CHAPTER 1

Introduction

Karluk River sockeye salmon—a wonder of the natural world.

One of Alaska's most famous runs of sockeye salmon, *Oncorhynchus nerka,* returns each year to spawn in the pristine waters of the Karluk River drainage on Kodiak Island. The sheer magnitude and long duration of the run are remarkable. Within recorded history, this run has, in peak years, exceeded 4,000,000 fish, a wondrous spectacle of nature. This abundance is particularly striking since, physically, the Karluk River is relatively small when compared with other notable salmon-stream systems of Alaska and the Pacific Coast. Such vibrant profusion has riveted human attention for as long as people have occupied Kodiak Island, an interest most often centered on the high value of these salmon as human food, for both direct subsistence and commercial profit. This species also has been intensely scrutinized by scientists for well over a century, with the goal of understanding all features of its life history and biology that help to sustain healthy runs. Likewise, attention has been focused on these sockeye salmon for aesthetic and spiritual reasons, to appreciate the untold intricacies and innate diversity of life that so superbly thrives in the beautiful Karluk River ecosystem.

Kodiak Island, often labeled as Alaska's "Emerald Isle" for the bright verdant plant life that flows across its mountains each summer, is located in the Gulf of Alaska about 50 km southeast of the Alaska mainland and across Shelikof Strait (Fig. 1-1). Being the largest island of the Kodiak Archipelago, it is positioned near the active junction of the Pacific and North American tectonic plates, a geologic location with considerable consequences (earthquakes, tsunamis, and volcanic ash falls) for humans and other life. Formed and buffeted by massive tectonic and glacial forces, Kodiak Island has experienced several cycles of complete elimination and reinvasion of its flora and fauna over the past 1,500,000 years as immense glaciers advanced and retreated across the landscape (Karlstrom et al., 1969).

During the last cycle, glaciers that had covered most of the island withdrew some 10,000 years ago, and life once again spread across the terrain and into its lakes and rivers. On southwest Kodiak Island, eleven fish species invaded Karluk Lake and River, seven of these being salmon, steelhead, and Dolly Varden that spend part of their life cycle in freshwater and part in the ocean (Table 1-1). The Karluk ecosystem, with suitable spawning sites and a large nursery lake, was ideal for sockeye salmon to flourish and, as a result, several million adult fish returned to spawn each year. This apparent limitless bounty of sockeye salmon was a central reason for Karluk's widespread fame.

Humans first arrived on Kodiak Island over 7,000 years ago and have resided along the Karluk River for at least the past 5,000 years. Archaeological surveys document the many sites of human habitation that existed along the river and lake. Besides the permanent residents, additional people moved to Karluk each summer from nearby winter camps to access its rich salmon resources (Knecht and Jordan, 1985; Knecht, 1995). In particular, the indigenous Alutiiq people and their ancestors have maintained a village for millennia near the

Table 1-1
Fishes of Karluk Lake and River, Kodiak Island, Alaska.

Scientific name	Common name	Level of abundance	Life cycle
1. *Cottus aleuticus*	Coastrange sculpin	Common	R[1]
2. *Gasterosteus aculeatus*	Threespine stickleback	Abundant	R
3. *Pungitius pungitius*	Ninespine stickleback	Few	R
4. *Oncorhynchus gorbuscha*	Pink salmon	Abundant	A[2]
5. *Oncorhynchus keta*	Chum salmon	Few	A
6. *Oncorhynchus kisutch*	Coho salmon	Common	A
7. *Oncorhynchus mykiss*	Steelhead/Rainbow trout	Common	A/R
8. *Oncorhynchus nerka*	Sockeye salmon	Abundant	A
9. *Oncorhynchus tshawytscha*	Chinook salmon	Common	A
10. *Salvelinus alpinus*	Arctic charr	Common	R
11. *Salvelinus malma*	Dolly Varden	Abundant	A/R

[1]R = Resident in freshwater.
[2]A = Anadromous.

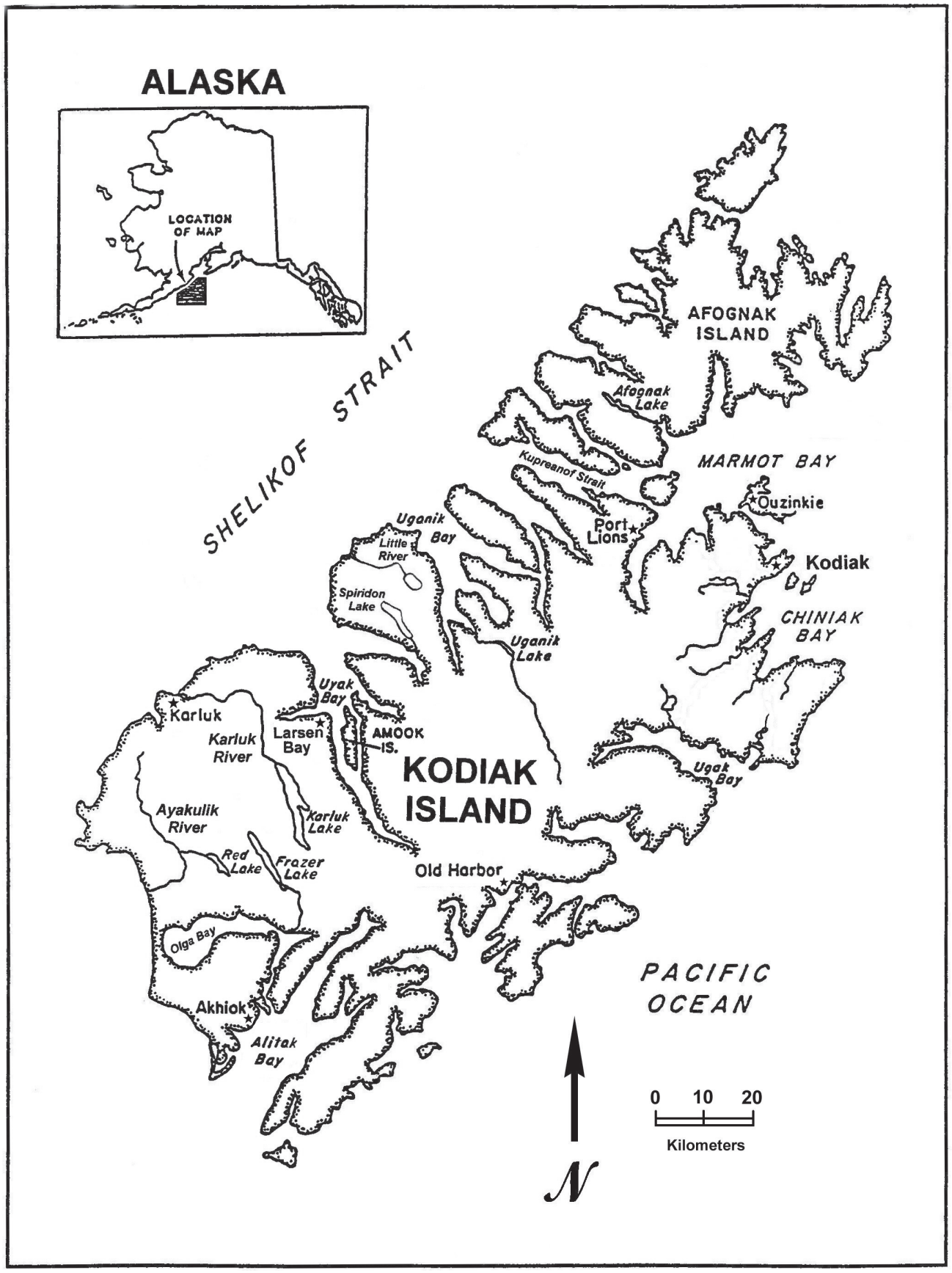


Figure 1-1. Map of Kodiak Island. (Modified from Barrett and Nelson, 1995.)

river's mouth, a strategic location for garnering food from the river, intertidal zone, and open ocean.

