An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska

Volume 2—Appendices A-D

Appendix A: Fishery Resources of the Bristol Bay Region

Fishery Resources of the Bristol Bay Region

Daniel Rinella, PhD.
Alaska Natural Heritage Program
University of Alaska Anchorage
Beatrice McDonald Hall, Suite 106
Anchorage, AK 99508
rinella@uaa.alaska.edu
907.786.4963

Rebecca Shaftel
Alaska Natural Heritage Program
University of Alaska Anchorage
Beatrice McDonald Hall, Suite 106
Anchorage, AK 99508
rsshaftel@uaa.alaska.edu
907.786.4965

Dave Athons
Environmental Protection Agency
Kenai River Center
514 Funny River Road
Soldotna, AK 99669
Athons.dave@epamail.epa.gov
907.714.2481

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INTRODUCTION

Millions of Pacific salmon return from feeding in the open ocean each year and swarm through Bristol Bay en route to their natal spawning streams. Nine major river systems comprise the spawning grounds for Bristol Bay salmon (Figure 1), and schools navigate toward the mouths of their respective rivers as they pass through the Bay. Each summer, thousands of commercial fishermen use drift and set gill nets to capture millions of returning fish, making Bristol Bay the largest sockeye salmon fishery in the world. Salmon that escape the fishery distribute throughout the Bay's watersheds and spawn in hundreds of discreet populations. Sport anglers target those salmon, especially sockeye, Chinook and coho, as they migrate through the river systems toward their spawning grounds. Also prized are abundant populations of rainbow trout and other sport fish, including Dolly Varden and Arctic grayling, which attain trophy size by gorging on energy-rich salmon eggs, flesh from salmon carcasses, and invertebrates dislodged by spawning salmon. The abundance of large game fish, along with the wilderness setting, makes the Bristol Bay region a world-class destination for sport anglers. Alongside recreationists, aboriginal people, guided by an age-old culture, harvest their share of migrating salmon and other fish species, which provide a primary source of sustenance.

In this report we reviewed the biology, ecology, and management of the fishes of the Bristol Bay watersheds, emphasizing those species of the greatest cultural and economic importance – sockeye salmon, Chinook salmon, and rainbow trout. Rather than to imply that other fishes are not important, this focus reflected the disproportionate amount of research on these species (especially sockeye salmon) and was necessary to keep the amount of material manageable. In contrast, there is relatively little information available for the region's freshwater species, despite the importance of some in subsistence and sport fisheries. Our objectives were to describe the commercial and sport fishery resources of the region and to discuss the importance of Bristol Bay salmon populations in the context of the greater North Pacific Ocean. The subsistence fisheries and their importance are discussed in the main body of the Assessment (Chapters 5 and 12). The literature reviewed consisted primarily of agency reports and peer-reviewed scientific papers, although unpublished data and personal communications were used where no pertinent published literature existed and popular sources were consulted to characterize the more subjective attributes of the sport fisheries. Our geographic focus was the Kvichak River watershed (including the Alagnak River) and the Nushagak River watershed (including the Wood River). Since the Kvichak and Nushagak sockeye salmon populations are components of the Bristol Bay-wide stock complex, however, we typically discuss their abundance trends at both the Bristol Bay scale and at the scale of the individual river systems. The economics of Bristol Bay's fisheries and the role of fish in the region's aboriginal cultures are each covered in separate sections of the Bristol Bay Watershed Analysis.

Figure 1. Major river systems and fishing districts in Bristol Bay, Alaska.

ECOLOGY AND LIFE HISTORY OF BRISTOL BAY FISHES

General salmon life history

Five species of Pacific salmon are native to North American waters – pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), coho (*O. kisutch*), and Chinook (*O. tshawytscha*) salmon – and all have spawning populations in the Bristol Bay region. These species share a rare combination of life history traits that contribute to their biological success, as well as their status as cultural icons around the North Pacific rim. These traits – anadromy, homing, and semelparity – are described briefly in the following paragraphs.

All Pacific salmon hatch in fresh water, migrate to sea for a period of relatively rapid growth, and return to fresh water to spawn. This strategy, termed anadromy, allows salmon to capitalize on the resource-rich marine environment, where growth rates are much faster than in fresh water. Thus, anadromy allows salmon to attain larger body size, mature more quickly, and maintain larger spawning populations than would be possible with a non-anadromous life history (McDowall 2001). A prevailing theory is that anadromy evolves where a disparity in productivity exists between adjacent freshwater and marine environments (Gross et al. 1988). Freshwater productivity generally declines with latitude, and in the spawning range of Pacific salmon is half (or less) of that in lower latitudes. Conversely, ocean productivity generally increases with latitude, peaking within the range of Pacific salmon (Gross et al. 1988).

When salmon enter fresh water to spawn, the vast majority return to the location where they were spawned. By this means, termed homing, salmon increase juvenile survival by returning to spawn in an environment with proven suitability (Cury 1994). Another adaptive advantage of homing is that it fosters reproductive isolation that enables populations to adapt to their particular environment (Blair et al. 1993, Dittman and Quinn 1996, Eliason et al. 2011). For instance, populations that travel long distances to reach inland spawning sites develop large lipid reserves to fuel the migration (Quinn 2005, pgs. 77–78 and figures 4-6), since adult salmon generally do not feed after entering fresh water. As another example, sockeye fry from populations that spawn downstream of nursery lakes are genetically programmed to migrate upstream after emergence, while fry from populations that spawn upstream of nursery lakes are programmed to migrate downstream (Burgner 1991, pgs. 33-35). Examples of adaptations are many, and include heritable anatomical, physiological, and behavioral traits. Without homing, gene flow would occur throughout the species, making adaptation to specific freshwater conditions impossible; in this sense, homing counteracts the dispersal effects of anadromy (McDowall 2001). Homing is not absolute, however, and a small amount of straying ensures that amenable habitats are colonized by salmon (e.g., Milner and Bailey 1989).

Pacific salmon, quite famously, die after spawning only once. This trait, termed semelparity, serves to maximize the investment in one reproductive effort at the expense of any future reproductive effort. In salmon, it may have evolved as a response to the high cost of migration to natal streams and the associated reduction in adult survival (Roff 1988). The evolution of semelparity in Pacific salmon was accompanied by increased egg size so, while long migrations may have been a prerequisite, the driving force behind the evolution of semelparity was likely the increase in egg mass and associated increase in juvenile survival (Crespi and Teo 2002).

As salmon approach sexual maturity, the countershading and silvery sheen that hide them at sea give way to characteristic spawning colors, often with hues of red. Males develop hooked snouts (the generic name *Oncorhynchus* refers to this trait) and protruding teeth, and their previously bullet-shaped bodies become laterally flattened. These spawning colors and secondary sexual characteristics, which develop to varying degrees among species and even among populations, probably serve multiple purposes on the spawning grounds, including species recognition, sex recognition, and territorial displays.

With few exceptions, preferred spawning habitat consists of gravel-bedded stream reaches with moderate depth and current (30–60 cm deep and 30–100 cm per second, respectively; Quinn 2005, pg. 108). Females excavate a nest (redd) in the gravel to receive the eggs, which are fertilized by one or more competing males as they are released and subsequently buried by the female. The seasonality of spawning and incubation is roughly the same for all species of Pacific salmon, although the timing can vary somewhat by species, population, and region. In general, salmon spawn during summer or early fall and the fry emerge from the spawning gravel the following spring. While in the gravel, the embryos develop within their eggs and then hatch into fry that continue to subsist on yolk sacs. After emerging from the gravel, basic life history patterns of the five species differ in notable ways.

Species-specific life history and ecology

Sockeye salmon

Sockeye salmon originate from river systems along the North American and Asian shores of the North Pacific and Bering Sea, roughly from the latitude of the Sacramento River to that of Kotzebue Sound. The largest North American populations occur between the Columbia and Kuskokwim rivers (Burgner 1991, pg. 5). Spawning sockeye are readily identified by their striking red bodies with green heads and tails; males additionally develop a large hump in front of the dorsal fin.

Sockeye are unique among salmon in that most stocks rely on lakes as the primary freshwater rearing habitat. Some sockeye spawn within the nursery lake where their young will rear. Others spawn in nearby stream reaches, and their fry migrate to the nursery lake after emerging from spawning redds. Sockeye are by far the most abundant salmon species in the Bristol Bay region (Salomone et al. 2011, pg. 1), undoubtedly due to the abundance of accessible lakes in this landscape (Figure 1; also see discussion of *habitat quantity*). Tributaries to Iliamna Lake, Lake Clark, and the Wood Tikchik Lakes are major spawning areas, and juveniles rear in each of these systems (Figure 2). On average, the Kvichak River, with Iliamna Lake as its primary rearing site, produces more sockeye than any other system in the Bristol Bay region (see Appendix 1). Juveniles in Bristol Bay systems rear for one or two years in their nursery lakes (West et al. 2009, pg. 235), feeding primarily on zooplankton in the limnetic zone (Burgner 1991, pg. 37). Many Nushagak River sockeye populations spawn and rear in riverine habitats throughout the basin and do not use lakes (Figure 2).

Fish then typically spend two or three years at sea (West et al. 2009), returning at an average weight of 5.9 lb (2.7 kg, based on recent commercial catches; Salomone et al. 2011, pg.

105). At sea, sockeye salmon feed on a range of invertebrates, small fish, and squid (Burgner 1991, pg 83).

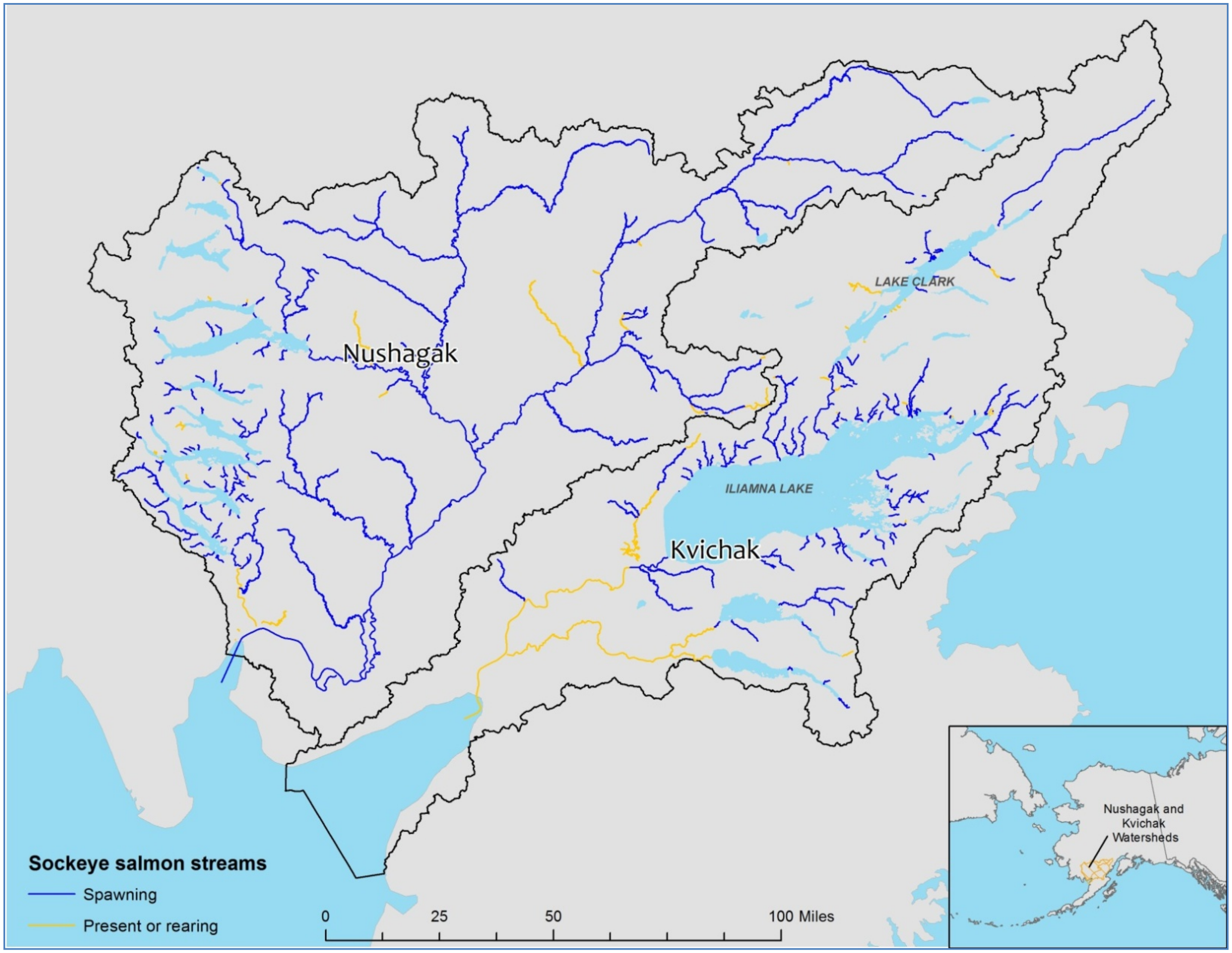

Figure 2. Documented sockeye salmon distribution in the Nushagak and Kvichak watersheds. Data are from the Alaska Department of Fish and Game's Anadromous Waters Catalog (AWC; Johnson and Blanche 2012). See Section 7.2.5 in the main body of the assessment for assumptions and caveats associated with interpreting AWC data.

Chinook salmon

Chinook salmon spawn in streams on both shores of the North Pacific and Bering Sea, roughly from the latitude of central California to that of Point Hope. There are more than a thousand North American spawning populations and a much smaller number in Asia. These populations tend to be relatively small, however, making Chinook the rarest of North America's Pacific salmon species (Healey 1991, pg. 316). They are also the largest of the Pacific salmon; at least one specimen over 60 kg has been reported, but most weigh less than 23 kg (Mecklenburg et al. 2002, pg. 207).

Chinook salmon have two different behavioral forms. The "stream type" form is predominant in Bristol Bay, as well as other areas of northern North America, Asia, and the headwaters of Pacific Northwest rivers (Healey 1991, pg. 314). These fish spend one or more years as juveniles in fresh water, range widely at sea, and return to spawning streams during spring or summer. "Ocean type" Chinook, by contrast, migrate to sea soon after hatching, forage primarily in coastal marine waters, and return to spawning streams in the fall (Healey 1991, pg. 314). In fresh water, juvenile Chinook tend to occupy flowing water and feed on aquatic insects. At sea, Chinook are generally pisciverous (Brodeur 1990) and feed higher on the food chain than other salmon species (Satterfield and Finney 2002).

Chinook spawn and rear throughout the Nushagak River basin and in many tributaries of the Kvichak River (Figure 3). Some life history data are available from adults returning to the Nushagak River, Bristol Bay's largest Chinook salmon run. Essentially all Chinook spend one year rearing in fresh water, and the vast majority (typically >90% of a given brood year) spend two to four years at sea (Gregory Buck, ADF&G, unpublished data). Fish that spend four years at sea are the dominant age class and comprise approximately 43% of the average return, followed by those that spend 3 years (35%) and two years (17%) at sea. Chinook salmon individuals in recent Bristol Bay commercial catches have averaged 16.6 lb (7.5 kg; Salomone et al. 2011, pg. 105).

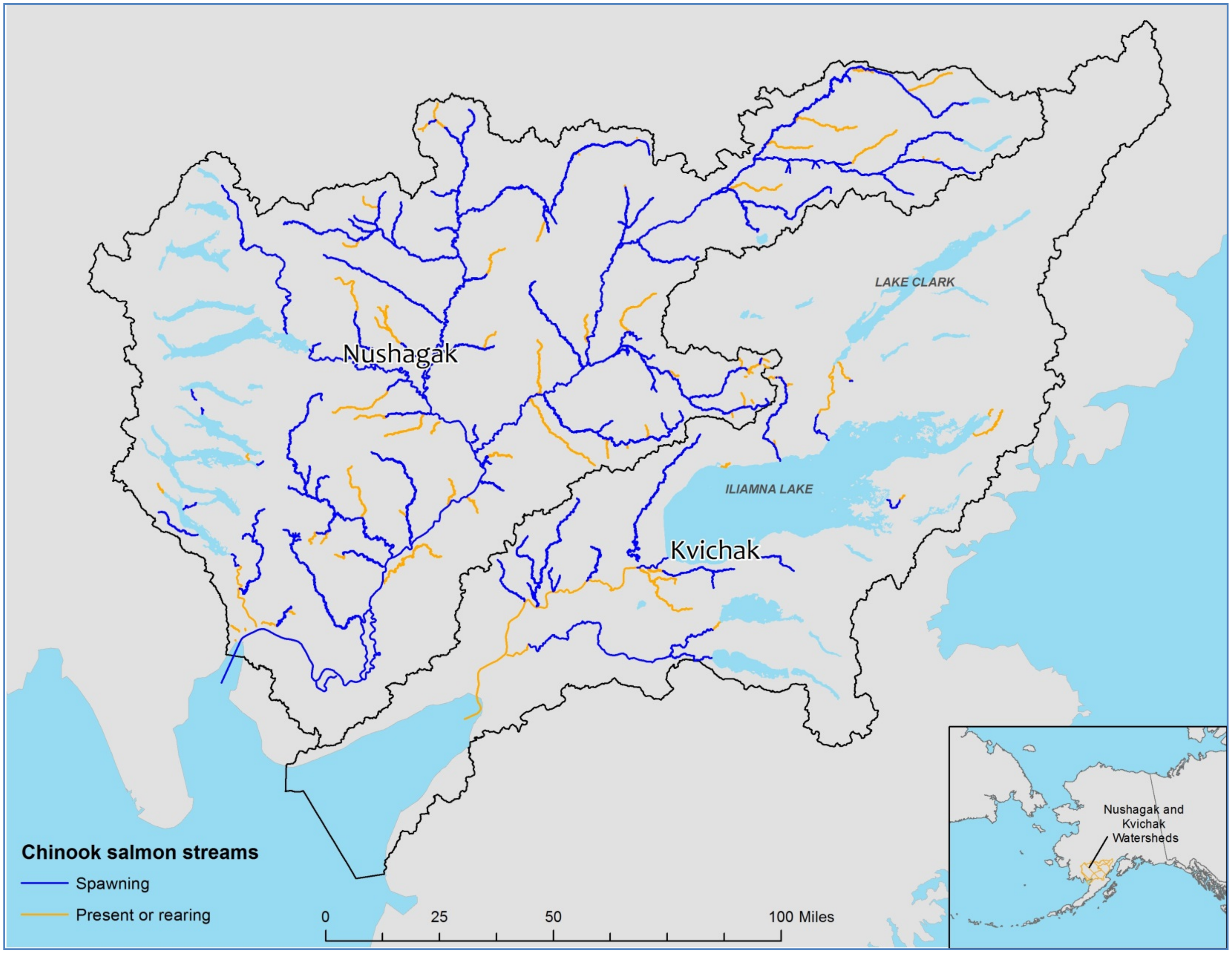

Figure 3. Documented Chinook salmon distribution in the Nushagak and Kvichak watersheds. Data are from the Alaska Department of Fish and Game's Anadromous Waters Catalog (AWC; Johnson and Blanche 2012).

Rainbow trout

Rainbow trout (*Oncorhynchus mykiss*) are native to western North America and the eastern coast of Asia, although their popularity as a sport fish has led to introduced populations around the world. Bristol Bay's rainbow trout are of the coastal variety (sensu Behnke 1992, pg. 193), which ranges from the Kuskokwim River to southern California. While classified in the same genus as the Pacific salmon, there are some key differences. Foremost, rainbow trout are not genetically programmed to die after spawning, making iteroparity (i.e., repeat spawning) a feature of most populations. Also, most coastal drainages support populations of both resident and anadromous (i.e., steelhead) forms, although only the resident form occurs near the northern and southern limits of rainbow trout distribution (Behnke 1992, pg. 197), including the Nushagak and Kvichak drainages. Finally, rainbow trout spawn in the spring, as opposed to summer or early fall, although their spawning habitat and behavior is otherwise generally similar to that of salmon.

Bristol Bay rainbow trout tend to mature slowly and grow to relatively large size. For example, 90% of spawners in Lower Talarik Creek were more than seven years old; the vast majority of these were longer than 500 mm and a few exceeded 800 mm (years 1971-1976; Russell 1977, pgs. 30-31). Growth (mm/year) was fastest for fish between four and six years of age and winter growth appeared to be minimal (Russell 1977, pgs. 44-45).

Bristol Bay trout utilize complex and varying migratory patterns that allow them to capitalize on different stream and lake habitats for feeding, spawning, and wintering. Fish from Lower Talarik Creek migrate downstream to Iliamna Lake after spawning. From there, they appear to utilize a variety of habitats, as some tagged individuals have been recovered in other Iliamna Lake tributaries and in the Newhalen and Kvichak Rivers (Russell 1977, pg. 23). In the Alagnak River watershed, a number of rainbow trout life history types have been identified, each with their own habitat use and seasonal migratory patterns (Meka et al. 2003). These consist of lake, lake-river, and river residents, the latter of which range from non-migratory to highly migratory (Meka et al. 2003). Individuals comprising each of these life history types migrate in order to spend the summer in areas with abundant spawning salmon (Meka et al. 2003).

