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

Volume 2 – Appendices A-D

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

Volume 2 – Appendices A-D

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U.S. Environmental Protection Agency

Seattle, WA

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CONTENTS

VOLUME 1

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

VOLUME 2

APPENDIX A: Fishery Resources of the Bristol Bay Region

APPENDIX B: Characterizations of Selected Non-Salmon Fishes Harvested in the Fresh Waters of Bristol Bay

APPENDIX C: Wildlife Resources of the Nushagak and Kvichak River Watersheds

APPENDIX D: Ecological Knowledge and Cultures of the Nushagak and Kvichak Watersheds, Alaska

VOLUME 3

APPENDIX E: Bristol Bay Wild Salmon Ecosystem Baseline Levels of Economic Activity and Values

APPENDIX F: Biological Characterization: Bristol Bay Marine Estuarine Processes, Fish, and Marine Mammal Assemblages

APPENDIX G: Foreseeable Environmental Impact of Potential Road and Pipeline Development on Water Quality and Freshwater Fishery Resources of Bristol Bay, Alaska

APPENDIX H: Geologic and Environmental Characteristics of Porphyry Copper Deposits with Emphasis on Potential Future Development in the Bristol Bay Watershed, Alaska

APPENDIX I: Conventional Water Quality Mitigation Practices for Mine Design, Construction, Operation, and Closure

Appendix A

Fishery Resources of the Bristol Bay Region

EPA-6363-000002836

Fishery Resources of the Bristol Bay Region

PUBLIC REVIEW DRAFT

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Table of Contents

INTRODUCTION 1
ECOLOGY AND LIFE HISTORY OF BRISTOL BAY FISHES 3
General salmon life history 3
Species-specific life history and ecology 4
Sockeye salmon 4
Chinook salmon 6
Rainbow trout 8
Coho salmon 8
Pink salmon 9
Chum salmon 10
BRISTOL BAY FISHERIES AND FISHERIES MANAGEMENT 10
Historical perspective on commercial salmon fisheries 10
Current management of commercial salmon fisheries 12
Description of sport fisheries 15
Management of sport fisheries 16
Chinook salmon 16
Sockeye salmon 17
Rainbow trout 17
SALMON ABUNDANCE TRENDS AROUND THE NORTH PACIFIC, WITH REFERENCE TO BRISTOL BAY POPULATIONS 18
Sockeye salmon 18
Size of Bristol Bay, Kvichak, and Nushagak sockeye salmon returns 18
Factors affecting Bristol Bay sockeye salmon abundance 25
The decline in Kvichak River sockeye salmon runs 26
Chinook salmon 28
Threatened and endangered salmon and conservation priorities 32
KEY HABITAT ELEMENTS OF BRISTOL BAY RIVER SYSTEMS (OR *WHY DO BRISTOL BAY WATERSHEDS PRODUCE SO MANY FISH?*) 37
Habitat quantity 37
Habitat quality 40
Habitat diversity 43

EPA-6363-000002838

Tables

Table 1. Mean harvest by species and fishing district, 1990-2009. 12
Table 2. Bristol Bay escapement goal ranges for sockeye salmon. 13
Table 3. Bristol Bay escapement goal ranges for Chinook and chum salmon 14
Table 4. The number of businesses and guides operating in the Nushagak and Kvichak watersheds in 2005, 2008 and 2010 16
Table 5. Mean annual returns of sockeye salmon in Bristol Bay, 1956-2010, and percent of total by river system 27
Table 6. Chinook average run sizes for 2000-2009 for rivers across the North Pacific 29
Table 7. Endangered Species Act listings for salmon ESUs in the United States 35
Table 8. Comparison of landscape features potentially important to sockeye salmon production for watersheds across the North Pacific and across the Bristol Bay watershed 38
Table 9. A summary of life history variation within the Bristol Bay stock complex of sockeye salmon 44
Table 10. Variation in time spent rearing in fresh water and at sea for Bristol Bay sockeye salmon 44

Figures

Figure 1. Major river systems and fishing districts in Bristol Bay, Alaska. 2
Figure 2. Sockeye salmon distribution in the Nushagak and Kvichak watersheds 5
Figure 3. Chinook salmon distribution in the Nushagak and Kvichak watersheds 7
Figure 4. Relative abundance of wild sockeye salmon stocks in the North Pacific, 1956-2005 19
Figure 5. Wild sockeye salmon abundances by region in the North Pacific, 1956-2005 20
Figure 6. Total sockeye returns by river system in Bristol Bay, 1956-2010 22
Figure 7. Sockeye salmon abundances for major rivers of the North Pacific, 1956-2010 24
Figure 8. Chinook salmon abundances by river system, 1966-2010 31
Figure 9. Map of surveyed anadromous streams in the Nushagak and Kvichak watersheds 39

Appendices

Appendix 1. Chinook and sockeye almon run sizes for Bristol Bay and other regions of the North Pacific. 56

EPA-6363-000002839

INTRODUCTION

Beginning each June, millions of Pacific salmon return from feeding in the open ocean 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 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.

EPA-6363-000002840

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-migratory 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).

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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 lakes (Figure 2). On average, Iliamna Lake produces more sockeye than any other lake in the Bristol Bay region (see data for Kvichak River in Appendix 1). Riverine sockeye populations spawn and rear throughout the Nushagak River basin (Figure 2). 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).

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).

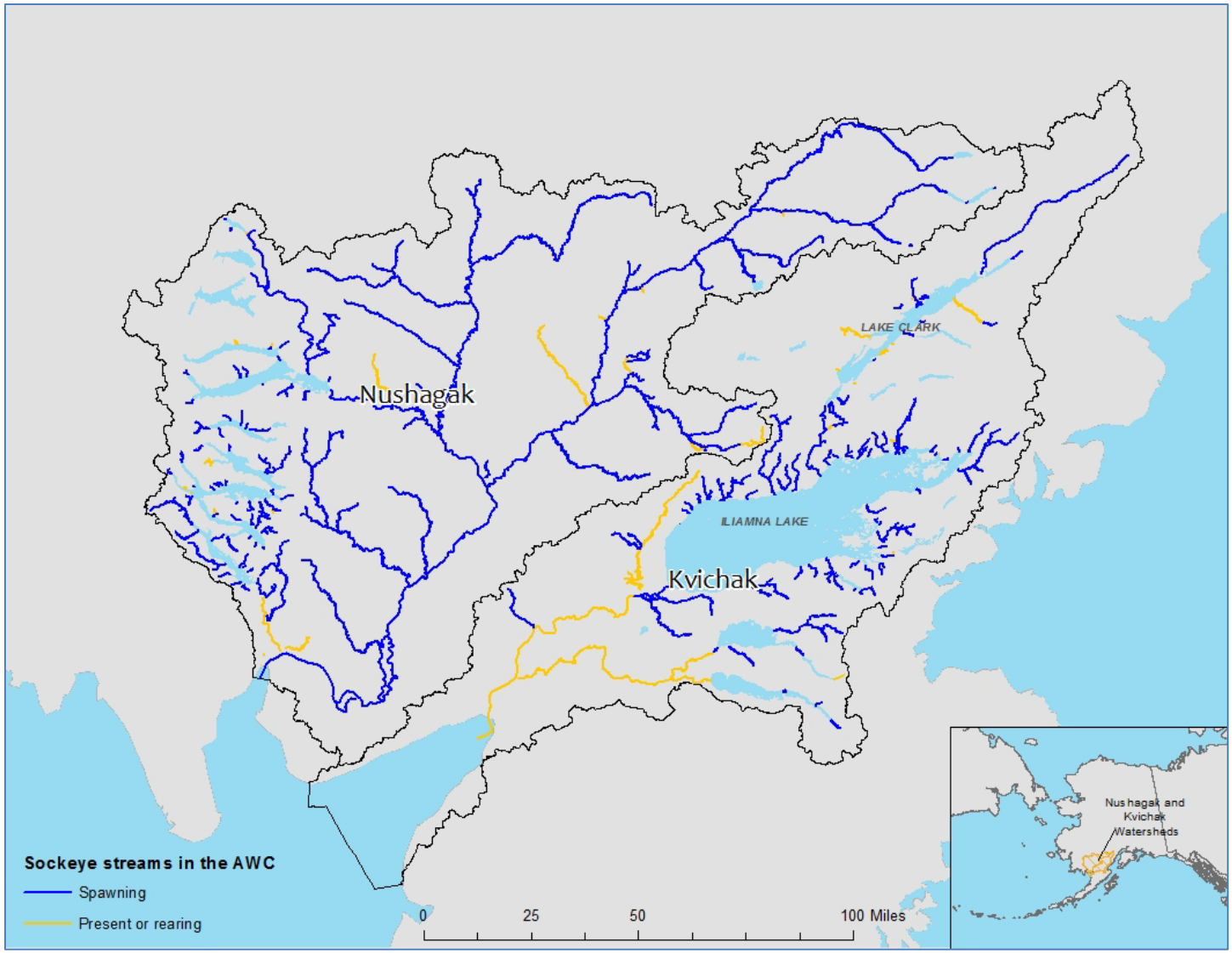

Figure 2. Sockeye salmon distribution in the Nushagak and Kvichak watersheds. Data are from the Alaska Department of Fish and Game's Anadromous Waters Catalog for 2011.

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).

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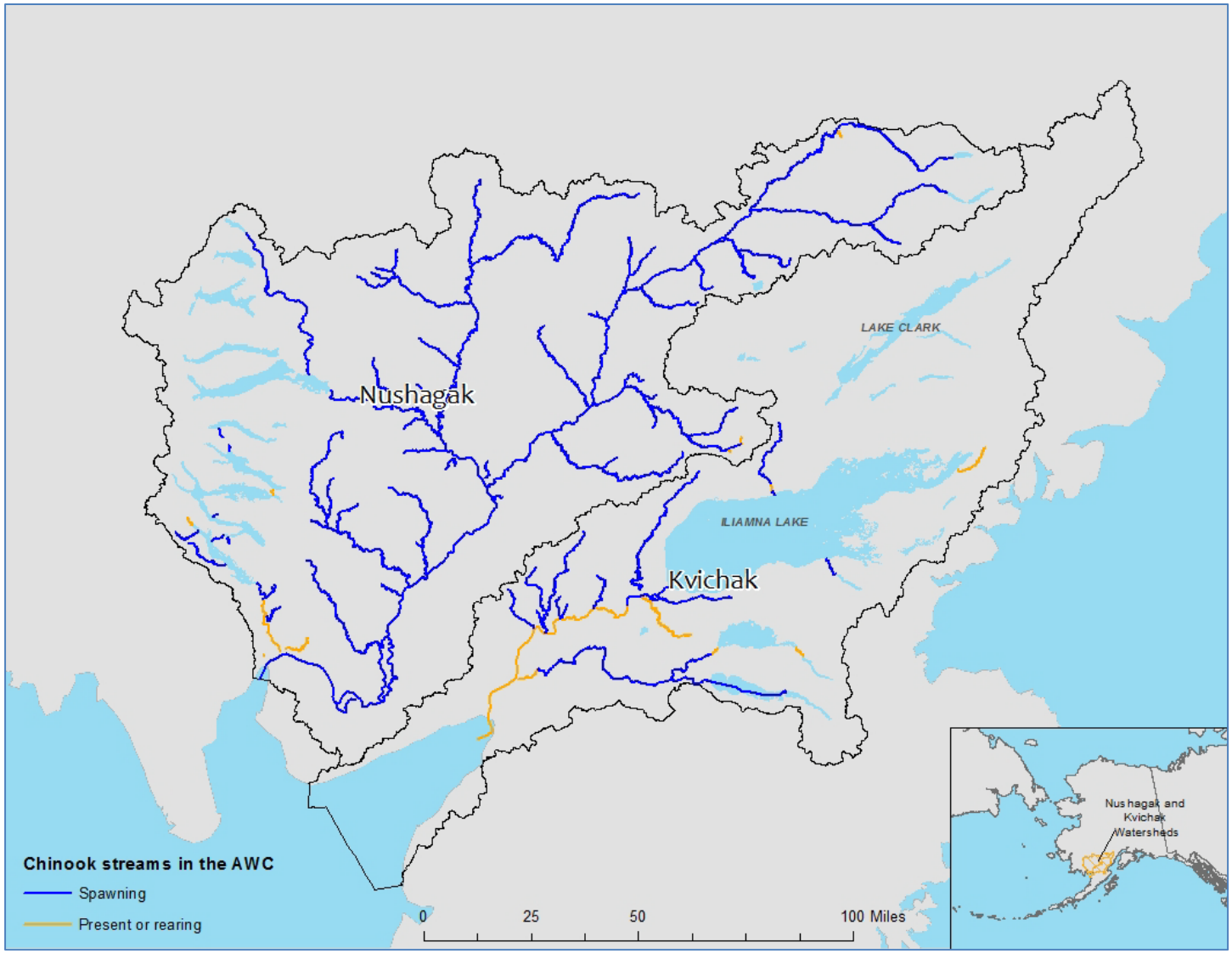

Figure 3. Chinook salmon distribution in the Nushagak and Kvichak watersheds. Data are from the Alaska Department of Fish and Game's Anadromous Waters Catalog for 2011.

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 rivers of Bristol Bay. 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

EPA-6363-000002847

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. In press). They utilize a wide range of lotic and lentic freshwater habitats, including stream channels, off-channel sloughs and alcoves, beaver ponds, and lakes. Coho distribute widely into headwater streams, 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).

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. 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. They typically spawn in shallow, rocky stream reaches relatively low in the watershed and their young migrate to sea soon after emerging (Heard 1991, pg. 144).

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 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."

EPA-6363-000002848

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). Scattered spawning populations also occur 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, 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), and one year's run in the Nushagak River showed similar age structure (West et al. 2009, pgs. 82-83). 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).

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

EPA-6363-000002849

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 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. Set 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	340-760
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. As salmon move upstream, 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

EPA-6363-000002852

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 Chinook salmon goals for the Togiak, Alagnak, Naknek, and Egegik rivers and a chum salmon goal for the Nushagak River (Table 3), but in-season management is not used to help attain these goals.

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 and chum salmon.

River	Species	Escapement goal
Togiak	Chinook	9,300 minimum
Nushagak	Chinook	40,000-80,000
Nushagak	chum	190,000 minimum
Alagnak	Chinook	2,700 minimum
Naknek	Chinook	5,000 minimum
Egegik	Chinook	450 minimum

EPA-6363-000002853

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

EPA-6363-000002854

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. Three 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 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 instated conservative trout management uniformly throughout the region, replacing 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).

Only single-hook artificial lures can be used in the Kvichak River drainage, and all sport fishing is banned 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

EPA-6363-000002856

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

North Pacific salmon species, from most to least abundant overall, 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 4). 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 5), 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 4), 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).

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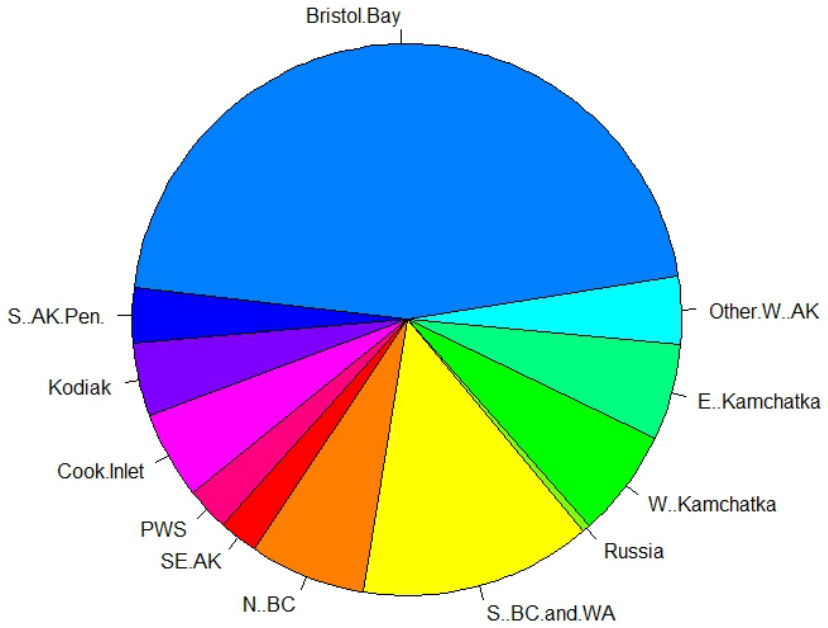
Figure 4. Relative abundance of wild sockeye salmon stocks in the North Pacific, 1956-2005. See



Appendix 1 for data and sources. Stocks are ordered from west to east across the North Pacific.

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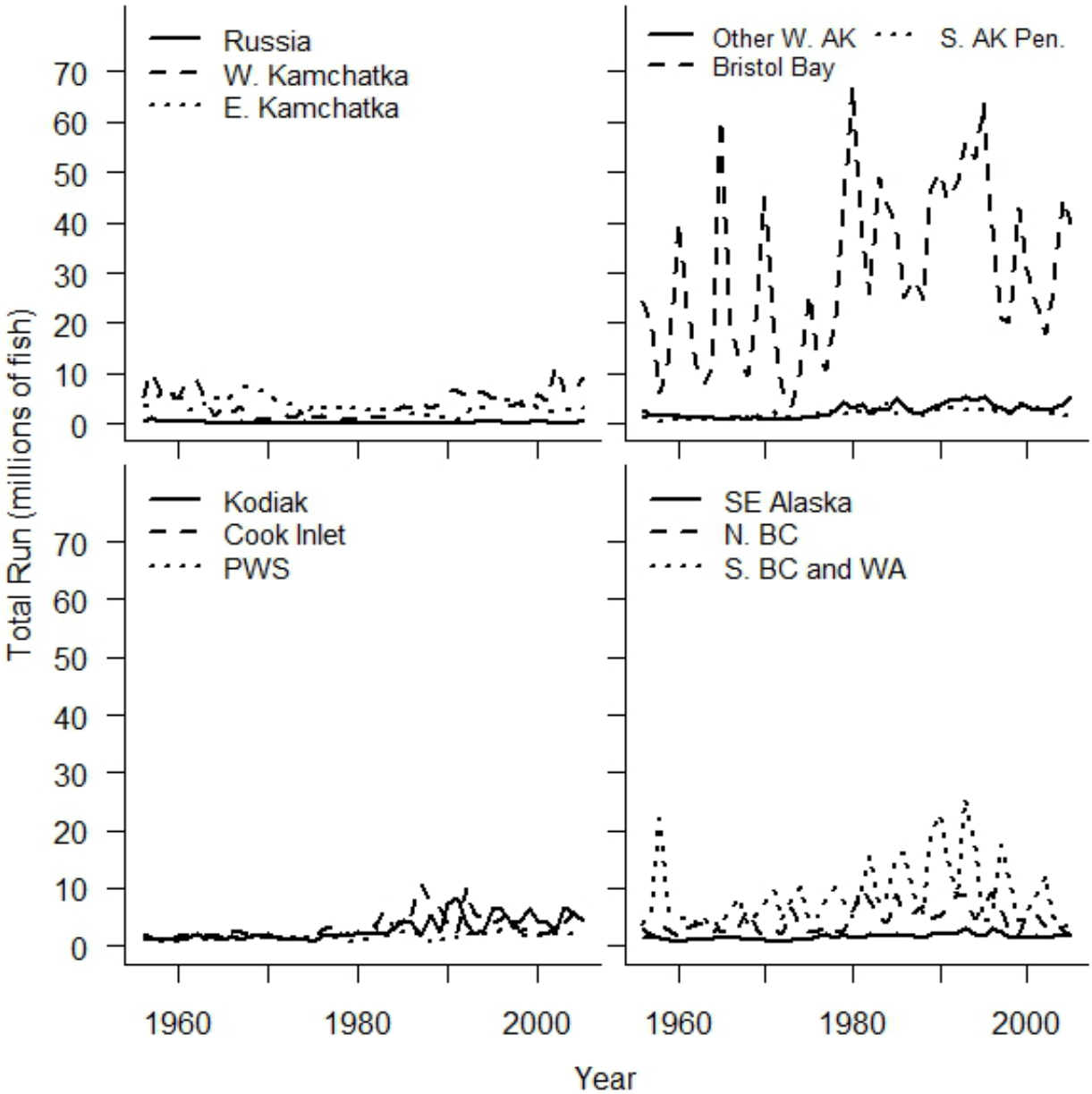

Figure 5. Wild sockeye salmon abundances by region in the North Pacific, 1956-2005. See Appendix 1 for data and sources. Each graph shows three regions organized from west to east across the North Pacific.