Although the early Karluk inhabitants heavily relied on the nearby marine resources in Shelikof Strait, they also settled beside the river and lake because abundant runs of sockeye salmon provided them with a dependable, nutrient-rich, food source. Fittingly, the name "Karluk" is derived from the Alutiiq word "iqalluk," a term used for fish. Fresh salmon could be caught in the river for at least half of the year, and by drying and storing these fish, sufficient provisions could be easily secured for later use in winter and early spring when adult salmon were absent. It appears that these early subsistence harvests of sockeye salmon were easily supplied by the profuse annual runs, even though early human populations in the Karluk vicinity may have approached 1,000 (Lisiansky, 1814). And yet, human reliance on Karluk's salmon undoubtedly varied over the millennia as long-term climatic changes affected the productive capacity of marine and freshwater food sources (Knecht, 1995; Finney et al., 2002).

During the period when Russia controlled Kodiak Island (1784–1867) and Alaska's fur trade in sea otters, *Enhydra lutris*, sockeye salmon from the Karluk River were regularly harvested, dried or salted, and distributed to sea otter hunters and support personnel at Karluk and other locations along Alaska's coast. The fur traders and officials of the Russian-American Company clearly recognized the value of these salmon resources and used Karluk as a vital provisioning base for their overall commercial ventures in Alaska for more than 80 years. Because these food supplies supported a much larger population than just the local residents of Karluk Village, sockeye salmon harvests may have been somewhat larger during the Russian era. Reportedly, several hundred thousand salmon were dried each year at Karluk in the early 1800s. These fish were easily procured by placing wood and rock barricades (known by the Russian term "zapors") in the river to block and concentrate the upstream migration (Pierce, 1978; Tikhmenev, 1978).

The first U.S. salmon cannery in southwestern Alaska was built on Karluk Spit at the mouth of the Karluk River in 1882, and it operated without competition for the next five years. The river's enormous runs of sockeye salmon, still strong despite the previous era of Russian harvests, easily supplied the entire cannery demand of 58,800 fish in 1882. But harvests continued to increase each year and reached 1,004,500 fish in 1887. The cannery's case pack production was shipped south 3,200 kilometers (2,000 miles) each year to San Francisco for sale and distribution.

Following the commercial success of this single cannery during 1882–87, five additional canneries were built on or near Karluk Spit in the next few years, and at least five other canneries that took salmon from the Karluk River were built at further locations around Kodiak and Afognak Island (see salmon canning labels in Photo Supplement that begins on page 19). Consequently, under intense competition between the canneries, annual harvests of Karluk River sockeye salmon quickly reached several million. In fact, their total case pack during the early years of the fishery made up a major proportion of that produced from all of Alaska. In 1893, most of Karluk's canneries were consolidated into the newly incorporated Alaska Packers Association (APA), with headquarters in San Francisco. The APA became the dominant cannery at Karluk for many decades.

Karluk Spit salmon canneries and Karluk River (right), 1897. (Frederic M. Chamberlain or Harry C. Fassett, from Moser, 1899)

Beach seining for sockeye salmon at Karluk Spit, June 1906. (John N. Cobb, University of Washington Libraries, Special Collections, Cobb 2390)

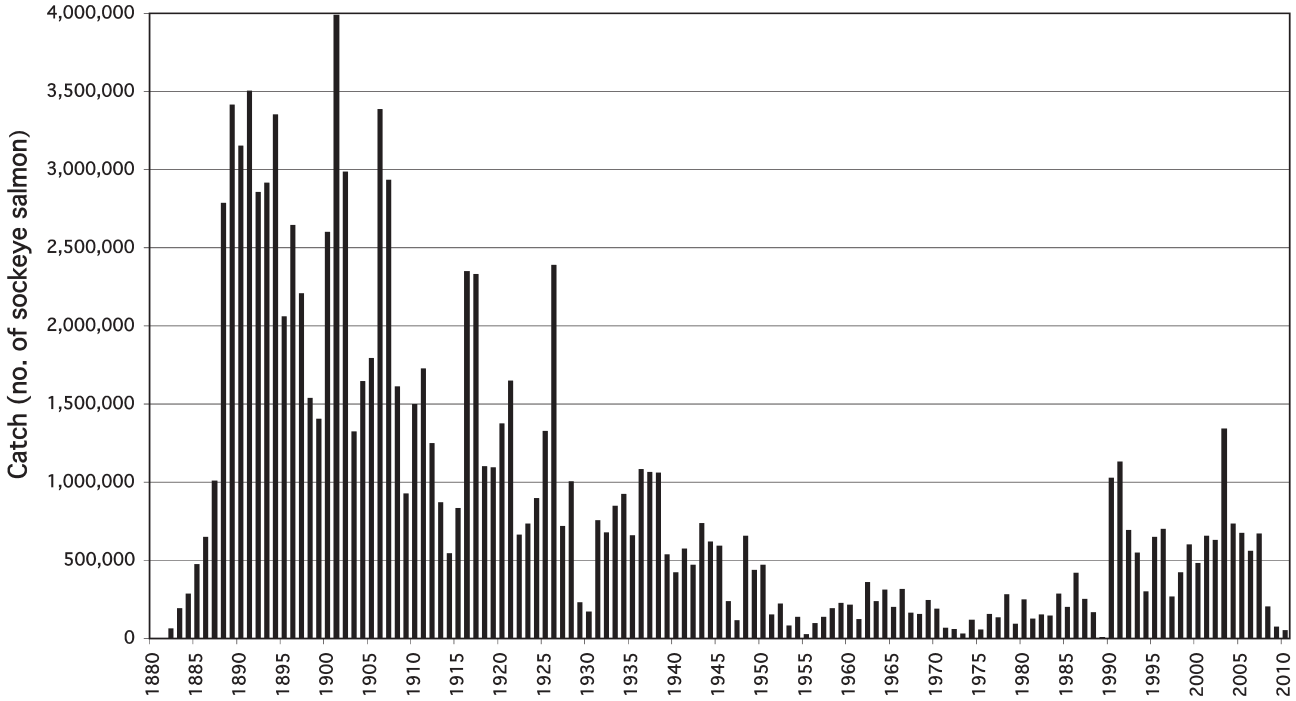


Figure 1-2. Karluk River sockeye salmon catch, 1882–2010. Sources: 1) 1882–1984: Ken Manthey, Dave Prokopowich, and JoAnn Strickert. 1984. 1984 annual finfish management report, Kodiak Management Area. ADFG, Division of Commercial Fisheries, Kodiak. Unpubl. rep., 338 p.; 2) 1985–2010: ADFG data files, Division of Commercial Fisheries, Kodiak.