Eggs from spawning salmon are a major food item for Bristol Bay trout and are likely responsible for much of the growth attained by these fish. Upon the arrival of spawning salmon in the Wood River basin, rainbow trout shifted from consuming aquatic insects to primarily salmon eggs for a 5-fold increase in ration and energy intake (Scheuerell et al. 2007). With this rate of intake, a bioenergetics model predicts a 100-g trout to gain 83 g in 76 days; without the salmon-derived subsidy, the same fish was predicted to lose five g (Scheuerell et al. 2007). Rainbow trout in Lower Talarik Creek were significantly fatter (i.e., higher condition factor) in years with high spawner abundance than in years with low abundance (Russell 1977, pg. 35).

Coho salmon

Coho salmon are native to coastal drainages in western North America and eastern Asia, approximately from the latitude of the Sacramento River to that of Point Hope (Sandercock

1991, pg. 398). Coho salmon occur in relatively small populations, and are second only to Chinook salmon in rarity.

Most Alaskan coho salmon populations tend to spend two years in fresh water and one year at sea (Sandercock 1991, pg. 405). Few age data exist for Bristol Bay, but samples from two years on the Nushagak River indicated that approximately 90% of escaped coho salmon shared this age structure, while the remaining fish had spent either one year or three years in fresh water (West et al. 2009, pg. 84). Coho salmon individuals in recent Bristol Bay commercial catches have averaged 6.7 lb (3.0 kg; Salomone et al. 2011, pg. 105).

At sea, coho salmon consume a mix of fish and invertebrates (Brodeur 1990, pg. 15). Their trophic position is intermediate for Pacific salmon; Chinook salmon consume more fish while sockeye, pink, and chum salmon eat more zooplankton and squid (Satterfield and Finney 2002).

In fresh water, coho salmon feed primarily on aquatic insects, although salmon eggs and flesh can be important nutritional subsidies (Heintz et al. 2010, Rinella et al. 2011). They utilize a wide range of lotic and lentic freshwater habitats, including stream channels, off-channel sloughs and alcoves, beaver ponds, and lakes. Coho spawn in many stream reaches throughout the Nushagak and lower Kvichak watersheds, and juveniles distribute widely into headwater streams (Figure 4), where they are often the only salmon species present (Woody and O'Neal 2010, King et al. 2012, ADF&G Anadromous Waters Catalog). Production of juvenile coho is often limited by the extent and quality of available wintering habitats (Nickelson et al. 1992, Solazzi et al. 2000), and preliminary work in southcentral Alaska suggests that upwelling groundwater is an important feature (D.J. Rinella, unpublished data).

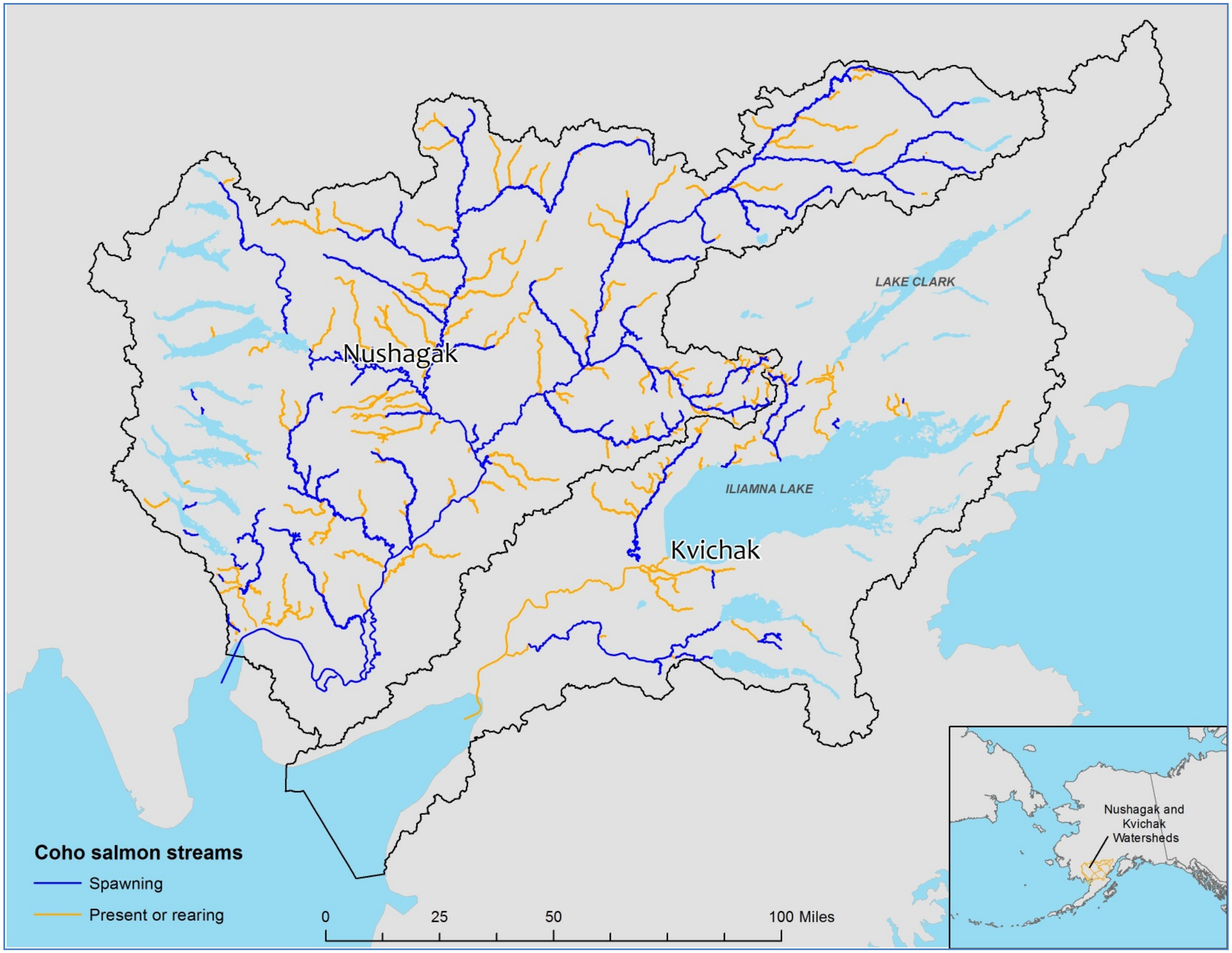

Figure 4. Documented coho salmon distribution in the Nushagak and Kvichak watersheds. Data are from the Alaska Department of Fish and Game's Anadromous Waters Catalog (AWC; Johnson and Blanche 2012).

Pink salmon

Pink salmon spawning populations occur on both sides of the North Pacific and Bering Sea, as far south as the Sacramento River and northern Japan. Northward, small spawning populations are scattered along the North American and Asian shores of the Arctic Ocean. Most pink salmon in the Kvichak and Nushagak watersheds spawn in mainstem habitats, although some tributary spawning occurs (Figure 5). The most abundant Pacific salmon overall (Irvine et al. 2009, pg. 2), pink salmon have a simplified life history that relies little on freshwater rearing habitat, and their young migrate to sea soon after emerging (Heard 1991, pg. 144). Pink salmon typically spawn in shallow, rocky stream reaches relatively low in the watershed, although most Nushagak River pink salmon spawn about 200 km above tidewater in the Nuyakuk River (Heard 1991, pg. 137).

Essentially all pink salmon breed at two years of age, and this strict two-year life cycle results in genetic isolation of odd- and even-year spawning runs, even within the same river system. For reasons not entirely clear, large disparities between odd- and even-year run sizes occur across geographic regions and extend over many generations. An extreme example is the Fraser River, in southern British Columbia, where millions of pink salmon return during odd-numbered years, yet no fish return during even-numbered years (Riddell and Beamish 2003, pg. 4). In Bristol Bay rivers, even-year runs currently dominate the returns (Salomone et al. 2011, pg. 5).

Pink salmon are the smallest of the Pacific salmon species; individuals in recent Bristol Bay commercial catches have averaged 3.6 lb (1.6 kg; Salomone et al. 2011, pg. 105). Sexually mature males become highly laterally compressed and develop a massive dorsal hump, hence the common name "humpy."

Chum salmon

Chum salmon spawn on both shores of the Bering Sea and North Pacific, extending south to the latitude of Japan and California (Salo 1991, pg. 234), with scattered spawning populations also occurring on the Asian and North American shores of the Arctic Ocean. Populations tend to be relatively large, and chum salmon are the third most abundant species, behind pink and sockeye salmon. Chum salmon spawn throughout the Nushagak and lower Kvichak watersheds (Figure 6).

Chum salmon, like pink salmon, migrate to sea soon after emerging from spawning gravel. Across their range, the vast majority spends two to four years at sea (Salo 1991, pg. 272). At sea, chum salmon consume a range of invertebrates and fishes, and gelatinous material is commonly found in stomachs leading to speculation that jellyfish may be a common prey item (Brodeur 1990, pg. 8, Azuma 1992). Individuals in recent Bristol Bay commercial catches have averaged 6.8 lb (3.1 kg, Salomone et al. 2011, pg. 105).

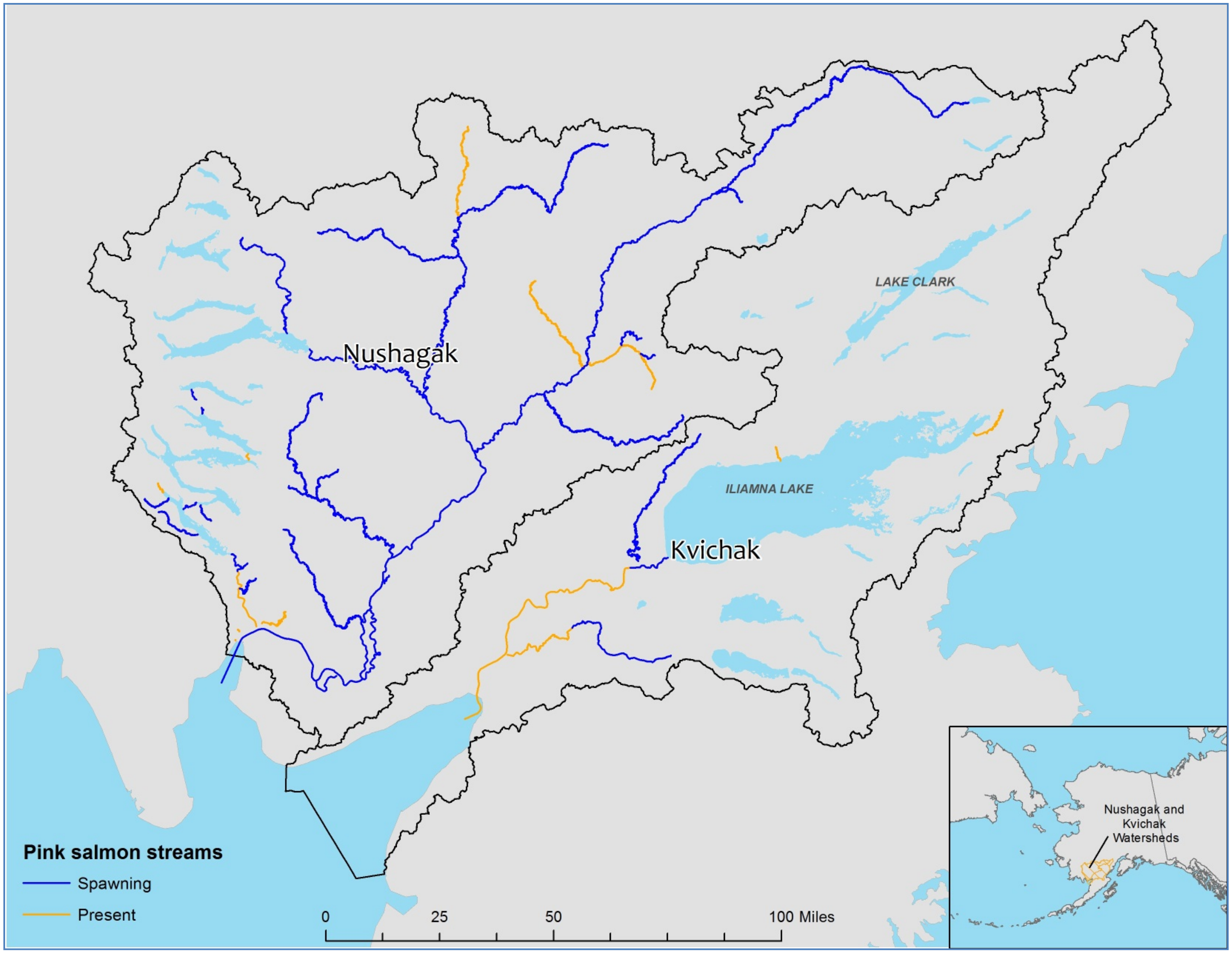

Figure 5. Documented pink salmon distribution in the Nushagak and Kvichak watersheds. Data are from the Alaska Department of Fish and Game's Anadromous Waters Catalog (AWC; Johnson and Blanche 2012).

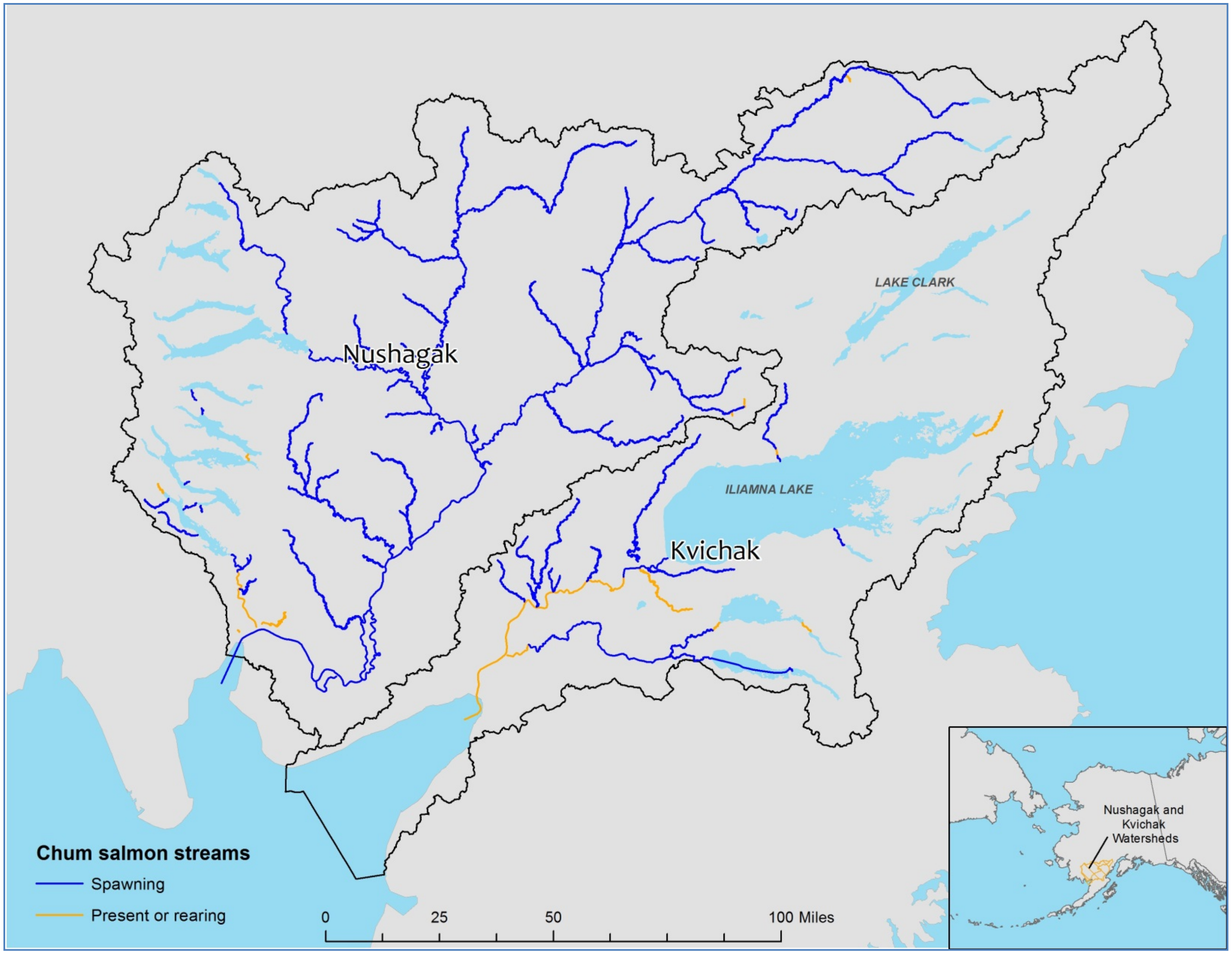

Figure 6. Documented chum salmon distribution in the Nushagak and Kvichak watersheds. Data are from the Alaska Department of Fish and Game's Anadromous Waters Catalog (AWC; Johnson and Blanche 2012).

BRISTOL BAY FISHERIES AND FISHERIES MANAGEMENT

Historical perspective on commercial salmon fisheries

Salmon have long been an important economic driver in Alaska's economy and have played an important role in the state's history. Commercial fishing interests were among the original supporters of the purchase of Alaska from Russia in 1867 (King 2009, pg. 1). The first canneries were established eleven years later, and by the 1920s salmon surpassed mining as Alaska's major industry as Alaska became the world's principal salmon producer (Ringsmuth 2005, pg. 21).

In the early years, fish packing companies essentially had a monopoly on the harvest of salmon. Packers in Bristol Bay and elsewhere built industrial fish traps, constructed of wood pilings and wire fencing with long arms that guided schools of migrating salmon into holding pens (King 2009, pg. 4). In Bristol Bay, packing interests also upheld a federal ban on fishing with power boats until 1951. Ostensibly a conservation measure, this law served to protect obsolete cannery-owned sailboat fleets by excluding independent Alaska-based fishermen who largely used power boats by this time (Troll 2011, pg. 39).

Salmon harvest peaked in 1936 then declined steadily for many years, leading to a federal disaster declaration in the 1950s (King 2009, pg. 1). A lack of scientific management, poor federal oversight, excessive harvest during World War II, and natural changes in ocean conditions contributed to the decline.

Declining salmon runs, along with Alaskans' desire for more control over their fisheries, was a significant factor in the drive toward Statehood (Augerot 2005, King 2009, pg. 2). In 1955, Alaskans began to develop a state constitution that included provisions intended to preserve Alaska's fisheries and, unique among state constitutions, to guarantee equal access to fish and game for all residents. Alaska became a state in 1959, the year that marked the lowest salmon harvest since 1900 (King 2009, pg. 3). Statehood was a turning point for Alaska's salmon fisheries, with the end of federal management, fish traps, and undue control of the resource by the canning industry. With the mandate for equal access came decentralization of the fishing industry, and thousands of individual fishermen began harvesting salmon for market to the canneries (Ringsmuth 2005, pg. 65).

When the Alaska Department of Fish and Game (ADF&G) assumed management of the fisheries in 1960, restoring salmon runs to their former abundance became a primary objective. Inventorying fish stocks, understanding basic ecology, and improving run strength forecasting were central research goals. Of particular importance was the development and application of methods for counting salmon runs in spawning streams, which allowed the establishment of escapement goals and management based on scientific principles of sustained yield. Bristol Bay salmon research has been conducted primarily by ADF&G staff and researchers at the University of Washington's Alaska Salmon Program (see http://fish.washington.edu/research/alaska/). The latter, funded largely by the salmon processing industry, began researching factors controlling sockeye salmon production in 1947. While the scope of their investigations has expanded over the years, sockeye monitoring is still a focus and represents the world's longest-running program for monitoring salmon and their habitats.