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 6). 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 6). The Nushagak and Wood rivers are smaller runs and average returns from 1956 to 2010 were 1.3 and 3.3 M fish, respectively.

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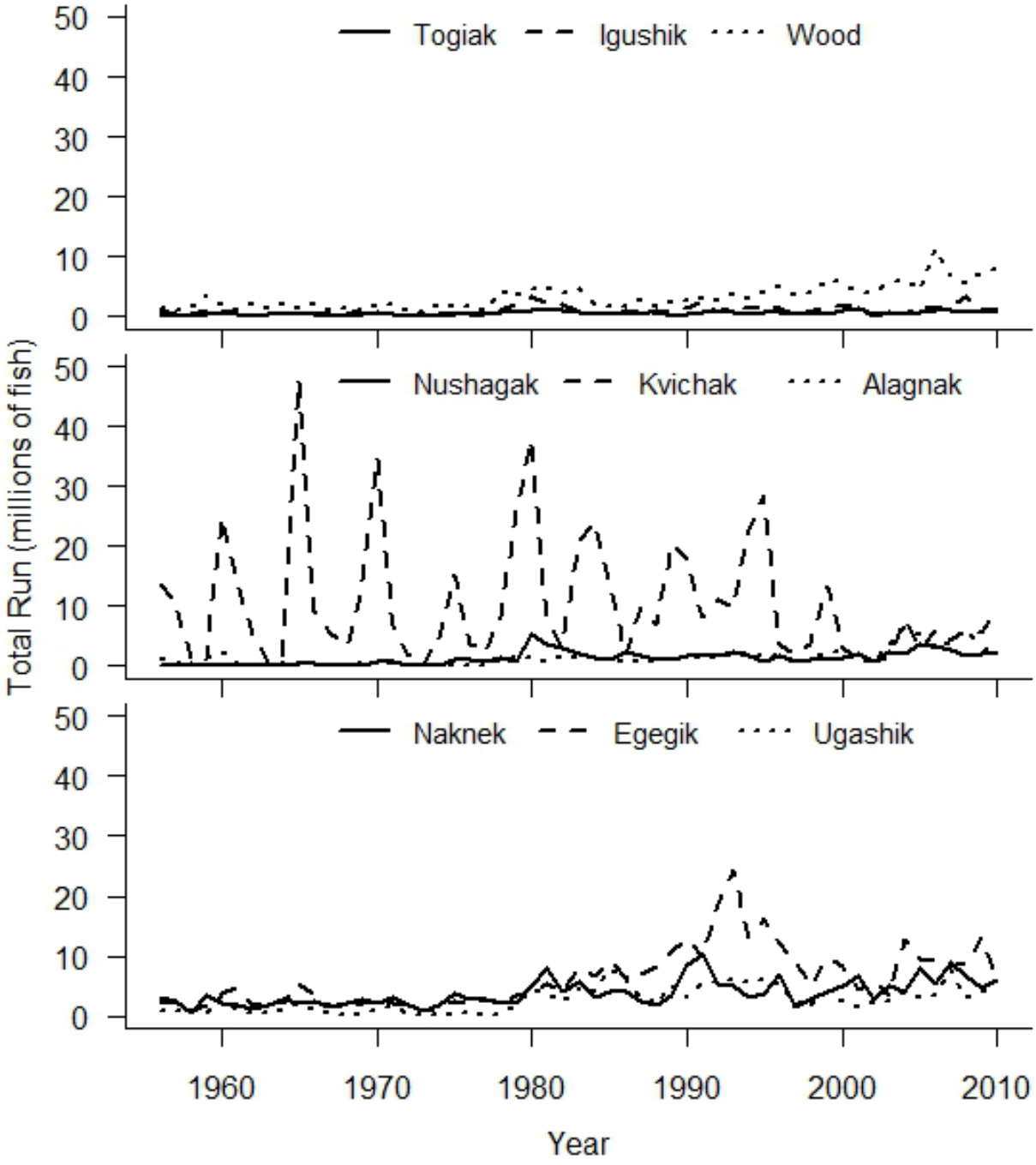

Figure 6. Total sockeye returns by river system in Bristol Bay, 1956-2010. See Appendix 1 for data and sources. Each graph shows three river systems listed from west to east across Bristol Bay.

The Kvichak River sockeye salmon runs are not only the largest in Bristol Bay, but also the largest in the world (Figures 5 through 7). 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 7). 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).

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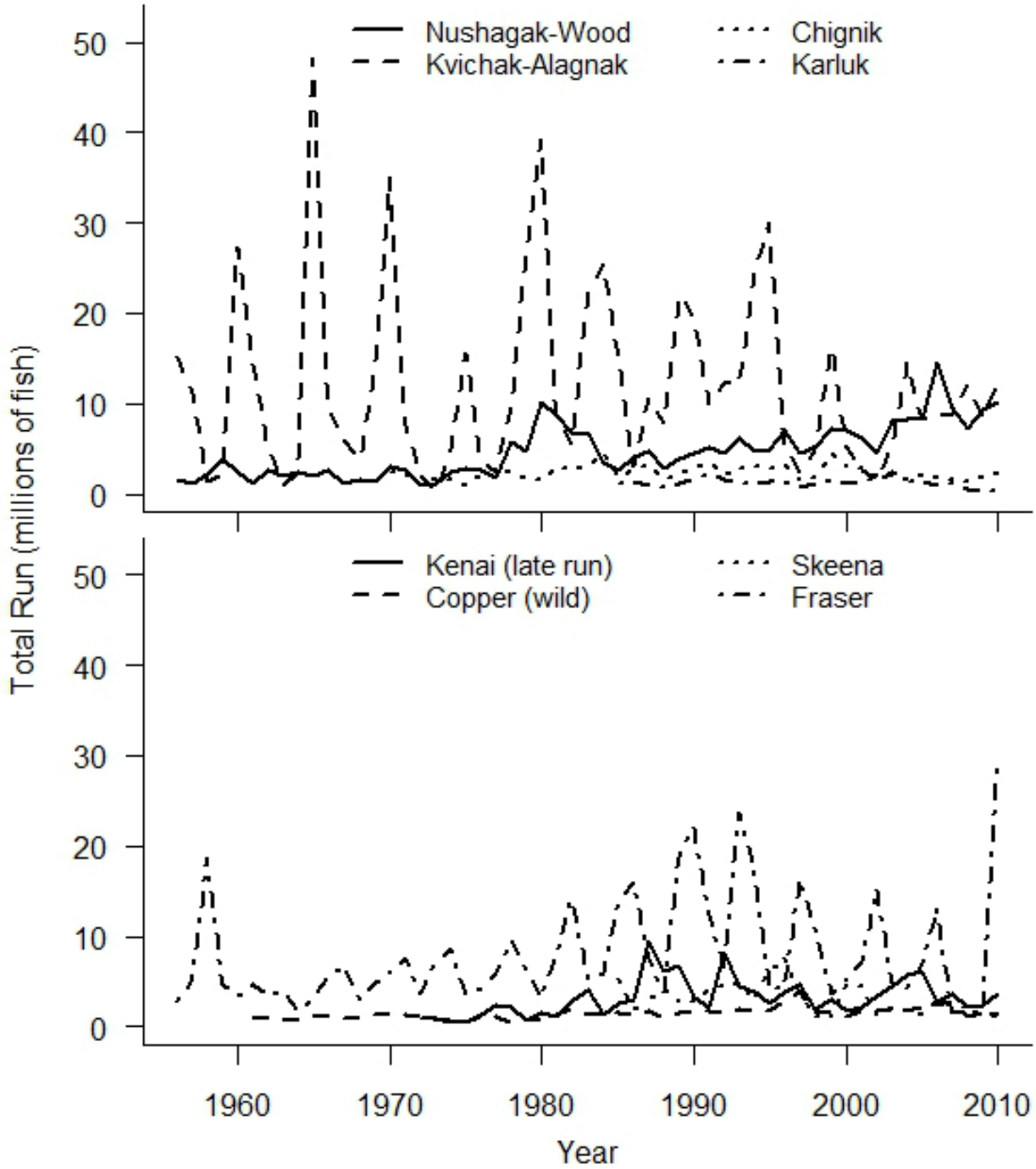

Figure 7. Sockeye salmon abundances for major rivers of the North Pacific, 1956-2010. See Appendix 1 for data and sources. The top graph includes time series for the Nushagak-Wood and Kvichak-Alagnak systems from 1956 to 2010, the Chignik River from 1970 to 2010, and the Karluk River from 1985 to 2010. 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 5). 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 fixed 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

EPA-6363-000002864

(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.

EPA-6363-000002865

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

EPA-6363-000002866

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).

EPA-6363-000002867

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	Bristish 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.)	Bristish 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.	Bristish Columbia, Canada	63,356 [9]	51,383
Yukon R., Canadian mainstem	Yukon Territory, Canada	59,346 [10]	323,800
Nass R.	Bristish 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).

EPA-6363-000002868

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 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 8). An especially productive six-year period from 1978-1983 produced three returns greater than 300,000 fish (Figure 8). 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.

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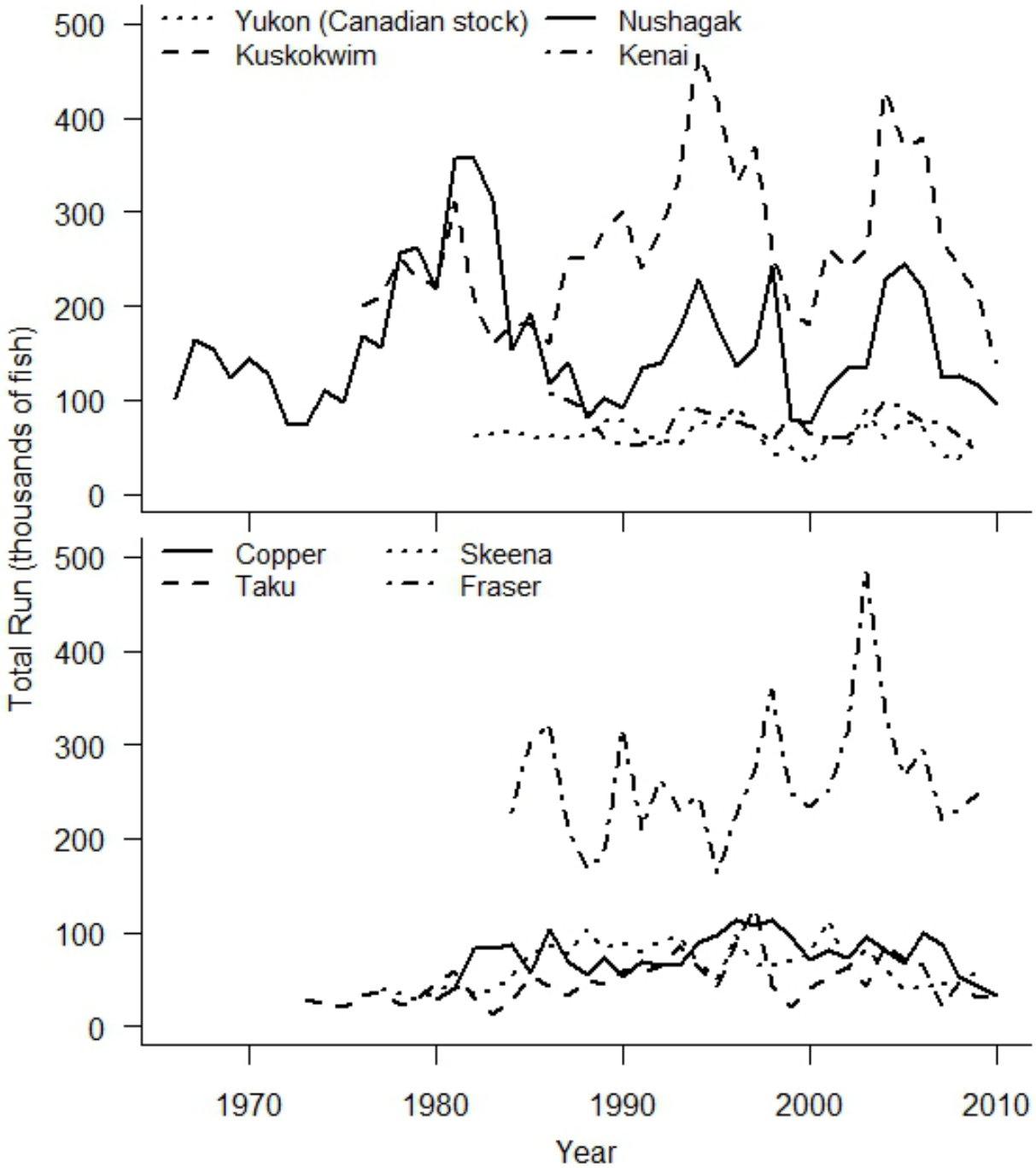

Figure 8. Chinook salmon abundances by river system, 1966-2010. See Appendix 1 for data and sources. The top graph shows total runs for the Yukon River (Canadian stock) from 1982 to 2009, the Kuskokwim River from 1976 to 2010, the Nushagak River from 1966 to 2010, and the Kenai River from 1986 to 2010. 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.

EPA-6363-000002870

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 1998, 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 1998). 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).

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 8 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

EPA-6363-000002871

extinction rates and are considered at higher risk than populations further to the north (Brown et al. 1994, Kope and Wainwright 1998, Rand 2008).

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). At the global population level, sockeye salmon are considered a species of least concern. Eighty subpopulations were identified for assessment, five of which are extinct and 26 did not have the necessary data with which to conduct a status assessment. Of the remaining 49 subpopulations, 17 were identified as threatened and two as nearly threatened. British Columbia has 12 threatened (vulnerable, endangered, or critically endangered) subpopulations, 70% 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 2008). Twenty-five subpopulations were assessed for Alaska: 10 were data deficient, 12 were of least concern (including the one subpopulation identified for Bristol Bay), one subpopulation in the eastern Gulf of Alaska was listed as vulnerable (four of six sites had declining trends: Bering, East Alsek, Italio, and Situk rivers), and two subpopulations in Southeast Alaska (McDonald and Hugh Smith Lakes) were 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

EPA-6363-000002872

(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).

EPA-6363-000002873

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 19th century followed by extensive impacts to river habitats

EPA-6363-000002874

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 9). 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). With the exception of Chikuminuk Lake, all of the major lakes named above are accessible to anadromous salmon.

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 9). 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).

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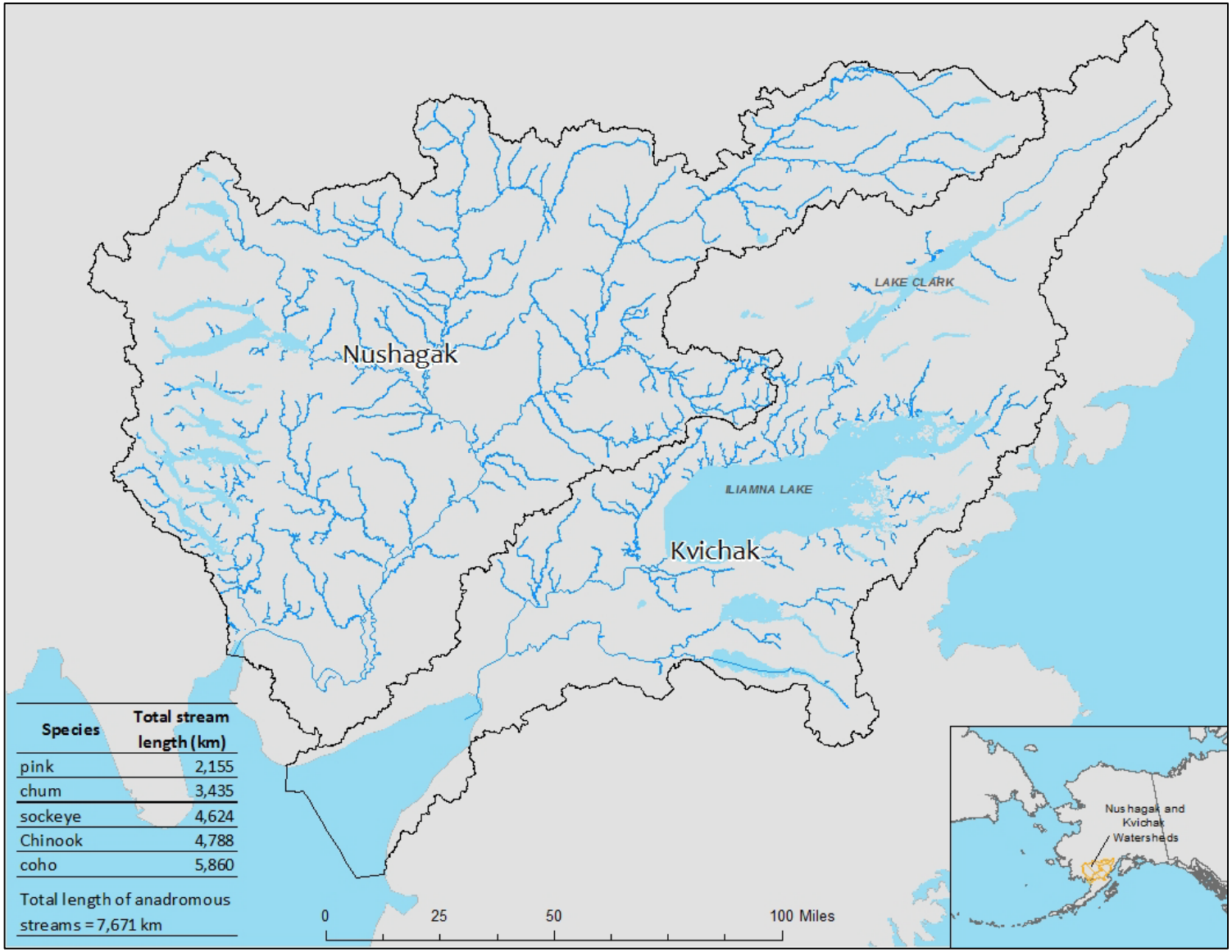
Table 8. Comparison of landscape features potentially important to sockeye salmon production for watersheds across the North Pacific (top portion of table) and across the Bristol Bay watershed (bottom portion of table). All landscape data are from the Riverscape Analysis Project (Luck et al. 2010).