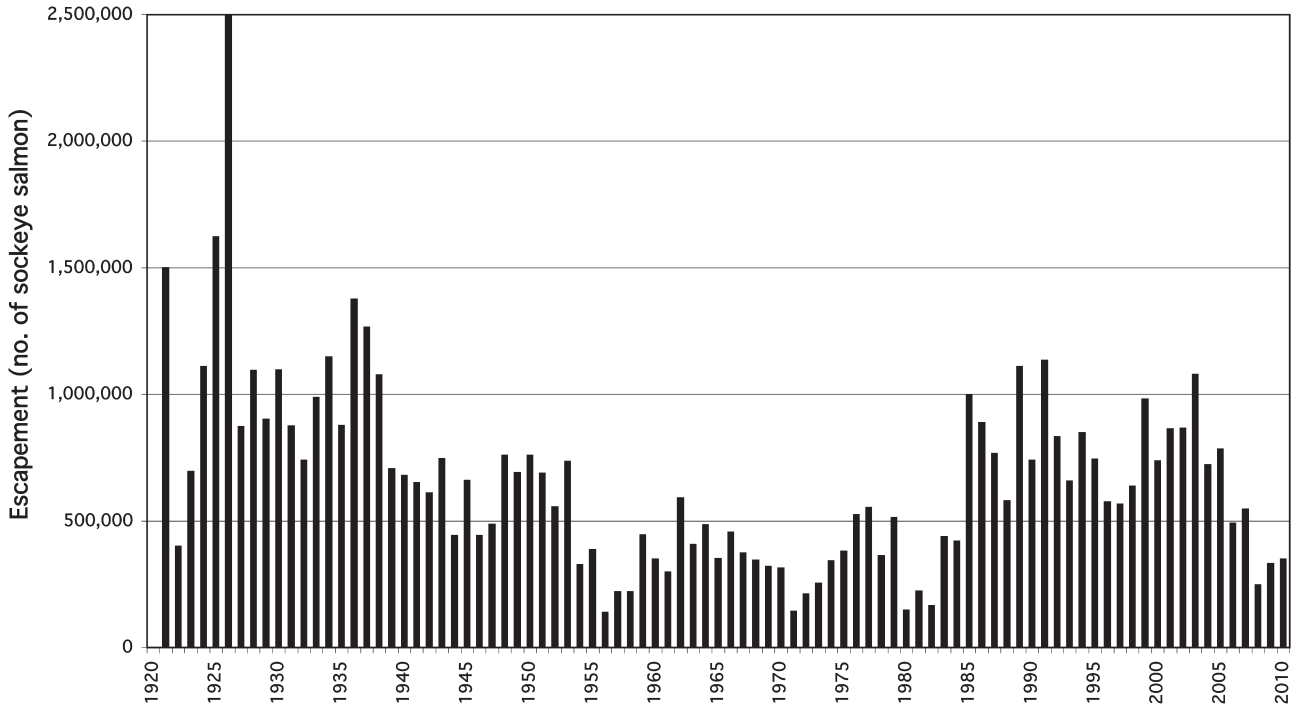


Figure 1-3. Karluk River sockeye salmon escapement, 1921–2010. Sources: 1) 1921–1984: Ken Manthey, Dave Prokopowich, and JoAnn Strickert. 1984. 1984 annual finfish management report, Kodiak Management Area. ADFG, Division of Commercial Fisheries, Kodiak. Unpubl. rep., 338 p; 2) 1985–1988: Malloy and Prokopowich (1992); 3) 1989–1996: Brodie (1996); 4) 1997–1998: Kuriscak (2004); 5) 1999–2008: Caldentey (2009a); 6) 2009–2010: Tiernan (2011).

As a result of these commercial enterprises, Karluk's bountiful sockeye salmon runs soon became widely known to many cannery personnel, fishermen, fishery inspectors, governmental officials, fishery biologists, visitors, and residents of Alaska and the Pacific Coast. Typically, written accounts of Karluk prior to 1900 marveled at its outstanding salmon runs. For example, Marshall McDonald, U.S. Commissioner of Fish and Fisheries, boasted in 1894 that "the Karluk River, on Kadiak Island, is probably the most wonderful salmon river in the world."

Despite the glowing reports about Karluk's salmon resources, the peak cannery production of 1888–94 was followed by 90 years of declining harvests and increasing debates over the cause of this reduction (Figs. 1-2 and 1-3). Governmental officials and fishery biologists sought to reverse this negative trend by imposing various regulations on the fishery and striving to understand the biological factors that controlled sockeye salmon abundance. Accordingly, a long-term program of biological research on sockeye salmon began in 1921 with the installation of a weir on the Karluk River to count the number of fish that reached the spawning grounds at Karluk Lake and to gather basic data on their age, length, weight, and sex.

As these fishery statistics were collected and analyzed, biologists began to advance different theories to explain what had caused the decline in the runs. Over the years, the number of theories grew and many prominent biologists became involved in this scientific controversy. The progression of the debate was followed not only by those directly involved in defending a particular theory, but also by the worldwide fisheries community that knew about Karluk's previous prolific runs, their subsequent decline, and the ongoing research. Thus, for most of the 1900s, the sockeye salmon runs at Karluk also were famous because of their long-term decline, attempts to explain the decline, and the biological research devoted to understanding this species.

While there has never been a formal end to the debate over the causes of the long-term decline, continuing research led many of the proposed theories to be set aside as implausible. Overfishing was most often viewed as the culprit at Karluk, but discussions continued about just how the commercial harvests had affected different biological mechanisms and led to progressively fewer returning salmon.

When Karluk's sockeye abundance greatly rebounded beginning in the mid 1980s, with runs often exceeding 1,500,000 fish, the emphasis of fisheries research shifted away from trying to explain the long-term decline, to understanding and perpetuating the growing success. Yet, with the intrinsic complexity of the interacting physical and biological factors at Karluk, it was not always obvious how much of any observed change in salmon abundance came from human management and how much came from uncontrolled, and partially unknown, environmental factors. That is, was human management solely responsible for reversing the long-term decline or did a particularly beneficial set of natural environmental conditions increase the salmon runs?

After two decades of highly successful sockeye salmon runs at Karluk (1985–2007), management of this fishery is on a solid scientific foundation, though it is also known that salmon populations respond to large-scale, long-term, environmental conditions in the North Pacific Ocean that are largely beyond human control (Finney et al., 2002; Clark et al., 2006; Martinson et al., 2008, 2009a, b). Thus, many important topics remain to be studied for sockeye salmon. Fortunately, individuals and institutions still have an intense desire to better understand this salmon species and continue to pursue the worthy goal of ensuring abundant and sustainable runs to the Karluk River.

Karluk Lake and River

Karluk Lake, located on southwestern Kodiak Island and the largest lake on the island (lat. 57°22′ N; long. 154°02′ W; Fig. 1-4), was formed many thousands of years ago by glacial scour and moraine deposits in a northwest trending valley flanked by rugged mountains that rise to elevations of 750–900 m. Having three internal lake basins and a surface elevation of 112 m, Karluk Lake is 19.6 km in length and 3.1 km in width at its maximum. Lake waters are clear, cold, and oligotrophic; summer surface temperatures seldom exceed 15°C and ice covers the lake in winter. The region has a maritime climate, with mild temperatures, moderate precipitation of 172 cm per year, and frequent cloudy skies. The lake and surrounding landscape are pristine wilderness. Terrestrial vegetation, still in a long-term succession after the last glaciers receded, is a luxuriant covering of grasses, sedges, herbs, shrubs (alder, willow, birch, elderberry), and cottonwood trees. Unlike northeastern Kodiak Island, conifer forests are absent in the Karluk area.