Over time, a number of state and federal policy changes have affected Bristol Bay salmon fisheries. A 1972 constitutional amendment set the stage for a bill that limited participation in Alaska commercial salmon fisheries. This legislation, designed to curb the expanding commercial fishery, set an optimum number of permits for each fishery, which were then issued by the State based on an individual's fishing history. Permits are owned by the individual fisherman and are transferable, making them a limited and valuable asset (King 2009, pg. 22). The Fishery Conservation and Management Act of 1976, commonly known as the Magnuson-Stevens Act, was introduced to Congress by the late senator Ted Stevens as a means to curtail high seas salmon fishing. In response to intensive Japanese gill netting in the western Aleutians and Bering Sea since 1952, this legislation extended America's jurisdiction from 12 to 200 miles (19 to 322 km) offshore. This ensured that salmon produced in Alaskan rivers would be harvested and processed locally and gave Alaska's fishery managers much more control in deciding when and where salmon are harvested. Both the Policy for the Management of Sustainable Salmon Fisheries and the Policy for Statewide Salmon Escapement Goals were adopted in the winter of 2000-2001 (Baker et al. 2009, pg. 2). The former established a comprehensive policy for the regulation and management of sustainable fisheries and the latter defined procedures for establishing and updating salmon escapement, including a process for public review of allocation disputes associated with escapement goals

The Alaska Department of Fish and Game is responsible for managing fisheries under the sustained yield principle. Fishing regulations, policies, and management plans are enacted by the Board of Fisheries, which it does in consultation with ADF&G, advisory committees, the public, and other state agencies. The Board of Fisheries consists of seven citizens, appointed by the governor and confirmed by the legislature, that serve three-year terms. Eighty-one advisory committees, whose members are elected in local communities around the state, provide local input. While regulations and management plans provide the framework for fisheries regulation, local fisheries managers are ultimately responsible for their execution. They are delegated authority to make "emergency orders," in-season changes to fishing regulations, which allow rapid adjustments to changing conditions, often with very short notice. Managers use them to provide additional protection to fish stocks when conservation concerns arise and to liberalize harvest when surplus fish are available. Management plans directed at specific fish stocks are often based on anticipated scenarios and give specific directions to managers, making the in-season management process predictable to ADF&G, commercial fishermen, and the public. Alaska's management of its salmon fishery has proven successful; it was the second fishery in the world to be certified as well managed by the Marine Stewardship Council (Hilborn 2006) and is regarded as a model of sustainability (Hilborn et al. 2003a, King 2009).

Current management of commercial salmon fisheries

While all five species of Pacific Salmon are harvested in Bristol Bay, sockeye salmon dominate the runs and harvest by a huge margin (Table 1). Salmon return predominately to nine major river systems, located on the eastern and northern sides of the Bay, and are harvested in five fishing districts in close proximity to the river mouths that allow managers to regulate harvest individually for the various river systems (Figure 1). The Naknek-Kvichak district includes those two rivers as well as the Alagnak. The Nushagak district includes the

Nushagak, Wood, and Igushik Rivers. The Egegik, Ugashik, and Togiak districts include the rivers for which they are named.

Table 1. Mean commercial harvest by species and fishing district, 1990-2009. Unpublished data, Paul Salomone, ADF&G Area Management Biologist.

	Naknek-Kvichak	Egegik	Ugashik	Nushagak	Togiak	Total
Sockeye	8,238,895	8,835,094	2,664,738	5,478,820	514,970	25,732,517
Chinook	2,816	849	1,402	52,624	8,803	66,494
Chum	184,399	78,183	70,240	493,574	158,879	985,275
Pink*	73,661	1,489	138	50,448	43,446	169,182
Coho	4,436	27,433	10,425	27,754	14,234	84,282

*Pink salmon data are from even-numbered years only since harvest is negligible during the smaller odd-year runs.

Fishing is conducted with drift or set gillnets. Drift gillnets have a maximum length of 150 fathoms (274 m) and are fished from boats no longer than of 32 ft. (9.8 m) in length. Set gillnets are fished from beaches, often with the aid of an open skiff, and have a maximum length of 50 fathoms (91 m). There are approximately 1900 drift gillnet permits and 1000 set gillnet permits in the Bristol Bay salmon fishery, of which around 90% are fished on a given year (1990-2010 average; Salomone et al. 2011, pg. 84).

The management of the Bristol Bay sockeye salmon fishery is focused on allowing an adequate number of spawners to reach each river system while maximizing harvest in the commercial fishery (Salomone et al. 2011, pg. 2). This balancing act is achieved through the establishment of escapement goals which represent the optimum range of spawners for a given river system. Escapement goals are established using a time series of spawner counts where a spawning run of a given size (i.e., stock) can be linked to the number of its offspring returning in subsequent years (i.e., recruits). Established stock-recruit models (Ricker 1954, Beverton and Holt 1957) are then used to estimate the stock size that results in the largest number of recruits, or the maximum sustained yield (Baker et al. 2009, pg. 4). In theory, spawning runs that are too small or large can result in reduced recruitment. With the former, too few eggs are deposited. With the latter, superimposition of spawning redds can diminish egg viability and competition in nursery lakes can reduce growth and survival. Once escapement goals are set, the timing and duration of commercial fishery openings are then adjusted during the fishing season (i.e., in-season management) to ensure that escapement goals are met and any additional fish are harvested. Escapement goals are periodically reviewed and updated based on regulatory policies, specifically, the Policy for the Management of Sustainable Salmon Fisheries and the Policy for Statewide Salmon Escapement Goals.

Each of Bristol Bay's nine major river systems has an escapement goal for sockeye salmon (Table 2), and in-season management of the commercial fishery is used to keep escapement in line with the goals. Management responsibility is divided among three managers: one for the Naknek, Kvichak, and Alagnak rivers; one for the Nushagak, Wood, Igushik, and Togiak rivers; and one for the Ugashik and Egegik rivers. Fishery openings are based on information from a number of sources, including preseason forecasts, the test fishery at Port Moller, the early performance of the commercial fishery, and in-river escapement monitoring.

Table 2. Bristol Bay escapement goal ranges for sockeye salmon.

River	Escapement range (thousands)
Kvichak	2,000–10,000
Alagnak	320 minimum
Naknek	800–1,400
Egegik	800–1,400
Ugashik	500–1,200
Wood River	700–1,500
Igushik	150–300
Nushagak-Mulchatna	370–840
Togiak	120–170

Preseason forecasts are the expected returns of the dominant age classes in a given river system, and they are based on the number of spawning adults that produced each age class. In the Port Moller test fishery, gill netting at standardized locations provides a daily index of the overall number of fish entering Bristol Bay (Flynn and Hilborn 2004), with approximately seven days' lead before they enter the commercial fishing districts. Genetic samples from the test fishery are analyzed within four days (Dann et al. 2009, pg. 3) to give managers an advance estimate of run strength for each of the nine major river systems. Test fisheries in selected districts give additional information on run strength and timing. As salmon move into fresh water, escapement is monitored with counting towers on each of the major rivers, except the Nushagak where a sonar system is used. Counting towers are elevated platforms along small to medium-sized (10-130 m wide), clear rivers from which migrating salmon are visually counted (Woody 2007). The Nushagak River's DIDSON sonar uses sound waves to detect and enumerate migrating salmon. Since tower and sonar monitoring occurs well upstream of the commercial fishery, all information regarding the performance of the fishery must be analyzed on a continual basis to ensure escapement levels will be met (Clark 2005, pg. 4, Salomone et al. 2011).

The fishery is typically opened on a schedule during the early part of the season, during which time the frequency and duration of openings are primarily based on preseason forecasts and management is conservative. As the fishing season progresses and more information becomes available, managers make constant adjustments to fishing time and area. If the escapement goal is exceeded at a given monitoring station, the fishery is opened longer and more frequently. If the escapement goal is not reached, the fishery is closed. Fishing time is opened and closed using emergency orders, and fishermen often learn of changes only a few hours before they go into effect. Since the bulk of the sockeye salmon harvest occurs during a short timeframe - from the last week of June until the middle of July - this short warning system is needed to maximize fishing time while ensuring that escapement levels are met. Migrating fish move quickly through the fishing districts, and delaying an opener by one day during the peak of the migration can forego the harvest of a million salmon. This is a significant loss of revenue to individual fishermen, and compounded by the missed revenue of workers, processors, and marketers (Clark 2005, pg. 5). The fishery will periodically close *de facto* during the peak of the season when catch rates exceed processing capacity and processors stop buying fish. This lack of buyers can also curtail salmon harvest early and late in the season when numbers of fish do not warrant keeping processing facilities operational.

In-season management is also used to help meet an escapement goal for Chinook salmon on the Nushagak River (Table 3), where escapement is monitored by sonar. There are also chum, coho, and pink salmon escapement goals on for the Nushagak River and Chinook salmon goals for the Alagnak and Naknek rivers (Table 3), but in-season management is not used to help attain these goals (Baker et al. 2009).

Bristol Bay salmon fisheries are regarded as a management success (Hilborn et al. 2003a, Hilborn 2006), and Hilborn (2006) lists four contributing factors: "(1) a clear objective of maximum sustainable yield, (2) the escapement-goal system, which assures maintenance of the biological productive capacity; (3) management by a single agency with clear objectives and direct line responsibility; and (4) good luck in the form of lack of habitat loss and good ocean conditions since the late 1970s."

Table 3. Bristol Bay escapement goal ranges for Chinook, chum, coho, and pink salmon.

River	Species	Escapement goal
Nushagak	Chinook	55,000–120,000
Nushagak	chum	200,000 minimum
Nushagak	coho	60,000–120,000
Nushagak	pink	165,000 minimum
Alagnak	Chinook	2,700 minimum
Naknek	Chinook	5,000 minimum

Description of sport fisheries

The sport fisheries in Bristol Bay's river systems are regarded as world class. A recent ADF&G report (Dye and Schwanke 2009) notes that "The BBMA [Bristol Bay Management Area] contains some of the most productive Pacific salmon, rainbow trout, Arctic grayling, Arctic char and Dolly Varden waters in the world. The area has been acclaimed for its sport fisheries since the 1930s." Similar views prevail in the popular sport fishing literature, where articles praising Bristol Bay as a destination are common. For example, *Fly Rod and Reel* (Williams 2006) says "No place on earth is wilder or more beautiful or offers finer salmonid fishing." Over the years, many other articles in *Field and Stream*, *Fly Fisherman*, *Fish Alaska*, *Fly Rod and Reel*, *Salmon Trout Steelheader*, *World Angler*, and other magazines have touted the high quality fishing and wilderness ambiance.

Large numbers of salmon and trout are caught in Bristol Bay's sport fisheries each year (see below), but the area is best known for its rainbow trout fishing. ADF&G (1990) notes that "Wild rainbow trout stocks of the region are world famous and are the cornerstone to a multimillion dollar sport fishing industry." Articles in the sport fishing press laud the trout fisheries, especially those of the Kvichak River drainage. *Fish Alaska* magazine calls the Iliamna system "One of the greatest trophy trout fisheries in the world…the crown of Alaska's sport fishing" (Weiner 2006) and names seven Bristol Bay drainages, five of which are in the Nushagak or Kvichak river basins, in a rundown of Alaska's top ten spots for trophy rainbow trout (Letherman 2003). Thirty-inch (76 cm) rainbow trout can be caught in many areas of the Kvichak River and other drainages (Randolph 2006) and 43% of clients at remote Bristol Bay sport fishing lodges reported catching a rainbow trout longer than 26 inches (66 cm) on their most recent trip (Duffield et al. 2006, pg. 48).

Unlike commercial fisheries, whose salient features tend to be readily quantifiable (e.g., economics, sustainability), the quality of a sport fishery can hinge on personal and subjective attributes. Despite the potential to catch high numbers of sizeable fish, Bristol Bay anglers rate aesthetic qualities as most important in selecting fishing locations. Of 11 attributes that capture different motivations and aesthetic preferences, including "catching and releasing large numbers of fish" and "chance to catch large or trophy-sized fish," Alaska resident and nonresident anglers picked the same top five: "natural beauty of the area", "being in an area with few other anglers", "being in a wilderness setting", "chance to catch wild fish", and "opportunities to view wildlife" (Duffield et al. 2006, pg. 45). The same priorities apply for nonresident anglers across Alaska (Romberg 1999, pg. 85).

The Bristol Bay region is not linked to the State's highway system and roads connected to the major communities provide very limited access. Small aircraft with floats are the primary source of access followed by boats based out of communities and remote lodges (Dye and Schwanke 2009, pg. 1). A range of services are available for recreational anglers. Anglers willing to pay $7,500 to $9,500 a week can stay in a plush remote lodge and fly to different streams each day with a fishing guide (Purnell 2011). Modest river camps, with cabins or wall tents, are a lower-budget option. Many self-guided expeditions center on multi-day raft trips that use chartered aircraft for transport to and from access points along a river.

Site-specific data regarding participation, effort and harvest have been collected from sport fishing guides and businesses since 2005 (Sigurdsson and Powers 2011). In 2010, the most recent year for which data are available, 72 businesses and 319 guides operated in the Kvichak and Nushagak watersheds (Table 4; Dora Sigurdsson, ADF&G, unpublished data). In addition, Table 4 shows figures for 2005, the first year of data collection, and 2008, a peak year.

Table 4. The number of businesses and guides operating in the Nushagak and Kvichak watersheds in 2005, 2008 and 2010.

Watershed	2005		2008		2010	
	Businesses	Guides	Businesses	Guides	Businesses	Guides
Kvichak River (including Alagnak River)	53	204	59	274	46	211
Nushagak River (including Wood River)	67	199	60	245	47	162
Kvichak and Nushagak combined[1]	91	336	92	426	72	319

[1] Business and guide totals are not additive because a business and/or guide can operate in multiple watersheds.

Management of sport fisheries

The Alaska Department of Fish and Game's Division of Sport Fish manages recreational fisheries in the Bristol Bay Management Area (BBMA), which includes all fresh waters flowing into Bristol Bay between Cape Menshikof, on the Bay's southeast shore, and Cape Newenham in the northwest. Four local management plans guide sport fishing regulations in the Bristol Bay region (in addition to several statewide plans). The Nushagak-Mulchatna King Salmon Management Plan, the Nushagak-Mulchatna Coho Salmon Management Plan and the Kvichak River Drainage Sockeye Salmon Management Plan call for sport fishing bag limit reductions or closures by emergency order during poor runs. The Southwest Alaska Rainbow Trout Management Plan recommended conservative trout management uniformly throughout the region, which replaced the fragmentary restrictions that had been established over the previous decades. Sport fishing regulations are updated annually and can be accessed on ADF&G's website: http://www.adfg.alaska.gov/index.cfm?adfg=fishregulations.sport.

The Division of Sport Fish uses the annual Statewide Harvest Survey, mailed to randomly-selected licensed anglers, to monitor effort, catch, and harvest. Between 1997 and 2008, angler-days of effort within the BBMA ranged from 83,994 to 111,838 (Dye and Schwanke 2009, pg. 4). Total annual sport harvest for the same period ranged from 39,362 to 71,539 fish, of which sockeye, Chinook and coho salmon comprise the majority (Dye and Schwanke 2009, pg. 8). Resident fish species, including rainbow trout, Dolly Varden, Arctic char, Arctic grayling, northern pike and whitefish, are also harvested in the BBMA (Dye and Schwanke 2009, pg. 8). Harvest rates are lower for these species than for salmon, likely due to restrictive bag limits and the popularity of catch-and-release fishing (Dye and Schwanke 2009, pgs. 6 and 8).

Chinook salmon

In the Nushagak drainage, the general season runs from May 1 to July 31 for Chinook salmon, although some areas close on July 24 in order to protect spawners. The daily limit is two per day, only one of which can be over 28 inches (71 cm). The annual limit is four fish. The Nushagak-Mulchatna King Salmon Management Plan calls for an in-river return of 75,000 fish with a spawning escapement of 65,000 fish. The guideline harvest for the sport fishery is 5,000 fish, although restrictions are triggered if the in-river return falls below 55,000 fish. In other Bristol Bay drainages, the daily limit for Chinook salmon is three and the annual limit is five, although there are additional restrictions in the Wood and Naknek river drainages.

The major Chinook salmon sport fisheries in the BBMA include the Nushagak, Naknek, Togiak and Alagnak rivers and the average annual harvest is 11,100 fish for the period from 1997 to 2008. The largest individual fishery takes place in the Nushagak River, where harvest from 2003 to 2007 averaged 7,281, approximately 58% of the total Bristol Bay sport harvest for that period (Dye and Schwanke 2009, pg. 13).

Sockeye salmon

Sockeye salmon fishing is open year round with a daily limit of five fish. Runs enter rivers starting in late June, peak in early July, and continue into late July or early August. The Kvichak River Drainage Sockeye Salmon Management Plan places restrictions on the sport fishery to avoid conflicts with subsistence users when the escapement falls below the minimum sustainable escapement goal of two million fish. Restrictions include actions such as reducing the daily limit for sockeye and closure of areas for sport fishing that are used by both subsistence and recreational anglers.

Sockeye are the most abundant salmon species in the BBMA. Recent annual sport harvest ranged from 8,444 to 23,002 fish (Dye and Schwanke 2009, pg. 22). The two locations that support the largest sport harvest are the Kvichak River, near the outlet of Iliamna Lake, and the Newhalen River, just above Iliamna Lake (Dye and Schwanke 2009, pg. 24). Other drainages that support moderate harvests of sockeye salmon include the Naknek and Alagnak rivers and the Wood River lake system (Dye and Schwanke 2009, pg. 22).

Rainbow trout

Due to their relatively small spawning populations and their popularity as a game fish, fishing regulations for rainbow trout are more restrictive than those for any other species. The Southwest Alaska Rainbow Trout Management Plan (ADF&G 1990) calls for conservative management, allows limited harvest in specific areas, and bans stocking of hatchery trout (although stocking had not been practiced previously). Special management areas were created to preserve a diversity of sport fishing opportunities: eight catch-and-release areas, six fly-fishing catch-and-release areas, and eleven areas where only single-hook artificial lures can be used (Dye and Schwanke 2009, pgs. 34-36).

In flowing waters throughout most of the Kvichak River drainage, only single-hook artificial lures can be used and sport fishing is closed from April 10 through June 7 to provide protection for spawning rainbow trout. From June 8 through October 31 anglers are allowed to keep one trout per day, with the exception of a number of streams where no harvest is allowed. From November 1 through April 9, when anglers are few, the daily limit increases to five fish although only one may be longer than 20 inches (51 cm). Rainbow trout fishing regulations are similarly restrictive in other drainages across the BBMA.

The most popular rainbow trout fisheries are found in the Kvichak drainage, the Naknek drainage, portions of the Nushagak and Mulchatna drainages, and streams of the Wood River Lakes system (Dye and Schwanke 2009, pg. 26). Field surveys and the Statewide Harvest Survey show that harvest has decreased over the past decade but that total catch and effort have remained stable or increased (Dye and Schwanke 2009, pg. 26). The annual BBMA-wide harvest between 1997 and 2008 averaged 1900 fish, but the catch estimate over this period was nearly 100 times greater (183,000 fish; (Dye and Schwanke 2009, pgs. 29 and 31). Although the fishery is widespread, approximately eighty percent of the total catch (144,400 fish) was from the eastern portion of the BBMA, where the Naknek and Kvichak systems are located. Eastern BBMA streams with estimated sport catches greater than 10,000 fish in 2008 included the Naknek, Brooks, Kvichak, Copper, and Alagnak rivers (Dye and Schwanke 2009, pg. 31).

SALMON ABUNDANCE TRENDS AROUND THE NORTH PACIFIC, WITH REFERENCE TO BRISTOL BAY POPULATIONS

Wild Pacific salmon, from most to least abundant, are pink, sockeye, chum, coho, and Chinook (Ruggerone et al. 2010). The relative abundance of Pacific salmon species relates to their life histories, as those species that are not constrained by the availability of stream rearing habitat (i.e., pink, sockeye, and chum salmon) are able to spawn and rear in greater numbers than those that are (i.e. coho and Chinook; Quinn 2005, pg. 319). The highest Pacific-wide salmon harvest occurred in 2007 and totaled 513 million fish, over 300 million of which were pink salmon (Irvine et al. 2009, pg. 2). Approximately five billion juvenile salmon are released annually from hatcheries around the North Pacific (Irvine et al. 2009, pg. 6), although none are reared or released in the Bristol Bay region.

Sockeye salmon

Size of Bristol Bay, Kvichak, and Nushagak sockeye salmon returns

Escapement monitoring within the Bristol Bay watershed has been conducted since the 1950s, when ADF&G established counting towers on the nine major river systems. When combined with commercial, subsistence and sport harvest, data from escapement monitoring allows estimates of total run sizes. A recent synthesis of salmon returns for 12 regions around the North Pacific also extends back to the 1950s, allowing comparisons of wild sockeye salmon returns between Bristol Bay and other regions for the period 1956 to 2005 (Ruggerone et al. 2010). The average global abundance of wild sockeye salmon over that period was 65.3 million (M) fish, and Bristol Bay constituted the largest proportion of that total at 46% (Figure 7). Total returns to Bristol Bay ranged from a low of 3.5 M in 1973 to a high of 67.3 M in 1980 (Figure 8), with an annual average of 29.8 M. The region with the second largest returns is southern British Columbia/Washington, which averaged 14% of the total (Figure 7), or 8.9 M salmon. Other regions that produce high abundances of wild sockeye salmon include the Kamchatka Peninsula, northern British Columbia, Cook Inlet and Kodiak Island (Ruggerone et al. 2010).