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).



Species	Total stream length (km)
pink	2,155
chum	3,435
sockeye	4,624
Chinook	4,788
coho	5,860

Total length of anadromous streams = 7,671 km

Figure 9. 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

EPA-6363-000002879

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. in press). 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, but any resulting effects on fish are less clear. 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 may benefit indirectly through increased macroinvertebrate production, but this has yet to be 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

EPA-6363-000002881

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.

EPA-6363-000002882

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	+		+	

EPA-6363-000002883

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 6).

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. in press). 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

EPA-6363-000002884

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.*

EPA-6363-000002885

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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 by river system, 1966-2010

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

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

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

Year	Nushagak	Kenai	Yukon, Canadian mainstem	Copper	Taku	Skeena	Nass	Nehalem	Skagit
1966	101,951	NA	NA	NA	NA	NA	NA	NA	NA
1967	164,960	NA	NA	NA	NA	NA	NA	NA	NA
1968	154,714	NA	NA	NA	NA	NA	NA	NA	NA
1969	123,007	NA	NA	NA	NA	NA	NA	NA	NA
1970	143,743	NA	NA	NA	NA	NA	NA	NA	NA
1971	127,231	NA	NA	NA	NA	NA	NA	NA	NA
1972	74,983	NA	NA	NA	NA	NA	NA	NA	NA
1973	73,113	NA	NA	NA	38,307	NA	NA	NA	NA
1974	109,185	NA	NA	NA	35,442	NA	NA	NA	NA
1975	98,279	NA	NA	NA	46,870	NA	17,874	5,060	22,252
1976	167,584	NA	NA	NA	44,555	NA	16,583	9,446	23,939
1977	156,196	NA	NA	NA	41,856	39,606	18,410	11,552	18,514
1978	255,590	NA	NA	NA	56,386	35,055	21,807	11,676	20,962
1979	261,875	NA	NA	NA	60,190	28,166	16,229	12,058	22,261
1980	218,515	NA	NA	29,659	64,247	38,626	18,744	5,645	30,346
1981	356,181	NA	NA	41,047	75,280	42,018	17,606	10,577	20,720
1982	356,190	NA	60,746	84,098	37,042	35,185	13,287	5,111	21,475
1983	312,771	NA	63,427	82,730	19,943	39,510	20,516	4,376	15,225
1984	154,396	NA	66,800	86,373	41,850	53,516	31,408	20,939	15,701
1985	193,138	NA	59,736	55,997	71,814	76,544	24,768	18,845	27,709
1986	117,720	106,917	61,789	103,024	51,190	87,566	47,967	11,570	23,507
1987	139,485	100,123	58,921	69,910	41,474	76,349	26,568	15,268	14,782
1988	80,845	89,462	61,126	55,801	66,601	102,563	21,094	16,684	16,390
1989	102,076	59,409	78,243	73,423	57,086	83,439	36,594	11,650	14,596
1990	92,317	50,751	78,439	52,899	66,517	89,447	33,384	6,617	20,717
1991	134,191	52,810	63,335	68,175	80,066	79,343	13,136	7,498	9,696
1992	140,511	54,302	57,058	64,172	84,882	92,184	25,405	11,558	10,211

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

Year	Nushagak	Kenai	Yukon, Canadian mainstem	Copper	Taku	Skeena	Nass	Nehalem	Skagit
1993	175,376	89,748	52,855	65,301	98,073	96,018	36,678	9,137	7,691
1994	228,739	90,552	77,647	90,073	70,253	68,127	32,864	9,194	7,082
1995	177,509	81,563	71,557	96,710	74,564	48,351	16,187	8,671	10,096
1996	136,663	77,228	93,672	113,868	98,184	96,453	30,889	12,975	13,364
1997	155,562	69,773	70,349	107,760	130,091	65,350	27,658	12,732	7,198
1998	242,184	55,540	41,434	112,365	51,706	65,167	34,922	10,591	16,067
1999	79,168	86,553	49,652	95,951	33,500	70,993	22,310	10,361	5,725
2000	75,074	63,373	30,749	70,746	51,055	77,320	31,159	10,817	18,231
2001	113,367	60,320	62,703	81,155	59,449	112,346	44,595	14,293	15,947
2002	133,552	61,878	51,616	72,972	71,902	63,069	21,528	20,552	20,979
2003	136,008	73,210	90,213	94,505	62,436	82,410	36,503	23,569	11,933
2004	227,994	99,765	59,707	80,559	113,923	61,065	25,137	14,456	25,863
2005	244,082	91,309	79,625	66,341	81,173	39,278	24,067	8,222	24,701
2006	218,005	76,186	72,005	99,877	68,842	43,689	37,098	13,129	23,115
2007	123,139	76,472	39,997	87,770	29,766	44,185	34,221	6,648	13,003
2008	126,700	61,152	37,434	53,880	126,700	54,279	26,202	5,651	15,942
2009	115,559	46,095	69,418	43,007	115,559	55,921	36,865	5,332	13,144
2010	95,592	NA	NA	32,999	NA	NA	NA	NA	NA

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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

EPA-6363-000002898

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: Pers. comm. Gregory Buck, ADF&G
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

EPA-6363-000002899

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

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

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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

EPA-6363-000002902

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

EPA-6363-000002904

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.

EPA-6363-000002905

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

EPA-6363-000002908

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

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

Data Sources: Bristol Bay, pers. comm. Tim Baker, ADF&G; Other regions are from Ruggerone et al. 2010

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Appendix B

Characterizations of Selected Non-Salmon Fishes Harvested in the Fresh Waters of Bristol Bay

EPA-6363-000002911

Characterizations of selected non-salmon fishes harvested in the fresh waters of Bristol Bay

EXTERNAL REVIEW DRAFT

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CHARACTERIZATIONS OF SELECTED NON-SALMON FISHES HARVESTED IN THE FRESH WATERS OF BRISTOL BAY

INTRODUCTION

The fresh waters of the EPA Bristol Bay Watershed Assessment Area (BBWAA) in southwest Alaska support diverse and robust populations of at least 11 families, 22 genera, and 35 species of fish (Table 1). This appendix provides biological, ecological, and human use information for selected species which are, or have been, targeted by sport, subsistence, and/or commercial fisheries within the BBWAA. This appendix does not review Pacific herring, Pacific cod, saffron cod, Pacific staghorn sculpin, Arctic flounder, and starry flounder that are primarily marine species that only venture intermittently into the lower reaches of some of the drainages (Mecklenburg et al. 2002; Morrow 1980b). This appendix also does not describe species harvested in fresh water for which there is limited BBWAA distributional or biological information (e.g., boreal smelt), nor the five species of North American Pacific salmon, which are reviewed in Appendix A of this assessment .

Each of the species described in this appendix: northern pike, humpback whitefish, rainbow trout, Arctic char, Dolly Varden, lake trout, and Arctic grayling, are well distributed within the BBWAA. Unlike the *obligate anadromous* BBWAA Pacific salmon populations, in which essentially all individuals migrate from lakes and streams to the sea to feed and grow, individual fish in these seven species do not need to journey to marine waters to successfully complete their life cycle, although some individuals of certain species (e.g., Dolly Varden and humpback whitefish) may. Anadromous fish spawn in fresh waters but feed for part of their lives in marine waters (Myers 1949). Nonanadromous (resident) fish remain throughout their lives in fresh water, but may move seasonally between habitats within a given drainage (see species descriptions below). Also unlike the North American Pacific salmon, individuals in each of these seven species can survive to spawn more than once (they are *iteroparous*, Stearns 1992, p. 180) and, compared to salmon, have longer potential life spans (see species descriptions below).

Northern pike *Esox lucius*

Freshwater distribution and habitats

Northern pike have a circumpolar distribution across the northern hemisphere and is the only species in the family Esocidae that has colonized arctic waters (Crossman 1978). In North America they inhabit lakes and low gradient rivers from the Arctic Ocean south to the Missouri and Mississippi river drainages, and from the North Atlantic Ocean west to the Rocky Mountains (Scott and Crossman 1998, p. 357). In Alaska, northern pike are native primarily north of the Alaska Range, including waters of the BBWAA (Mecklenburg et al. 2002, p. 144; Morrow 1980b, p. 168). In Bristol Bay, northern pike occur in coastal plain lakes (Hildreth 2008, p. 9), inland lakes (Burgner et al. 1965, p. 4; Dye et al. 2002, p. 1; Russell 1980, p. 87), and river systems (ADF&G 2011) providing suitable habitat. The Nushagak and Nuyakuk river mainstems, Lake Aleknagik, and the Lake Clark drainage support the largest sport fisheries within the BBWAA (Jennings et al. 2011, p. 126, 128).

Northern pike primarily spawn in sections of lakes, wetlands, or very low gradient streams providing shallow (less than 1 m), slow or still waters with soft substrates and aquatic vegetation

(Cheney 1971d, p. 13; Chihuly 1979, p. 48, 57; Dye et al. 2002, p. 5, 6-7; Rutz 1999, p. 15). Summer habitat is in slightly deeper, but still warm water with dense aquatic vegetation (Chihuly 1979, p. 46, 58; Dye et al. 2002, p. 5; Joy and Burr 2004, p. 22; Roach 1998, p. 3; Rutz 1999, p. 9). In southcentral Alaska's Susitna River drainage, river-dwelling northern pike are often found in side sloughs where water temperatures are several degrees warmer than the adjacent main channel (Rutz 1999, p. 19). Among the large, deep, cold, glacially-formed lakes of the BBWAA, shallow, vegetated habitats are scarce, making those found in Lake Clark's Chulitna Bay and the shallow bays of Lake Aleknagik particularly important northern pike concentration areas (Chihuly 1979, p. 48; Dye et al. 2002, p. 6-7; Russell 1980, p. 91).

Northern pike overwinter in lakes, spring-fed rivers, or larger deep rivers where there is likely to be sufficient water and oxygen to survive until spring (Dye et al. 2002, p. 5; Roach 1998, p. 18-21; Scanlon 2009, p. 17; Taube and Lubinski 1996, p. 5-8). Water depth beneath winter ice may be 0.8 m or less (Taube and Lubinski 1996, p. 8). In winter, local residents ice fish for northern pike along the BBWAA's large rivers (Krieg et al. 2009, p. 135, 220, 215, 344).

Life cycle

At spring ice-out in the BBWAA's Lake Aleknagik, large fish are in water 1 to 1.5 m deep and within 10 m of shore. In late May to mid-June, as water temperatures rise to about 6 °C, mature fish move inshore to spawn in brush and aquatic vegetation (Dye et al. 2002. p. 5). Female northern pike can produce over 100,000 adhesive 3-mm diameter ova, which they scatter in small batches among aquatic vegetation or rocks, while an attending male fertilizes them. Neither females nor males construct redds (Morrow 1980b, p. 166-167; Scott and Crossman 1998, p. 359). After spawning, as Lake Aleknagik water temperatures rise above 8 °C, fish move slightly offshore, to 1 to 3 m of water, but remain in the bays where they spawned, moving little for the remainder of the summer (Dye et al. 2002, p. 5). As water levels and temperatures drop in mid-September through October, fish move out of shallow bays to depths of 3 to 5 m in the main lake and then move little until the following spring (Dye et al. 2002, p. 5).

Mature northern pike living in Alaskan river systems and river-lake complexes ascend tributaries in spring, beneath the ice. Spawning occurs from mid-May to early July as ice melts in side-channel slack waters or lake margins. After spawning, mature pike move to deeper water to feed, where they remain until moving in September and October to lakes, spring-fed streams, and larger, deeper rivers where they overwinter (Cheney 1971d, p. 13-14; Cheney 1972, p. 5; Chythlook and Burr 2002, p. 13; Kepler 1973, p. 75; Russell 1980, p. 91; Taube and Lubinski 1996, p. 6-8).

Northern pike eggs hatch in less than a month. At hatching, fry are 6 to 9 mm long, and have a yolk sac, but no mouth. Before they start actively feeding, fry cling to the substrate, debris, or vegetation for around 10 days, absorbing their yolk sacs while their mouths develop (Morrow 1980b, p. 167; Scott and Crossman 1998, p. 359). In BBWAA lakes, young-of-the-year northern pike are actively swimming by at least late June to early July and grow rapidly through the summer (Chihuly 1979, p. 32, 34; Russell 1980, p. 91, 93). In river systems, fry remain near or downstream of spawning areas (Cheney 1971d, p. 13). In interior Alaska, age-0 fish reach a mean length of 140 mm by September (Cheney 1972, p. 15). In Lake Aleknagik, northern pike grow rapidly to about age 4 and a total length of around 419 mm, then growth slows to about an average of 25 mm per year (Chihuly 1979, p. 27-28, 33). Some male northern pike in Lake

Aleknagik mature at age 3, and by around age 5 and lengths of approximately 438 to 469 mm, all fish are mature (Chihuly 1979, p. 34).

Many mature northern pike do not travel far (Chihuly 1979, p. 64; Dye et al. 2002, p. 5; Joy and Burr 2004, p. 25; Rutz 1999, p. 8), but some river-system individuals make extensive seasonal migrations between spawning, feeding, and overwintering areas (Scanlon 2009, p. 11), sometimes moving at least 290 km per year (180 mi per year, Cheney 1971a, p. 7). Mature northern pike may disperse through the summer and then aggregate prior to moving to overwintering locations and while overwintering (Roach 1998, p. 14). Mature northern pike show high fidelity to spawning (Joy and Burr 2004, p. 29; Roach 1998, p. 13) and winter areas (Scanlon 2009, p. 20; Taube and Lubinski 1996, p. 8) and moderate fidelity to summer feeding areas (Taube and Lubinski 1996, p. 8). Because fish must exceed a minimum size before they can be successfully tracked with standard telemetry methods, most movement studies are limited to bigger individuals and seasonal movements of immature Alaskan northern pike are largely unknown.

Mature females often tend to be larger than males of the same age (Clark et al. 1988, p. 22, 25; Pearse 1991, p. 36; Rutz 1999, p. 9), but males appear to have a greater mortality rate (Cheney 1971c, p. 17; Chihuly 1979, p. 26; Pearse 1991, p. 36). In the BBWAA, northern pike can reach total lengths of at least 1.04 m, weights in excess of 7 kg, and ages of 18 years (Chihuly 1979, p. 33, 37; Dye et al. 2002, p. 6; Russell 1980, p. 92, 93). In the Yukon River drainage, fish can reach 1.2 m in length (Scanlon 2009, p. 20), and 26 years in age (Cheney 1971c, p. 15).

Predator–prey relationships

Northern pike are highly adaptable predators able to consume a wide range of invertebrates and vertebrates, but they are particularly efficient consumers of fish (Craig 2008). Where they are available, a wide variety of fish dominate the diet of larger BBWAA northern pike, including Alaska blackfish, round whitefish, least cisco, smaller northern pike, ninespine and threespine stickleback, juvenile sockeye salmon, Arctic char, pygmy whitefish, sculpins, longnose suckers, and lake trout (Chihuly 1979, p. 79-86; Russell 1980, p. 95-97). The diet of larger northern pike illegally introduced into southcentral Alaska's Susitna River drainage was dominated by coho and sockeye salmon, whitefish species, stickleback species, and rainbow trout (Rutz 1999, p. 17). Immediately after hatching, young-of-the-year fry eat zooplankton and immature aquatic insects, but quickly transition to small sticklebacks and other small fish (Chihuly 1979, p. 85-88; Morrow 1980b, p. 167). Northern pike smaller than 200 mm feed substantially on invertebrates; fish over 400 mm eat invertebrates (e.g., crustaceans, leeches, beetle larvae, and mollusks, Russell 1980, p. 95-97) only incidentally (Cheney 1972, p. 29; Chihuly 1979, p. 79-88). Northern pike diets are adaptable and can include a wide variety of foods in the absence of fish prey, although growth rates are then lower (Cheney 1971b, p. 23). Northern pike are a keystone predator and often the greatest predator of northern pike are larger northern pike (Cheney 1972, p. 27; Chihuly 1979, p. 82; Craig 2008).

Abundance and harvest

Total abundance of northern pike in the BBWAA is unknown. Dye et al. (2002, p. 6) estimated that in 1998 and 1999, the abundance of northern pike longer than 299 mm in Lake Aleknagik was more than 11,580. Chulitna Bay on Lake Clark has supported a large subsistence fishery; in June 1978 an estimated 350 to 500 large northern pike were harvested from Turner Bay at the

head of Chulitna Bay (Russell 1980, p. 91). In the mid-2000s, residents in ten of the BBWAA villages annually harvested an estimated 4,385 northern pike (Fall et al. 2006, p. 45, 80, 113, 150, 194; Krieg et al. 2009, p. 40, 78, 118, 162, 202), and they were the most important non-salmon fish in four of those villages (Fall et al. 2006, p. 152; Krieg et al. 2009, p. 46, 124, 171). From the mid-1970s to the mid-2000s, northern pike were estimated to represent between 9.9 and 14.1% of the total weight of the Kvichak River drainage non-salmon freshwater fish subsistence harvest (Krieg et al. 2005, p. 214). In 2009, sport anglers caught an estimated 8,217 northern pike in the BBWAA and the adjacent Togiak River drainage (10% of the statewide total) and harvested (kept) an estimated 1,177 (6% of the statewide total; Jennings et al. 2011, p. 75). Annual sport harvests have declined, due at least in part to both lower bag limits and the increasing popularity of catch-and-release fishing (Dye and Schwanke 2009, p. 6). In 1966 and 1967, an experimental freshwater commercial fishery on Tikchik Lake harvested 316 northern pike, the third-most commonly harvested fish (6% of total number of fish harvested; Yanagawa 1967, p. 10).