More than 15 small creeks and two larger rivers flow into Karluk Lake (Fig. 1-5). The small creeks, important spawning habitats for sockeye salmon, descend steep mountain slopes and often have waterfalls and

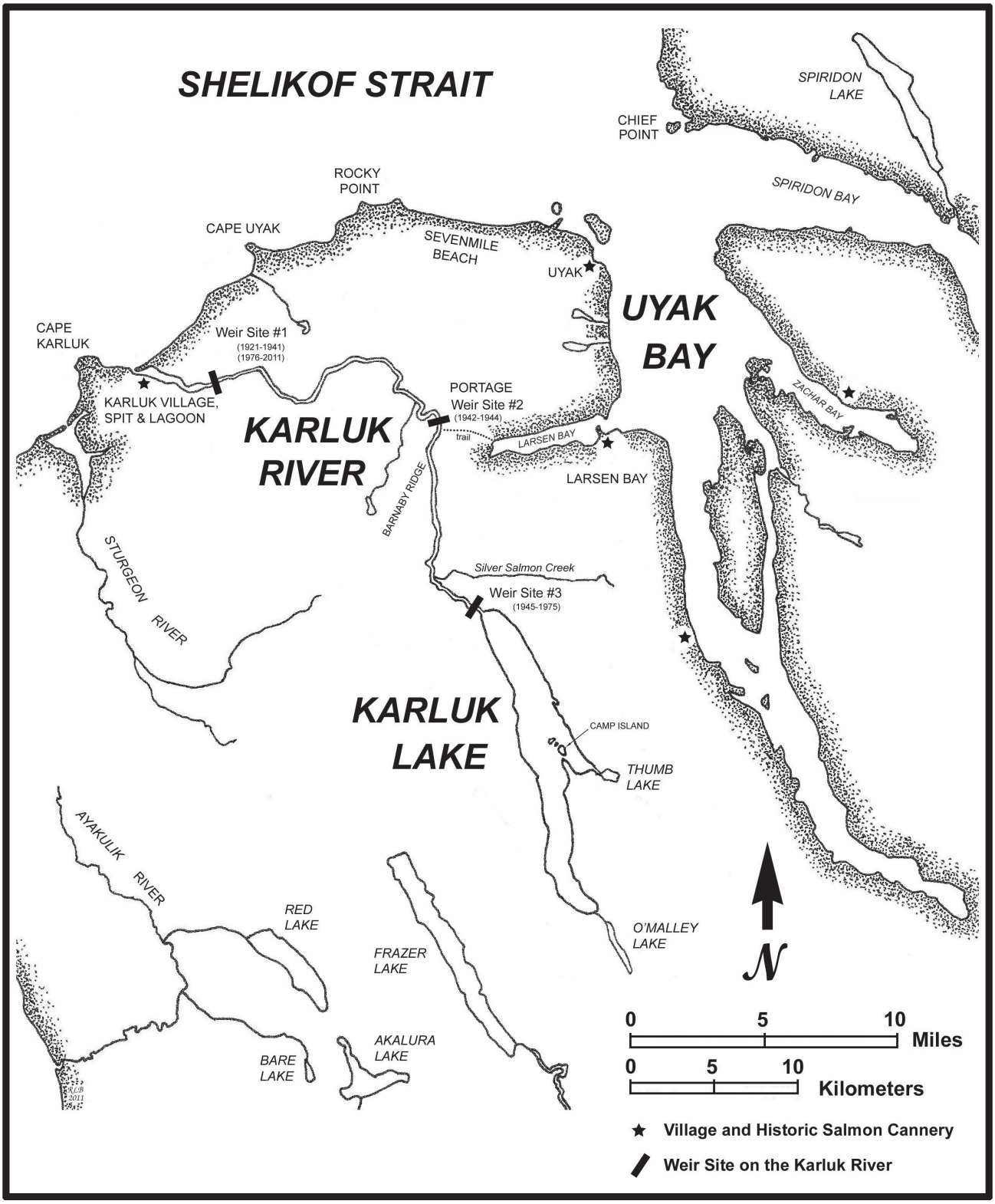


Figure 1-4. Map of the Karluk River watershed and southwest Kodiak Island, Alaska.