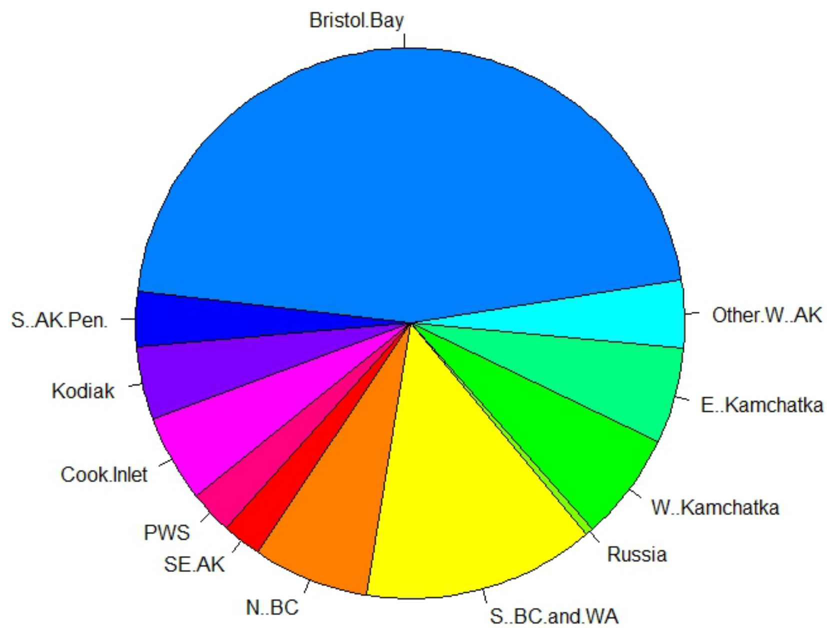

Figure 7. Relative abundance of wild sockeye salmon stocks in the North Pacific, 1956-2005. See Appendix 1 for data and sources. Stocks are ordered from west to east across the North Pacific.

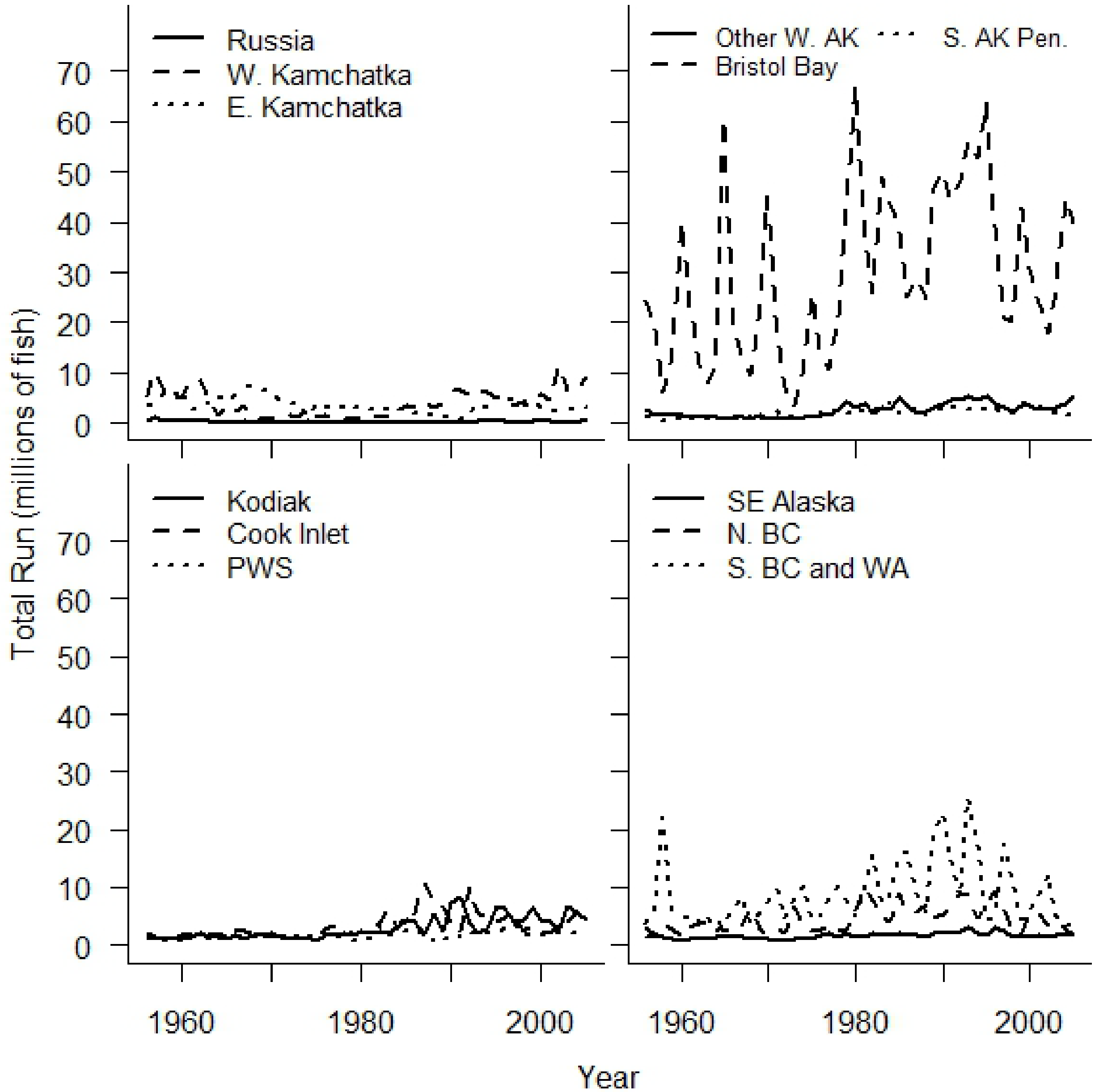

Figure 8. Wild sockeye salmon abundances by region in the North Pacific, 1956-2005. See Appendix 1 for data and sources. Each graph shows three regions organized from west to east across the North Pacific.

Hatchery production of sockeye salmon started in 1977 and accounted for an annual average of 3 M fish, or 4% of the world total, during the 10-year period from 1995 to 2005 (Ruggerone et al. 2010). No hatchery production has occurred in the Bristol Bay region. Regions with major hatchery production include Prince William Sound, Cook Inlet, and Kodiak Island, which produced a respective 1.0, 0.9 and 0.6 M hatchery fish, on average, from 1995-2005 (Ruggerone et al. 2010).

Although the Alagnak River is part of the Kvichak watershed and the Wood River is part of the Nushagak watershed, we report sockeye salmon data separately for these systems (unless noted otherwise) because ADF&G monitors returns on each. On average, the Kvichak River has the largest sockeye salmon run in Bristol Bay, with an average annual return of 10.4 M fish between 1956 and 2010 (Figure 9). Iliamna Lake provides the majority of the rearing habitat for sockeye in the Kvichak watershed, followed by Lake Clark where the estimated proportion of the escapement ranges from 7 to 30% (Young 2005, pg. 2). Runs exceeding 30 M fish have occurred three times in the Kvichak River: 47.7 M, 34.6 M and 37.7 M fish returned in 1965, 1970 and 1980, respectively (Tim Baker, ADF&G, unpublished data). Those runs accounted for 57%, 49% and 40% of world production of sockeye salmon during those years (Ruggerone et al. 2010). The Egegik River supports Bristol Bay's second largest run, with a mean annual return of 6.3 M fish from 1956 to 2010 (Figure 9). The Nushagak and Wood rivers are smaller runs and average returns from 1956 to 2010 were 1.3 and 3.3 M fish, respectively.

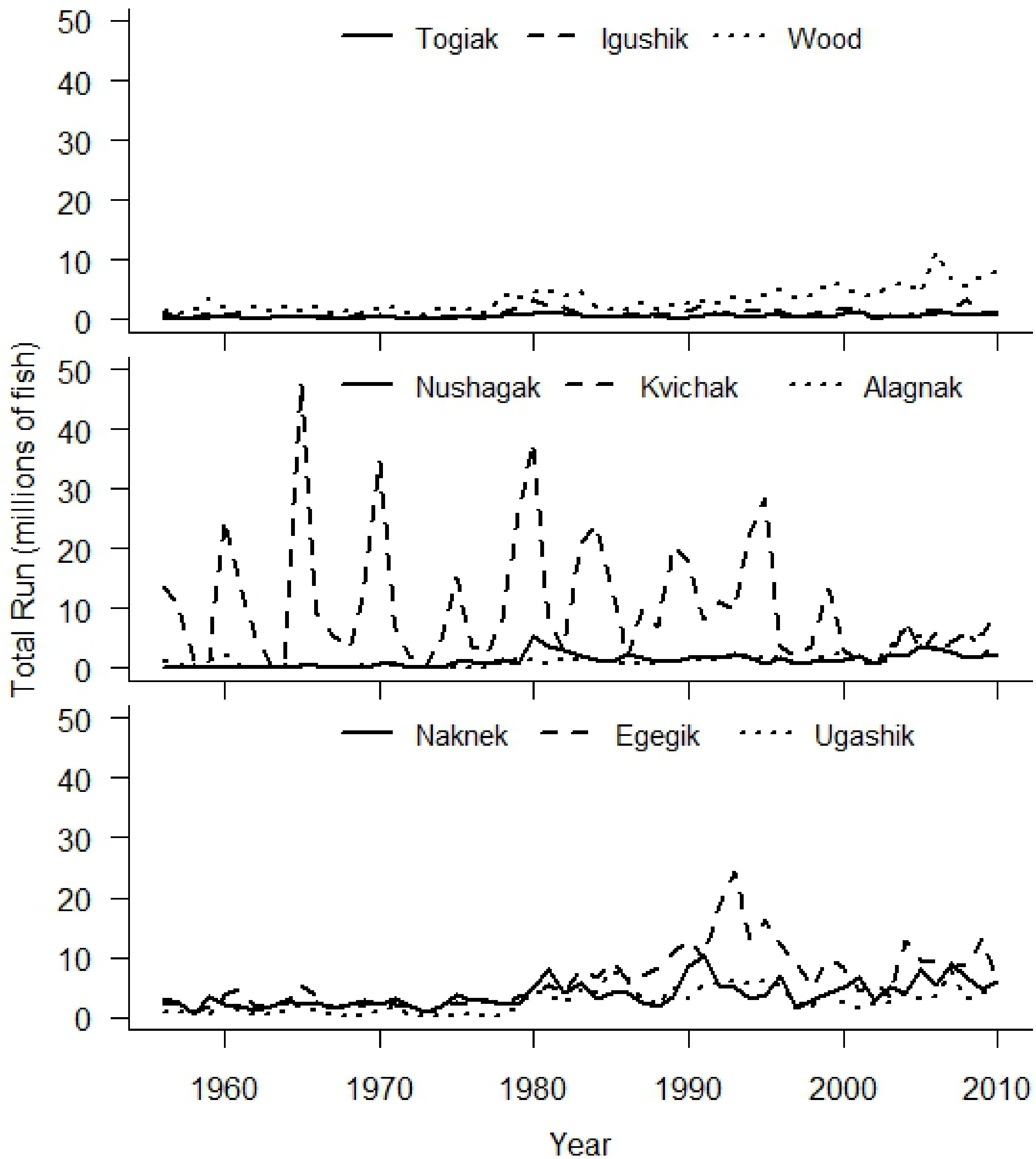

Figure 9. Total sockeye returns by river system in Bristol Bay, 1956-2010. See Appendix 1 for data and sources. Each graph shows three river systems listed from west to east across Bristol Bay.

The Kvichak River sockeye salmon runs are not only the largest in Bristol Bay, but also the largest in the world (Figures 8 through 10). As noted above, returns to the Kvichak River have averaged 10.4 M fish, and this number climbs to 11.9 M fish when returns to the Alagnak River are included (Tim Baker, ADF&G, unpublished data). The Fraser River system supports the world's second largest run, with an average of 8.1 M fish for the same period (Catherine Michielsens, Pacific Salmon Commission, unpublished data). Other major producers outside of Bristol Bay include the Copper, Kenai, Karluk, and Chignik rivers in Alaska and the Skeena River in British Columbia (Figure 10). The Kamchatka Peninsula in Russia also has rivers with large sockeye runs, but abundances for individual rivers were not readily available. The combined runs for the western and eastern Kamchatka Peninsula averaged less than 5 M sockeye during the period from 1952 to 2005 (Ruggerone et al. 2010).

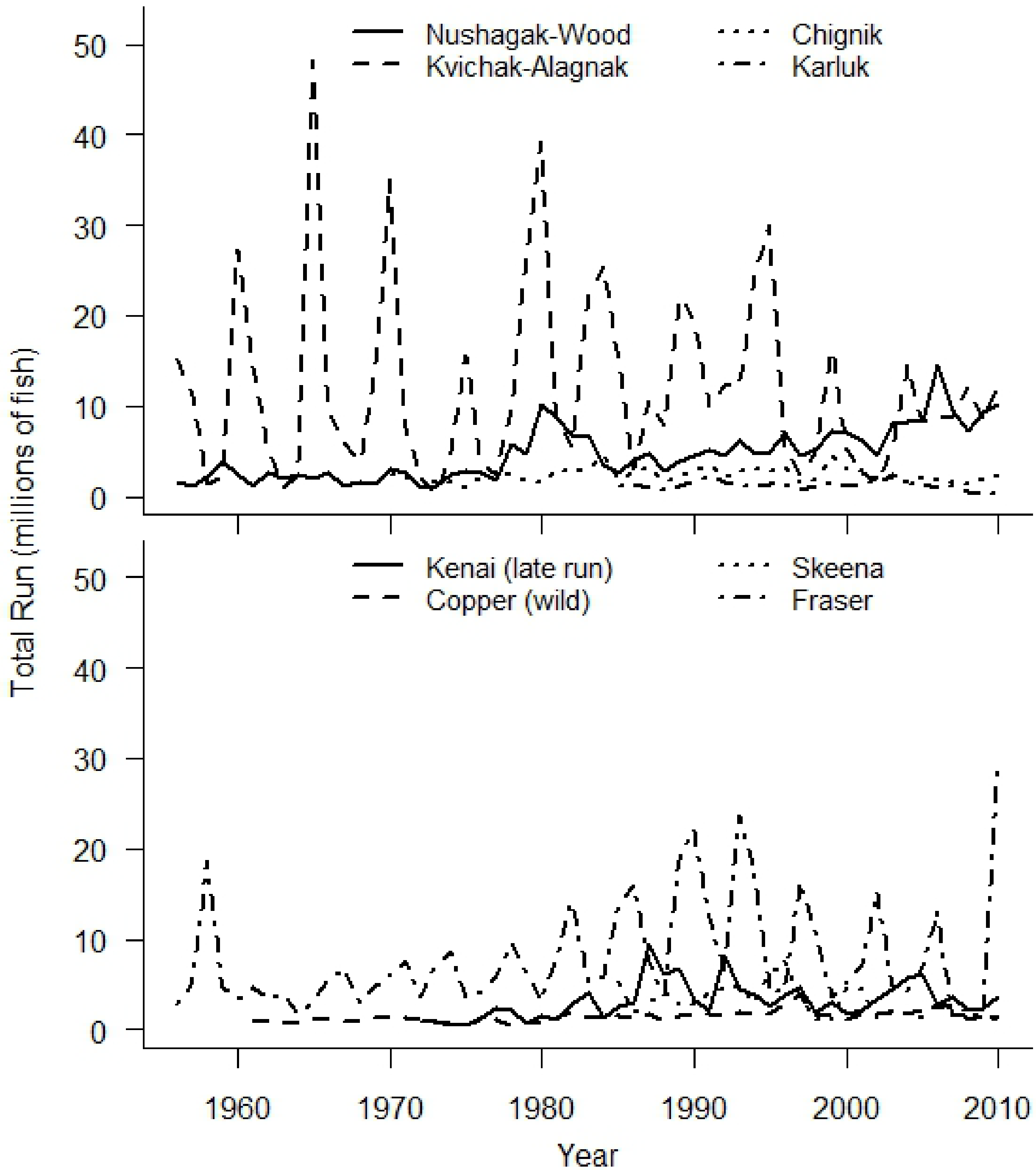

Figure 10. Sockeye salmon abundances for major rivers of the North Pacific, 1956-2010. See Appendix 1 for data and sources. The top graph includes time series for the Nushagak-Wood and Kvichak-Alagnak systems from 1956 to 2010, the Chignik River from 1970 to 2010, and the Karluk River from 1985 to 2010. The bottom graph shows the Kenai River late run from 1972 to 2010, the Copper River wild run from 1961 to 2010, the Skeena River from 1985 to 2010, and the Fraser River from 1956 to 2010. Rivers are listed in the graphs as they occur from west to east across the North Pacific.

Factors affecting Bristol Bay sockeye salmon abundance

Changes in the ocean and freshwater environments that affect sockeye salmon abundances and trends across the North Pacific are many. A major driver is the Pacific decadal oscillation (PDO), an inter-decadal pattern of correlated changes in sea-level pressures and sea-surface temperatures (Mantua et al. 1997). The warm phase of the PDO is characterized by warmer than average winter sea surface temperatures along the western coastline of North America and increased stream flows around the Gulf of Alaska, both of which are linked to increased salmon survival (Mantua et al. 1997, Ruggerone et al. 2007). There are three regime shifts documented in the recent climate record that correlate with salmon productivity: 1947, 1977 and 1989. From 1947 to 1977, the PDO was in a cool phase marked by low productivity for Alaskan and British Columbia sockeye salmon. The PDO shifted to a warm phase in 1977, after which most North American stocks increased (Figure 8). For Bristol Bay stocks, this warm phase corresponded with increased marine growth and, in turn, increased abundances and numbers of recruits (returning adults) generated per spawner (Ruggerone et al. 2007). Bristol Bay stocks more than doubled during this warm phase and remained high until the mid-90s, when declines in the Kvichak and other rivers reduced the overall abundance (Figure 4, Ruggerone et al. 2010). Biological indicators suggest that decreased productivity associated with a cool phase began in 1989, while climate indices point to a short-lived reversal from 1989 to 1991, followed by a return to a warm phase (Hare and Mantua 2000). Late marine growth and adult length-at-age of Bristol Bay sockeye decreased after the 1989 regime shift, potentially reducing stock productivity (Ruggerone et al. 2007).

Another factor affecting sockeye salmon productivity is competition with increasing numbers of hatchery smolts released into the North Pacific. Alaska produces the most hatchery pink salmon in the world, averaging 42 M fish for the period 1995 to 2005, followed next by Russia, with 12.6 M for the same period (Ruggerone et al. 2010). Approximately 75% of the pink salmon hatchery production in Alaska occurs in Prince William Sound, with other facilities located in Kodiak, Cook Inlet, and Southeast Alaska. Japan dominates the production of hatchery chum salmon, with 67.3 M fish returning on average for 1995 to 2005 (Ruggerone et al. 2010). Coming in a distant second behind Japan, Southeast Alaska averaged 9.7 M hatchery chum salmon for the same period (Ruggerone et al. 2010). Bristol Bay sockeye smolts that migrated to sea during even-numbered years and interacted with dominant odd-year Asian pink salmon experienced decreased growth, survival and adult abundance compared to the smolts that migrated during odd-numbered years (Ruggerone et al. 2003). Additionally, Kvichak sockeye salmon productivity was negatively correlated with a running three-year mean of Kamchatka pink salmon abundances (Ruggerone and Link 2006).

In the freshwater environment, spawning and rearing habitats can limit sockeye salmon populations through negative density dependence. The amount of suitable spawning habitat is limited within a given system, so when spawning densities are high and suitable spawning sites are occupied, females will dig nests on top of existing nests, dislodging many of the previously laid eggs, or die without spawning (Semenchenko 1988, Essington et al. 2000). As such, the amount of available spawning habitat can impose an upper limit on potential fry production. In nursery lakes, juvenile growth rates decrease with rearing densities (Kyle et al. 1988, Schindler et al. 2005a), leading to decreased survival for small individuals in the subsequent marine stage (Koenings et al. 1992). Together, these processes limit the number of recruits potentially produced by a large spawning run.

Kvichak sockeye abundances follow five-year cycles that are unique amongst the nine major systems of Bristol Bay. Previous hypotheses for the cycle included natural depensatory mechanisms, such as predation, and fishing-related depensation. Since the first escapement goal was established for the Kvichak River in 1962 until the most recent change in 2010, the escapement goals were managed to match the cycle year. Most recently, off-cycle years had an escapement goal range of 2 to 10 M spawners, while pre-peak and peak cycle years were managed for escapement of 6 to 10 M spawners (Baker et al. 2009, pg. 6). In 2010, the escapement goal was changed to one goal for all years of 2 to 10 M spawners. Ruggerone and Link (2006) recently analyzed the population characteristics of Kvichak sockeye and found that the cycle is likely perpetuated by three factors: density dependence during pre-peak and peak cycle years reducing productivity in off-cycle years, higher percentage interceptions in off-cycle years biasing productivity low, and the dominance of age 2.2 salmon (2 years in fresh water and two years in the ocean), which return after five years. Kvichak salmon were shown to have high interception rates in the Egegik and Ugashik fisheries in years when the Egegik and Ugashik returns were more than double the Kvichak return, which biased the number of returning recruits during off-cycle years. They did not find any evidence of natural depensatory mechanisms, nor did they find reason to believe that the change in the escapement goal in 1984 could have had any effect on the decline in the 1990s.