Stressors

Because northern pike are long-lived, have a piscivorous diet, and prefer relatively warm water, they bioaccumulate and biomagnify atmospherically deposited mercury, and tissue mercury concentrations correlate strongly with length and age (Headlee 1996; Mueller et al. 1996, p. 36). Lindesjöö and Thulin (1992) reported that wild northern pike exposed to pulp mill effluents developed severe jaw deformities. They did not determine if the deformities were directly caused by constituents of the effluents, if the deformities resulted from a secondary reduction of dissolved oxygen (DO) levels, or through some other mechanism. Northern pike are highly tolerant of low DO levels. In laboratory experiments, juvenile northern pike survived DO levels down to at least 0.25 $mg \cdot l^{-1}$ (Petrosky and Magnuson 1973).

Casselman (1978) found that, for a Canadian stock of northern pike, maximum summer growth occurred at 19 °C, growth stopped at 28 °C, and 29.4 °C was the upper incipient lethal temperature. For an Ohio stock, Bevelhimer et al. (1985) reported maximum summer growth occurred at 25 °C and that northern pike continued to grow at 30 °C. Combined, these results suggest a possible latitudinal cline in temperature tolerances and optimal and lethal temperatures for BBWAA northern pike may be lower than those reported by Casselman (1978).

Humpback whitefish *Coregonus pidschian*

The taxonomic status of humpback whitefish remains unsettled. Some sources (e.g., Mecklenburg et al. 2002, p. 180; Morrow 1980b, p. 24) distinguish three separate Alaskan whitefish species (lake *C. clupeaformis,* Alaska *C. nelsonii, and* humpback *C. pidschian*) based on gill raker counts; other authors (e.g., Alt 1979; Brown 2006, p. 2; McDermid et al. 2007) consider them a single variable species (the *C. clupeaformis* complex). This appendix treats the three forms synonymously. In addition, Bernatchez and Dodson (1994) suggest that this species should be considered synonymous with the European whitefish *C. lavaretus*.

Freshwater distribution and habitats

In combination with the European whitefish, the humpback whitefish has a circumpolar distribution across the northern hemisphere (Bernatchez and Dodson 1994). In North America, the humpback whitefish freshwater range extends from the Arctic Ocean coastal plain south to

approximately the southern border of Canada, and from the Atlantic seaboard to the Bering Strait (Scott and Crossman 1998, p. 271). Humpback whitefish are found in lakes, streams, and brackish water across much of Alaska, primarily north of the Alaska Range (Alt 1979; Mecklenburg et al. 2002, p. 186-188). In the BBWAA, humpback whitefish are reported in deeper lakes, mainstem rivers, and slow-flowing tributaries (ADF&G 2011; Burgner et al. 1965, p. 4, 5; Fall et al. 2006, p. 321, 337, 354, 381; Krieg et al. 2009, p. 301, 318, 339, 365, 370; Metsker 1967, p. 6; Russell 1980, p. 72-76; Woody and Young 2007, p. 8; Yanagawa 1967, p. 12).

In northwest Ontario, lake spawning sites were found in nearshore areas at average depths of 2.7 to 3.5 m; primarily over boulders, cobbles, and detritus (Anras et al. 1999). In interior Alaska, stream spawning sites are in spatially discrete reaches, often glacially-fed, with moderate to high gradients, moderate to swift currents, and gravel substrates (Alt 1979; Brown 2006, p. 25-26; Kepler 1973, p. 71). In interior Alaska's Chatanika River, fish spawn in water 1.3 to 2.6 m deep, flowing at approximately 0.5 $m \cdot s^{-1}$ (Kepler 1973, p . 71).

After spawning, adults migrate downstream to more slowly flowing waters with fine substrates (Brown 2006, p. 26). In Canada's Mackenzie River system, overwintering locations are in deep mainstem channels or delta areas (Reist and Bond 1988). Lakes supporting summer feeding aggregations in interior Alaska are well connected to mainstem channels, ensuring that feeding fish can reliably enter in spring and exit in late summer to migrate to spawning and overwintering areas (Brown 2006, p. 31).

In early August, apparently mature fish were collected in the lower Swan River, about 2 km upstream of the confluence with the Koktuli River (ADF&G 2011, sites FSN0604A02, FSN0604A04), and mature fish were collected at the mouth of Koggiling Creek, at its confluence with the lower Nushagak River (ADF&G 2011, sites FSN0607C08, FSN0607C10). The stomachs of most of the Koggiling Creek fish were empty (Wiedmer *unpublished*). These fish may have recently left summer feeding lakes in the Swan River and Koggiling Creek drainages and were staging before beginning their upstream spawning migration (see Life cycle and Predator-prey discussions below).

In late August, apparently mature and perhaps larger immature fish were collected in small upland lakes draining to the upper North Fork Koktuli River (ADF&G 2011, sites PEB91NK011, PEB91NK019). Whether these fish overwinter in these lakes is not known. In fall, BBWAA residents harvest humpback whitefish in mainstem rivers, as the whitefish move upstream to spawn. In winter, residents also harvest humpback whitefish in Sixmile and Iliamna lakes, Lake Clark, and mainstem rivers (Fall et al. 2006, p. 39, 200, 289, 321, 337, 354, 381; Krieg et al. 2009, p. 55, 135, 159, 178, 220, 301, 339, 365).

In Alaska, the habitat preferences of juvenile humpback whitefish have been particularly difficult to define (Brown 2004, p. 19; Brown 2006, p. 25, 30; Brown et al. 2002, p. 18). In the lower Mackenzie River, nursery habitats and foraging areas for young-of-the-year are in delta lakes and main delta channels (Chang-Kue and Jessop 1992, p. 27). No young-of-the-year were found in main-channel rivers and streams in the Nushagak River drainage in August 2006 (ADF&G 2011), suggesting either a year-class failure (Bogdanov et al. 1992) or that they were occupying off-channel habitats. In Lake Clark and adjacent lakes, juveniles were captured mostly in shallow

(less than 3 m) nearshore areas, while larger fish were more broadly distributed (Woody and Young 2007, p. 8).

Life cycle

North of the BBWAA, some humpback whitefish populations include anadromous individuals, but the proportion of anadromy within stocks appears to decrease with increasing distance from marine waters (Brown 2004, p. 17; Brown 2006, p. 14; Sundet and Pechek 1985, p. 34). Within the BBWAA, limited otolith isotope analyses have yet to reveal evidence for anadromy in fish collected in Lake Clark or the lower Nushagak River (Randy Brown, U. S. Fish and Wildlife Service, Fairbanks, personal communication; Woody and Young 2007, p. 12).

In interior Alaska, large fish feed in lakes until late summer. They then move into mainstem rivers and stay near lake outlets for up to 3 weeks before beginning to migrate upstream to spawning areas in late August to early September. Most spawners arrive in the spawning areas by mid-September, and spawning extends from late September to mid-October (Brown 2006, p. 26). Russell (1980, p. 72) reported spawning in late September in BBWAA lakes. Lake spawning in northwest Ontario occurs at temperatures between 2 and 6 °C, shortly before lake surfaces begin to freeze (Anras et al. 1999). Kepler (1973, p. 71) reported spawning in an interior Alaskan stream from mid-September to early October, at temperatures ranging from 0 to 3 °C.

In interior Alaska, males mature at ages 4 to 6; females at ages 5 to 7 (Alt 1979; Brown 2006, p. 28). Fish are reported to mature at lengths of about 310 to 380 mm (FL; Alt 1979; Brown 2004, p. 19; Brown 2006, p. 23; Chang-Kue and Jessop 1992, p. 17; Kepler 1973, p. 71), and age and length at maturity may vary among locations (Alt 1979; Brown 2004, p. 19; Chang-Kue and Jessop 1992, p. 17). Three females from the lower Nushagak River (ADF&G 2011, sites FSN0607C08, FSN0607C10), had fork lengths of 435 to 460 mm, were mature, while one 370 mm female was not (Wiedmer *unpublished*). In interior Alaska, females apparently spawn every year (Brown 2006, p. 29). Farther north, at least some females do not spawn every year, although males may (Brown 2004, p. 16, 17).

Humpback whitefish broadcast spawn instead of digging redds; after fertilization their 2- to 3-mm diameter eggs sink and lodge in the interstitial spaces of the substrate (Anras et al. 1999; Morrow 1980b, p. 36, 38; Scott and Crossman 1998, p. 271). Fecundity of interior Alaska humpback whitefish ranges from 8,400 to 65,400 ova for females ranging in length from 320 to 520 mm (Clark and Bernard 1992). The estimated fecundity of three mature females collected in August in the mouth of Koggiling Creek in the BBWAA (ADF&G 2011, sites FSN0607C08, FSN0607C10) fell within this range (Wiedmer *unpublished*).

In Siberian rivers, the time from spawning to hatching is about 185 to 190 days and survival from egg to fry appears to vary greatly from year to year (Bogdanov et al. 1992). Larval fish, weighing 4.9 to 6.3 mg, with lengths of 9 to 13 mm, drift downstream immediately after hatching (Bogdanov et al. 1992; Shestakov 1991). Studies in both Norway and Siberia found that these fry still have yolk sacs and do not begin feeding for the first several days of their downstream drift (Næsje et al. 1986; Shestakov 1991). In Siberia's Anadyr River, larvae drift downstream for two to three weeks, from late May to early June (Shestakov 1991; Shestakov 1992). The scale and speed of downstream migrations correlate with increases in river discharge (Bogdanov et al.

EPA-6363-000002918

1992; Næsje et al. 1986; Shestakov 1991). Russell (1980, p. 72) observed fry in the shallows of BBWAA lakes by mid-June.

In interior Alaska and northern Canada, immature fish, from age 0 to about age 4, appear to rear far downstream of spawning areas in off-channel sites such as deltas, lakes, and sloughs, or in mainstem eddies (Brown 2006, p. 31; Reist and Bond 1988). Age-0 juveniles in the Anadyr River primarily inhabit lakes that connect to the mainstem during spring high flows (Shestakov 1992). By mid-July, age-0 fish reach 43 mm, with growth faster in floodplain lakes than in streams (Shestakov 1992).

In the BBWAA, humpback whitefish reach at least age 27 and lengths to 584 mm. (Woody and Young 2007, p. 8). Elsewhere, maximum age can be up to 57 years (Power 1978). In interior Alaska, maturing and mature fish show fidelity to both summer feeding (Brown 2006, p. 21; Brown et al. 2002, p. 16), and fall spawning areas, which can be more than 300 km apart (Brown 2006, p. 22, 31).

Predator–prey relationships

Large humpback whitefish from BBWAA lakes feed predominantly on benthic invertebrates, particularly mollusks, chironomids (non-biting midges), planktonic crustaceans, and caddis fly larvae (Metsker 1967, p. 29; Russell 1980, p. 76), but apparently feed on salmon eggs and small fry when available (Van Whye and Peck 1968, p. 37; Woody and Young 2007, p. 13). Adults preparing to spawn stop eating earlier than mature non-spawners, and large humpback whitefish feed little during the spawning migration and while overwintering (Brown 2004, p. 21; Brown et al. 2002, p. 16). In lakes, young-of-the-year fry initially feed primarily on planktonic crustaceans (Claramunt et al. 2010; Hoyle et al. 2011). When they reach lengths greater than 40 mm, their diet transitions to benthic macroinvertebrates, particularly chironomids (Claramunt et al. 2010).

Round whitefish and Arctic grayling feed on humpback whitefish eggs (Brown 2006, p. 23; Kepler 1973, p. 71), and other species likely do as well. Humpback whitefish are vulnerable to predation by piscivorous fish, such as lake trout (Van Whye and Peck 1968, p. 37) and in the BBWAA, northern pike may be important predators (Russell 1980, p. 95).

Abundance and harvest

The total abundance of humpback whitefish in the BBWAA is not known. The estimated mid-2000s annual subsistence harvests in nine of the villages within the BBWAA totaled over 4,000 fish (Fall et al. 2006, p. 45, 80, 113, 150, 194; Krieg et al. 2009, p. 40, 78, 118, 162, 202). From the mid-1970s to the mid-2000s, whitefish, the majority of which are humpback whitefish, were estimated to represent between 8.3 to 26.8% of the total weight of the Kvichak River drainage non-salmon freshwater fish subsistence harvest (Krieg et al. 2005, p. 214).

The 2009 estimated sport catch of all whitefish species in the BBWAA plus the Togiak River drainage was 1,118 fish (11% of the total statewide catch of all whitefish species except sheefish *Stenodus leucichthys*), and the estimated harvest was 520 (18% of the total statewide harvest of all whitefish species, except sheefish; Jennings et al. 2011, p. 76). In the mid-1960s, Iliamna Lake and Lake Clark supported a commercial humpback whitefish fishery (Metsker 1967, p. 8, 10). In 1966 and 1967, humpback whitefish comprised 62% of the total number of fish harvested in a freshwater commercial fishery on Tikchik Lake (Yanagawa 1967, p. 12).

Stressors

Mature humpback whitefish aggregate in discrete spawning habitats, leaving them at risk to both acute events during fall spawning and chronic changes to spawning habitat (Brown 2006, p. 32). Extreme high water events shortly before fall spawning may cause adult whitefish to leave spawning areas and delay spawning to another year (Underwood et al. 1998, p. 13). The spawning success of lake-dwelling whitefish is vulnerable to lake level manipulation during the winter incubating period (Anras et al. 1999) and to elevated substrate sedimentation (Fudge and Bodaly 1984). Age-0 fish are vulnerable to low flows in spring, which can prevent access to preferred floodplain lake habitats (Shestakov 1992).

Mature humpback whitefish appear not to feed during spawning migrations or during the winter (Brown 2004, p. 21; Brown et al. 2002, p. 16). Almost all annual feeding occurs in summer, often in off-channel lakes. Mature whitefish must have access to and from these lakes, both in spring to immigrate and in late summer to emigrate (Brown 2006, p. 26).

Fertilized eggs need cold water (optimally around 0.5 °C; Morrow 1980b) during development; eggs incubating in 10 °C waters suffer 99% mortality rates (Scott and Crossman 1998, p. 272). In an experiment mimicking Great Lakes summer conditions, Edsall (1999) found juvenile survival peaked at water temperatures of 10 to 15 °C and declined at lower and warmer temperatures and that juvenile growth peaked at 18.5 °C. For Great Lakes young-of-the-year acclimated to warmer waters, the upper lethal temperature was 26.6 °C (Edsall and Rottiers 1976). Metabolically, whitefish do not swim as efficiently as other salmonids (Bernatchez and Dodson 1985). Swimming performance peaks at around 12 °C and declines at lower temperatures. Bernatchez and Dodson (1985) speculate that the timing of seasonal migrations may be a function of the combined influence of seasonal stream velocities and temperatures. Optimal and lethal temperatures may be lower for Alaskan populations.

Rainbow trout *Oncorhynchus mykiss*

Rainbow trout and steelhead are two forms of one species and belong to the same genus (*Oncorhynchus*) as the Pacific salmon. Rainbow trout is the common name for individuals with nonanadromous life histories and steelhead is the common name for individuals with anadromous life histories. Unlike the Pacific salmon, southwest Alaska rainbow trout/steelhead are mostly nonanadromous. In Bristol Bay, the Alaska Department of Fish and Game (ADF&G) documents steelhead only in a few spawning streams near Port Moller, in the southwestern portion of the basin, outside the BBWAA (Johnson and Blanche 2011, Chignik and Port Moller 1:250,000 quadrangles). As no steelhead are known to occur in the fresh waters of the BBWAA (e.g., Russell 1977, p. 44), they are not discussed further here.

Freshwater distribution and habitats

The native freshwater range of rainbow trout is largely restricted to Pacific Ocean drainages: in North America from the Kuskokwim River system in Alaska south to mountain drainages of central Mexico (MacCrimmon 1971, p. 664), and in Asia in the Kamchatka region (Froese and Pauly 2011). Native rainbow trout in Alaskan fresh waters are restricted to southwest, southcentral, and southeast Alaska, from the Holitna River region south to Dixon Entrance (Morrow 1980b, p. 78). Rainbow trout have been extensively and successfully transplanted outside their native range, including sites in interior Alaska (MacCrimmon 1971; Morrow 1980b,

EPA-6363-000002920

p. 51). While rainbow trout of the Nushagak and Kvichak river drainages are near the northern limit of their global range, they are widely distributed in the BBWAA, except in Lake Clark and its tributaries (Minard and Dunaway 1991, p. 2; Minard et al. 1998, p. 32), and the Tikchik Lakes system, except for Tikchik Lake itself (Burgner et al. 1965, p. 11; Yanagawa 1967, p. 16-17). They are most often found in medium to large streams and rivers and in lakes (ADF&G 2011; Meka et al. 2003).

Rainbow trout typically spawn in flowing water, but can spawn along lake shores, near groundwater upwellings (Northcote and Bull 2007). Rainbow trout in the Naknek River, downstream of several large lakes, spawn in fast water of the mainstem, with much of the spawning occurring in the transition between the upstream confined reach and the downstream unconfined reach (Gwartney 1982, p. 9; Gwartney 1985, p. 47). Females deposit eggs, which are immediately fertilized by males, into excavated redds (Morrow 1980b, p. 51). In Lower Talarik Creek, Russell (1977, p. 9) reported that redds were dug in the gravel of side channels, near the upstream ends of islands, and in pool tails above riffles. Typical water depths at Lower Talarik Creek redd locations were less than 0.6 m (2 ft.) and current velocities were 0.3 to 0.6 $m \cdot s^{-1}$. The most suitable sites for rainbow trout spawning in southcentral Alaska's Copper River system had water temperatures ranging from 2 to 9 °C, average depths ranging from 0.3 to 0.4 m, average current velocities of 0.5 to 0.7 $m \cdot s^{-1}$, and substrate diameters ranging from 20 to 60 mm (Brink 1995, p.71-75). In northern Idaho, rainbow trout spawned after the peak of spring snowmelt, and redds had a mean area of 1.19 m^2 (standard deviation (SD) = 0.62; range = 0.27 to 2.40 m^2), a mean water depth at the pit head of 0.18 m (SD = 0.08; range = 0.05 to 0.38 m), and a mean water velocity at the pit head of 0.39 $m \cdot s^{-1}$ (SD = 0.15; range = 0.08 to 0.67 $m \cdot s^{-1}$) (Holecek and Walters 2007). Steelhead in Alaska's Copper River, the size of large BBWAA rainbow trout, dug redds averaging 3.4 m^2 in area (Brink 1995, p. 125).

