* case, the state challenged the authority of the federal agencies to preempt state management of subsistence harvests on public lands. The U.S. District Court in Anchorage ruled that Congress granted the secretaries authority in ANILCA to preempt state management. In January 1995, the state withdrew its appeal of the *Alaska v. Babbitt* case.

1995: KENAITZE DECISION

In *State v. Kenaitze Indian Tribe*, 894 P.2d 632 (Alaska 1995), the Alaska Supreme Court upheld the nonsubsistence area provisions of the state's 1992 subsistence law. However, the court struck down the state's "tier II" criteria of proximity of domicile in light of *McDowell v. State of Alaska*. The court ruled that the practice of considering proximity of the applicant's domicile to a fish or game population in determining eligibility for tier II permits violated the equal access clauses of the state constitution.

1995: TOTEMOFF DECISION

In October 1995, the Alaska Supreme Court ruled in *Totemoff v. State*, 905 P.2d 954 (Alaska 1995), that the state may enforce its hunting and fishing laws against subsistence users on federal land so long as state laws do not conflict with federal laws or regulations. The state therefore could prosecute a subsistence user charged with spotlighting deer, because state law was not in conflict with ANILCA. The court also ruled that the state had jurisdiction to prosecute the subsistence hunter because he violated Alaska law in navigable waters and ANILCA does not give the federal government authority to regulate subsistence uses in navigable waters of Alaska. This decision directly conflicts with the Ninth Circuit's holding in *Katie John v. United States*.

1998: LEGISLATIVE COUNCIL LAWSUIT

In January 1998, the Alaska Legislative Council and 17 state legislators in their individual and official capacities filed suit challenging Title VIII and federal regulations for subsistence harvests on public lands. The District Court dismissed the case in July 1998. Although the Legislative Council's claims were different from the state's claims in the *Alaska v. Babbitt* case, the court barred claims that could have been brought in that case. The court also found that the 6-year statute of limitations bars a facial Equal Protection challenge to ANILCA's rural/nonrural distinction. Lastly, the court declined on ripeness grounds to review the proposed rule extending federal jurisdiction to navigable waters because the rule was not final when the case was initiated.

On July 13, 1999, the Court of Appeals for the D.C. Circuit affirmed on other grounds, ruling that the plaintiffs lacked standing to sue. The court held that the claimed injuries to the council and legislators in their official capacities are losses of political power, not personal losses, and are not sufficient to confer standing. Similarly, the Legislative Council suffers no injury distinct from the state's, and the Council is not authorized to bring suit on behalf of the state. The legislators in their individual capacities did not allege sufficient facts to show injury that would entitle them to challenge ANILCA on equal protection grounds or to challenge federal subsistence regulations under the Administrative Procedures Act.

1999: EXPANDING FEDERAL PROGRAM

In January 1999, the secretaries issued a final rule implementing the *Katie John v. United States* decision. The rule became effective on October 1, 1999. The final rule expands the federal subsistence program to include all waters within the exterior boundaries of 34 identified federal areas, including waters passing through inholdings within these areas as well as inland waters adjacent to the exterior boundaries of the 34 areas.

The rule also expands federal jurisdiction to lands selected but not conveyed to the state of Alaska and Alaska Native Corporations if the land is within the boundaries of the National Park System, National Wildlife Refuge System, National Wild & Scenic River Systems, National Forest Monument, National Recreation or Conservation Areas, or new national forest or forest addition.

Appendix B

Visits and Meetings of the NRC Committee

BETHEL: 27 SEPTEMBER 2003

Testimony was heard from representatives of the Kuskokwim Salmon Working Group, the Association of Village Council Presidents, Alaska Fish and Game, U.S. Fish and Wildlife Service, Kuskokwim Fisheries Resources Coalition, Federal Regional Advisory Council, Bering Sea Fisherman's Association, and the Lower Kuskokwim Advisory Council. The concept of "THE FOOD" was presented to the committee, meaning that salmon was far more than just one of the items eaten by the native community. Salmon is "THE FOOD." There was concern that the future was uncertain because human populations are growing and salmon populations might be shrinking. Therefore, the pressures on the subsistence salmon fishery are increasing. While in-season fishery management is needed we are "Fishing in scientific darkness." It is essential that we coordinate the research efforts for the AYK region to maximize the gains in knowledge. Concerns were expressed about the problems resulting from management decisions by Alaska Fish and Game. Boat traffic within spawning grounds was cited as a potential cause for decreased salmon populations. Mention was made of the changing ecosystem due to climate change—i.e., the warming of bottom waters on the shelf of the eastern Bering Sea—though there have been some episodic events of shorter duration such as cold spells and El Niño events superimposed on the long-term changes.