In recent years, ADF&G has developed genetic stock identification methods, which are being used to reanalyze past interceptions of Kvichak salmon from the mixed stock fisheries on the east side of the Bay (Dann et al. 2009, pg. 37). It is anticipated that current brood tables from which total runs by system are reconstructed will change as this analysis progresses (Tim Baker, ADF&G, personal communication) giving researchers a more accurate understanding of the dynamics of Bristol Bay stock composition and return dynamics.

The decline in Kvichak River sockeye salmon runs

From 1977 through 1995, during the warm PDO phase, Bristol Bay runs averaged almost 41 M fish annually, while runs to the Kvichak River averaged nearly 15 M, comprising about 36% of the entire Bristol Bay run (Table 5). Beginning in 1996, with the spawning return of the 1991 brood year, Kvichak runs dropped to an average of 4.7 M fish, comprising less than 14% of the total Bristol Bay run (Table 5). This decline was accompanied by a decline in stock productivity, as expressed by the number of recruits generated per spawner (R/S). Bristol Bay systems averaged approximately two recruits for every spawner prior to the 1977 regime shift, and R/S increased substantially for many systems, such as the Egegik and Ugashik rivers, during the subsequent warm phase (Hilborn 2006). R/S for the Kvichak averaged 3.2 for the 1972 to 1990 broods, but five of the nine broods from 1991 onward failed to replace themselves (i.e., R/S <1). Productivity also decreased during this time in two other systems on the east side of Bristol Bay, the Egegik and Ugashik rivers (Ruggerone and Link 2006). The decline in the Kvichak River run led ADF&G to classify it as a stock of yield concern in 2001 (Morstad and Baker 2009, pg. 1), indicating an inability to maintain a harvestable surplus. The Kvichak run was further downgraded to a stock of management concern in 2003, based on failure to meet escapement goals.

Table 5. Mean annual returns of sockeye salmon in Bristol Bay, 1956-2010, and percent of total by river system. See Appendix 1 for data and sources. Rivers are listed from east to west across Bristol Bay.

Rivers	1956-1976	%	1977-1995	%	1996-2010	%	1956-2010	%
Ugashik	882,458	4.6	4,123,115	10.1	3,522,697	10.1	2,722,023	8.8
Egegik	2,320,059	12.0	9,100,953	22.2	8,402,365	24.1	6,321,361	20.4
Naknek	2,200,534	11.4	4,454,164	10.9	5,251,810	15.1	3,811,227	12.3
Alagnak	514,544	2.7	1,360,651	3.3	3,008,922	8.6	1,487,121	4.8
Kvichak	10,482,754	54.3	14,784,340	36.1	4,757,008	13.7	10,407,190	33.6
Nushagak	392,574	2.0	1,919,420	4.7	1,933,461	5.6	1,340,272	4.3
Igushik	516,021	2.7	1,349,775	3.3	1,341,581	3.9	1,029,198	3.3
Wood	1,707,120	8.8	3,150,620	7.7	5,834,787	16.8	3,331,511	10.7
Togiak	305,069	1.6	661,011	1.6	742,696	2.1	547,384	1.8
Total	19,321,134		40,904,050		34,795,327		30,997,285	

Ruggerone and Link (2006) analyzed the decline in the Kvichak run starting with the 1991 brood year and identified a number of potential factors. The number of smolts per spawner declined by 48% and smolt-to-adult survival declined by 46%, suggesting that factors in both freshwater and marine habitats were involved. The average number of smolts out-migrating from the Kvichak River during the years 1982 to 1993 was approximately 150 M, which declined to an approximate average of 50 M from 1994 to 2001 (Ruggerone and Link 2006). The declines were accompanied by a shift in the dominant age structure of Kvichak spawners from 2.2 (i.e., two years in fresh water followed by two years at sea), which represented an average of 84% of the return, to 1.3, indicating that salmon were spending less time in fresh water and more time at sea. Across the nine monitored Bristol Bay watersheds, the decrease in the percentage of 2.2 salmon in the total return correlated strongly with decreases in R/S and run size. The decrease in spawner length at age starting in 1991 and higher than normal sea surface temperatures in June from 1990-1998 both may have contributed to lower reproductive potential, since smaller females produce fewer eggs. Competition with Asian pink salmon also may have played a role. Abundances of Asian pink salmon have been linked to decreased size at age of returning Bristol Bay sockeye salmon in addition to decreased abundance during even-year migrations when interactions are highest (Ruggerone et al. 2003). Abundances of Kamchatka pink salmon were high from 1994 to 2000, the beginning of which correlates to age-1 smolts from the 1991 brood year. The three eastern Bristol Bay stocks that experienced the largest declines during the 1990s (Kvichak, Egegik and

Ugashik rivers) have greater overlap with Asian pink salmon stocks in their marine distribution than other stocks that did not decline significantly (Ruggerone and Link 2006, pg. 31).

Ultimately, conditions outside of the freshwater environment likely led to the decline of Kvichak sockeye salmon. Warmer summer temperatures in both fresh water (Schindler et al. 2005a) and the ocean (Hare and Mantua 2000) and interactions with Asian pink salmon affected Kvichak sockeye salmon disproportionately to other systems due to the dominance of ocean-age-two salmon in the Kvichak watershed (Ruggerone and Link 2006, pg. 12). Because ocean-age-two salmon interact with only one Asian pink salmon population at sea, the effects on growth and abundance are greater than for ocean-age-three salmon, which interact with both large (even) and small (odd) Asian pink salmon populations at sea and thus, have the opportunity for higher growth rates during odd years (Ruggerone et al. 2003). The decrease in spawner to smolt survival may also be related to marine conditions causing smaller length at age of returning adults and reduced reproductive success (Ruggerone and Link 2006, pg. 15).

In 2009, following several years of improvement, ADF&G upgraded the Kvichak's classification to a stock of yield concern (Morstad and Baker 2009). Since 2004, Bristol Bay returns have again totaled more than 40 million fish annually and in 2010 the Kvichak run increased to over 9.5 million fish, equating to 23% of the total for the Bay.

Chinook salmon

The total commercial harvest of Chinook salmon in the North Pacific ranged between three and four million fish until the early 90s; recent total catches have decreased to one to two million fish (Eggers et al. 2005). Lacking escapement data for many runs, commercial harvest is a good surrogate for salmon abundance, and suggests a decline in Chinook salmon abundance in recent decades. The U.S. makes over half of the total commercial catch, followed by Canada, Russia, and Japan (Heard et al. 2007). Recreational, subsistence, and aboriginal catch is significant for this salmon species and totaled approximately one million annually in 2003-2004 (Heard et al. 2007). Washington dominates hatchery production of Chinook salmon, with over one billion juveniles released annually from 1993-2001 (Heard et al. 2007).

The Columbia River historically produced the largest Chinook salmon run in the world, with peak runs (spring, summer, and fall combined) estimated at 3.2 M fish during the late 1800s (Chapman 1986). Peak catches for the Columbia River summer-run Chinook salmon occurred at this time, until overfishing decimated the run. Fishing effort then shifted to the fall run, which suffered a similar demise in the early 1900s. There are currently five stocks of Chinook salmon in the Columbia River watershed listed under the Endangered Species Act and the majority of the current returns are hatchery fish (70%, 80% and 50% of the spring, summer and fall runs, respectively; Heard et al. 2007).

Currently, the largest runs of Chinook salmon in the world originate from three of the largest watersheds that drain to the North Pacific: the Yukon, Kuskokwim and Fraser rivers (Table 6). Total Chinook escapements to the Kuskokwim and Yukon rivers have not been quantified directly due to their large watershed area, but recent total run estimates based on mark-recapture studies put them at 217,000 and 265,000 fish, respectively (Molyneaux and Brannian 2006, pg. 102, Spencer et al. 2009, pg. 28). On the Fraser River, the average size of the spring, summer, and fall Chinook runs combined (including the Harrison River) for the most recent ten-year period (2000-2009) was 287,000 fish (PSC 2011, pg. 87).

Table 6. Nushagak River Chinook average run sizes for 2000-2009, in comparison to other rivers across the North Pacific. Other rivers are sorted in order of decreasing run size.

Watershed	Region	Average run size (2000-2009)	Area[15] (km^2)
Nushagak R.	Bristol Bay, Western Alaska	151,348 [1]	31,383
Fraser R., total run	British Columbia, Canada	287,475 [2]	233,156
Kuskokwim R., total run	Western Alaska	284,000 [3]	118,019
Yukon R., total run	Western Alaska	217,405 [4]	857,996
Harrison R. (trib. of Fraser R.)	British Columbia, Canada	98,257 [5]	7,870
Taku R.	Southeast Alaska	78,081 [6]	17,639
Copper R.	Southcentral Alaska	75,081 [7]	64,529
Kenai R. (early and late runs)	Southcentral Alaska	70,976 [8]	5,537
Skeena R.	British Columbia, Canada	63,356 [9]	51,383
Yukon R., Canadian mainstem	Yukon Territory, Canada	59,346 [10]	323,800
Nass R.	British Columbia, Canada	31,738 [11]	20,669
Grays Harbor (Chehalis R. + 5 others)	Washington	23,964 [12]	6,993
Skagit R.	Washington	18,286 [13]	8,234
Nehalem R.	Oregon	12,267 [14]	2,193

[1] Unpublished data, Gregory Buck, ADF&G
[2] Pacific Salmon Commission 2011, pg. 88
[3] Unpublished data, Kevin Schaberg, ADF&G
[4] Average from 2000-2004, Spencer et al. 2009, pg. 28
[5] Pacific Salmon Commission 2011, pg. 88
[6] McPherson et al. 2010, pg. 14
[7] Unpublished data, Steve Moffitt, ADF&G
[8] Begich and Pawluk 2010, pg. 69
[9] Pacific Salmon Commission 2011, pg. 87
[10] Howard et al. 2009, pg. 35
[11] Pacific Salmon Commission 2011, pg. 87
[12] Pacific Salmon Commission 2011, pg. 90
[13] Pacific Salmon Commission 2011, pg. 89
[14] Pacific Salmon Commission 2011, pg. 93
[15] Watershed area from the Riverscape Analysis Project 2010 (http://rap.ntsg.umt.edu).

Chinook sport and commercial harvests in the Nushagak River are larger than all of the other systems in Bristol Bay combined (Dye and Schwanke 2009, pg. 13, Salomone et al. 2011, pg. 86). The Nushagak produces entirely wild runs that are periodically at or near the world's largest (Figure 8), which is remarkable considering its relatively small watershed area (Table 6). Returns consistently number over 100,000 fish, while returns greater than 200,000 fish have occurred eleven times between 1966 and 2010 (Figure 11). An especially productive six-year period from 1978-1983 produced three returns greater than 300,000 fish (Figure 11). Other rivers that produce large returns of Chinook salmon include the Copper, Kenai, and Taku rivers in Alaska and the Skeena and Harrison rivers in British Columbia (Table 6). The Harrison River is the dominant fall run stock for the Fraser River.

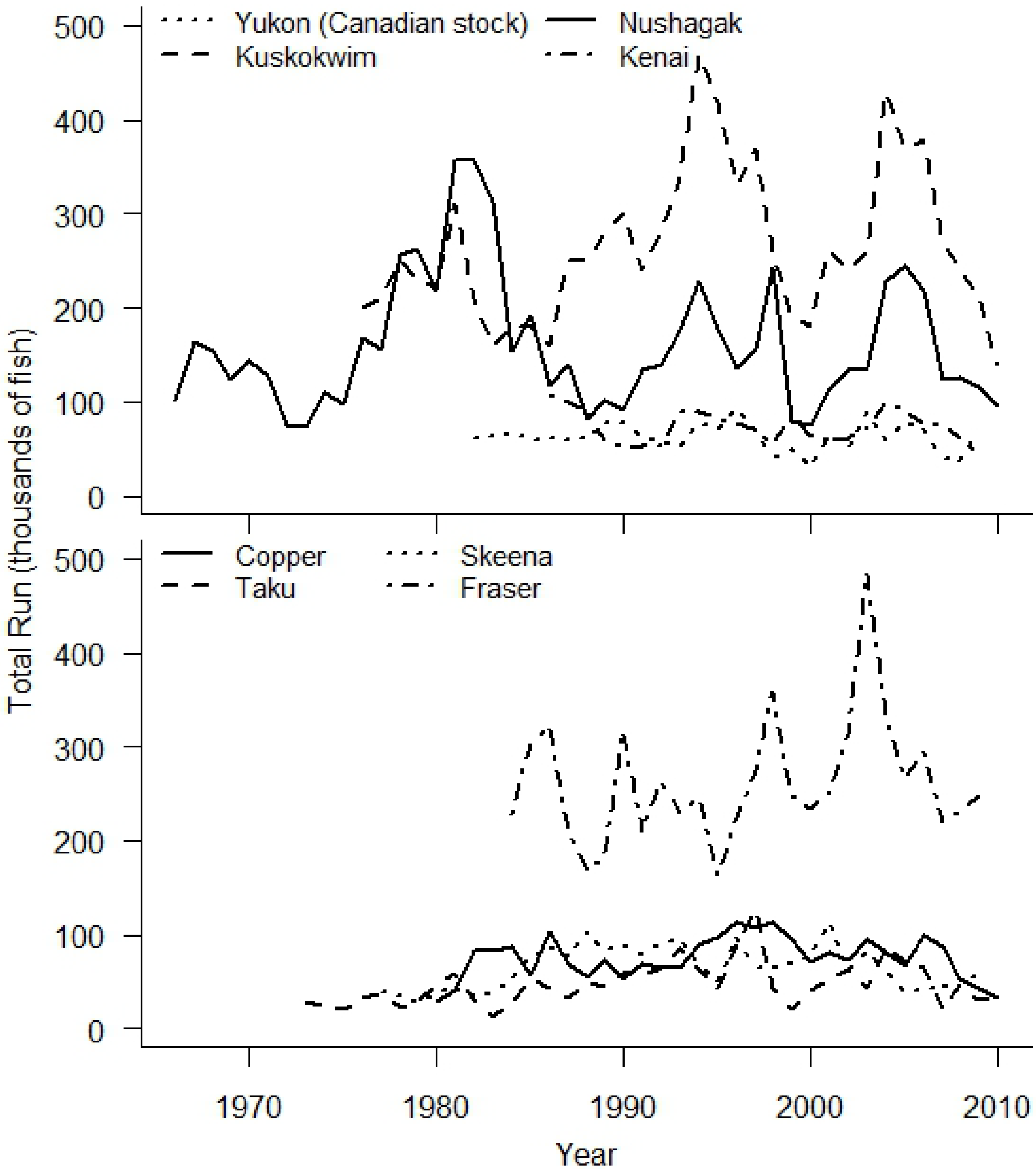

Figure 11. Chinook salmon abundances by river system, 1966-2010. See Appendix 1 for data and sources. The top graph shows total runs for the Yukon River (Canadian stock) from 1982 to 2009, the Kuskokwim River from 1976 to 2010, the Nushagak River from 1966 to 2010, and the Kenai River from 1986 to 2010. The bottom graph shows total runs for the Copper River from 1980 to 2010, the Taku River from 1973 to 2010, the Skeena River from 1977 to 2009, and the Fraser River from 1984 to 2009. Rivers are organized from west to east across the North Pacific.

A sustainable escapement goal (SEG) was implemented for Nushagak Chinook salmon in 2007 with a target of 40,000 to 80,000 fish. Sonar counts used to estimate escapement were initiated in 1989 and since that time, the Nushagak run has consistently met the minimum escapement for the current SEG and was over the SEG 12 times (Gregory Buck, ADF&G, unpublished data). The Nushagak Chinook stock is considered stable (Heard et al. 2007, Dye and Schwanke 2009, pg. 17), in contrast to Chinook stocks on the Kuskokwim and Yukon rivers, which experienced declines starting in the late 1990s. Both the Yukon and Kuskokwim Chinook were listed as stocks of yield concern in 2000 (Estensen et al. 2009, pg. 2, Howard et al. 2009, pg. 1). The Yukon River stock is still listed but the Kuskokwim River Chinook stock was delisted as a stock of concern in 2007, based on higher than normal returns starting in 2004 (Estensen et al. 2009, pg. 2).

The decline in Yukon and Kuskokwim Chinook stocks that began in the late 1990s may have resulted from the 1997-1998 El Nino (Kruse 1998b, Myers et al. 2010 pg. 199). That event was characterized by sea surface temperatures at least 2° C higher than normal in the Bering Sea, along with weak winds and high solar radiation that led to two anomalous phytoplankton blooms, typically associated with nutrient-limited waters (Kruse 1998a). The decline in Chinook stocks that persisted after the 1997-1998 El Nino indicate that multiple ocean age classes were affected by this event (Ruggerone et al. 2009). Alternative hypotheses for these declines have been proposed, including density-dependent effects, freshwater mortality, spawner fitness, and pathogens, leading to calls for additional research (e.g., Schindler et al. 2013).

Chinook salmon hatchery production contributes to harvests in both southeast and southcentral Alaska. The average number of returning hatchery Chinook salmon in Alaska for 2000 to 2009 was 118,000 fish annually and, in 2009, hatchery Chinook salmon contributed 16% of the total commercial harvest for the State (White 2010). There are no salmon hatcheries located in western Alaska and none of the total runs for the Alaskan rivers listed in Figure 11 or Table 6 include contributions from hatcheries (Yukon, Kuskokwim, Nushagak, Kenai, Copper, and Taku rivers). Salmon enhancement programs for Chinook salmon in British Columbia are significant; for the period 1990 to 2000, hatchery releases averaged approximately 50 million fish annually and hatcheries contributed approximately 30% to the total Canadian catch (MacKinlay et al. Undated). The Chehalis River hatchery in the Harrison River watershed and the Chilliwack River, Inch Creek, and Spius Creek hatcheries in the Fraser River watershed all contribute to the Chinook salmon runs on those systems (FOC 2011).

Threatened and endangered salmon and conservation priorities

Although it is difficult to quantify the true number of extinct salmon populations around the North Pacific, estimates for the Western United States (California, Oregon, Washington and Idaho) have ranged from 106 to 406 populations (Nehlsen et al. 1991, Augerot 2005, pg. 65, Gustafson et al. 2007). Chinook had the largest number of extinctions followed by coho and then either chum or sockeye (Nehlsen et al. 1991, Augerot 2005, pg. 67). Many of the patterns of population extinction are related to time spent in fresh water: interior populations have been lost at a higher rate than coastal populations, stream-maturing Chinook and steelhead (which may spend up to nine months in fresh water before spawning) had higher losses than their ocean-maturing counterparts, and species that relied on fresh water for rearing (Chinook, coho, and sockeye) had higher rates of extinction than pink or chum salmon, which go to sea soon after emergence (Gustafson et al. 2007). No populations from Alaska are known to have gone extinct. Salmon populations in the southern extent of their range have suffered higher extinction rates and are considered at higher risk than populations further to the north (Brown et al. 1994, Kope and Wainwright 1998, Rand 2008, Rand et al. 2012).

In addition to the large number of populations now extinct, there are many that are considered at risk due to declining population trends. The Columbia River basin dominated the list of at risk stocks identified by Nehlson et al. (1991), contributing 76 stocks to the total of 214 for California, Oregon, Washington, and Idaho. Approximately half of the 214 stocks evaluated were listed as high risk because they failed to replace themselves (fewer than one recruit per spawner) or had recent escapements below 200 individuals. More recent analyses of the status of salmon populations in the North Pacific continue to highlight the declines in the Pacific Northwest. A detailed assessment of salmon populations in the Columbia River basin from 1980 to 2000 showed that many are declining and this trend is heightened when hatchery fish are excluded (McClure et al. 2003). A comparison between time periods reflecting both good and bad ocean productivity for Columbia River salmon populations further indicates that the declining trends are not due to the regime shift of 1977 (McClure et al. 2003). An analysis of over 7,000 stocks across the North Pacific found that over 30% of sockeye, Chinook, and coho stocks were at moderate or high risk and that the Western U.S. (Washington, Oregon, California, and Idaho) had the highest concentrations of high-risk stocks (Augerot 2005, pgs. 66-67).

A detailed assessment of sockeye salmon populations across the North Pacific highlights threats for this species in British Columbia (Rand 2008, Rand et al. 2012). At the global population level, sockeye salmon are considered a species of least concern. Ninety-eight subpopulations were identified for assessment, five of which are extinct and 31 did not have the necessary data with which to conduct a status assessment. Of the remaining 62 subpopulations, 19 were identified as threatened (critically endangered, endangered, or vulnerable) and two as nearly threatened. British Columbia has 15 threatened (vulnerable, endangered, or critically endangered) subpopulations, 79% of the worldwide total. Three key threats to sockeye salmon were identified: mixed stock fisheries that lead to high harvests of small, less productive populations; poor marine survival rates and high rates of disease in adults due to changing climatic conditions; and negative effects of enhancement activities such as hatcheries and spawning channels (Rand 2012). Twenty six subpopulations were assessed for Alaska: 10 were data deficient, 13 were of least concern (including the one subpopulation identified for Bristol Bay), and two populations were listed as vulnerable; one subpopulation in the eastern Gulf of Alaska and the Lake McDonald population in Southeast Alaska. The Hugh Smith Lakes subpopulation in Southeast Alaska was listed as endangered. Both the Hugh Smith and McDonald Lake populations were listed as stocks of management concern by ADF&G in 2003 and 2009, respectively (Piston 2008, pg. 1, Eggers et al. 2009, pg. 1). Both were de-listed within four years after runs met escapement goals for several consecutive years following implementation of successful fishing restrictions (Piston 2008, pg. 1, Regnart and Swanton 2011).