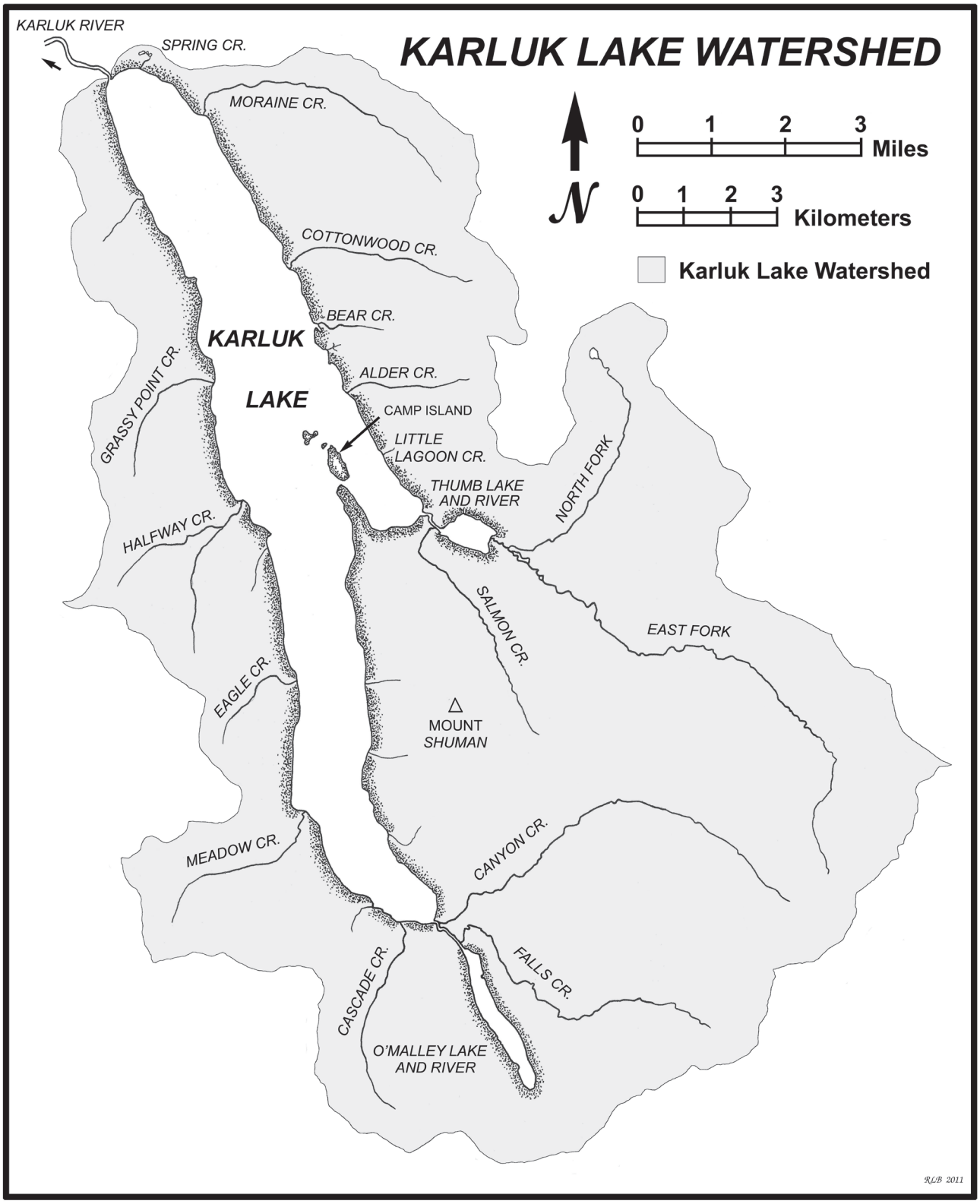


Figure 1-5. Map of the Karluk Lake watershed and tributary streams.

tumbling cascades that restrict spawning salmon to the creeks' lower reaches. In contrast, the two rivers, both with small lakes (Thumb and O'Malley), originate in large tributary valleys, have lower gradients, and provide large spawning areas.

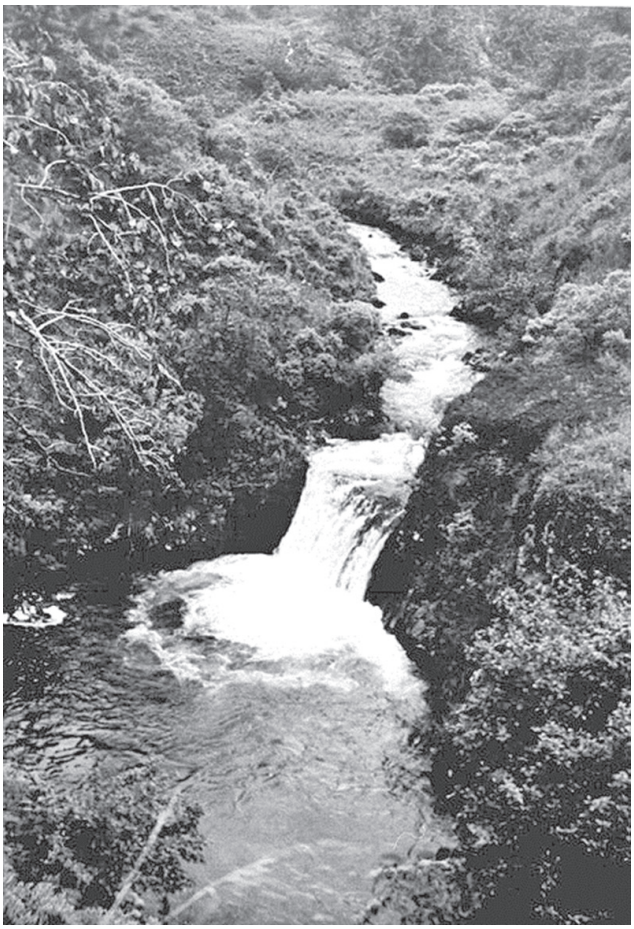
The Karluk River originates at the outlet of Karluk Lake and flows northward and westward 40 km to the ocean at Shelikof Strait. After leaving the lake, the river winds 22 km through a broad valley before turning west through mountainous terrain. Physically, it has a width of 20–160 m and a depth typically less than 1 m. River flow varies seasonally with snowmelt and rainfall runoff—the river's mean discharge is only 12 m^3/sec. The upper 2–4 km of the river is an important spawning area for fall-run sockeye salmon. No barriers to salmon migration exist in the river, except during very dry years when mid summer flows are low; rarely, fish movements are restricted by river ice-cover in early spring. The river enters Karluk Lagoon, a shallow estuary, 5 km upstream from the river's mouth and ocean at Shelikof Strait. Karluk Spit, a 1 km narrow strand beach that rises just a few meters above sea level, separates Karluk Lagoon from the ocean.

For many years Karluk Lake and the upper river were under federal ownership and located within the Kodiak National Wildlife Refuge, which was established in 1941 to protect the island's abundant population of brown bears, *Ursus arctos middendorffi*. Following the Alaska Native Land Claims Settlement Act of 1971, ownership of the Karluk River and northern half of Karluk Lake was transferred to the region's Native groups (the Koniag Corporation).

Eight salmonid species occur in the Karluk ecosystem, including sockeye, pink, coho, Chinook, and chum salmon, steelhead and rainbow trout, Dolly Varden, and Arctic charr (Table 1-1). In addition, threespine stickleback, ninespine stickleback, and coastrange sculpin are present. Though Karluk is renowned for its sockeye salmon, there are also abundant runs of pink

Karluk Lake, showing Island Point (left near), Camp Island (larger island), and Gull Island (smaller island), 1940. (Allan C. DeLacy, from Catherine J. DeLacy, Seattle, WA)

Karluk Lake, with Camp Island in the distance (right center), ca. 1958. (Robert F. Raleigh, Saint George, UT)



Canyon Creek, a salmon spawning tributary at the south end of Karluk Lake, 1948. (Richard F. Shuman, Auke Bay Laboratory, Auke Bay, AK)

North end of Karluk Lake and upper Karluk River, May 1954. (Clark S. Thompson, Shelton, WA)

Lower Karluk River near Alaska Department of Fish and Game salmon counting weir, 1996. (Richard Lee Bottorff, South Lake Tahoe, CA)

Upper Karluk Lagoon, 1996. (Richard Lee Bottorff, South Lake Tahoe, CA)

Karluk River and Karluk Spit salmon canneries, 4 May 1901. (W. C. Fitchie, William J. Aspe Collection, Anchorage Museum, Gift of Mary Rolston, B1990.13.4)

Shelikof Strait (left), Karluk Spit salmon canneries (center), and Karluk River (right), June 1906. (John N. Cobb, University of Washington Libraries, Special Collections, Cobb 2388)

Karluk Lagoon (left), Karluk Spit (center), Karluk Head (upper right), and Shelikof Strait (right), ca. 1953. (Rev. Norman L. Smith, from Timothy L. Smith, Fontana, CA)

Karluk Lagoon (center), Karluk Spit, and Shelikof Strait (left), ca. 1952. (Charles E. Walker, Sechelt, BC)

Karluk Spit and Karluk Lagoon. 1964. (U.S. Fish and Wildlife Service, National Digital Library)

Shelikof Strait (left), Karluk Spit (center), and Karluk Lagoon (right), 1990. (Jet Lowe, Library of Congress, Historic American Buildings Survey, AK, 12-KARLU, 1-1)

salmon during even-numbered years, when several million of them can return to the river. The Karluk River has good runs of coho salmon, Chinook salmon, and steelhead, each of these typically numbering from a few thousand to several tens of thousands of fish annually. Interestingly, only a few hundred chum salmon return to the Karluk River each year, in contrast to major runs that enter the nearby, lake-free Sturgeon River.