As the only spring-spawning member of its genus in the BBWAA, with eggs hatching later in the summer than other Bristol Bay freshwater fish, young-of-the-year rainbow trout have a very short time to complete incubation and initial growth before the onset of winter. Therefore, spawning and early rearing habitats may be limited to locations with warmer summer temperatures, as fry size in late fall is positively related to winter survival (Smith and Griffith 1994). Spawning areas in southcentral Alaska's Susitna and Copper river tributaries are often at lake outlets, presumably because of warmer water there (Brink 1995, p. 16-18, 99; Sundet and Pechek 1985, p. 37). Spawning began in spring when Lower Talarik Creek water temperatures reached 2 to 3 °C, peaked at 4 to 7 °C, and stopped at temperatures greater than 16 °C (Russell 1977, p. 12).

In streams, rainbow trout summer rearing density increases with pool depth and overhead cover (Bryant and Woodsmith 2009; Nakano and Kaeiryama 1995). Winter rearing density increases with increasing availability of multiple cover types (Bjornn and Reiser 1991, p. 135). In summer in southeast Alaska, rearing juveniles leave small tributaries and are relatively more abundant in larger streams (≥3rd order; *sensu* Strahler 1952, p. 1120). In spring and fall, juveniles are equally distributed in both headwater tributaries and larger streams (Bramblett et al. 2002). However, beginning in September, juvenile rainbow in Idaho move downstream from summer rearing to winter overwintering areas (Chapman and Bjornn 1968, p. 165). Given the very low winter flows and water temperatures in southwest Alaska low-order streams (e.g., USGS 2012), BBWAA juvenile rainbow trout may follow the movement pattern of Idaho fish.

In southeast Alaska, juvenile rainbow trout rear in streams with gradients up to at least 16% (Bryant et al. 2004), but there are no reports of trout in such steep streams within the BBWAA (ADF&G 2011). In streams of southwestern Alaska, in spring and early summer before the arrival of adult salmon, large rainbow trout are lower in drainages, in slower velocity currents, often in sloughs (Alt 1986). Later in the summer the distribution of age 1 and older Alaskan rainbow trout is closely tied to the distribution of spawning salmon (Alt 1986; Brink 1995, p. 102, 104; Meka et al. 2003; Sundet and Pechek 1985, p. 39-40). In fall, after salmon spawning is complete (except for coho), large southwestern Alaska rainbow trout occupy stream reaches with moderate currents and gravel substrates, often near grassy banks (Alt 1986). Stream fish may congregate in discrete overwintering habitats with moderate currents, often in areas of groundwater upwelling (Sundet and Pechek 1985, p. 40). Groundwater influence may be an important habitat characteristic because in regions where they are non-native, rainbow trout invasion can be limited to only groundwater-fed streams with stable flows (Inoue et al. 2009).

Radio telemetry, tagging, and genetic studies indicate the presence of multiple rainbow trout populations within Bristol Bay watersheds (Burger and Gwartney 1986, p. 22, 26; Gwartney 1985, p. 70-71; Krueger et al. 1999; Meka et al. 2003; Minard et al. 1992, p. 34).

Life cycle

Rainbow trout spawning in the Bristol Bay region is associated with spring ice-out and occurs from late March through mid-June (Burger and Gwartney 1986, p. 22; Dye 2008, p. 21; Gwartney 1985, p. 45-46, 51; Minard et al. 1992, p. 2; Russell 1977, p. 41). Pre-spawner movements to spawning tributaries begins prior to ice-out, in early March (Dye 2008, p. 13). Within a given drainage, the timing of spawning can vary by several weeks depending on spatial and interannual stream temperature patterns (Burger and Gwartney 1986, p. 22; Hartman et al. 1962, p. 195; Russell 1977, p. 12). While post-spawners are often in poor physical condition (Russell 1977, p. 15), BBWAA rainbow trout can spawn in consecutive years and some spawn at least three years in a row (Minard et al. 1992, p. 17, 22; Russell 1977, p. 15).

In small lakes in southcentral Alaska, males matured at a smaller size than females and approximately one-third of males smaller than 178 mm (SL, standard length; 7 in) were mature. In this population most females did not mature until about 300 mm (SL; 12 in), while all males matured at about 250 mm (SL; 10 in) (Allin 1954, p. 36). In Moose Creek, in the Wood River lake system, half of the fish over 376 mm (FL) were sexually mature (Dye 2008, p. 22). In Lower Talarik Creek, most spawners were ages 7 to 9 (Russell 1977, p. 17); in the upper Kvichak River, from 1989 to 1991, spawners were primarily ages 5 to 7 (Minard et al. 1992, p. 15). Fecundity of Lower Talarkik Creek females (lengths ranging from 533 to 692 mm FL) averaged 3,431 (n = 16, SD = 1,053) and ova diameter averaged 5.5 mm (n = 25, SD = 0.6, Russell 1977, p. 18). In the BBWAA rainbow trout can reach at least age 14 (Minard and Dunaway 1991, p. 111, 189; determined by scale pattern analysis, a conservative measure; e.g., Sharp and Bernard 1988), with lengths to at least 814 mm (FL; Russell 1977, p. 30).

Post-spawning adults exhibit multiple movement patterns (Gwartney 1985, p. 68, 70; Meka et al. 2003). In Bristol Bay watersheds, many adults migrate shortly after spawning in inlet or outlet streams of large lakes to feeding areas in large lakes (Burger and Gwartney 1986, p. 20; Meka et al. 2003; Minard et al. 1992, p. 2; Russell 1977, p. 44). After a summer of feeding in lakes, from September through November these mature rainbow trout move back to, or near, lake inlets and

outlets to overwinter (Burger and Gwartney 1986, p. 20; Meka et al. 2003; Minard et al. 1992, p. 2; Russell 1977, p. 32). In the Wood River lakes system, mature rainbow trout from many spawning streams aggregate to feed in the inter-lake rivers and remain there, or nearby in the adjacent lakes, through the following winter (Dye 2008, p. 13). After spawning in tributaries to southcentral Alaska's Susitna River, some mature rainbow trout remained near spawning areas, some moved downstream, some moved into other tributaries, and some moved upstream (Sundet and Pechek 1985, p. 39). Even in watersheds with large lakes, some fish may remain in outlet rivers year-round (Meka et al. 2003). Fish grow little in winter (Russell 1977, p. 32).

While some mature fish may not undergo large seasonal migrations, others move considerable distances (Dye 2008, p. 15; Meka et al. 2003; Minard et al. 1992, p. 33; Russell 1977, p. 23), to at least 200 km (122 mi) or more (Burger and Gwartney 1986, p. 16). Meka et al. (2003) speculated that seasonal migrations may be longer in watersheds with large lakes than in watersheds without large lakes. In southwest Alaska's Goodnews River, most adult fish moved less than 10 km throughout the year, and the movement that does occur is primarily upstream to spring spawning locations, and downstream to overwintering locations (Faustini 1996. p. 19-20).

Incubating rainbow trout eggs develop much more rapidly than do those of salmon, and juveniles emerge from spawning gravels between mid-July and mid-August at about 28 mm long (ADF&G 2011, e.g., site FSN0616E01; Johnson et al. 1994; Russell 1977, p. 30). Juveniles grow quickly during late summer and early fall, nearly doubling their length by late September (Russell 1977, p. 30). Immature fish may remain in their natal stream for several years before moving to other habitats (Russell 1977, p.18, 22).

In the Alagnak River, within the BBWAA, Meka et al. (2003) distinguished three unique adult life history patterns: lake-resident, lake-river, and river-resident. Each of these populations migrates seasonally, and Meka et al. (2003) suggested that Alagnak rainbow trout evolved these movements to take advantage of seasonal food sources (salmon eggs and carcasses) and warmer winter water temperatures. Russell (1977, p. 37) noted that Lower Talarik Creek trout were in better condition following large Kvichak drainage sockeye salmon escapements than after small escapements.

Predator–prey relationships

The diet of rearing rainbow trout includes a broad range of aquatic and terrestrial invertebrates (Nakano and Kaeiryama 1995). When available, sockeye salmon eggs dominated rainbow trout diet in Lower Talarik Creek. While their diet was highly varied, other important Lower Talarik Creek rainbow trout food items included aquatic dipterans (chironomids) and caddis fly larvae (Russell 1977, p. 36). Many larger Lower Talarik Creek rainbow trout appear to feed primarily in Iliamna Lake and not in the stream (Russell 1977, p. 35). In rivers of the BBWAA, Russell (1980, p. 103) reported that aquatic insects, salmon eggs, shrews and voles, unidentified fish and Chinook salmon fry, and salmon carcasses made up the bulk of the summer and fall diet of rainbow trout.

In the Wood River lakes system, Scheuerell et al. (2007) reported that before the seasonal arrival of adult salmon, rainbow trout primarily feed on dipterans (39%), stoneflies (18%), mayflies (12%), and caddis flies (11%). When spawning sockeye salmon arrive, rainbow trout diet shifts to primarily salmon eggs (64%), larval blowflies (which feed on salmon carcasses; (11%)), and

salmon carcasses (9%). This diet shift in conjunction with seasonal salmon spawning activity increases rainbow trout energy intake more than five-fold (Scheuerell et al. 2007).

In the laboratory, slimy sculpin, a ubiquitous species throughout the lakes and streams of the BBWAA, consume rainbow trout eggs (Fitzsimons et al. 2006). While BBWAA rainbow trout are certainly consumed by predators, they are not specifically identified in the diet of regional predatory fish (Metsker 1967, p. 26, 29; Russell 1980, p. 55-56, 62-63, 67, 73, 76, 81-83, 95-97, 103, 108), perhaps due at least in part to their comparatively low abundance relative to other available prey species.

Abundance and harvest

In the BBWAA total rainbow trout abundance is unknown, but there have been population estimates of larger fish in selected streams. From 2,000 to 4,500 fish available to hook and line angling gather in the upper Kvichak River in spring (Minard et al. 1992, p. 30); an average of 950 fish spawn in Lower Talarik Creek (Russell 1977, p. 9); and 950 fish larger than 199 mm occur in the Tazimina River, north of Iliamna Lake (Schwanke and Evans 2005, p. 9). In the Wood River lakes system, counts have been as high as 13,700 rainbow trout larger than 250 mm in the Agulowak River and 2,400 larger than 340 mm in the Agulukpak River (Dunaway 1993, p. 10, 24).

In the BBWAA and the adjacent Togiak River drainage, sport anglers caught more rainbow trout in 2009 (an estimated 159,685, or 22% of the statewide total) than all other non-salmon fish species combined (Jennings et al. 2011, p. 69). In 2009 sport anglers harvested 225 rainbow trout within the BBWAA and adjacent Togiak River drainage (Jennings et al. 2011, p. 69). Annual sport harvests have declined, due at least in part to the increasing popularity of catch-and-release fishing (Dye and Schwanke 2009, p. 6). The State of Alaska's Southwest Alaska Rainbow Trout Management Plan includes policies to manage BBWAA rainbow trout populations to maintain historic size and age composition without relying on hatcheries, to provide a range of harvest opportunities, and to economically develop the sport fishing industry while acknowledging the intrinsic value of the resource to Alaskans (Dye and Schwanke 2009, p. 32).

From the mid-1970s to the mid-2000s, rainbow trout were estimated to represent between 19 and 30.9% of the total weight of the Kvichak River drainage non-salmon freshwater fish subsistence harvest (Krieg et al. 2005, p. 214). In the mid-2000s, villagers from nine of the BBWAA communities annually harvested, as part of their subsistence activities, about an estimated 3,740 rainbow trout (Fall et al. 2006, p. 45, 80, 113, 150, 194; Krieg et al. 2009, p. 40, 78, 118, 162, 202).

Stressors

Low pH (less than or equal to pH 5.5) impairs adult egg and sperm development and reduces early embryonic survival (Weiner et al. 1986). Pre-emergent embryo survival depends strongly on elevated DO concentrations and movement of groundwater through redds. Embryo survival is minimal where mean DO is less than 5.2 $mg \cdot l^{-1}$; at higher DO levels, embryo survival increases in relation to the velocity of intergravel flows greater than 5 $cm \cdot h^{-1}$ (Sowden and Power 1985). Bjornn and Reiser (1991, p. 84, 85) concluded that upstream migrating large trout need stream depths no less than 0.18 m, velocities no more than 2.44 $m \cdot s^{-1}$, and DO levels at least 80% of saturation and never less than 5.0 $mg \cdot l^{-1}$. For spawning rainbow trout in the more central part of

their North American range, Bell (1986, p. 96) recommended water temperatures between 2.2 and 20 °C (36 to 68 °F), and optimally 10 °C (49.5 °F). Russell (1977, p. 12) observed that Lower Talarik Creek rainbows stopped spawning at stream temperatures above 16 °C. In the laboratory, at temperatures below 2.8 °C age-0 fry become inactive and seek refuge within the stream substrate. At temperatures below 5.5 °C, fry stop feeding (Chapman and Bjornn 1968, p. 168).

The survival of incubating embryos rapidly declines as the proportion of fines (sediments less than 6.35 mm in diameter) increases in spawning gravels, probably because the fines reduce intragravel flow (Bjornn and Reiser 1991, p. 99, 100). The success rate of fry emergence from spawning gravels and juvenile rearing density also decline with increasing proportion of fines in the substrate (Bjornn and Reiser 1991, p. 103, 132). Rainbow trout populations are particularly vulnerable when adult fish aggregate in spring spawning grounds and overwintering locations.

Ten steelhead population segments in California, Oregon, and Washington are currently listed as threatened or endangered primarily due to the lack of access to their historic range that has resulted from constructed barriers to migration and to stream dewatering. Nonanadromous rainbow trout populations are not listed (NMFS 2006).

Char

The BBWAA is home to three species of char: Arctic char, Dolly Varden, and lake trout. These char all spawn in fall. Bristol Bay basin Dolly Varden are often anadromous; Arctic char and lake trout are typically nonanadromous. The habitats of Dolly Varden and Arctic char occasionally overlap within the BBWAA, and when they do these species may hybridize (Taylor et al. 2008).

The taxonomic distinctions between Arctic char and Dolly Varden historically have been inconsistent. Some earlier authors (e.g., Craig 1978; Craig and Poulin 1975; Yoshihara 1973) called riverine and anadromous Alaskan char "Arctic char" *Salvelinus alpinus*. More recent assessments suggest these fish are Dolly Varden (Behnke 1980, p. 454; Cavender 1980, p. 319-320; Taylor et al. 2008). In general, researchers currently believe that the North American char west of Canada's Mackenzie River living primarily in flowing water are Dolly Varden, and Arctic char (and lake trout) are largely limited to lakes and adjacent reaches of their inlet and outlet streams (Reist et al. 1996).

The State of Alaska's 2011 edition of the *Catalog of Waters Important for the Spawning, Rearing or Migration of Anadromous Fishes*, or "Anadromous Waters Catalog" (AWC; e.g., Johnson and Blanche 2011) identifies Dolly Varden as the anadromous char across most of the state. However, in Bristol Bay the AWC identifies some streams as anadromous Dolly Varden habitat and some as anadromous Arctic char habitat. The AWC lists both anadromous Dolly Varden and anadromous Arctic char in the Kvichak River drainage, but only anadromous Arctic char in the Nushagak River drainage. These distinctions result from the history of regional variations in species naming and do not accurately reflect the ranges of different species and life histories. Current terminology labels the river-dwelling BBWAA char Dolly Varden. That is, the rivers and streams in the AWC currently designated as Arctic char habitat should, in almost all cases, be interpreted as Dolly Varden habitat. As a result of recent field work, ADF&G

concluded that the Nushagak River, and the Koktuli River in particular, likely supported anadromous Dolly Varden (Schwanke 2007, p. 14).

Arctic char *Salvelinus alpinus*

Freshwater distribution and habitats

The Arctic char is a circumpolar species, distributed at high latitudes across the northern hemisphere (Brunner et al. 2001). In fresh water, Arctic char range closer to the North Pole than any other fish species (Johnson 1980, p. 16). In the fresh waters of North America, Arctic char are not typically far from the ocean. They range from Maine and New Hampshire north to the Canadian mainland Arctic Coast and through the Canadian Arctic archipelago (Scott and Crossman 1998, p. 203). The Alaskan Arctic char distribution is disjunct. They occur in the Brooks Range, on the North Slope and the Seward Peninsula, in Bristol Bay, and a few other isolated locations in southcentral and interior Alaska (Mecklenburg et al. 2002, p. 199). Multiple distinct Arctic char races, differing in growth rate and life history, can occupy a single lake (Baroudy and Elliott 1994; Sandlund et al. 1992).

Alaskan Arctic char appear primarily restricted to lakes and adjacent reaches of their inlet and outlet streams in well-drained areas (Morrow 1980b, p. 58; Scanlon 2000, p. 56, 58; Taylor et al. 2008) and do not appear to undertake extensive seasonal migrations outside their home lakes (McBride 1980, p. 17). However, some Alaskan Arctic char are known to move 15 to 20 km upstream and downstream between connected lakes (Troyer and Johnson 1994, p. 49) and Scanlon (2000, p. 43-48) suggested some move seasonally to estuarine or marine areas. Within the BBWAA, they are reported in the Tikchik and Wood River lakes, Iliamna Lake, and other upland lakes (Bond and Becker 1963; Burgner et al. 1965; Russell 1980, p. 49; Taylor et al. 2008). Metsker (1967, p. 23) believed that Intricate Bay in Iliamna Lake is a particularly important spawning area. Adults and juveniles are common in the east end of Iliamna Lake, but not in tributaries (Bond and Becker 1963).

The depth of Arctic char lake spawning habitat can vary from 1 to 100 m (reviewed in Johnson 1980, p. 44), but is often in gravel shoals less than 5 m deep (Klemetsen et al. 2003, p. 31). McBride (1980, p. 6) found Wood River lakes spawners concentrated in the mouths of small tributary streams. DeLacy and Morton (1943) concluded that Kodiak Island's Karluk Lake Arctic char spawn in the lake and not in the tributary streams.

During the spring and early summer, McBride (1980, p. 20) estimated that approximately 40% (approximately 65,000) of the Wood River lakes Arctic char population greater than 300 mm long congregated in the inlets and outlets of the inter-lake rivers to feed on the sockeye salmon smolt outmigration. In Bristol Bay's Ugashik lakes, Plumb (2006, p. 14-15) found Arctic char at depths greater than 75 m; but 90% of her catch was in waters less than 10 m deep. Fish sizes were not segregated by depth (Plumb 2006, p. 19-20). Similar to Dolly Varden (discussed below), Arctic char often occupy different habitats depending on the presence or absence of competitors (reviewed in Klemetsen et al. 2003, p. 29-30)

Life cycle

Arctic char in Bristol Bay are thought to be primarily nonanadromous (e.g., Reynolds 2000, p. 16), but Scanlon (2000, p. 43-48) suggested that some Becharof Lake Arctic char were

anadromous. In BBWAA lakes, maturity is reached at around ages 3 to 6, at a length of approximately 330 mm (FL; 13 in.) (Metsker 1967, p. 23; Russell 1980, p. 48, 54). Metsker (1967, p. 23, 26) concluded that individual Iliamna Lake Arctic char spawned in alternating years, but McBride (1980, p. 16) provided evidence that at least some Lake Aleknagik Arctic char return annually to spawning locations. Wood River lakes Arctic char demonstrated high level of interannual fidelity to both spawning and feeding sites (McBride 1980, p. 6, 8, 19). Lake Aleknagik Arctic char periodically provide eggs for Alaska's sport fish hatcheries (Dunaway and Jaenicke 2000, p. 138).