Government agencies in the United States and Canada are tasked with identifying and protecting salmon populations at risk. In the U.S., the National Marine Fisheries Service (NMFS) manages listings of salmon species under the Endangered Species Act (ESA). Salmon stocks considered for listing under ESA must meet the definition of an Evolutionarily Significant Unit (ESU): it must be substantially reproductively isolated from other nonspecific population units and it must represent an important component of the evolutionary legacy of the species (Federal Register 58612, November 20, 1991). Current determinations for the U.S. include one endangered and one threatened ESU for sockeye; two threatened ESUs for chum; one endangered, three threatened, and one ESU of concern for coho; two endangered, seven threatened, and one ESU of concern for Chinook; and one endangered, ten threatened, and one ESU of concern for steelhead (Table 7, NMFS 2010). All listed ESUs occur in the western contiguous U.S. (California, Oregon, Washington, and Idaho). In Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) conducts status assessments to determine if a species is at risk nationally. The Minister of the Environment and the federal cabinet then decide whether to list the species under the Species at Risk Act (SARA). Currently, COSEWIC status assessments have recommended listing two endangered sockeye salmon populations, one endangered coho salmon population, and one threatened Chinook salmon population, but none of these assessments have resulted in legal listings under SARA (COSEWIC 2009). On the Asian side of the Pacific, no information was found regarding listings of threatened or endangered salmon populations under a legal framework. Other assessments of Asian salmon distribution and status have relied on interviews with fishery biologists due to the scarcity of data and the dominance of hatcheries in Japanese fisheries (Augerot 2005, pg. 66, Rand 2008).

Table 7. Endangered Species Act listings for salmon ESUs in the United States.

Species	ESU Name	ESA Listing Status	Date of Most Recent Review
Chinook	Sacramento River Winter-run	endangered	8/15/2011
Chinook	Upper Columbia River Spring-run	endangered	8/15/2011
Chinook	California Coastal	threatened	8/15/2011
Chinook	Central Valley Spring-run	threatened	8/15/2011
Chinook	Lower Columbia River	threatened	8/15/2011
Chinook	Puget Sound	threatened	8/15/2011
Chinook	Snake River Fall-run	threatened	8/15/2011
Chinook	Snake River Spring/Summer-run	threatened	8/15/2011
Chinook	Upper Willamette River	threatened	8/15/2011
Chinook	Central Valley Fall- and Late Fall-run	species of concern	4/15/2004
chum	Hood Canal Summer-run	threatened	8/15/2011
chum	Columbia River	threatened	8/15/2011
coho	Central California Coast	endangered	8/15/2011
coho	Southern OR/Northern CA Coasts	threatened	8/15/2011
coho	Lower Columbia River	threatened	8/15/2011
coho	Oregon Coast	threatened	8/15/2011
coho	Puget Sound/Strait of Georgia	species of concern	4/15/2004
sockeye	Snake River	endangered	8/15/2011
sockeye	Ozette Lake	threatened	8/15/2011
steelhead	Southern California	endangered	1/5/2006
steelhead	California Central Valley	threatened	8/15/2011
steelhead	Central California Coast	threatened	1/5/2006
steelhead	Lower Columbia River	threatened	8/15/2011
steelhead	Middle Columbia River	threatened	8/15/2011
steelhead	Northern California	threatened	1/5/2006
steelhead	Puget Sound	threatened	8/15/2011
steelhead	Snake River Basin	threatened	8/15/2011
steelhead	Southcentral California Coast	threatened	1/5/2006
steelhead	Upper Columbia River	threatened	8/15/2011
steelhead	Upper Willamette River	threatened	8/15/2011
steelhead	Oregon Coast	species of concern	4/15/2004

The causes leading to extinction and continued population declines are numerous and analyses are confounded by the effects of interacting factors within watersheds. In California, both the building of dams that eliminated access to upstream spawning and rearing areas and destruction of coastal habitat from extensive logging were major contributors to the decline of coho salmon populations in the southern extent of their range (Brown et al. 1994). Heavy fishing pressure at the end of the 19^{th} century followed by extensive impacts to river habitats from agriculture, logging, mining, irrigation and hydroelectric dams all led to the extensive decline of Columbia River salmon by the mid 20th century (Chapman 1986, McConnaha et al. 2006).

Restoration activities to help restore salmon habitat and populations in the Pacific Northwest require huge expenditures with results that are often difficult to measure due to annual variation, the time lapse between restoration action and effect on the population, and changing climate and ocean conditions (GAO 2002, pg. 4). Approximately $1.5 billion was spent on Columbia River salmon and steelhead for the period 1997 through 2001 (GAO 2002, pg. 2). Predicted outcomes from restoration rarely take into account climate change scenarios. Models developed to predict the outcome of restoration on Snohomish basin Chinook salmon habitat showed that increased temperatures resulting from climate change changed snow to rain in high elevation watersheds and affected three hydrologic parameters that decreased fish populations: higher flows during egg incubation, lower flows during spawning, and increased temperatures during pre-spawning (Battin et al. 2007). Often used as mitigation for lost habitat, salmon hatcheries have resulted in decreased survival of the wild populations they are intended to support (NRC 1996, pg. 319, Naish et al. 2008). Impacts of hatchery fish include overfishing of wild populations in mixed-stock fisheries (Hilborn and Eggers 2000), competition with wild salmon in both fresh water and the ocean (Ruggerone and Nielsen 2009), and a reduction in life history diversity making populations more susceptible to climate variability (Moore et al. 2010).

Due to the high costs of restoration and the difficulty in predicting or measuring outcomes, some have argued that the best way to protect salmon for future generations is to create salmon sanctuaries that maintain intact and connected habitats throughout the watershed from headwaters to the ocean (Rahr et al. 1998, Lichatowich et al. 2000, Rahr and Augerot 2006). Protecting entire watersheds is especially important to sockeye, Chinook, and coho salmon, which spend 1-2 years rearing in fresh water prior to entering the ocean. These sanctuaries would provide habitat for salmon populations with heightened resilience to factors outside of management control, such as climate change and changes in the ocean environment. The salmon populations in Bristol Bay meet all the criteria for selecting sanctuaries across the North Pacific by having intact habitats, abundant populations, and a high diversity of life history patterns (Schindler et al. 2010). In addition, several studies have targeted Bristol Bay as a high priority for salmon conservation. The Kvichak, Nushagak, and Wood watersheds were ranked third, 44th, and fourth, respectively, in an analysis of physical complexity of 1574 watersheds from California to the Kamchatka Peninsula (Luck et al. 2010, FLBS 2011). Pinsky et al. (2009) characterized high conservation value salmon catchments across the North Pacific as the top 20% (out of 1046 total) based on abundance and run timing diversity. Bristol Bay, the Kamchatka Peninsula, and coastal British Columbia all had clusters of high conservation value catchments. Fewer than 9% of the high conservation value watersheds had greater than half of their area under protected status.

KEY HABITAT ELEMENTS OF BRISTOL BAY RIVER SYSTEMS (OR *WHY DO BRISTOL BAY WATERSHEDS PRODUCE SO MANY FISH?*)

No published materials specifically address the question "*Why do Bristol Bay watersheds support so many salmon?"* While this isn't particularly surprising given the complexity and scope of the question, it does require us to draw on experts and a diverse body of literature to posit an answer. Obviously, the simplest answer is "*Habitat*." But what is it about the habitat in Bristol Bay watersheds that allows them to sustain such prolific fisheries? Our inquiry led us to the conclusion that interplay between the quantity, quality, and diversity of habitats in these river systems accounts for their productivity. The major habitat attributes discussed here were identified in personal communications with Dr. Tom Quinn (University of Washington) and Dr. Jack Stanford (University of Montana).

Habitat quantity

An obvious feature of the Bristol Bay watershed is the abundance of large lakes (Figure 12). The Kvichak River drains Iliamna Lake, Alaska's largest, in addition to Lake Clark, Nonvianuk Lake, Kukaklek Lake, and an array of smaller lakes. The Nuyakuk River, a major tributary to the upper Nushagak River, drains Nuyakuk, Tikchik, Chauekuktuli, Chikuminuk, Upnuk, Nishlik, and a number of smaller lakes. The Wood River, a major tributary to the lower Nushagak River, drains an interconnected chain of four major lakes – lakes Kulik, Beverly, Nerka, and Aleknagik – and several smaller lakes. Lakes cover 7.9% of the Bristol Bay region, which is substantially higher than the other major salmon-producing regions analyzed (Table 8). Lakes cover 13.7% of the Kvichak River basin (Table 8). Within the Nushagak River basin, lakes cover 11.3% of the Wood River drainage and a much smaller percentage of the remainder (1.7%; Table 8).

Since watershed elevations in the Bristol Bay region are relatively low (Table 8), barriers to fish migration are few and a large proportion of the watershed can be accessed by salmon. The Nushagak and Kvichak watersheds have over 58,000 km of streams (National Hydrography Dataset), of which 7,671 km (13%) have been documented as anadromous fish streams (ADF&G 2011 Anadromous Waters Catalog; Figure 12). Since fish use must be documented firsthand by field biologists, a large proportion of anadromous fish habitat undoubtedly remains undocumented. For example, a recent survey targeted 135 undocumented headwater (i.e., 1st- and 2nd-order) stream reaches with low to moderate gradient (i.e., <10% channel slope) north of Iliamna Lake (Woody and O'Neal 2010, pgs. 11-12). Of these stream reaches, 16% were dry or nonexistent, 53% had juvenile salmon, 66% had resident fish, and 3% contained no fish at the time of sampling (Woody and O'Neal 2010, pg. 22).

Table 8. Comparison of landscape features potentially important to sockeye salmon production for watersheds across the North Pacific (top portion of table) and across the Bristol Bay watershed (bottom portion of table). All landscape data are from the Riverscape Analysis Project (Luck et al. 2010).

Watershed	Location	Watershed area (km^2)	Mean watershed elevation (m)	Number of lakes > 1 km^2	Average elevation of lakes (m)	% Lake coverage in watershed	Mean annual sockeye run (millions of fish, 1990-2005)[+]
Kamchatka	Russia	53,598	549	82	15	0.4	3.2
Kenai	Central Alaska	5,537	522	2	97	2.9	5.2
Copper	Prince William Sound	64,529	1,194	9	448	0.5	3.0
Fraser	British Columbia	233,156	1,188	119	763	1.6	10.7
Columbia	Washington	669,608	1,328	68	1,212	0.2	
Bristol Bay	Western Alaska	88,233	269*	69	219*	7.9*	42.8
Togiak	Bristol Bay	4,600	322	6	160	1.4	0.7
Igushik	Bristol Bay	2,126	74	2	15	3.3	1.3
Nushagak (inc. Wood)	Bristol Bay	35,237	250	20	325	2.7	6.0
Kvichak (inc. Alagnak)	Bristol Bay	25,328	340	29	193	13.7	10.9
Naknek	Bristol Bay	9,624	312	8	230	8.3	5.2
Egegik	Bristol Bay	7,117	168	1	4	16.5	11.0
Ugashik	Bristol Bay	4,201	104	3	4	9.9	3.8

[*]Some figures for Bristol Bay represent the weighted average of individual Bristol Bay watersheds.
[+]Salmon abundance sources: Kamchatka, Fraser, and Columbia are from Ruggerone et al. 2010 (Fraser and Columbia rivers were combined into one region "Southern B.C. and Washington."); Kenai is from sockeye brood tables for Kenai River (pers. comm. Pat Shields, 2011); Copper is from sockeye brood tables for Copper River (pers. comm. Jeremy Botz, 2011); Bristol Bay and individual watersheds within Bristol Bay are from sockeye brood tables for Bristol Bay (pers. comm. Tim Baker, 2011).

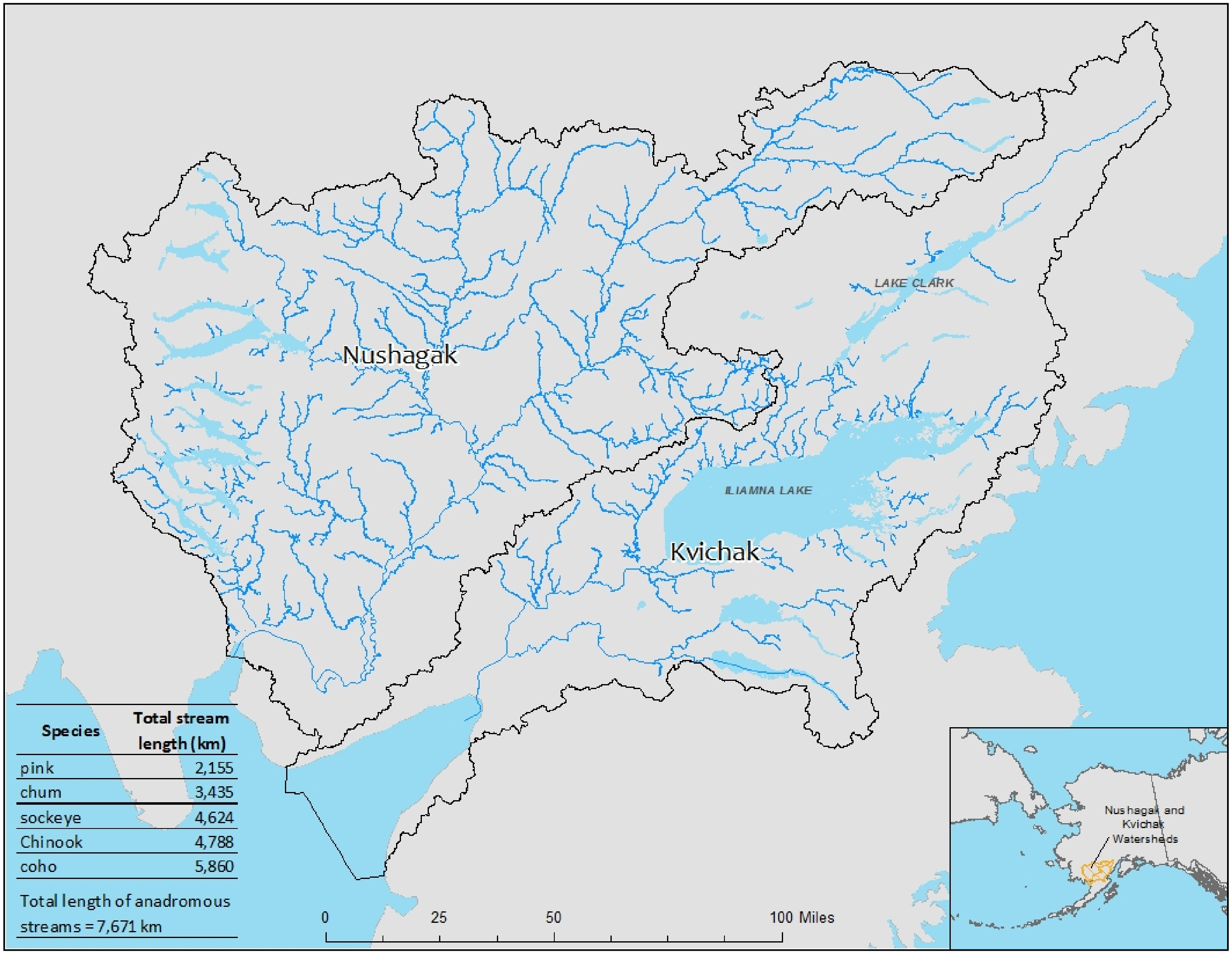

Figure 12. Map of surveyed anadromous streams in the Nushagak and Kvichak watersheds. Data are from ADF&G 2011 Anadromous Waters Catalog.

Habitat quality

In addition to the overall abundance of salmon habitat, there are a number of habitat attributes that likely contribute to the productivity of Bristol Bay's river systems. First of all, Bristol Bay streambeds tend to have abundant gravel, which is essential substrate for salmon spawning and egg incubation (Bjornn and Reiser 1991, pgs. 95-97 , Quinn 2005, pg. 108). Several Pleistocene glacial advances have left behind a complex landscape of gravel-rich moraines, melt-water deposits, and outwash plains (Stilwell and Kaufman 1996, Hamilton and Kleiforth 2010). As stream channels meander and cut through these deposits, gravel and other sediments are captured and formed into riffles, bars and other habitat features. In a survey of 76 wadeable stream reaches across the Kvichak and Nushagak watersheds, gravel (2-64 mm) was the dominant substrate, covering 56% (±15%) of each streambed (D.J. Rinella, unpublished data).

Groundwater inputs to streams and lakes are also an important feature of salmon habitat in the Kvichak and Nushagak watersheds. Rainwater and melting snow infiltrate the extensive glacial deposits and saturate pore spaces below the water table, thus recharging the groundwater aquifer (Power et al. 1999, pg. 402). Ponds are common on the Bristol Bay landscape and contribute disproportionately to groundwater recharge (Rains 2011). Once in the aquifer, groundwater flows slowly downhill and eventually surfaces in areas of relatively low elevation, like stream channels or lake basins. Areas of groundwater upwelling are heavily used by spawning sockeye salmon because they provide circulation, stable flows, and stable temperatures (Burgner 1991, pgs. 16-19). These habitats include lake beaches and spring-fed ponds, creeks, and side channels (Burgner 1991, pgs. 16-19). Studies in the Wood River system of Bristol Bay demonstrate the importance of groundwater upwelling to spawning sockeye salmon. In lakes, densities of beach spawners were highest at sites with the strongest upwelling, while spawners were absent at beach sites with no upwelling (Burgner 1991, pg. 19). Beach spawners comprise substantial portions of the spawning populations in three of the four main Wood River lakes: 47% in Nerka, 87% in Beverly, 59% in Kulik, but only 3% in Aleknagik (1955-1962; Burgner et al. 1969, pg. 420). In a spring-fed tributary to Lake Nerka, the distribution of sockeye salmon spawners also corresponded with areas of groundwater upwelling (Mathisen 1962, pgs. 145-146). Large numbers of sockeye salmon in the Kvichak River system also spawn in lake beaches, spring-fed ponds, and other groundwater-associated habitats (Morstad 2003, pgs. 2-17). In addition to spawning sockeye, groundwater is an important habitat feature for other salmon species and life history stages. Chum salmon have been shown to preferentially spawn in areas of groundwater upwelling (Salo 1991, pg. 240, Leman 1993). Groundwater also maintains ice-free habitats used extensively by wintering fishes, helps to maintain streamflow during dry weather, and provides thermal refuge during periods of warm water (Reynolds 1997, Power et al. 1999).

Salmon themselves are another important habitat feature of Bristol Bay watersheds. Each year, the region's spawning salmon populations convey massive amounts of energy and nutrients from the North Pacific to fresh waters. These marine-derived nutrients (MDN), released as excreta, carcasses, and energy-rich eggs, greatly enhance the productivity of freshwater ecosystems, making Pacific salmon classic examples of keystone species that have large effects on the ecosystems where they spawn (Willson and Halupka 1995, Power et al. 1996).

Salmon contain limiting nutrients (i.e, nitrogen and phosphorus) and energy (i.e., carbon) in the same relative proportions as needed for growth by rearing fishes, making MDN an ideal fertilizer for salmon ecosystems (Wipfli et al. 2004). Given the high densities of spawning salmon in some streams, MDN subsidies can be large. On average, spawning sockeye salmon import 50,200 kg of phosphorus and 397,000 kg of nitrogen to the Kvichak River system and 12,700 kg of phosphorus and 101,000 kg of nitrogen to the Wood River system each year (Moore and Schindler 2004). In high latitudes, the importance of marine nutrients is magnified by the low ambient nutrient levels in freshwater systems (Gross et al. 1988, Perrin and Richardson 1997). In Iliamna Lake, for example, nitrogen inputs from spawning salmon greatly exceed inputs from the watershed (Kline et al. 1993).