Sockeye Salmon

The anadromous life cycle of Karluk's sockeye salmon takes place in two aquatic habitats—the marine waters of the North Pacific Ocean and the fresh waters of Karluk Lake. Each year, mature adults return from the ocean to spawn in their natal fresh waters in and around Karluk Lake. To reach the lake, the salmon ascend 40 km of the Karluk River from the ocean, this upstream migration taking from one to several weeks. Eggs deposited in spawning gravels over-winter there and hatch into young sockeye (known as alevins while they still have an egg yolk sac). In the early spring and summer, these young fish (now known as fry, 24–30 mm long) emerge from the gravel and migrate to Karluk Lake, first feeding for a few months in the shallow shore zone (the littoral) before moving further offshore into the open-water limnetic zone. After rearing in Karluk Lake for two to three years, the juvenile sockeye (now called smolts, 100–150 mm long) make their spring migration to the ocean, where they feed and grow for another two to three years before returning to the Karluk River as mature adults. During their ocean life in the Gulf of Alaska and Bering Sea, Karluk's sockeye migrate thousands of kilometers from their natal river. At maturity, Karluk's sockeye salmon measure about 500–600 mm in length and weigh about 2–3 kg. Typically, the most abundant age group of sockeye salmon adults at Karluk is labeled as 5_3 (or 2.2 in another aging system), meaning that their total age is 5 years between egg deposition and adult spawning, with 3 of these years spent in freshwater as an egg and juvenile before the smolts migrate to the ocean. For the 5_3 sockeye salmon, juveniles rear for two years in Karluk Lake and two years in the ocean before returning to the river as mature adults

Adult sockeye salmon in ocean colors, Karluk Spit beach, 1956. (John Q. Hines, Mt. Shasta, CA)

Male sockeye salmon in spawning colors, Karluk River weir, 1970. (Benson Drucker, Reston, VA)

(the Appendix describes the many different life cycles of Karluk's sockeye salmon). Age groups 6_3 (2.3) and 6_4 (3.2) are also common, and in some years these categories are abundant or dominant components of the run. The colors of adult sockeye salmon change from bright silver-blue in the ocean to vivid red and green when spawning in freshwater. Sockeye salmon adults die within a few weeks of spawning.

Compared with other species of Pacific salmon that occur in Alaska, sockeye salmon possess several unique characteristics. First, sockeye salmon almost invariably return to spawn in river systems that have an upstream lake, the juveniles rearing in this lacustrine habitat for several years before returning to the ocean. Second, the annual return of adult sockeye to a river system is composed of over 20 different combinations of freshwater and ocean ages. That is, juvenile sockeye can spend anywhere from zero to four years feeding in their nursery lake, followed by zero to five years in the ocean before returning to spawn in their natal freshwaters. Thus, compared with other salmon species, the life cycle of sockeye salmon is rather complex. A third unique characteristic is that sockeye salmon have distinctive morphological, physiological, and behavioral adaptations in their life cycle and feeding habits. Both juvenile and adult sockeye salmon have long, fine gill rakers along the inner edge of their gill arches that let them capture small planktonic foods in the limnetic or pelagic waters of the lake or ocean. Hence, sockeye salmon feed at a somewhat lower trophic level than other salmon species. Sockeye salmon also differ from other salmon species in their schooling behavior. It took biologists many years to fully understand the uniqueness of sockeye salmon.

Karluk's sockeye salmon possess another extraordinary biological feature—the ability to modify the productivity of their freshwater nursery lake and the growth and survival of their young. Although this capacity is not yet fully understood, juvenile sockeye benefit via the food chain from nutrients released into the lake when adult salmon die and their bodies decompose. This nutrient interaction between adults and juveniles provides an important insight into at least one controlling mechanism of sockeye salmon in freshwater. Further, this ability to transform the environment of their nursery lake strongly suggests that sockeye salmon are keystone species in the Karluk ecosystem, directly and indirectly influencing a wide range of the region's fauna and flora.

Although Karluk is renowned for its many sockeye salmon, another remarkable aspect of these runs is their long seasonal duration. Adult sockeye first enter the Karluk River in late May and continue throughout most of the summer and early autumn. Two peaks of abundance occur, one in June and a second in early August or September. Typically, the runs decline by late September, but they can extend into October, and more rarely, into November. Sustained large runs of sockeye salmon in August–September are uncommon in other river systems of Kodiak Island and southwestern Alaska. The extended run duration at Karluk was an attractive biological feature for the commercial fishery and canneries to exploit.

Purpose

The main purpose of this book is to review the more than 100 years of fisheries research on Karluk River sockeye salmon. We have summarized and integrated the large mass of research data that has been collected on many complex, dynamic, and interrelated biological topics. This research history is interesting and revealing because it spans the years when knowledge about sockeye salmon grew from near complete ignorance about its life history and biology in 1880, to a relatively detailed understanding in 2010. Scientific facts about salmon accumulated rather slowly before 1900, but discoveries quickened after the foundations and techniques of the new discipline of fishery biology developed.

Over the past century, a long succession of biologists have studied many aspects of Karluk's sockeye salmon and published their findings in scientific journals or agency reports. Yet, many significant results have remained unpublished and unknown to other researchers. This deficiency has obscured a more complete biological understanding of sockeye salmon and caused later biologists to unknowingly repeat previous studies. Thus, in this comprehensive review of sockeye salmon research at Karluk, we have tried to clearly present what has been done and where the original data exists for both published and unpublished studies. While this review demonstrated that substantial knowledge now exists about sockeye salmon, it also revealed that important biological questions remain.

Throughout this review we used the term "Karluk" as an abbreviated way to designate the whole Karluk River and Lake ecosystem. When greater specificity was needed we used the following geographic terms, proceeding upstream from the ocean—Karluk Spit, Karluk Village, Karluk Lagoon, Karluk River, Karluk Portage, and Karluk Lake (Fig. 1-4).

A central theme of this research history is the scientific controversy that arose about the fundamental cause(s) of the long-term decline and subsequent recent recovery of sockeye salmon abundance at Karluk. Many well-known fishery biologists of the 1900s discussed and promoted at least 12 different theories to explain these population trends: 1) overfishing of the entire run, 2) reduced lake fertility, 3) asynchrony of plankton blooms and fry emergence, 4) overfishing of productive midseason subpopulations, 5) environmental changes, 6) reduced reproductive capacity, 7) charr predation on juvenile sockeye, 8) brown bear predation on adult sockeye, 9) counting weir impediments to salmon migrations, 10) competition between juvenile sockeye and sticklebacks, 11) operation of the Karluk Lagoon hatchery in 1896–1916, and 12) interaction between ocean climate and lake fertility.

As fisheries research continued at Karluk over many decades, certain theories gained prominence for a time, only to be replaced by other ideas as new data were analyzed. Some theories that initially were widely accepted fell into disfavor, but later regained prominence. Because the search for the correct theory has been such a prominent part of Karluk's fisheries history, much of this book is organized around these theories, with different aspects of the scientific debate being reviewed in separate chapters.