In the BBWAA Russell (1980, p. 48) found individuals ready to spawn in mid-September and McBride (1980, p. 6) collected Wood River lakes spawning fish between mid-September and mid-October. Ripening females in Brooks Range lakes have ova diameters ranging from 1.62 to 4.75 mm and fecundity ranges from 3,200 to 4,000 ova (Troyer and Johnson 1994, p. 41). If the substrate is not too coarse (approximately 10 cm or more, Sigurjónsdóttir and Gunnarsson 1989) females excavate redds into which they deposit their ova, which males immediately fertilize (Johnson 1980, p. 45). The incubating eggs and alevins remain in spawning gravels until the following spring (summarized in Johnson 1980, p. 47-48). Bristol Bay Arctic char live at least 15 years (Plumb 2006, p. 19), are particularly slow growing (Russell 1980, p. 48), reach fork lengths to at least 684 mm, and weights to at least 3.8 kg (Scanlon 2000, Appendix Table A). As with Dolly Varden, multiple life history patterns and morphologies (Klemetsen et al. 2003, p. 36) occur with the basin (Russell 1980, p. 48; Scanlon 2000, p. 63-64). Tagging studies indicated that the Wood River lakes supported at least 20 discrete stocks (McBride 1980, p. 20).

Predator–prey relationships

The diet of young-of-the-year is poorly understood, but is thought in general to be dominated by small benthic and planktonic invertebrates (reviewed in Klemetsen et al. 2003, p. 32). In larger Brooks Range fish, planktonic crustaceans, insects, and snails were the most frequently occurring food items and fish were not an important part of the diet (Troyer and Johnson 1994, p. 44). In Iliamna Lake, summer diet was dominated by snails (Bond and Becker 1963) and winter diet was dominated by threespine stickleback (Metsker 1967, p. 26, 28). In other BBWAA lakes, mollusks and caddis fly larvae were the dominant benthic organisms consumed (Russell 1980, p. 55-56). In summer, freshwater crustaceans dominated the diet of Ugashik Lakes Arctic char (Plumb 2006, p. 27) and crustaceans, sticklebacks, insects, pygmy whitefish, sculpins, and juvenile sockeye salmon dominated the diet of Becharof Lake Arctic char (Scanlon 2000, p. 51, 53-54).

In the BBWAA, larger Arctic char eat outmigrating sockeye salmon smolt, often in spring and early summer at lake outlets (McBride 1980, p. 1; Metsker 1967, p. 29). Karluk Lake Arctic char eat mostly insects until the arrival of spawning sockeye, when their diet shifts to drifting salmon eggs, benthic invertebrates dislodged by salmon redd excavation, and adult salmon carcasses (DeLacy and Morton 1943).

Arctic char are eaten by other predatory fish, including lake trout (Troyer and Johnson 1994, p. 42) and larger Arctic char (Klemetsen et al. 2003, p. 33). Mink eat mature Wood River lakes Arctic char when they have the opportunity (Dunaway and Jaenicke 2000, p. 138).

EPA-6363-000002927

Abundance and harvest

In the BBWAA total Arctic char abundance is unknown. Meacham (reported in McBride 1980, p. 20) estimated that in the 1970s the Wood River lakes supported between 135,000 and 210,000 (presumably larger) Arctic char. Russell (1980, p. 48, 49) considered them common in some lakes in the Lake Clark area, but absent or rare in lakes of the upper Mulchatna River watershed and Lake Clark itself. In the mid-1960s, Iliamna Lake supported a commercial fishery and char made up 84% (2,979 kg, 6,553 lb) of the total dressed weight harvest (Metsker 1967, p. 9). These fish are thought to be mostly Arctic char (Bond and Becker 1963; Taylor et al. 2008).

Between 1971 and 1980, the annual estimated abundance of Arctic char larger than 249 mm ranged from 8,000 to 12,000 fish at the mouth of the Agulowak River and 4,300 to 7,800 fish at the mouth of the Agulukpak River (Minard et al. 1998, p. 131). By 1993 the estimated abundance of the Agulowak River population declined to only 5,400 fish, prompting a substantial reduction in bag limits and harvest means (Minard and Hasbrouck 1994, p. 13, 22). While excessive sport harvests were thought to be responsible for the decline (Minard et al. 1998, p. 16), anecdotal reports suggest that the more conservative sport harvest regulations were leading to the recovery of the stock (Dunaway and Sonnichsen 2001, p. 131). Minard et al. (1998, p. 16) also reported a similar apparent significant decline in Iliamna River stocks, both in overall abundance and in larger, older age classes. These observations prompted adoption of a catch-and-release fishing regulation.

The State of Alaska's sport and subsistence fisheries statistics do not distinguish between Arctic char and Dolly Varden. Sport anglers caught an estimated 48,438 Arctic char/Dolly Varden in the BBWAA and the adjacent Togiak River system in 2009 (8% of the statewide total) and harvested (kept) an estimated 2,159 (5% of the statewide total; Jennings et al. 2011, p. 73). Arctic char/Dolly Varden consistently support the greatest sport harvest of any non-salmon freshwater fish in Bristol Bay (Dye and Schwanke 2009, p. 8). Sport harvests have declined, due at least in part to both lower bag limits and the increasing popularity of catch-and-release fishing (Dye and Schwanke 2009, p. 6).

In the mid-2000s, villagers from ten of the BBWAA communities annually harvested, as part of their subsistence activities, about an estimated 3,450 Arctic char and Dolly Varden combined (Fall et al. 2006, p. 45, 80, 113, 150, 194; Krieg et al. 2009, p. 40, 78, 118, 162, 202). Arctic char and Dolly Varden combined were the most important non-salmon fish harvested in the villages of Iliamna, Newhalen, and Pedro Bay (Fall et al. 2006, p. 49, 84, 117). From the mid-1970s to the mid-2000s, Arctic char/Dolly Varden were estimated to represent between 16.2 and 26.9% of the total weight of the Kvichak River drainage non-salmon freshwater fish subsistence harvest (Krieg et al. 2005, p. 214).

Stressors

Arctic char are not tolerant of warm water. In tests of European Arctic char, egg mortality was 100% at temperatures at or above 12 to 13 °C (Jungwirth and Winkler 1984). Even when acclimated to water temperatures between 15 and 20 °C, pre-emergent fry could not survive exposures to temperatures above 26.6 °C for more than 10 minutes and could not survive temperatures over 21° C for more than a week (Elliott and Klemetsen 2002). Apparent over-harvests have been implicated for historic population declines within the BBWAA (Minard et al. 1998, p. 16).

Dolly Varden *Salvelinus malma*

Dolly Varden is a highly plastic species: multiple genetically, morphologically, and ecologically distinct morphs (e.g., benthic specialist, riverine specialist, lacustrine generalist, specialized piscivore) can exist in the same water body (Ostberg et al. 2009). Researchers currently recognize two geographically distinct forms of Dolly Varden: northern and southern, based on differences in life history (Armstrong and Morrow 1980, p. 107-130), phenotype (Behnke 1980, 465-466; Cavender 1980, p. 299-318), and genotype (Taylor et al. 2008). Dolly Varden in the BBWAA are of the northern form (Behnke 1980, p. 465).

Freshwater distribution and habitats

The global native freshwater range of Dolly Varden is restricted to waters draining to the Beaufort, Chukchi and Bering seas and the North Pacific. The North American range extends from the Arctic coast of Alaska and Canada west of the Mackenzie River south to northern Washington. The Asian range stretches from the Chukotka Peninsula south to Japan and Korea (Mecklenburg et al. 2002, p. 200). In Alaska, Dolly Varden are found in waters draining to all coasts (Mecklenburg et al. 2002, p. 200) and the Alaska Peninsula divides the northern and southern forms (Behnke 1980, p. 453). Dolly Varden are known to occur widely in Bristol Bay, but their true distribution across the waters of the BBWAA is underreported. Within the BBWAA, popular sport fishing areas include the Alagnak, Newhalen, Nushagak, Mulchatna, and the Wood River–Tikchik Lakes systems (Minard et al. 1998, p. 188).

As in southeast Alaska (Bryant et al. 2004), BBWAA Dolly Varden occur farther upstream in high-gradient headwater streams than other fish species (ADF&G 2011, e.g., site FSN0604E01). In both southeast Alaska (Bramblett et al. 2002; Wissmar et al. 2010) and the BBWAA (ADF&G 2011, e.g., site FSN0616E01; e.g., Tazimina Lakes, Russell 1980, p. 31-32, 73), resident Dolly Varden occur above migratory barriers that currently prevent access to anadromous salmon populations.

Spawning occurs well upstream from areas used for overwintering (DeCicco 1992). Northern-form anadromous Dolly Varden overwinter primarily in lakes and in lower mainstem rivers where sufficient groundwater provides suitable volumes of free-flowing water (DeCicco 1997; Lisac 2009, p. 13, 15-16). In stream systems, spawning occurs in fast-flowing channels, primarily in upper reaches (Bramblett et al. 2002; Fausch et al. 1994; Hagen and Taylor 2001; Kishi and Maekawa 2009; Koizumi et al. 2006) and small, spring-fed tributaries (Hagen and Taylor 2001). Stream-resident Dolly Varden are reported to spawn in channels that are 1 to 3 m wide and 10 to 35 cm deep (Hino et al. 1990; Maekawa et al. 1993), with a mean depth of 9 cm, mean velocity of 21 $cm \cdot s^{-1}$, and median substrate diameter of 1.6 cm (Hagen and Taylor 2001). Stream-resident females select spawning sites where gravel is prevalent (Kitano and Shimazaki 1995). Spawning site substrate and current velocity do not correlate significantly with female size, but redd depth does (Kitano and Shimazaki 1995). Anadromous individuals spawn in deeper water than resident fish, ranging from 20 to 60 cm (Blackett 1968). They construct redds approximately 30 cm long, 15 to 25 cm wide, and 15 cm deep (Blackett 1968); composite redds, potentially containing several individual nests can be up to 3.5 m long and 1.2 m wide (Yoshihara 1973, p. 47).

In Kamchatka Eberle and Stanford (2010) found rearing Dolly Varden in floodplain springbrooks and 7th-order mainstem channels. Within the BBWAA, juveniles appear to be

limited primarily to low-order headwaters (ADF&G 2011), and infrequently to side channels and the main channel of larger rivers downstream to the confluence of 5th-order streams (ADF&G 2011, e.g., site FSN0609A02). In southeast Alaska Dolly Varden rear in channels with gradients steeper than 20% (Wissmar et al. 2010), but in the BBWAA, Dolly Varden have been reported only in gradients of 12% or less (ADF&G 2011, e.g., site FSM0503A07). Rearing Dolly Varden normally stay close to the stream bottom over gravels and cobbles (Dolloff and Reeves 1990; Hagen and Taylor 2001; Nakano and Kaeiryama 1995). Fry density is inversely related to stream depth (Bryant et al. 2004) and use of shallows increases if cover is available (Bugert et al. 1991). Different juvenile age classes can segregate in different micro- (Bugert et al. 1991; Dolloff and Reeves 1990) and macro- (ADF&G 2011; Denton et al. 2009) habitats. Affinity for cover, including cobbles and boulders, increases with age and tolerance for other Dolly Varden declines (Dolloff and Reeves 1990). Gregory (1988, p. 49-53) found stream-resident juvenile Dolly Varden in beaver ponds, where they grow faster than fish in adjacent streams, because of relatively warmer water temperatures and increased productivity.

Dolly Varden occur in upland Bristol Bay lakes, often in large numbers, feeding both at the surface and on the lake bottom, but they are uncommon or absent in lakes supporting Arctic char populations (Russell 1980, p. 49, 69-72; Scanlon 2000, p. 56). Dolly Varden will use all lake habitats in the absence of competitors (other salmonids), but concentrate in offshore and near-bottom habitats where competitors occupy nearshore and near-surface habitats (Andrew et al. 1992; Jonsson et al. 2008; Schutz and Northcote 1972). In the absence of competitors, lake-dwelling Dolly Varden move from deeper offshore waters, where they spend the day, perhaps in loose aggregations, to spend the night in onshore waters, near the surface (Andrusak and Northcote 1971). Dolly Varden vision is more sensitive to low light than competing salmonids (Henderson and Northcote 1985; Henderson and Northcote 1988; Schutz and Northcote 1972), allowing them to feed in deeper water and at night.

Life cycle

Northern-form Dolly Varden express several life history patterns, including anadromous, nonanadromous stream-resident, nonanadromous spring-resident, nonanadromous lake-resident, nonanadromous lake-river-resident, and nonanadromous residuals (nonanadromous male offspring of anadromous parents; (Armstrong and Morrow 1980, p. 107-130; Behnke 1980, p. 466). The Bristol Bay basin supports Dolly Varden with both anadromous (Reynolds 2000, p. 16-17; Scanlon 2000, p. 48-51) and nonanadromous (Denton et al. 2009; Scanlon 2000, p. 48-51) life histories.

Anadromous Dolly Varden exhibit very complex migratory patterns (Armstrong and Morrow 1980, p. 108-109), frequently leaving one drainage, traveling through marine waters, and reentering distant drainages, including those on separate continents (DeCicco 1992; DeCicco 1997; Lisac 2009, p. 14; Morrow 1980a). Even apparently nonanadromous fish can seasonally move more than 200 km within complex Bristol Bay watersheds (Scanlon 2000, p. 60).

Anadromous Dolly Varden of the Togiak River system, just west of the BBWAA, spawn from approximately mid-September to mid-October, overwinter downstream from spawning locations, and migrate annually to sea, where they spend approximately six weeks feeding (Lisac and Nelle 2000, p. 31-34). The timing of adult seaward migration generally corresponds with spring ice-out and high water, with adults migrating to sea in May and June. Their return to fresh water appears

to relate to decreased stream discharge (Lisac and Nelle 2000, p. 33-34, 35). Anadromous Dolly Varden migrate upstream from the ocean to spawning areas in July and August (Lisac 2011). Russell (1980, p. 72) observed Dolly Varden spawning in the upper Mulchatna River system in mid-September.

Anadromous Dolly Varden home to spawn (Crane et al. 2003; Lisac and Nelle 2000, p. 31), but stocks can mix at sea and in overwintering areas (DeCicco 1992). In northwest Alaska anadromous Dolly Varden usually undertake three to five ocean migrations before reaching sexual maturity (DeCicco 1992). In the Togiak River, some anadromous fish mature at age 2 and most mature at age 4 (Lisac and Nelle 2000, p. 31; Reynolds 2000). Bristol Bay Dolly Varden can live at least 14 years (Plumb 2006, p. 19; Scanlon 2000, Appendix Table B) and reach lengths of 740 mm or more (Faustini 1996, p. 16). The minimum length of anadromous spawners in southwest Alaska's Goodnews River is about 330 to 360 mm (Lisac 2010, p. 4).

Stream-residents mature from age 2 to 5 (Blackett 1973; Craig and Poulin 1975; Maekawa and Hino 1986; Russell 1980, p. 72) and live at least to age 7 (Blackett 1973). They are smaller than their anadromous counterparts, ranging at maturity from 113 mm (Hagen and Taylor 2001) to 520 mm (Gregory 1988, p. 29) in length, with most less than 200 mm (Gregory 1988, p. 21-25). Like anadromous individuals, after spawning stream-resident adults move quickly to downstream overwinter areas (Maekawa and Hino 1986).

Although anadromous Dolly Varden in northern Alaska tend to spawn only every second year (DeCicco 1997), Lisac and Nelle (2000, p. 31) speculated that most anadromous Dolly Varden in the Togiak River near the BBWAA can spawn in consecutive years. Female fecundity is a function of size (Jonsson et al. 1984), and anadromous females can produce up to 7,000 ova (Armstrong and Morrow 1980, p. 102), a productivity more than 50 times that of resident females (Blackett 1973). Ripe eggs of anadromous females are 3.5 to 6 mm in diameter; ripe eggs of resident females can be as small as 2.8 mm (Armstrong and Morrow 1980, p. 101, 102).

In most cases, a spawning group consists of one female and several males, one of which is a dominant male that actively courts the female (Hino et al. 1990; Maekawa et al. 1993). Females excavate redds in stream gravels, and then deposit their eggs while a male fertilizes them. Chars show little evidence of nest-guarding behavior (Kitano and Shimazaki 1995). Males appear to suffer a much higher post-spawning mortality than do females (Armstrong 1974).

In streams on both sides of the Bering Strait, egg hatching peaks from the end of April to mid-May (Radtke et al. 1996). Embryos are 15 to 20 mm long at hatching and remain in the spawning substrate while they absorb their yolk sac. Alevins emerge from the nest around the time of ice break-up (April to June), at a length of about 25 mm (Armstrong and Morrow 1980, p. 108). Radtke et al. (1996) found that first feeding begins from June to early July, 42 to 52 days after hatching. Newly emerged alevins tend to stay on the bottom of pools and are relatively inactive except when feeding (Armstrong and Morrow 1980, p. 108). Growth greatly increases through the summer as water becomes warmer; by September, age-0 fish average about 60 mm long (Armstrong and Morrow 1980, p. 108). Young anadromous Togiak River Dolly Varden make their first seaward migration between their first summer and age 3 (Reynolds 2000, p. 15). Size, rather than age, appears to govern the timing of initial smolt out-migration (Armstrong 1970).

Predator–prey relationships

Dolly Varden primarily target benthic invertebrates in streams (Eberle and Stanford 2010; Russell 1980, p. 73; Stevens and Deschermeier 1986) and lakes (Scanlon 2000, p. 53-55; Schutz and Northcote 1972). During the day, foraging from stream drift (food drifting in the current) is more important than benthic foraging, but the relative importance of benthic foraging increases at night; surface feeding is not important (Hagen and Taylor 2001). Dolly Varden also switch to benthic feeding when drift availability is limited (Fausch et al. 1997; Nakano et al. 1999; Nakano and Kaeiryama 1995).