BETHEL: 28 SEPTEMBER 2003

A meeting with the Arctic-Yukon-Kuskokwim Scientific and Technical Committee and Steering Committee was conducted with participation by many village elders. Concern was expressed for the ability of the salmon populations to sustain themselves.

ST. MARY'S: 29 SEPTEMBER 2003

Testimony was presented by representatives of Algaaciq Tribal Government, the Federal Regional Advisory Council, Yukon Delta Fisheries Development Association, Lower Yukon River communities, Emmonak Tribal Council, Nerklikmut Native Corporation Andrefski, Alaska Fish and Game, and Yukon River Drainage Fisheries Association. The discussion of upstream versus downstream fisheries led to issues of intercepts by offshore fisheries and bycatch. Conflicts between subsistence fisheries were outlined, including changing the timing and duration of the windows for the intercept fishery either within the river system or in the open ocean. Concerns about the changing ecosystem were expressed, including the recent abundance of eels, beluga whales, and jellyfish in Bering Sea coastal waters. Increased populations of beavers were cited as a possible cause for the demise of the salmon populations. It was believed that Alaska Fish and Game was making a concerted effort to incorporate traditional ecological knowledge into their management decisions. Is the climate changing? The community hosted a potluck dinner.

ANIAK: 30 SEPTEMBER 2003

Representatives of the Kuskokwim Native Association, Alaska State Legislature, Middle and Upper Kuskokwim River communities, Central Kuskokwim State Advisory Committee, Alaska Fish and Game, and individual citizens gave testimony. They expressed concern about erosion of the way of life. There are conflicts between commercial fishing and mining communities and subsistence fishers. This is divided further by the differences between the upstream and downstream fishing communities. Problems with spawning grounds were mentioned including jet boats, beavers, and spot fishers. Open ocean conditions were considered a threat to the salmon fisheries such as the carrying capacity of the North Pacific, increases in the pollock populations in the Bering Sea, and the effectiveness of the False Pass fishery in diverting salmon resources. It was believed that the knowledge of the village elders was being ignored in the scientific and management programs. The community hosted a potluck dinner.

ANCHORAGE: 18-21 NOVEMBER 2003
AYK SALMON WORKSHOP

An assessment of the current state of knowledge of salmon ecology and life history in the AYK region was made with presentations. Information gaps were identified and the AYK symposium for 2005 was organized.

FAIRBANKS: 22-23 JANUARY 2004

Several committee members attended the Tanana Chiefs Conference Natural Resources Coalition to meet with natural resources professionals working in the Tanana region. Upriver-downriver issues were discussed, in particular, the effects of downriver commercial fishing on subsistence fishing upriver. The effects of ocean fishing on river fishing also were discussed.

NOME: 2 FEBRUARY 2004

Members gave testimony of the Nome Eskimo and King Island Native Communities. Representatives of Norton Sound Economic Development Corporation and Kawerak, Inc., and government agencies (Alaska Fish and Game and National Parks Service) made presentations. Comments were presented about the historical developments around Nome including mining, dog teams, and the introduction of modern fishing techniques. The use of hatcheries to increase fish returns was discussed. Potential causes for the decrease in salmon populations were suggested such as False Pass interceptions, beaver dams, and jellyfish predation. A holistic approach to the scientific studies of salmon was endorsed including early life histories, nutrient cycles, and climate; the collaboration of research programs was encouraged. It was emphasized that subsistence fishing was a way of life in this region. The community hosted a potluck dinner for committee and participants.

UNALAKLEET: 3 FEBRUARY 2004

Members of the Unalakleet and White Mountain IRA Councils, the Unalalkleet Native Corporation, Southern Norton Sound Advisory Committee, Bering Sea Fisherman's Association, Norton Sound Economic Development Corporation, Kawerak, Inc., and Alaska Department of Fish and Game gave testimony. The False Pass (Area M) intercept fishery was cited as a potential cause for the decrease in salmon returns for this region. Increases in beaver populations have changed the stream conditions. There seems to be more vegetation on the sea floor, more stream erosion, and less permafrost. Science is becoming more popular in the region and there is the development of a youth program for environmental monitoring. An ecosystem approach was endorsed for the salmon studies. Generally, biological escapement goals were viewed unfavorably. Concern was expressed about the conflict between economics and culture. A community potluck dinner was held.

ANCHORAGE: 4-6 FEBRUARY 2004

A committee drafting session of the interim report was held.