Resident fishes (e.g., rainbow trout, Dolly Varden, Arctic grayling) and juvenile salmon of species that rear for extended periods in streams (i.e., coho and Chinook) derive clear and substantial nutritional benefits through the consumption of salmon eggs and flesh and other food sources related to spawning salmon (Bilby et al. 1996). In streams in the Nushagak River basin, for example, ration size and energy consumption among rainbow trout and Arctic graying increased by 480 to 620% after the arrival of spawning salmon (Scheuerell et al. 2007). The increase in rainbow trout diet was attributable to salmon eggs, salmon flesh, and maggots that colonized salmon carcasses, while the increase in Arctic grayling diet was attributable to consumption of benthic invertebrates dislodged by spawning salmon (Scheuerell et al. 2007). A bioenergetics model suggested that these subsidies were responsible for a large majority of the annual growth of these fish populations (Scheuerell et al. 2007). In a stream in the Kvichak River basin, Dolly Varden moved into ponds where sockeye salmon spawned and fed almost entirely on salmon eggs (Denton et al. 2009). The growth rate of these Dolly Varden increased three-fold while salmon eggs were available (Denton et al. 2009). On the Kenai Peninsula, Alaska, recent work has shown that the number of salmon spawning in a given stream is an important predictor of the growth rate and energy storage among coho salmon and Dolly Varden rearing there (Rinella et al. 2011). These and other studies indicate that the availability of MDN enhances growth rates (Bilby et al. 1996, Wipfli et al. 2003, Giannico and Hinch 2007), body condition (Bilby et al. 1998), and energy storage (Heintz et al. 2004) of stream-dwelling fishes, likely leading to increased chances of survival to adulthood (Gardiner and Geddes 1980, Wipfli et al. 2003, Heintz et al. 2004).

MDN is also linked with bottom-up effects on aquatic food webs. In streams, increased standing stocks of biofilm (Wipfli et al. 1998, Wipfli et al. 1999, Johnston et al. 2004, Mitchell and Lamberti 2005) and macroinvertebrates (Claeson et al. 2006, Lessard and Merritt 2006, Walter et al. 2006) have been associated with MDN inputs. Stream-dwelling fishes likely benefit indirectly through increased macroinvertebrate production, but this has yet to be directly established. Likewise, MDN can comprise a major proportion of the annual nutrient budget in Bristol Bay lakes (Mathisen 1972, Koenings and Burkett 1987, Schmidt et al. 1998) and salmon-derived nitrogen is ultimately taken up by juvenile sockeye salmon (Kline et al. 1993). However, it is not clear if these nitrogen inputs have measurable effects on sockeye salmon populations (Schindler et al. 2005b, Uchiyama et al. 2008).

The importance of MDN to fish populations is perhaps most clearly demonstrated in cases where MDN supplies are disrupted by depletion of salmon populations. The prolonged depression of salmon stocks in the Columbia River basin is a prime example, where a chronic nutrient deficiency hinders the recovery of endangered and threatened Pacific salmon stocks (Gresh et al. 2000, Petrosky et al. 2001, Achord et al. 2003, Peery et al. 2003, Scheuerell et al. 2005, Zabel et al. 2006) and diminishes the potential of expensive habitat improvement projects (Gresh et al. 2000). Density-dependent mortality has been documented among juvenile Chinook, despite the fact that populations have been reduced to a fraction of historic levels, suggesting that nutrient deficits have reduced the carrying capacity of spawning streams in the Columbia River basin (Achord et al. 2003, Scheuerell et al. 2005). A population viability analysis has indicated that declines in MDN have very likely contributed to low productivity of juvenile salmon and that increasing the productivity could lead to large increases in the salmon population (Zabel et al. 2006). Diminished salmon runs, thus, present a negative feedback loop where the decline in spawner abundance reduces the capacity of streams to produce new spawners (Levy 1997). Fisheries managers recognize the importance of MDN in sustaining the productivity of salmon systems and are now attempting to supplement nutrient stores by planting hatchery salmon carcasses and analogous fertilizers in waters throughout the Pacific Northwest (Stockner 2003, Shaff and Compton 2009).

In addition to their inherent natural productivity, Bristol Bay watersheds have not been subjected to anthropogenic watershed disturbances that have contributed to declining salmon populations elsewhere. For example, Nehlsen et al. (1991) reviewed the status of native salmon and steelhead stocks in California, Oregon, Washington, and Idaho. They found that 214 stocks appeared to face a risk of extinction; of these, habitat loss or modification was a contributing factor for 194. These cases were in addition to at least 106 stocks that had already gone extinct (Nehlsen et al. 1991). A National Research Council committee (NRC 1996), convened to review the population status of Pacific Northwest salmon, summarized that:

> *The ecological fabric that once sustained enormous salmon populations has been dramatically modified through heavy human exploitation – trapping, fishing, grazing, logging, mining, damming of rivers, channelization of streams, ditching and draining of wetlands, withdrawals of water for irrigation, conversions of estuaries, modification of riparian systems and instream habitats, alterations to water quality and flow regimes, urbanization, and other effects.*

Thus, it is generally agreed that a complex and poorly understood combination of factors – with direct and indirect effects of habitat degradation at the fore – are responsible for declining Pacific Northwest salmon stocks (NRC 1996, Gregory and Bisson 1997, Lackey 2003).

In watersheds of the Bristol Bay region, including the Nushagak and Kvichak rivers, human habitation is confined to a few small towns and villages, roads are few, and large-scale habitat modifications are absent. The Riverscape Analysis Project, using spatial data from the Socioeconomic Data and Applications Center (Sanderson et al. 2002), ranked 1574 salmon-producing watersheds around the North Pacific based on an index of human footprint (http://rap.ntsg.umt.edu/humanfootprintrank; accessed 9/1/11). Of these, the Kvichak River ranked 197, the Nushagak (exclusive of the Wood River) ranked 131, and the Wood River ranked 332. Additionally, invasive fishes and riparian plants, which can negatively impact native fish populations, have not been introduced to Bristol Bay's watersheds.

Habitat diversity

A diverse assemblage of spawning and rearing habitats is an exceedingly important feature of Bristol Bay's riverine ecosystems. Since salmon adapt in predictable ways to conditions within their specific environments, a high level of habitat diversity fosters a correspondingly high level of population and life history diversity. The utilization of different types of spawning habitat is an easily observable example. Suitable lotic habitats range from small gravel-bed creeks to large cobble-bed rivers (Hilborn et al. 2003b), and even silt-laden glacial streams (Ramstad et al. 2010). Spring-fed ponds are also used, as are areas of groundwater upwelling on mainland lake beaches, and rocky beaches of low-lying islands (Hilborn et al. 2003b). Sockeye salmon have adapted to each of these environments in predictable ways, optimizing behavioral and physiological traits like timing of spawning, egg size, and the size and shape of spawning adults (Table 9; Hilborn et al. 2003b). The result is a stock complex comprised of hundreds of distinct spawning populations, each adapted to its own spawning and rearing environment.

This complexity is compounded by variation within each spawning population, likely in ways that are not yet fully understood (Hilborn et al. 2003b). One clear example is variation in the amount of time spent rearing in fresh water and at sea (Table 10). Within a given cohort, most individuals rear for either one or two years in fresh water, although a small number may spend three years or go to sea shortly after hatching (i.e., zero years in fresh water). The latter life history is relatively common among Nushagak River sockeye, many of which rear in rivers as opposed to lakes. Once at sea, most fish will rear for an additional two or three years, although a few will rear for as little as one year or as many as five years. This life history complexity superimposed on localized adaptations results in a high degree of biological complexity within the stock complex.

Table 9. A summary of life history variation within the Bristol Bay stock complex of sockeye salmon (from Hilborn et al. 2003).

Element of biocomplexity	Range of traits or options found
Watershed location within Bristol Bay complex	Seven different major watersheds, ranging from maritime-influenced systems on the Alaska Peninsula to more continental systems
Time of adult return to fresh water	June – September
Time of spawning	July – November
Spawning habitat	Major rivers, small streams, spring fed ponds, mainland beaches, island beaches
Body size and shape of adults	130 – 190 mm body depth at 450 mm male length: sleek, fusiform to very deep bodied, with exaggerated humps and jaws
Egg size	88 – 166 mg at 450 mm female length
Energetic allocation within spawning period	Time between entry into spawning habitat and death ranges from 1 – 3 days to several weeks
Time spent rearing in fresh water	0 – 3 years
Time spent at sea	1 – 4 years

Table 10. Variation in time spent rearing in fresh water and at sea for Bristol Bay sockeye salmon. Numbers represent percentage of fish returning to the respective river systems after a given combination of freshwater and sea rearing periods. + indicate combinations that were represented in the data but comprised <1% of returns to the respective river system. Data are from ADF&G and cover 1956 to 2005 brood years, except for Nushagak River data which cover 1979 to 2003 brood years.

Number of years spent in fresh water	0				1					2				3		
Number of years spend at sea	2	3	4	5	1	2	3	4	5	1	2	3	4	1	2	3
Kvichak	+	+	+		+	25	10	+		+	58	7	+	+	+	+
Alagnak	+	+	+		+	42	40	+		+	12	5	+			+
Nushagak	2	17	2	+	+	11	60	5	+	+	1	2	+		+	+
Wood	+	+	+		+	48	43	+		+	5	3	+		+	+
Naknek	+	+	+		+	16	44	+	+	+	17	21	+	+	+	+
Egegik	+	+	+		+	9	17	+		+	44	29	+	+	+	+
Ugashik	+	+	+		+	27	28	+	+	+	30	15	+		+	+
Igushik	+	+	+		+	20	68	+		+	5	5	+			
Togiak	+	1	1		+	21	63	+		+	6	7	+		+	

These layers of biocomplexity result in a situation where different stocks within the complex show asynchronous patterns of productivity (Rogers and Schindler 2008). This is because differences in habitat and life history lead to different population responses despite exposure to the same prevailing environmental conditions. For example, a year with low stream flows might negatively impact populations that spawn in small streams but not those that spawn in lakes (Hilborn et al. 2003b). Asynchrony in population dynamics of Bristol Bay sockeye has been demonstrated at both the local scale (i.e., individual tributaries) and the regional scale (i.e., major river systems; Rogers and Schindler 2008). The latter is demonstrated nicely by the relative productivity of Bristol Bay's major rivers during different climatic regimes (Hilborn et al. 2003b), where small runs in the Egegik River were offset by large runs in the Kvichak prior to 1977, but declining runs in the Kvichak River in the 2000s were in turn offset by large runs in the Egegik River (see Figure 9).

Population and life history diversity within Bristol Bay sockeye populations can be equated to spreading risk with a diversified portfolio of financial investments (Schindler et al. 2010). Under any given set of conditions, some assets perform well while others perform poorly, but maintenance of a diversified portfolio stabilizes returns over time. Within the sockeye stock complex, the portfolio of population and life history diversity greatly reduces year-to-year variability in run size, making the commercial salmon fishery much more reliable than it would be otherwise. With the current level of biocomplexity in Bristol Bay sockeye, salmon runs are large enough to meet bay-wide escapement goals of ~10 M fish nearly every year and fishery closures are rare (i.e., less than four closures per 100 years; Schindler et al. 2010). If Bristol Bay sockeye lacked biocomplexity and the associated stabilizing effects, run sizes would fluctuate widely and complete fishery closures would happen every two to three years (Schindler et al. 2010).

While the analyses described here apply to the Bristol Bay commercial sockeye fishery, portfolio effects certainly stabilize populations of other fish species and increase the reliability of sport and subsistence fisheries. In addition, portfolio effects stabilize and extend the availability of salmon to consumers in the watershed food webs. Poor runs in some habitats will be offset by large runs in others, allowing mobile predators and scavengers (e.g., bears, eagles, rainbow trout) to access areas of relatively high spawner density each year (Schindler et al. 2010). Different populations vary in the timing of spawning, which substantially extends the period when salmon are occupying spawning habitats (Schindler et al. 2010).

Since a diversified salmon stock complex is contingent upon a complex suite of habitats, an important question becomes: How does habitat diversity in Bristol Bay watersheds compare to that in other salmon-producing regions? The Riverscape Analysis Project calculated remotely-sensed indices of physical habitat complexity, allowing comparisons among salmon producing watersheds at the North Pacific Rim scale (Luck et al. 2010, Whited et al. 2012). Rankings of overall physical complexity were based on 10 attributes: variation in elevation; floodplain elevation; density of floodplains and stream junctions; human footprint; the proportion of watershed covered by glaciers, floodplains, and lakes; and the elevation and density of lakes. While the characterization of habitat complexity at this broad spatial scale is necessarily imprecise and certainly fails to detect nuanced habitat features, it does seem to quantify attributes that are important to salmon as it explained general patterns in salmon abundance in validation watersheds (Luck et al. 2010). Overall physical complexity was relatively high for the watersheds considered in this assessment; of the 1574 Pacific Rim watersheds characterized, the Kvichak River ranked the 3rd highest, the Nushagak River (exclusive of the Wood River) ranked 44th, and the Wood River ranked 4th (http://rap.ntsg.umt.edu/overallrank; accessed 9/1/11).

The studies reviewed here demonstrate how biocomplexity in salmon populations provides resilience to environmental change. This resilience can break down when habitats are degraded or when the genetic diversity that allows salmon to utilize the full complement of available habitats is diminished. The loss of habitat diversity and associated loss of population diversity has contributed to declines of once prolific salmon fisheries, including those in the Sacramento (Lindley et al. 2009) and Columbia rivers (Bottom et al. 2005, Moore et al. 2010). Lindley et al. (2009), summarizing causes for the recent crash in Sacramento River fall Chinook, highlighted the importance of life history diversity:

> *In conclusion, the development of the Sacramento-San Joaquin watershed has greatly simplified and truncated the once-diverse habitats that historically supported a highly diverse assemblage of populations. The life history diversity of this historical assemblage would have buffered the overall abundance of Chinook salmon in the Central Valley under varying climate conditions.*

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Appendix A. Chinook and sockeye salmon run sizes for Bristol Bay and other regions of the North Pacific

Table A1. Chinook total run sizes (harvest plus escapement) by river system, 1966-2010

Table A2. Sockeye total run sizes (harvest plus escapement) by river system, 1956-2010

Table A3. Sockeye total run sizes (harvest plus escapement) by region, 1956-2005

Table A1. Chinook total run sizes by river system, 1966-2010

Year	Nushagak	Kenai	Yukon, Canadian mainstem	Copper	Taku	Skeena	Nass	Nehalem	Skagit
1966	144,145	NA	NA	NA	NA	NA	NA	NA	NA
1967	234,216	NA	NA	NA	NA	NA	NA	NA	NA
1968	228,551	NA	NA	NA	NA	NA	NA	NA	NA
1969	158,627	NA	NA	NA	NA	NA	NA	NA	NA
1970	196,081	NA	NA	NA	NA	NA	NA	NA	NA
1971	169,206	NA	NA	NA	NA	NA	NA	NA	NA
1972	101,001	NA	NA	NA	NA	NA	NA	NA	NA
1973	107,999	NA	NA	NA	38,307	NA	NA	NA	NA
1974	183,287	NA	NA	NA	35,442	NA	NA	NA	NA
1975	172,144	NA	NA	NA	46,870	NA	17,874	5,060	22,252
1976	273,657	NA	NA	NA	44,555	NA	16,583	9,446	23,939
1977	224,104	NA	NA	NA	41,856	39,606	18,410	11,552	18,514
1978	393,636	NA	NA	NA	56,386	35,055	21,807	11,676	20,962
1979	361,210	NA	NA	NA	60,190	28,166	16,229	12,058	22,261
1980	366,555	NA	NA	29,659	64,247	38,626	18,744	5,645	30,346
1981	513,708	NA	NA	41,047	75,280	42,018	17,606	10,577	20,720
1982	509,867	NA	60,746	84,098	37,042	35,185	13,287	5,111	21,475
1983	482,196	NA	63,427	82,730	19,943	39,510	20,516	4,376	15,225
1984	237,104	NA	66,800	86,373	41,850	53,516	31,408	20,939	15,701
1985	314,434	NA	59,736	55,997	71,814	76,544	24,768	18,845	27,709
1986	165,950	106,917	61,789	103,024	51,190	87,566	47,967	11,570	23,507
1987	231,453	100,123	58,921	69,910	41,474	76,349	26,568	15,268	14,782
1988	141,908	89,462	61,126	55,801	66,601	102,563	21,094	16,684	16,390
1989	187,644	59,409	78,243	73,423	57,086	83,439	36,594	11,650	14,596
1990	156,663	50,751	78,439	52,899	66,517	89,447	33,384	6,617	20,717
1991	246,718	52,810	63,335	68,175	80,066	79,343	13,136	7,498	9,696
1992	232,103	54,302	57,058	64,172	84,882	92,184	25,405	11,558	10,211

Table A1. Chinook total run sizes by river system, 1966-2010

Year	Nushagak	Kenai	Yukon, Canadian mainstem	Copper	Taku	Skeena	Nass	Nehalem	Skagit
1993	283,385	89,748	52,855	65,301	98,073	96,018	36,678	9,137	7,691
1994	334,604	90,552	77,647	90,073	70,253	68,127	32,864	9,194	7,082
1995	271,126	81,563	71,557	96,710	74,564	48,351	16,187	8,671	10,096
1996	193,029	77,228	93,672	113,868	98,184	96,453	30,889	12,975	13,364
1997	247,097	69,773	70,349	107,760	130,091	65,350	27,658	12,732	7,198
1998	370,883	55,540	41,434	112,365	51,706	65,167	34,922	10,591	16,067
1999	148,963	86,553	49,652	95,951	33,500	70,993	22,310	10,361	5,725
2000	137,979	63,373	30,749	70,746	51,055	77,320	31,159	10,817	18,231
2001	213,128	60,320	62,703	81,155	59,449	112,346	44,595	14,293	15,947
2002	228,919	61,878	51,616	72,972	71,902	63,069	21,528	20,552	20,979
2003	224,724	73,210	90,213	94,505	62,436	82,410	36,503	23,569	11,933
2004	351,928	99,765	59,707	80,559	113,923	61,065	25,137	14,456	25,863
2005	307,245	91,309	79,625	66,341	81,173	39,278	24,067	8,222	24,701
2006	218,031	76,186	72,005	99,877	68,842	43,689	37,098	13,129	23,115
2007	125,077	76,472	39,997	87,770	29,766	44,185	34,221	6,648	13,003
2008	128,445	61,152	37,434	53,880	126,700	54,279	26,202	5,651	15,942
2009	117,530	46,095	69,418	43,007	115,559	55,921	36,865	5,332	13,144
2010	93,677	NA	NA	32,999	NA	NA	NA	NA	NA

Table A1. Chinook total run sizes by river system, 1966-2010

Year	Gray's Harbor	Harrison	Fraser	Yukon	Kuskokwim
1966	NA	NA	NA	NA	NA
1967	NA	NA	NA	NA	NA
1968	NA	NA	NA	NA	NA
1969	NA	NA	NA	NA	NA
1970	NA	NA	NA	NA	NA
1971	NA	NA	NA	NA	NA
1972	NA	NA	NA	NA	NA
1973	NA	NA	NA	NA	NA
1974	NA	NA	NA	NA	NA
1975	NA	NA	NA	NA	NA
1976	6,852	NA	NA	NA	200,000
1977	10,086	NA	NA	NA	210,000
1978	7,919	NA	NA	NA	250,000
1979	10,869	NA	NA	NA	230,000
1980	17,067	NA	NA	NA	220,000
1981	10,581	NA	NA	NA	310,000
1982	9,886	NA	NA	NA	210,000
1983	8,473	NA	NA	NA	160,000
1984	23,888	131,740	227,421	NA	180,000
1985	14,225	181,367	303,308	NA	180,000
1986	25,139	177,662	322,279	NA	160,000
1987	35,114	81,799	210,498	NA	250,000
1988	42,811	38,285	167,872	NA	250,000
1989	57,787	76,294	183,137	NA	280,000
1990	40,606	180,837	315,961	NA	300,000
1991	34,569	93,363	209,918	NA	240,000
1992	34,813	132,042	262,291	NA	280,000

Table A1. Chinook total run sizes by river system, 1966-2010

Year	Gray's Harbor	Harrison	Fraser	Yukon	Kuskokwim
1993	31,513	120,600	230,837	NA	340,000
1994	32,468	100,839	246,142	NA	470,000
1995	34,067	29,840	164,318	NA	420,000
1996	39,102	38,568	224,127	NA	330,000
1997	35,927	72,061	274,856	NA	370,000
1998	23,390	189,103	358,436	NA	260,000
1999	14,865	107,884	248,823	NA	190,000
2000	18,595	78,098	233,307	144,173	180,000
2001	22,405	74,419	251,427	392,000	260,000
2002	19,787	91,122	312,142	243,443	240,000
2003	24,945	251,453	483,142	372,697	260,000
2004	48,690	138,890	333,330	311,377	430,000
2005	26,365	92,993	265,274	NA	370,000
2006	27,230	52,798	295,676	NA	380,000
2007	17,976	83,445	220,651	NA	270,000
2008	19,149	43,798	231,389	NA	240,000
2009	14,493	75,550	248,408	NA	210,000
2010	NA	NA	NA	NA	140,000