Dolly Varden eat juvenile salmon (Armstrong 1970; Bond and Becker 1963), but they have been largely exonerated (Armstrong and Morrow 1980, p. 133; DeLacy and Morton 1943; Morton 1982) from earlier accusations that they were salmon run destroyers. From 1921 to 1939, Alaskan Dolly Varden were the target of a bounty program designed to increase salmon abundance. Now it is believed that Dolly Varden were not responsible for the declines in salmon abundance (Harding and Coyle 2011, p. 19). When spawning salmon are present, salmon eggs–probably those flushed by high flows and superposed redd construction–can be important food (Armstrong 1970, p. 53-54; Scanlon 2000). Denton et al. (2009) reported that resident age-1 and older Dolly Varden in certain ponds near Iliamna Lake feed on sockeye salmon fry for a brief time in late June to mid-July, then migrate to sockeye spawning areas and feed almost exclusively on eggs from late July to mid-September. From late August through September they also eat blowfly larvae that had fed on adult sockeye salmon carcasses. Salmon eggs are too big for age-0 fry to consume, but blowfly maggots, when available, dominate their diet. Resident Dolly Varden actively follow adult sockeye salmon to spawning areas and grow significantly faster after the arrival of spawning salmon (Denton et al. 2009; Wipfli et al. 2003). In May in Iliamna Lake tributaries such as the Copper River, Dolly Varden feed heavily on the spawning run of mature pond smelt (Richard Russell, Alaska Department of Fish and Game (retired), King Salmon, AK, personal communication).

The summer diet of stream-resident Dolly Varden in northcentral British Columbia is primarily adult dipterans (true flies; 33.6%) and hymenopterans (wasps, bees, and ants; 7.5%), with other aquatic insects comprising the remainder (Hagen and Taylor 2001). In southeast Alaska Dolly Varden also feed on terrestrial insects, but do so less than other salmonids occupying the same habitat (Wipfli 1997). Juvenile stream-rearing Dolly Varden consume a wide variety of predominantly aquatic invertebrates (Eberle and Stanford 2010), preferentially selecting immature blackflies, non-biting midges (chironomids), and mayflies (Milner 1994; Nakano and Kaeiryama 1995), but also feed on terrestrial invertebrates (Baxter et al. 2007; Nakano et al. 1999), particularly in the absence of competing salmonids (Baxter et al. 2004; Baxter et al. 2007). Some juvenile Dolly Varden eat age-0 Arctic grayling (Stevens and Deschermeier 1986).

In the absence of competitors, lake-dwelling Dolly Varden feed heavily in summer on terrestrial insects and during fall on zooplankton. In the presence of competition, they feed heavily on chironomids (both pupae and larvae) and trichopterans (caddis flies; Andrusak and Northcote 1971; Hindar et al. 1988).

River otters *Lutra canadensis* can extensively prey on rearing Dolly Varden (Dolloff 1993). Armstrong and Morrow (1980, p. 110) noted that bears and wolves take some mature fish from spawning areas (also observed by Wiedmer; ADF&G 2011, site FSS0424A07) and speculated

that fish-eating birds also take a few. Fish-eating birds such as harlequin ducks *Histrionicus histrionicus,* common *Mergus merganser* and red-breasted *M. serrator* mergansers, and bald eagles *Haliaeetus leucocephalus* are common in southwest Alaska throughout the year and ospreys (*Pandion haliaetus,* a fish-eating raptor) are more abundant along the waters of Bristol Bay than elsewhere in Alaska (Armstrong 1980, p. 69, 80, 81, 89, 92). Russell (1980, p. 81) reported that Lake Clark National Park and Preserve lake trout feed on Dolly Varden. Perhaps the greatest predators on smaller Dolly Varden are larger Dolly Varden (Armstrong and Morrow 1980, p. 110; Russell 1980, p. 73). Wiedmer (ADF&G 2011, site FSS0406A01) collected a 195 mm (FL) northern- form Dolly Varden that had partially swallowed a 98 mm Dolly Varden.

Abundance and harvest

In the BBWAA total Dolly Varden abundance is unknown. Annual runs of anadromous Dolly Varden to southwest Alaska's Kanektok River average 13,115 (range: 8,140 to 43,292, Lisac 2011). The State of Alaska's sport and subsistence fisheries statistics do not distinguish between Arctic char and Dolly Varden. Sport anglers caught an estimated 48,438 Arctic char/Dolly Varden in the BBWAA and the adjacent Togiak River system in 2009 (8% of the statewide total) and harvested (kept) an estimated 2,159 (5% of the statewide total; Jennings et al. 2011, p. 73). The combination of Arctic char/Dolly Varden consistently support the greatest harvest of any non-salmon freshwater fish in Bristol Bay (Dye and Schwanke 2009, p. 8). Sport harvests have declined, due at least in part to both lower bag limits and the increasing popularity of catch-and-release fishing (Dye and Schwanke 2009, p. 6).

In the mid-2000s, villagers from ten of the BBWAA communities annually harvested, as part of their subsistence activities, about an estimated 3,450 Dolly Varden and Arctic char combined (Fall et al. 2006, p. 45, 80, 113, 150, 194; Krieg et al. 2009, p. 40, 78, 118, 162, 202). Dolly Varden and Arctic char combined were the most important non-salmon fish harvested in the villages of Iliamna, Newhalen, and Pedro Bay (Fall et al. 2006, p. 49, 84, 117). From the mid-1970s to the mid-2000s, Dolly Varden/Arctic char were estimated to represent between 16.2 and 26.9% of the total weight of the Kvichak River drainage non-salmon freshwater fish subsistence harvest (Krieg et al. 2005, p. 214).

Stressors

Dolly Varden are not tolerant of warm water (Fausch et al. 1994; Kishi et al. 2004; Nakano et al. 1996). Feeding activity declines to low levels at water temperatures above 16 °C and their upper lethal limit is 24 °C (Takami et al. 1997). As a result, activities that increase water temperatures beyond tolerance levels will reduce available habitat (Kishi et al. 2004; Nakano et al. 1996), including the refuge from potential competitors that cold stream temperatures provide (Fausch et al. 2010).

Total dissolved solids (TDS) do not have a significant impact on Dolly Varden fertilization, up to the highest concentrations evaluated (1,817 $mg \cdot l^{-1}$); however, elevated TDS did significantly affect embryo water absorption at concentrations as low as 964 $mg \cdot l^{-1}$ (Brix et al. 2010). Brix et al. (2010) concluded that the water-hardening phase immediately following fertilization was the most sensitive life stage to elevated TDS.

McDonald et al. (2010) reported that Dolly Varden are relatively insensitive to selenium exposure (perhaps due to low rearing temperatures) and estimated that concentrations of 44 and

49 $mg \cdot kg^{-1}$, dry weight affected 10 and 20% of the study population, respectively. Dolly Varden in fresh water metabolize naphthalene much more rapidly than seawater, which may explain the greater toxicity of naphthalene to fish when in seawater (Thomas and Rice 1980). Whether in fresh water or sea water, toluene is more readily metabolized by Dolly Varden than is naphthalene (Thomas and Rice 1986b), and toluene is more rapidly metabolized in warmer water (Thomas and Rice 1986a).

In southeast Alaska Dolly Varden are typically the first salmonid colonizers of new streams formed by glacial retreat, suggesting they have lower requirements for microhabitat features (e.g., pools) that are a function of stream age (Milner 1994). Because they often use small isolated stream habitats and spawning populations can be small, both anadromous and nonanadromous Dolly Varden are particularly vulnerable to barriers to migration (Dunham et al. 2008; Fausch et al. 2010; Kishi and Maekawa 2009; Koizumi 2011; Koizumi and Maekawa 2004) and to alterations of the small headwater streams in which they spawn and rear (Armstrong and Morrow 1980, p. 133). The closely related bull trout *S. confluentus* is listed as threatened in the contiguous United States (USFWS 1999), due in large part to habitat fragmentation and warming stream temperatures.

Lake trout *Salvelinus namaycush*

Freshwater distribution and habitats

The global native distribution of lake trout is limited almost entirely to Canada and Alaska, from the just south of the southern border of Canada north to the Canadian Arctic archipelago and from Canada's eastern maritime provinces west to near the Bering Sea coast (Martin and Olver 1980, p. 209-210). This native range is almost entirely restricted to the limits of North American late-Pleistocene glaciations (Lindsey 1964). In Alaska lake trout occur in suitable habitats across most of the state except for southern southeast Alaska, much of western Alaska, and maritime islands (Mecklenburg et al. 2002, p. 198), but within that broad range, there is great discontinuity between occupied habitats (Lindsey 1964). Bristol Bay marks the westernmost limit of the lake trout's native range (Mecklenburg et al. 2002, p. 198). Bristol Bay lake trout appear to be restricted to upland lakes and their inlet and outlet streams (ADF&G 2011, FSN0616C03; Burgner et al. 1965; Metsker 1967, p. 9, 11; Russell 1980, p. 47, 78, 79; Yanagawa 1967, p. 10). They are common in the Tikchik Lake system but absent from the main Wood River lakes (Burgner et al. 1965). Russell (1980, p. 77) considered them widely distributed in the Lake Clark area and their diet indicated they fed at lake surfaces and bottoms, and through the water columns. Anglers target lake trout in many BBWAA upland lakes, particularly Lake Clark, Iliamna Lake, and the Tikchik Lakes (Minard et al. 1998, p. 152-155).

Almost all spawning occurs along lake shorelines or shoals, above coarse, often angular substrate (Martin and Olver 1980, p. 218; Scott and Crossman 1998, p. 222; Viavant 1997, p. 6-7). Lake trout typically spawn along exposed shorelines off points or islands or in mid-lake shoals (Martin and Olver 1980, p. 218). Russell (1980, p. 77) reported apparent spawning habitat on shoals around islands in Lake Clark. Spawning can occur in very spatially discrete locations (Viavant 1997, p. 6-7). Spawning areas appear to be kept clean of fine sediments by wind-driven or deep-water currents and not by springs or seeps. The maximum depth of spawning may be positively related to lake size, particularly fetch length, but is often less than 6 m (Martin and Olver 1980,

p. 218; Royce 1951). In lakes that thermally stratify, lake trout may migrate seasonally from warming surface waters to cool deep waters (Martin and Olver 1980, p. 228-230).

Life cycle

Compared to many other salmonids, lake trout exhibit little tendency toward anadromy (Rounsefell 1958), but some individuals in far northern areas do migrate seasonally to marine waters (Swanson et al. 2010). Like other char, lake trout is a highly variable species and multiple forms, differing in diet, growth, and life span can occupy a single lake (Martin 1966). Adults can live to at least 51 years (Keyse et al. 2007); in the BBWAA, lake trout are known to live at least 29 years, begin to reach maturity at about 6 years (Russell 1980, p. 77), reach lengths of at least 910 mm (FL; Wiedmer *unpublished*), and weights of at least 14.5 kg (Richard Russell, Alaska Department of Fish and Game (retired), King Salmon, AK, personal communication). In some southcentral Alaska lakes, lake trout mature at ages 7 to 10 at lengths of 450 to 550 mm (FL; Van Whye and Peck 1968, p. 35). In the BBWAA and lakes in southcentral and interior Alaska, lake trout spawn in mid- to late September and perhaps later (Russell 1980, p. 77; Van Whye and Peck 1968, p. 35; Viavant 1997, p. 6). Mature lake trout, particularly those in more northern habitats, may not spawn annually, but will skip one or two years between spawning events (Martin and Olver 1980, p. 215). Most lake trout appear to home each year to specific spawning sites, but not all do (Martin and Olver 1980, p. 218).

The number of ova produced by mature females is a function of size and perhaps stock; reported average fecundities range from 996 to 15,842, and the diameter of ripe ova range from 3.7 to 6.8 mm (Martin and Olver 1980, p. 211, 213, 214). Lake trout may clean fine debris from the general area of spawning locations, but they do not construct redds, nor cover or guard their fertilized eggs (Royce 1951). Eggs and alevins incubate in spawning substrates until the following spring (Martin and Olver 1980, p. 224). The movements of young-of-the-year fry are poorly understood, but they are suspected to move to deeper water, often using the cover of coarse substrates (Martin 1966, p. 224, 226; Royce 1951). Larger fish can be nomadic within their home lake (Martin and Olver 1980, p. 226-227), and may move short distances between lakes (Scanlon 2010, p. 22). One probably mature, and apparently healthy 565 mm (FL) lake trout was captured in mid-August in the Tikchik River approximately 14 km from the nearest large lake (ADF&G 2011, site FSN0616C03). As a result of spawning stress, some adults move from lakes downstream into outlet rivers, and many likely do not survive to return to their natal waters (Richard Russell, Alaska Department of Fish and Game (retired), King Salmon, AK, personal communication).

Predator–prey relationships

In Lake Clark, growth remains fairly constant up to lengths of about 560 mm (FL), after which the relationship between weight and length significantly increases. Metsker (1967) attributed this to a transition, occurring at a length of about 480 mm (FL), from a diet of invertebrates to a diet of fish, primarily least cisco. A similar diet transition from insects and mollusks to fish, coupled with a potential influence on growth rate, was observed in lake trout from lakes in southcentral Alaska (Van Whye and Peck 1968, p. 30, 37).

Aquatic and terrestrial insects and small crustaceans are important foods for young-of-the-year fry (Martin and Olver 1980, p. 234). In Alaskan lakes, Arctic grayling, sculpins, humpback, round, and pygmy whitefish, least cisco, sockeye salmon fry, salmon eggs, ninespine stickleback,

EPA-6363-000002935

longnose suckers, Dolly Varden, Arctic char, rodents, shrews, and smaller lake trout are all prey items for large lake trout (Plumb 2006, p. 29; Russell 1980, p. 81-83; Troyer and Johnson 1994, p. 42; Van Whye and Peck 1968, p. 37). In the absence of fish prey, large lake trout in arctic Alaskan lakes are generalist feeders and feed primarily on benthic invertebrates (Keyse et al. 2007). In the presence of large lake trout, small lake trout limit their use of available habitats to avoid predation (Hanson et al. 1992; Keyse et al. 2007; McDonald and Hershey 1992).

In the laboratory, slimy sculpin consume lake trout eggs (Fitzsimons et al. 2006). In the wild small lake trout (Royce 1951), are known to feed on lake trout eggs, as are round whitefish (Loftus 1958), which are found throughout the BBWAA (ADF&G 2011). Royce (1951) suspected humpback whitefish, which are found in many of the same BBWAA lakes as lake trout, also feed on lake trout eggs. Burbot and large lake trout in the BBWAA feed on small lake trout (Russell 1980, p. 67, 82-83). Power and Gregoire (1978) concluded that, of the all the members of the fish community in Lower Seal Lake, Quebec, lake trout were the species most affected by freshwater seal *Phoca vitulina* predation. In 1998, Small (2001) reported that Iliamna Lake in the BBWAA supported a minimum harbor seal population of 321.

Abundance and harvest

In Bristol Bay total lake trout abundance is unknown, but in 2009 the BBWAA and the adjacent Togiak River system supported an estimated sport catch of 3,651 (12% of the statewide total) and harvest of 588 (11% of the statewide total; Jennings et al. 2011, p. 72). Dye and Schwanke (2009, p. 6) speculated that the trend of decreasing sport harvests are due in part to increasing catch-and-release practices.

In the mid-1960s, Iliamna Lake and Lake Clark supported a commercial winter lake trout fishery (Metsker 1967, p. 8, 10). In 1966 and 1967 Tikchik Lake also supported an experimental commercial freshwater fishery (Yanagawa 1967). Lake trout were the second-most commonly harvested species in that fishery, representing 30% of the overall harvest. The Tikchik Lake fishery harvested 1,502 fish, which averaged 2.2 kg in weight, and ranged in length from 500 to 575 mm and in age to more than 15 years (Yanagawa 1967).

In the mid-2000s, villagers from ten of the BBWAA communities annually harvested, as part of their subsistence activities, about an estimated 1,030 lake trout (Fall et al. 2006, p. 45, 80, 113, 150, 194; Krieg et al. 2009, p. 40, 78, 118, 162, 202). From the mid-1970s to the mid-2000s, lake trout were estimated to represent between 4.6 and 11.8% of the total weight of the Kvichak River drainage non-salmon freshwater fish subsistence harvest (Krieg et al. 2005, p. 214).

Stressors

As with lake-spawning humpback whitefish, excessive variation in lake level is suspected to reduce egg and alevin survival (Martin and Olver 1980, p. 223). Sedimentation of lake spawning areas has resulted in declines or elimination of successful reproduction (reviewed in Martin and Olver 1980, p. 223-224). In nature, lake trout are reported in water temperatures ranging from -0.8 to 18 °C, appear to prefer summer temperatures around 6 to 13 °C (Martin and Olver 1980. p. 230-231), and to have an upper lethal temperature of approximately 23.5 °C (Gibson and Fry 1954). Martin and Olver (1980, p. 231) concluded that a DO level of approximately 4 mgl^{-1} is the minimum tolerated by lake trout. Late maturity, long life, and slow growth make lake trout particularly vulnerable to over-harvest (Martin and Olver 1980, p. 259). Like the similarly long-

EPA-6363-000002936

lived piscivore, northern pike, lake trout bioaccumulate and biomagnify atmospherically deposited mercury (Swanson et al. 2011). Lake acidification has extirpated lake trout from some Canadian lakes (Matuszek et al. 1992).

Arctic grayling *Thymallus arcticus*

Freshwater distribution and habitats

Arctic grayling are found in fresh waters of higher latitudes of the Northern Hemisphere, from Hudson Bay west across the Bering Strait to the Ob and Kara river drainages east of Asia's Ural Mountains. In North America, the current native distribution of Arctic grayling is almost entirely restricted to northwestern Canada and Alaska (Scott and Crossman 1998, p. 301, 302). Arctic grayling native to northern Michigan were extirpated by around 1936 (Scott and Crossman 1998, p. 301), and by the 1990s their former broad distribution in streams of the Upper Missouri River were limited to the Big Hole River in southwestern Montana (Lohr et al. 1996). In Alaska, the Arctic grayling native range stretches across the entire mainland, but they are absent from most islands, except those formerly part of the Bering land bridge (Morrow 1980b, p. 145-146). Throughout their range, Arctic grayling are primarily restricted to fresh waters. Along the Arctic Ocean coast, they will descend downstream to feed in nearshore marine waters, but they appear to remain in the low salinity plume at the mouths of rivers or in lagoons (Furniss 1975; Tack 1980, p. 26).

Arctic grayling are widely distributed in Bristol Bay lakes (Burgner et al. 1965; Russell 1980, p. 49, 57; Yanagawa 1967, p. 12) and streams (Coggins 1992). They can occur in slow-flowing lowland streams where salmon, rainbow trout, and Dolly Varden are absent (ADF&G 2011), but they do not occur in many of the small shallow ponds on the coastal plain (Hildreth 2008, p. 9). Their range does not extend quite as far up the BBWAA's higher gradient headwater streams as do Dolly Varden and rearing coho salmon, but they are found, at some time of the year, in most tributaries and downstream to the lower Nushagak River (ADF&G 2011; Krieg et al. 2009, p. 383). Sport anglers catch Arctic grayling across most of the BBWAA, with a particular focus on the Kvichak, Alagnak, Newhalen, Tazimina, Nushagak, Mulchatna, and Koktuli rivers, Lake Clark, and the Wood River and Tikchik lake systems (Minard et al. 1998, p. 189).