It should be clearly stated, however, that biologists still do not fully understand the controlling factors of Karluk's sockeye salmon abundance, and it is likely that additional theories and explanations will be proposed in the future. The difficulty of settling on a theory is a result of the inherent complexity of sockeye salmon and its environment—this includes marine and freshwater life stages, ocean climate regimes, marine and lake water temperatures, upwelling areas, nutrients, primary production, plankton, variable foods, competing species, multiple predators, diseases, parasites, long migrations, multiple age classes, size variations, and subpopulations. And beyond the numerous natural factors, there is the impact of commercial harvests. Predicting the outcome of such a diverse and complex system requires a large dose of humility. For that reason, we do not disparage any of the proposed theories to explain the abundance of Karluk River sockeye salmon. All were originally formulated after due consideration of then available facts and with the notable goal of sustaining this salmon resource.

An important goal of this project was to prepare a useful historical and biological resource for biologists, fishery managers, historians, fishermen, naturalists, and Alaskan enthusiasts that summarizes the many years of research on Karluk River sockeye salmon. Besides the many people and organizations directly involved in sockeye salmon research and management in Alaska, we sense that the Karluk River system engenders keen interest from biologists worldwide because of the early prolific runs, long-term decline and recent rebound, and many years of research.

Thus, we have attempted to provide a comprehensive review of past sockeye salmon research at Karluk, access to the full range of research literature, a description of a fascinating period of Alaska's history, and suggestions for future research. Our goals will be partially realized if past studies at Karluk can be readily identified and future research can avoid unnecessary duplication. Of course, we hope this book will ultimately lead to an even greater understanding of Karluk's sockeye salmon and to the perpetuation of abundant and healthy runs of this adaptable and resilient salmon in a magnificent river-lake ecosystem of Alaska.

Report Organization

This research history is divided into 11 chapters that summarize and discuss many important topics of sockeye salmon research at Karluk. First, we chronologically review the research efforts and discoveries of nearly 20 biologists who studied Karluk's sockeye salmon during the 90 years between 1880 and 1970 (Chapter 2). Fisheries research during this era was conducted by a series of naturalists, biologists, and ichthyologists of the U.S. Government, primarily from its U.S. Fish Commission (USFC), Bureau of Fisheries (USBF), Fish and Wildlife Service (FWS), and Bureau of Commercial Fisheries (BCF). Additional research was conducted during the latter part of this era by biologists from other organizations, including the Fisheries Research Institute (FRI) of the University of Washington, Seattle; the Alaska Department of Fisheries (ADF) before statehood; and the Alaska Department of Fish and Game (ADFG) after statehood.

Second, we review the history of the Karluk River counting weir, from its first operation in 1921 to current times (Chapter 3). This fisheries research tool has provided a wealth of basic data on sockeye salmon escapements (the number of fish that escape the fishery and reach the spawning grounds), migration timing, and run composition, as well as similar facts for other salmonid species that inhabit the system. The weir history

is interesting because of its various operational problems, the long-term debate over its proper location, its changing uses, and the insights it provided into the dynamism of the Karluk River ecosystem.

Third, we summarize the life history of Karluk's sockeye salmon (Chapter 4). Compared with the little that was known about this species in 1880, a substantial amount has been learned over the decades. Nevertheless, some important details of its life history still remain unclear and continue to be topics for future study.

Following these initial chapters that summarize information across many fishery subjects, the next six chapters (Chapters 5–10) provide detailed reviews of specific topics, controversies, and questions that have persisted about sockeye salmon throughout most of Karluk's research history: 1) the existence of subpopulations, 2) the seasonal run distribution, 3) the importance of limnological knowledge and lake fertilization, 4) the interaction of sticklebacks and juvenile sockeye, 5) the effect of charr predation, and 6) the effect of bear predation. To summarize and conclude the central theme of this book, the final chapter (Chapter 11) briefly reviews the different theories that have been proposed to explain the historic decline and recent recovery of sockeye salmon runs at Karluk. In all chapters, we trace the origin and historical development of thought about each major topic and conclude with a statement of the current understanding.

Supporting this historical review of sockeye salmon research at Karluk are two major supplements: 1) an appendix of long-term fisheries data and biological resources, and 2) a comprehensive bibliography (published as a companion volume). The appendix includes the daily weir counts of sockeye salmon from 1921 to 2010, plus a gazetteer, glossary, timeline, summary of management reports, scale resources, life cycle and age composition graphs, and summary of biotic resources. The bibliography includes both published and unpublished references on Karluk's sockeye salmon, in addition to many citations on the region's fauna, flora, history, and physical environment. Most references have been annotated to quickly reveal their contents. We have tried to include all Karluk references up to 2010.

Throughout this book, we have included many historical images of the research gear, weir, personnel, facilities, scenery, fauna, and flora. We believe the historical photographs give clear insights into the many years of field studies and reveal what for many biologists was a stimulating research experience and an exciting Alaskan adventure.

This history of sockeye salmon research at Karluk complements, but has little overlap with, previous histories of the salmon canneries of Kodiak Island and the salmon hatcheries of Alaska by Patricia Roppel (1982, 1986). Since Roppel has admirably discussed these two subjects, we have not repeated her work, except to occasionally add specific information about Karluk.

Sources of Information

This research history is based upon many primary and secondary sources of published and unpublished information. Without a doubt, the number of pertinent references that we discovered far exceeded our initial expectations. We focused our literature search on the biology of Karluk's sockeye salmon, but we also gathered literature on other species of its fauna and flora, the physical environment, and the fishery. Published references included those in peer-reviewed journals and fishery agency reports, while unpublished documents were found in various libraries, archives, and personal collections. Within the time constraints of this project, we believe that a major portion of Karluk's fisheries literature was examined, especially for the pre-statehood period of Alaska. Although the Bare Lake study of the 1950s was an offshoot of the Karluk research program, we did not thoroughly examine this literature. The results of our literature search are presented in the Karluk Sockeye Salmon Bibliography.

To supplement our literature search, we directly interviewed many active and retired biologists, all of whom conveyed valuable insights into the Karluk ecosystem and the past and current research programs. They discussed technical facts about sockeye salmon and recalled biological studies from as far back as the 1930s. Overwhelmingly, these biologists were highly enthusiastic about the Karluk ecosystem and their own research experiences there. Further, many biologists supplied us with personal photographs taken during their years of field work at Karluk; these images added considerable detail about past field studies, facilities, and personnel.

As the Karluk references were gathered, we chronologically organized the published and unpublished information into a large computer database that included about 90 biological, fisheries, historical, and other topics. Most subjects dealt with some aspect of sockeye salmon biology, but some computer files summarized data on the physical, historical, archeological, and other biological properties of Karluk. Besides sockeye salmon,

the database included information on a broad spectrum of the flora and fauna—all fish species, aquatic invertebrates, parasites, birds, mammals, and plants. Though not all of these topics were included in our subsequent review, this database provided a broad foundation for the discussion of Karluk's sockeye salmon.

As we reviewed the past research and interacted with many biologists, one fact became exceedingly clear—the dynamic nature of the Karluk lake-river ecosystem. Its sockeye salmon, plus many other of its fish and wildlife species, undergo large seasonal changes in abundance and distribution. For its fishes, each life stage is often associated with a major migration among different habitats, either between freshwater and the ocean or within the lake and its tributaries. Likewise, the aquatic habitats experience large seasonal variations in their physical and chemical properties. We emphasize the dynamic nature of the Karluk ecosystem because it adds an important overriding qualification to most research programs. That is, only by collecting samples over a wide range of places and times can the full complexity of many biological phenomena be understood. Sometimes in the past, research conclusions have been incorrectly extrapolated from a few measurements of location and season. Because of the inherent dynamism that defines the Karluk system, we have attempted in this history to clearly specify the times and places when discussing biological topics about sockeye salmon.