Data Sources

Nushagak: Buck et al. 2012, pg. 20; Kenai: Begich and Pawluk 2010, pg. 69; Yukon, Canadian mainstem: Howard et al. 2009, pg. 35; Copper: Pers. comm. Steve Moffitt, ADF&G; Taku: McPherson et al. 2010, pg. 14. 2008/2009 data are preliminary pers. comm. Ed Jones, ADF&G; Skeena: PSC 2011, pg. 87; Nass: PSC 2011, pg. 87; Nehalem: PSC 2011, pg. 93; Skagit: PSC 2011, pg. 89; Gray's Harbor: PSC 2011, pg. 90; Harrison: PSC 2011, pg. 88; Fraser: PSC 2011, pg. 88; Yukon: Spencer et al. 2009, pg. 28; Kuskokwim: Pers. comm. Kevin Schaberg, ADF&G

Table A2. Sockeye total run sizes by river system, 1956-2010

Year	Ugashik	Egegik	Naknek	Alagnak	Kvichak	Nushagak	Wood	Igushik
1956	779,000	2,324,000	3,155,000	1,282,000	13,800,000	106,788	1,494,000	903,000
1957	940,000	2,044,000	2,588,000	474,000	10,711,000	262,805	945,000	440,000
1958	776,702	812,799	603,781	206,930	1,180,705	543,003	1,744,000	276,000
1959	678,064	1,827,157	3,403,474	1,295,000	1,004,118	113,107	3,668,000	995,000
1960	3,377,000	3,600,000	2,095,000	2,289,000	24,942,000	237,544	2,124,466	1,177,000
1961	960,000	4,600,000	1,865,815	509,000	14,279,000	185,798	957,144	632,000
1962	559,409	1,878,432	1,277,933	150,000	4,961,330	114,209	2,438,322	107,024
1963	673,000	1,981,649	1,786,728	368,227	657,349	452,272	1,460,090	212,000
1964	1,101,179	2,056,111	2,685,504	554,998	1,801,221	244,344	2,263,164	338,000
1965	2,236,533	5,344,000	2,270,357	506,729	47,657,000	513,460	1,468,609	410,000
1966	1,315,949	3,331,241	2,418,111	354,000	9,064,868	402,292	2,310,435	470,000
1967	449,557	1,908,340	1,372,352	298,956	5,577,403	114,332	1,017,456	563,134
1968	179,413	1,195,917	2,119,324	302,531	3,471,140	290,366	1,357,407	398,190
1969	372,879	2,273,888	2,623,702	329,748	13,472,862	197,135	1,218,238	1,114,000
1970	1,030,000	2,660,244	2,011,095	479,019	34,599,600	885,640	2,169,211	754,083
1971	1,790,000	2,282,819	3,247,238	599,080	6,948,068	662,007	1,912,659	529,000
1972	129,031	1,884,000	1,810,000	235,000	1,763,000	99,603	935,000	161,000
1973	60,108	788,940	724,941	53,833	336,241	428,733	716,226	133,000
1974	65,801	1,530,000	1,728,781	236,681	4,761,892	240,197	2,211,000	471,000
1975	464,000	2,365,792	3,804,529	128,700	15,359,808	1,071,353	1,836,317	365,000
1976	594,000	2,031,920	2,619,548	152,000	3,789,238	1,079,065	1,602,770	388,000
1977	325,175	2,714,435	2,744,790	177,471	2,266,442	946,903	928,878	164,000
1978	95,380	2,230,099	2,005,239	1,178,690	8,266,273	1,482,163	4,294,726	1,145,339
1979	2,158,312	3,385,860	2,292,995	1,562,870	25,297,982	930,285	3,775,140	1,910,000
1980	4,469,800	3,921,579	5,027,516	1,594,128	37,695,437	5,343,159	4,760,312	3,276,190
1981	3,705,000	5,430,399	7,913,237	862,018	7,489,183	3,764,287	4,926,000	2,410,000
1982	2,603,342	3,919,251	4,226,271	2,173,398	3,328,986	2,889,822	3,864,630	2,029,000
1983	4,565,269	8,024,339	5,754,315	1,531,412	20,983,178	2,073,502	4,484,000	853,000

Table A2. Sockeye total run sizes by river system, 1956-2010

Year	Ugashik	Egegik	Naknek	Alagnak	Kvichak	Nushagak	Wood	Igushik
1984	4,093,955	6,623,390	3,056,116	1,522,640	23,907,123	1,421,706	2,076,000	455,000
1985	7,874,523	9,093,576	3,912,742	733,068	14,061,000	963,888	1,693,723	489,000
1986	6,216,732	6,173,448	4,069,000	1,086,130	2,025,616	2,267,373	1,822,225	908,000
1987	2,925,832	6,884,561	2,485,316	811,320	9,839,116	1,794,967	2,917,462	644,000
1988	2,256,139	8,369,057	1,796,819	872,367	6,940,540	1,093,735	1,793,902	414,000
1989	5,049,283	10,983,145	3,303,641	1,456,693	20,548,328	1,260,160	2,601,691	1,253,000
1990	2,982,276	12,931,258	8,678,358	1,517,000	17,988,530	1,797,229	2,687,000	1,317,000
1991	5,628,282	9,938,166	10,285,831	1,652,944	8,329,970	1,800,480	3,424,694	2,515,000
1992	5,831,999	18,614,125	5,327,022	1,349,052	10,969,638	1,898,491	2,570,505	830,000
1993	5,912,214	24,481,560	4,905,051	2,257,321	9,901,170	2,330,448	3,937,623	1,663,194
1994	5,605,405	12,998,886	3,144,067	1,733,796	22,734,248	1,618,150	3,111,885	1,379,000
1995	6,040,271	16,200,980	3,700,788	1,780,054	28,329,704	792,229	4,191,376	1,991,000
1996	5,237,819	12,253,942	7,076,342	1,916,634	3,538,945	1,804,324	5,160,000	1,514,000
1997	2,239,051	9,362,876	1,515,318	680,123	1,826,856	929,880	3,629,898	314,000
1998	1,794,126	5,060,215	2,784,308	1,072,721	3,550,243	1,022,443	4,101,957	602,074
1999	4,058,177	9,407,420	3,970,846	2,841,755	13,309,000	991,826	6,160,000	1,626,000
2000	2,301,000	8,403,612	4,935,000	2,014,897	3,031,000	1,528,923	5,545,000	1,812,000
2001	1,356,716	4,323,287	6,682,794	1,106,728	1,436,000	2,126,175	4,013,792	1,325,000
2002	2,563,977	5,839,236	2,775,032	793,470	727,186	663,000	3,841,698	213,000
2003	2,584,062	3,503,084	5,182,926	3,790,173	1,750,361	2,273,000	5,743,906	1,036,071
2004	4,160,179	12,865,161	3,948,000	6,667,385	7,902,000	2,227,000	5,948,000	523,000
2005	3,093,169	9,553,946	8,059,330	5,436,640	2,924,275	3,567,000	4,607,385	2,089,000
2006	3,507,652	9,066,558	5,503,654	2,866,000	5,882,074	3,308,000	11,304,221	1,466,000
2007	7,897,526	8,209,756	9,047,000	4,430,633	4,381,000	2,670,000	6,755,813	1,826,000
2008	3,053,322	9,027,266	6,518,196	6,157,000	5,869,320	1,713,315	5,456,186	3,433,000
2009	4,033,383	13,039,645	4,870,271	2,699,010	5,723,862	1,983,000	7,402,102	953,000
2010	4,960,291	6,119,472	5,908,135	2,660,659	9,503,000	2,194,032	7,851,845	1,391,576

Table A2. Sockeye total run sizes by river system, 1956-2010

Year	Togiak	Kenai	Copper, wild fish	Fraser
1956	331,000	NA	NA	2,866,977
1957	108,066	NA	NA	5,401,219
1958	118,000	NA	NA	18,778,820
1959	310,000	NA	NA	4,769,576
1960	338,000	NA	NA	3,421,281
1961	421,520	NA	860,258	4,713,837
1962	174,191	NA	1,112,218	3,512,304
1963	352,000	NA	664,596	3,985,486
1964	367,058	NA	949,861	1,824,500
1965	391,000	NA	1,208,709	3,166,871
1966	338,000	NA	1,402,430	5,459,849
1967	171,109	NA	850,993	6,803,585
1968	135,086	NA	829,329	2,955,662
1969	306,027	NA	1,258,136	4,941,025
1970	425,000	NA	1,492,530	6,163,676
1971	484,000	NA	1,250,648	7,696,359
1972	175,000	831,241	1,168,448	3,708,113
1973	270,000	920,826	668,670	6,878,291
1974	238,000	435,344	869,756	8,616,165
1975	407,392	485,352	538,743	3,683,576
1976	546,000	1,374,607	1,161,149	4,340,815
1977	401,000	2,268,568	1,047,326	5,887,114
1978	770,000	2,096,341	502,359	9,420,144
1979	614,000	797,838	618,538	6,358,912
1980	1,173,000	1,495,962	651,014	3,133,187
1981	999,000	1,184,445	1,297,758	7,741,247
1982	972,230	2,766,912	1,883,434	13,985,095
1983	784,000	3,982,112	1,395,556	5,240,936

Table A2. Sockeye total run sizes by river system, 1956-2010

Year	Togiak	Kenai	Copper, wild fish	Fraser
1984	383,000	1,287,187	1,821,370	5,919,324
1985	306,198	2,498,144	1,600,390	13,878,493
1986	405,215	2,955,276	1,329,070	15,927,438
1987	574,000	9,425,518	1,721,153	7,680,095
1988	1,001,000	6,094,157	985,913	3,773,551
1989	178,117	6,662,137	1,435,481	18,594,484
1990	342,000	3,290,388	1,459,380	21,985,937
1991	805,000	2,226,730	1,766,134	12,390,664
1992	863,250	8,273,968	1,537,006	6,442,239
1993	697,000	4,451,954	2,039,851	23,630,664
1994	520,207	3,908,776	1,839,406	17,284,640
1995	771,000	2,658,341	1,778,450	4,020,414
1996	585,349	3,743,751	2,888,442	4,520,445
1997	264,239	4,650,889	3,820,171	16,351,769
1998	312,646	1,953,963	1,661,543	10,873,000
1999	565,258	3,018,164	1,568,335	3,643,000
2000	1,127,000	1,842,904	1,206,275	5,217,000
2001	1,436,000	2,214,605	2,000,609	7,213,000
2002	406,000	3,511,797	1,774,724	15,137,000
2003	897,000	4,447,000	1,839,605	4,873,502
2004	508,000	5,716,924	1,739,197	4,184,200
2005	580,171	6,117,166	2,060,867	7,077,100
2006	905,450	2,835,742	2,305,355	12,981,200
2007	1,066,000	3,592,167	2,828,457	1,510,600
2008	891,541	2,065,205	1,051,154	1,755,355
2009	854,568	2,440,138	1,583,006	1,505,096
2010	741,211	3,595,867	1,248,019	29,005,410

Table A2. Sockeye total run sizes by river system, 1956-2010

Data Sources: Ugashik, Egegik, Naknek, Alagnak, Kvichak, Nushagak, Wood, Igushik, and Togiak rivers, pers. comm. Tim Baker, ADF&G; Kenai River, pers. comm. Pat Shields, ADF&G; Copper River, pers. comm. Jeremy Botz, ADF&G; Fraser River, pers. comm. Catherine Michielsens, PSC.

Table A3. Sockeye total run sizes by region, 1956-2005.

Year	Bristol Bay	Russia Mainland and Islands	West Kamchatka	East Kamchatka	Western Alaska (excluding Bristol Bay)	South Alaska Peninsula	Kodiak	Cook Inlet	Prince William Sound
1956	24,174,788	312,723	5,568,959	3,508,292	2,921,799	1,439,813	1,036,251	2,107,703	1,357,869
1957	18,512,871	1,212,664	10,172,076	4,146,156	1,651,132	823,438	976,164	1,272,942	1,219,564
1958	6,261,920	442,975	6,286,252	6,080,691	1,477,590	654,585	1,064,076	1,026,900	795,032
1959	13,293,920	391,364	5,046,656	5,879,205	1,713,792	837,418	1,134,597	1,227,947	767,304
1960	40,180,010	439,229	5,520,707	6,741,619	1,649,156	1,301,201	1,189,167	1,663,849	921,272
1961	24,410,277	441,422	8,884,293	2,865,949	1,284,695	728,145	1,265,417	1,982,278	1,246,740
1962	11,660,850	402,798	8,304,347	2,940,810	1,236,964	856,552	1,870,103	1,962,984	1,446,375
1963	7,943,315	343,339	5,294,022	4,291,282	1,080,004	936,188	1,263,847	1,690,524	965,103
1964	11,411,579	238,866	1,681,381	5,400,484	1,281,320	918,361	1,415,449	1,727,099	1,413,881
1965	60,797,688	293,827	3,616,954	4,299,788	879,413	1,136,937	1,161,768	2,304,205	1,631,195
1966	20,004,896	279,251	2,496,149	5,651,091	1,100,324	816,878	1,630,675	2,849,643	1,867,747
1967	11,472,639	362,571	3,438,364	7,534,661	1,197,823	1,022,036	1,098,764	2,263,184	1,119,440
1968	9,449,374	297,307	952,912	7,347,250	1,017,865	1,771,470	1,832,648	1,906,856	1,334,651
1969	21,908,479	249,157	705,033	6,672,415	1,459,903	997,774	1,566,384	1,341,961	1,728,312
1970	45,013,892	245,200	1,051,653	6,377,430	1,028,643	2,477,613	2,071,227	1,399,803	2,007,971
1971	18,454,871	221,785	1,908,446	4,283,328	1,224,259	2,224,301	1,382,529	1,262,215	1,362,728
1972	7,191,634	201,509	1,708,238	3,917,303	1,025,402	996,272	957,567	1,604,503	1,671,399
1973	3,512,022	202,599	1,266,604	4,389,459	877,777	1,745,569	880,634	1,310,905	986,426
1974	11,483,352	538,427	2,914,942	1,096,312	1,184,430	1,515,481	1,283,380	1,056,869	1,361,911
1975	25,802,891	185,335	1,315,733	3,858,358	1,171,178	1,048,430	854,537	1,331,877	1,092,387
1976	12,802,541	180,082	1,556,672	3,470,759	1,587,266	2,219,569	1,586,702	2,619,311	1,713,575
1977	10,669,094	177,717	412,752	2,648,024	1,469,757	3,082,269	1,645,986	3,194,737	1,629,798
1978	21,467,909	188,339	936,931	3,596,414	2,695,103	2,547,058	1,925,502	3,250,421	1,026,705
1979	41,927,444	256,120	835,766	3,328,120	4,264,190	1,855,669	1,745,390	1,626,406	798,885
1980	67,261,121	192,795	1,353,186	3,221,802	3,261,091	1,534,564	2,235,004	2,485,427	553,557
1981	37,499,124	175,829	1,641,425	2,910,208	3,764,080	3,009,576	1,977,914	2,266,861	1,396,065

Table A3. Sockeye total run sizes by region, 1956-2005.

Year	Bristol Bay	Russia Mainland and Islands	West Kamchatka	East Kamchatka	Western Alaska (excluding Bristol Bay)	South Alaska Peninsula	Kodiak	Cook Inlet	Prince William Sound
1982	26,006,930	256,135	1,317,999	2,495,343	1,960,326	2,647,192	2,304,607	4,058,186	3,298,288
1983	49,053,015	272,271	1,363,540	3,255,333	2,962,209	3,289,732	1,994,142	5,983,442	1,544,252
1984	43,538,930	188,414	1,853,895	2,869,830	2,854,259	4,463,088	3,164,169	3,023,601	2,058,228
1985	39,127,718	129,556	3,456,410	2,266,824	5,074,028	1,879,199	4,325,529	4,911,883	2,224,415
1986	24,973,739	177,623	2,993,349	2,088,398	3,648,527	2,750,217	4,020,270	5,195,708	1,999,005
1987	28,876,574	173,853	4,388,792	2,244,085	1,881,441	3,234,737	1,573,040	10,612,907	2,503,899
1988	24,537,559	134,865	2,961,712	1,735,950	2,428,248	1,577,614	5,179,735	7,981,926	591,622
1989	46,634,058	162,907	3,929,794	1,614,359	2,984,749	2,239,029	2,465,794	6,653,855	1,196,514
1990	50,240,651	131,959	6,533,656	683,440	4,066,861	3,209,313	7,291,759	3,791,787	672,793
1991	44,380,367	278,341	6,654,665	716,325	4,709,511	3,506,006	8,376,886	2,341,570	1,737,506
1992	48,254,082	290,791	5,946,498	2,171,680	4,550,924	2,376,718	3,727,396	9,803,503	2,109,967
1993	56,085,581	414,830	6,867,277	3,721,809	5,252,589	2,946,843	1,977,835	5,525,342	2,269,986
1994	52,845,644	330,884	6,052,779	3,184,687	4,707,327	3,067,554	2,732,833	4,823,347	1,925,999
1995	63,797,402	547,226	5,142,880	5,342,393	5,231,199	2,921,709	6,683,435	3,916,052	1,917,252
1996	39,087,355	578,622	5,416,529	5,181,509	3,904,663	3,148,403	6,366,442	4,828,498	3,031,366
1997	20,762,241	273,153	3,623,111	4,525,486	3,327,626	1,613,997	4,081,554	5,623,149	3,734,337
1998	20,300,733	186,020	4,216,452	3,350,431	2,342,865	1,928,313	4,297,254	2,240,231	1,653,216
1999	42,930,282	314,421	4,198,803	4,688,991	3,551,763	4,462,260	6,441,216	3,448,544	2,340,818
2000	30,698,432	402,372	5,731,743	3,228,330	3,417,071	3,054,013	4,468,203	2,071,076	1,640,060
2001	23,806,492	458,915	4,698,927	3,295,161	2,741,406	3,234,246	4,042,683	2,035,309	2,118,769
2002	17,822,599	254,755	11,373,958	1,969,758	2,750,691	2,357,095	2,842,606	3,058,610	1,877,644
2003	26,760,583	189,284	6,430,409	3,111,533	2,998,568	2,108,670	6,492,011	4,147,632	2,104,632
2004	44,748,725	92,408	6,655,869	2,370,070	3,968,890	1,724,633	5,735,821	5,507,777	2,039,862
2005	39,910,916	681,161	9,281,680	3,082,258	5,282,123	2,045,602	4,370,163	6,028,983	2,162,713

Table A3. Sockeye total run sizes by region, 1956-2005.

Year	Southeast Alaska	North British Columbia	South British Columbia, Washington, and Oregon
1956	1,223,955	2,874,454	3,724,473
1957	1,433,321	1,785,678	5,923,358
1958	1,348,999	3,563,691	22,137,627
1959	1,191,656	2,827,063	5,976,277
1960	787,118	1,505,791	4,497,613
1961	996,105	3,161,029	5,430,221
1962	1,033,237	3,567,790	4,092,561
1963	907,045	3,841,872	4,991,161
1964	1,236,191	4,200,152	2,315,203
1965	1,452,134	2,214,164	3,698,689
1966	1,410,391	1,954,638	6,316,328
1967	1,299,903	3,624,937	8,400,670
1968	1,111,561	6,486,401	3,609,851
1969	1,085,977	2,737,311	5,809,127
1970	893,721	1,270,879	7,194,502
1971	833,222	2,565,992	9,733,215
1972	714,626	2,187,271	4,565,063
1973	907,999	6,614,542	8,336,516
1974	1,010,069	2,691,442	10,137,727
1975	924,210	2,341,434	4,472,874
1976	1,638,128	2,592,622	5,296,487
1977	2,040,197	3,045,063	8,025,282
1978	1,480,429	2,612,221	10,353,993
1979	1,927,777	2,414,113	8,310,609
1980	1,506,153	5,903,153	5,106,260

Table A3. Sockeye total run sizes by region, 1956-2005.

Year	Southeast Alaska	North British Columbia	South British Columbia, Washington, and Oregon
1981	1,484,281	9,878,197	9,518,792
1982	1,951,773	7,676,011	15,580,715
1983	1,803,879	4,742,841	7,330,812
1984	1,641,315	4,030,945	8,240,361
1985	2,133,525	8,899,568	15,583,867
1986	1,596,155	5,738,111	16,389,443
1987	1,755,611	5,591,872	9,113,405
1988	1,332,203	7,076,794	5,538,086
1989	2,022,589	4,706,414	19,501,105
1990	2,041,318	5,204,017	22,849,561
1991	2,001,214	7,068,326	14,639,516
1992	2,493,953	8,841,375	8,320,825
1993	3,183,080	8,529,952	25,605,669
1994	2,052,188	4,533,119	18,058,968
1995	1,625,062	7,471,188	4,253,526
1996	3,066,710	9,353,278	5,386,660
1997	2,232,489	5,836,899	17,469,309
1998	1,351,217	2,339,626	11,600,660
1999	1,569,562	2,145,620	4,283,929
2000	1,255,042	5,784,376	6,008,081
2001	1,827,078	5,418,729	8,409,348
2002	1,537,801	3,512,452	12,222,016
2003	1,670,133	4,119,532	5,028,196
2004	1,915,752	2,661,373	3,501,674
2005	1,693,703	1,709,492	3,827,344

Table A3. Sockeye total run sizes by region, 1956-2005.