Wonderful Karluk

We close this introduction with a group of historical comments about the original productivity and uniqueness of the sockeye salmon runs in the Karluk River. Visitors to Karluk between the 1880s and the early 1900s marveled at these bountiful runs, a magnificent cornucopia of silver fish that arrived from the sea and flowed upriver with tenacious force for months on end. Documents from this period, and somewhat later, often included glowing reports about the "wonder of the Karluk sockeye salmon runs." The following quotations demonstrate the special attraction that this remarkable salmon species and Karluk ecosystem have had for many people:

> [Speaking of Karluk's salmon, 1880] Looking down into the water, it would seem that a lead-pencil could not be passed down between the densely crowded fish; a bidarka cannot be paddled over them when the salmon are thick. Red salmon are abundant every year at Karluk. [Bean, 1887: 96]

> [1889] The run is confined chiefly to the smaller streams, such as the Karluk, in which they crowd in numbers absolutely incredible to one who is not an eye witness, and actually force each other out of the water in their eager struggles to reach the sources of the rivers and deposit their spawn. [Bean, 1891: 168]

> [1889] The number of salmon actually caught in Karluk Bay, near the river mouth and in the lower portion of the river, is so large as to make a true statement concerning them seem incredible. In 1888 the canneries put up over 200,000 cases, averaging about 13 red salmon to the case, or more than 2,500,000 fish. In 1889 the number of fish put up was still larger, reaching probably 250,000 cases, containing more than 3,000,000 salmon. [Bean, 1891: 182]

> [1890] The Karluk river became known to the Russians as the most prolific salmon stream at an early date, and they utilized it as a depot for supplying their numerous hunting parties with dry fish as early as 1793. Ever since that time that wonderful little river has been made to yield its annual quota for the subsistence of Alaskan people. [Porter, 1893: 79]

> [1890] You see, the best fishing of all was right there at Karluk at the seining grounds. I thought I'd seen fish down on the Columbia and in at the mouth of the Fraser River, but I never seen fish anywhere to equal them runs at Karluk. We'd bring in twenty-five to thirty thousand big salmon in a haul. [McKeown, 1960: 42]

> [1895] It is unusual for more than one establishment to be found on any salmon stream, but at Karluk . . . there are five canneries, and the salmon seem inexhaustible. The river at its mouth, and for a long distance out into the salt water . . . seems to be fairly swarming with these fish. They fill the water to such extent as to almost dam it up, and those below, in their eagerness to ascend the river, crowd those on top so that their fins and part of their body are exposed to view. The first season I beheld the sight I though an appropriate name would be the "River of Life". [Bruce, 1895: 40]

> [1897] In 1896 several hauls on Karluk Spit yielded 75,000 salmon to the haul. Hauls of from 25,000 to 30,000 fish are not unusual during the height of the run. It is said that some years ago 100,000 salmon were taken at a single haul on the spit. . . . The waters surrounding the outlet to Karluk Lagoon are probably the most remarkable in salmon production in Alaska, not only in point of numbers, but in the length of the runs. [Moser, 1899: 145–146]

> [1903] The four greatest of red salmon streams are the Fraser River, Karluk River, Nushegak River and Kvichak River, all large streams flowing through lakes. In

proportion to the amount of water, probably no stream in the world normally carries more salmon than the Karluk River. [Jordan, 1903: 171]

[Speaking of Karluk, 1909] When the salmon runs began there were so many fish that they almost pushed each other out of the water. When we went out in rowboats it sounded like someone beating a tattoo on the bottom of the boat, we had to pole because the fish were so thick you couldn't get the oars down to row. [Taylor 1964: 36]

[At the Karluk River, 21 July 1916] This was the first time I had seen the river above the hatchery. It is easy to understand why the Karluk River has been such a wonderful salmon stream. As a breeding ground for salmon, it so far surpasses anything that I have seen in Alaska as to be entirely in a class by itself. Conditions, as observed by me in a very limited time and over a small area as compared with the whole, are perfect and ideal in every respect. [Ball 1916]

[Speaking of Karluk, 1931] Although other species are taken in the fishery the remarkable red-salmon runs are of predominant importance. Both the river and the lake are relatively small, yet the abundance of red salmon is so great as to indicate that conditions are particularly favorable for this species. No other stream of similar size is known to produce such large runs, and there are only a few larger streams, such as the Fraser and the Kvichak Rivers, that have been more productive. . . . The history of this district is particularly interesting, and marks the rise and fall of one of the world's greatest red-salmon fisheries. [Rich and Ball 1931: 664–665]

[Speaking of Karluk, 1932] This watershed, for it size, has been one of the greatest producers of red-salmon in the world. [Barnaby 1932: 1]

[Speaking of Karluk, 1958] That night I lay in the forward bunk listening to the gurgle of the mighty Karluk as it bubbled against the port planks. I wondered if people appreciated what this great river had meant to them in the past as they casually reached for a can of red salmon on a grocery shelf in New York or Austin. Karluk, the river of giants, where bloody wars were once fought over the right to fish for the fresh-run horde as they piled in from the Shelikoff Straits by the thousands, only to die in the spawning beds of Karluk Lake where their decaying bodies produced the plankton so vital as food for the fingerlings. . . . But these great salmon runs into the Karluk River are a thing of the past and only a trickle remains. For years commercial fishermen exploited the big fish, and protective laws were passed too late. [Woodworth 1958: 105]

[Speaking of Karluk, 1971–1972] Karluk Lake is the largest lake . . . on Kodiak Island and historically supported a sockeye run of greater magnitude, in relation to lake size, then any other sockeye producing system in the world. [Blackett 1973: 70]

As these statements confirm, most visitors to Karluk, whether professional biologists, officials, laborers, sportsmen, or tourists, soon grasped the exceptional nature of this river-lake ecosystem and its abundant sockeye salmon runs. Indeed, a near reverence for these fish and the wild setting soon permeates those who visit or study the Karluk system, the admiration flowing from diverse sources—from seeing the bold natural landscape, clear waters, and persistent salmon masses; from understanding the extended evolutionary history that adapted these salmon to flourish in this river system; from appreciating the long human prehistory and

Bidarka on Karluk River (near), Karluk Spit cannery buildings, and steamers *Bertha* and *Haytien Republic* in Shelikof Strait (far), 1889. (Tarleton H. Bean, National Oceanic and Atmospheric Administration Photo Library, fish7460, from National Archives, Washington, DC)

varied fisheries history that unfolded on these now quiet shores; from knowing the 100-year succession of biologists who worked to unlock the secrets of sockeye salmon; and from experiencing a powerful connection with untamed nature. Nowadays, such sentiments come from people of many backgrounds, interests, and origins, the enthusiasm being particularly ardent from worldwide visitors that travel long distances to sport fish for Karluk's salmon, steelhead, and charr and to experience a unique adventure in an intact Alaska wilderness. Clearly, whether viewed from the perspectives of modern ecological principles and sensibilities or of Alaskan history, the sockeye salmon runs at Karluk are a remarkable phenomenon.