BBWAA stream spawning locations may represent sites that provide both warm spring and summer temperatures and suitable hydrology (Tack 1980, p. 3-4, 14-16, 27; Warner 1957). Some spawning may occur in lakes, at stream outlets (Warner 1957). Arctic grayling and rainbow trout are the only spring-spawning salmonids in the BBWAA, and both likely seek spawning sites that enhance incubation rates and early fry growth. Tack (1980, p. 14) reported that most interior Alaska spawning occurred in riffles with sand and gravel substrates and minimal silt, in currents ranging from 0.25 to 1 $m \cdot s^{-1}$. Reed (1964, p. 14) concluded that Alaskan Arctic grayling did not target specific spawning substrates.

Best egg survival in the closely-related European grayling *T. thymallus* was 6 to 13.5 °C (Jungwirth and Winkler 1984). For much of the summer, age-0 fish tend to remain near the sites where they emerged from the spawning substrate (Craig and Poulin 1975; MacPhee and Watt 1973, p. 14, 15; Tack 1980, p. 27; Tripp and McCart 1974, p. 56). Given the August distribution of age-0 fry in the Nushagak–Mulchatna drainage (ADF&G 2011), it appears that most Arctic grayling spawning in this system occurs in tributaries.

When food is not limiting, optimal growth for age-0 juveniles in interior Alaska is at about 17 °C (Dion and Hughes 2004; Mallet et al. 1999). Older age classes may segregate to different habitats (Craig and Poulin 1975; Tack 1980, p. 29; Vincent-Lang and Alexandersdottir 1990, p. 50), but the details of that segregation may depend on the drainage-specific patterns of water temperature and food availability (Hughes 1998).

After spawning, adults may migrate further upstream (Hughes and Reynolds 1994; Vascotto 1970, p. 77; Wojcik 1954), or descend back to the mainstem (Craig and Poulin 1975; MacPhee and Watt 1973, p. 14; Tripp and McCart 1974, p. 49-51; Warner 1957), often using the same summer feeding areas annually (Ridder 1998, p. 17; Tack 1980, p. 21). Juveniles age 1 and older often follow adults, perhaps to imprint the complex migratory routes (Tack 1980, p. 20). In interior and southcentral Alaska, adult Arctic grayling overwinter in deep lakes and large rivers (Reed 1964, p. 13; Ridder 1998, p. 10-15; Sundet and Pechek 1985, p. 44; Tack 1980, p. 8, 28). Available evidence suggests the same pattern applies in the Nushagak River drainage. In August, Arctic grayling are absent or uncommon in the lower mainstem of the Nushagak River (ADF&G 2011). However, in this same area, local residents harvest large numbers of Arctic grayling through the ice during winter (Krieg et al. 2009, p. 220, 383).

Life cycle

Arctic grayling are nonanadromous, but often do undertake extensive seasonal migrations. Prior to spring breakup, large fish concentrate in mainstem rivers, at the mouths of tributaries. During and immediately after breakup, fish begin entering tributaries, even below ice cover and through channels on the ice surface (Reed 1964, p. 12-13; Warner 1957). In at least parts of Alaska, the upstream migration correlates with the peak of the spring freshet (Tack 1980, p. 13) and adults appear to show some fidelity to spawning areas (Craig and Poulin 1975; Tack 1980, p. 27). BBWAA Arctic grayling spawn in May through early June, shortly after breakup (Dye 2008, p. 26; Russell 1980, p. 57).

Mature female fecundity probably averages between about 4,000 and 7,000 ova, with some large fish producing much more (Scott and Crossman 1998, p. 303). Water-hardened eggs have an average diameter of around 3 mm and are non-adhesive (Reed 1964, p 14). Spawning adults do not actively construct redds (Craig and Poulin 1975), but their actions may create slight depressions in the stream substrate (Reed 1964, p. 13-14). Fertilized eggs fall into interstitial spaces, hatch in 2 to 3 weeks at lengths of about 8 mm (Scott and Crossman 1998, p. 303), and fry start feeding a few days later (Morrow 1980b, p. 146). Some BBWAA age-0 fish are free-swimming in early June, and perhaps even earlier in certain locations (Russell 1980, p. 57). Early growth rates appear related to temperature and benthic invertebrate densities (Tripp and McCart 1974, p. 21); on Alaska's North Slope, growth rates of age-0 Arctic grayling correlate positively to stream temperature (Luecke and MacKinnon 2008).

In the BBWAA, age-0 fish reach a mean fork length of about 69 mm (n = 700, SD = 13.6 mm) by August (calculated from data provided by ADF&G 2011). After age 0, BBWAA Arctic grayling grow about 47 mmy^{-1} until age 5 when growth begins to slow (Russell 1980, p. 60). Fish begin maturing at lengths of about 300 mm (FL), and once mature, grayling appear to spawn every year (Craig and Poulin 1975; Engel 1973, p. 8; Tripp and McCart 1974, p. 34). Bristol Bay Arctic grayling mature around age 5 (Russell 1980, p. 57), can live up to at least 13 years (Plumb 2006, p. 56), reach lengths of at least 650 mm (FL; MacDonald 1995, Table 7) and

weights at least 0.9 kg (Russell 1980, p. 57). Alaskan Arctic grayling may travel over 320 km between spawning, summer feeding, and overwintering locations (Reed 1964, p. 13; Ridder 1998, p. 10; Tripp and McCart 1974, p. 53).

Predator–prey relationships

Arctic grayling appear to feed on whatever is available to them, primarily aquatic and terrestrial insects, sequentially taking advantage of temporary peaks of abundance of different invertebrate populations (Plumb 2006, p. 62; Reed 1964, p. 20; Scheuerell et al. 2007; Tripp and McCart 1974, p. 60-61). Arctic grayling typically feed at the surface and mid-depth in the water column (Vascotto 1970), but food items include benthic slimy sculpin and slimy sculpin eggs (Bond and Becker 1963) and humpback whitefish eggs (Kepler 1973, p. 71). Scheuerell et al. (2007) discovered that, in the Wood River lakes system, after the arrival of spawning sockeye salmon, the energy intake of Arctic grayling increases more than five-fold, due primarily to the increased availability of benthic invertebrates. As spawning salmon construct redds and bury fertilized eggs, they disturb the substrate, displacing benthic macroinvertebrates, thus making them more available to Arctic grayling predation. In addition, Arctic grayling feed on salmon eggs and the larval blowflies that colonize salmon carcasses. These salmon-derived resources contribute a large majority of the energy necessary for the annual growth of resident Arctic grayling (Scheuerell et al. 2007). In lakes, Arctic grayling can be the most important prey species of lake trout (Troyer and Johnson 1994, p. 42). In Alaskan Arctic streams, Stevens and Deschermeier (1986) found that some juvenile Dolly Varden eat age-0 Arctic grayling fry .

Abundance and harvest

In Bristol Bay total Arctic grayling abundance is unknown, but in 2009 the BBWAA and the adjacent Togiak River drainage supported an estimated sport fish catch of 44,762 fish (11% of the statewide total) and a harvest of 1,094 (4% of the statewide total; Jennings et al. 2011, p. 74). Dye and Schwanke (2009, p. 6) speculated that the trend of decreasing sport harvests are due in part to increasing catch-and-release practices.

In the mid-2000s, villagers from nine of the BBWAA communities annually harvested, as part of their subsistence activities, about an estimated 7,790 Arctic grayling (Fall et al. 2006, p. 45, 80, 113, 150, 194; Krieg et al. 2009, p. 40, 78, 118, 162, 202). From the mid-1970s to the mid-2000s, Arctic grayling were estimated to represent between 6.9 and 9.7% of the total weight of the Kvichak River drainage non-salmon freshwater fish subsistence harvest (Krieg et al. 2005, p. 214).

Stressors

Total dissolved solids up to 2,782 $mg \cdot l^{-1}$ do not have a significant impact on Arctic grayling egg fertilization; however, concentrations as low as 1,402 $mg \cdot l^{-1}$ do significantly affect water absorption during the water-hardening phase immediately following fertilization, when embryos gain resistance to mechanical damage (Brix et al. 2010). As a result, Brix et al. (2010) identified that period as the most sensitive early developmental stage.

Egg mortality in the closely-related European grayling *T. thymallus* was 100% at temperatures over 16 °C or under 4 °C (Jungwirth and Winkler 1984). In interior Alaska, the minimum and maximum temperatures at which growth occurs are 4.5 °C and 21 °C (Dion and Hughes 2004;

Mallet et al. 1999). In interior Alaska, age-0 fish are more tolerant of high water temperatures than alevins and older juveniles, with a median tolerance limit in excess of 24.5 °C, compared to 20 to 24.5 °C for the other life stages (LaPerrier and Carlson 1973, p. 29).

In North Slope streams, the growth of age-0 fry is positively correlated with temperature, while adult growth has no temperature correlation (Deegan et al. 1999; Luecke and MacKinnon 2008). Adult and age-0 juveniles may also respond differently to stream discharge. Adult growth in North Slope streams is positively correlated with discharge, while age-0 growth is negatively correlated with it (Deegan et al. 1999; Luecke and MacKinnon 2008). Wojick (1954, p. 67) speculated that elevated stream discharges during the incubation and early fry rearing stage would harm Arctic grayling stocks.

Although reasons for the dramatic contraction in the native range of stream-resident Upper Missouri River Arctic grayling is not well understood, constructed barriers to fish migration and stream dewatering appear to be major contributing factors (Barndt and Kaya 2000).

EPA-6363-000002940

Table 1. Fish species reported in the EPA Bristol Bay Watershed Assessment Area (ADF&G 2011; Mecklenburg et al. 2002; Morrow 1980).

Scientific/Common Family Name	Common Name	Scientific Name	Principal Life History[1]
Petromyzontidae/lampreys	Arctic lamprey	*Lethenteron camtschaticum*[2]	Anadromous
	Alaskan brook lamprey	*L. alaskense*[2]	Nonanadromous
	Pacific lamprey	*Entosphenus tridentatus*[2]	Anadromous
Clupeidae/herrings	Pacific herring	*Clupea pallasii*	Amphidromous
Catostomidae/suckers	longnose sucker	*Catostomus catostomus*	Nonanadromous
Esocidae/pikes	northern pike	*Esox lucius*	Nonanadromous
Umbridae/mudminnows	Alaska blackfish	*Dallia pectoralis*	Nonanadromous
Osmeridae/smelts	rainbow smelt	*Osmerus mordax*	Anadromous
	pond smelt	*Hypomesus olidus*	Nonanadromous
	eulachon	*Thaleichthys pacificus*	Anadromous
Salmonidae/salmonids	Bering cisco	*Coregonus laurettae*	Nonanadromous and Anadromous[3]
	humpback whitefish	*C. pidschian*	Nonanadromous and Anadromous[3]
	least cisco	*C. sardinella*	Nonanadromous and Anadromous[3]
	pygmy whitefish	*Prosopium coulterii*	Nonanadromous
	round whitefish	*P. cylindraceum*	Nonanadromous
	coho salmon	*Oncorhynchus kisutch*	Anadromous
	Chinook salmon	*O. tshawytscha*	Anadromous
	sockeye salmon	*O. nerka*	Anadromous
	chum salmon	*O. keta*	Anadromous
	pink salmon	*O. gorbuscha*	Anadromous
	rainbow trout	*O. mykiss*	Nonanadromous
	Arctic char	*Salvelinus alpinus*	Nonanadromous
	Dolly Varden	*S. malma*	Nonanadromous and Anadromous
	lake trout	*S. namaycush*	Nonanadromous
	Arctic grayling	*Thymallus arcticus*	Nonanadromous
Gadidae/cods	burbot	*Lota lota*	Nonanadromous
	Pacific cod	*Gadus macrocephalus*	Amphidromous
	saffron cod	*Eleginus gracilis*	Amphidromous
Gasterosteidae/sticklebacks	threespine stickleback	*Gasterosteus aculeatus*	Nonanadromous and Anadromous
	ninespine stickleback	*Pungitius pungitius*	Nonanadromous
Cottidae/sculpins	coastrange sculpin	*Cottus aleuticus*	Nonanadromous
	slimy sculpin	*C. cognatus*	Nonanadromous
	Pacific staghorn sculpin	*Leptocottus armatus*	Amphidromous
Pleuronectidae/righteye flounders	Arctic flounder	*Pleuronectes glacialis*	Amphidromous
	starry flounder	*Platichthys stellatus*	Amphidromous

[1] **Anadromous**: fishes that spawn in fresh waters and migrate to marine waters to feed; **Nonanadromous**: fishes that spend their entire life in fresh waters, with possible migrations between habitats within a drainage (resident fish); **Anadromous and Nonanadromous/Nonanadromous and Anadromous**: fish populations in which some individuals have anadromous life histories and some have potamodromous life histories—the most common form listed first; **Amphidromous**: fishes that may move between fresh and salt water during some part of life cycle, but not for spawning. The Bristol Bay fishes classified amphidromous are primarily marine species that may move into estuaries and lower rivers for feeding, particularly as juveniles.

[2] Nomenclature follows Brown et al. (2009).

[3] Anadromy known in other Alaskan locations, but not verified within the BBWAA.

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Appendix C

Wildlife Resources of the Nushagak and Kvichak River Watersheds

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U. S. Fish and Wildlife Service

Report to the U.S. Environmental Protection Agency for the Bristol Bay Watershed Assessment

Wildlife Resources of the Nushagak and Kvichak River Watersheds

External Review Draft

January 2012

Edited by: Philip J. Brna and Lori A. Verbrugge
Anchorage Fish and Wildlife Field Office

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EXECUTIVE SUMMARY

Background

At the request of the U.S. Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (USFWS) prepared this report which summarizes known information related to brown bear, moose, caribou, wolf, waterfowl, bald eagle, shorebirds, and landbirds in the Bristol Bay region of Alaska, with a focus on the Nushagak and Kvichak watersheds. These species were selected for review because of their importance to ecosystem function, their direct link to salmon, or their importance to local and Alaska residents. EPA is conducting a watershed assessment in the Nushagak and Kvichak watersheds in response to requests from various organizations under the authority of the Clean Water Act, and requested assistance from the USFWS, as the agency with responsibilities and expertise for the nation's fish and wildlife resources. This report is a small portion of the larger EPA effort which includes evaluation of fish resources of the region, hydrology, and an ecological risk assessment related to potential effects of large scale mineral development on fish, wildlife, water quality, and humans. In addition to being part of the EPA Bristol Bay Watershed Assessment, the information in this report will be useful for Statewide or regional land use planning, completion of environmental documentation for permitting of development projects, or activities related to Landscape Conservation Cooperatives in Alaska.

In this report, we describe: habitat use; food habits; behavior; interspecies interactions; productivity, mortality and survivorship; populations, subpopulations, and genetics; human use and interactions, and management for wildlife with a focus on the Nushagak and Kvichak watersheds, to the extent that existing data allow. We describe the relationship of these wildlife species (brown bear, moose, caribou, wolf, and bald eagle) or species guilds (waterfowl, shorebirds and landbirds) with salmon. We describe the dependence of wildlife on marine derived nutrients (MDN) transported to these watersheds by salmon and the role of wildlife in distributing MDN through the ecosystem to the extent this information is available.

About 40 current or retired biologists and scientists from USFWS, National Park Service, Bureau of Land Management, U.S. Geological Survey, U.S. Forest Service, and Alaska Department of Fish and Game were involved with preparation and review of this report. Collectively, these biologists and scientists have significant experience with research and management of wildlife in Alaska and many have extensive experience in the Nushagak and Kvichak watersheds.

The Importance of Marine-Derived Nutrients to Bristol Bay

One of the most important ecological functions of salmon is to transfer large quantities of nutrients from the marine environment into terrestrial and freshwater ecosystems within the watersheds where adults return to spawn. Marine-derived nutrients (MDN), in combination with other ecosystem features such as suitable spawning habitat and oceanic carrying capacity, are essential for the survival and growth of the next generation of salmon, and also greatly benefit other fish and wildlife species. Herbivores benefit from increased vegetative growth in riparian areas stimulated by MDN, while carnivores and scavengers directly consume migrating salmon or their carcasses. In both aquatic and terrestrial ecosystems, MDN are also integrated into the base of food chains, and increased productivity is transferred to species at higher trophic levels. It is likely that southwest Alaska and the Nushagak and Kvichak watersheds support large

populations of wildlife both because habitat in the region is almost totally intact and because of the presence of millions of salmon annually spawning, rearing, and migrating to sea and back. The annual introduction of millions of pounds of MDN from salmon and the lack of significant anthropogenic watershed disturbances make Bristol Bay relatively unique in the world.

Brown bears within the Nushagak and Kvichak watersheds depend on salmon for food and survival. Accumulation of fat reserves is important for successful hibernation, and for female reproductive success. Wolves also consume salmon seasonally when available, and this marine-derived source of food is a major component of the lifetime total diet of wolves in areas where the two species co-exist. Brown bears and wolves play an important role in distributing MDN from streams to the terrestrial environment, both by transporting salmon carcasses prior to consumption and through excretion of wastes rich in salmon nutrients. Both brown bears and wolves have been documented travelling long distances to feed on salmon.

Waterfowl benefit from salmon which provide a large influx of nutrients to riverine and terrestrial systems, both directly as sources of prey and carrion, and indirectly as nutrient drivers of aquatic systems. Of the 24 duck species that regularly occur in Bristol Bay, at least eleven species are known to prey on salmon eggs, parr, smolts, and scavenge on carcasses. Of these, greater and lesser scaup, harlequin duck, bufflehead, common and Barrow's goldeneyes, and common and red-breasted mergansers exhibit directed foraging on salmon. Among dabbling ducks, mallards feed most on salmon because they are distributed across a diversity of summer habitats in spawning areas, and they are the principal wintering dabbling duck on the North Pacific coast where fall-winter salmon runs occur. Fish predators like mergansers feed extensively on salmon fry and smolts. Other duck species may prey on smolt incidentally. Salmon eggs are a seasonally rich food source for harlequin ducks, goldeneyes and scaup that frequent rivers and streams and probably for other opportunistic ducks. Species ranging from dabbling ducks (mallard, green-winged teal) and diving ducks to sea ducks that inhabit spawning waters probably opportunistically scavenge easy protein-rich meals from salmon carcasses.

Spawned-out salmon carcasses provide an ideal food resource to bald eagles. The abundance of salmon in the region affects bald eagle population size, distribution, breeding and behavior. In one studied population, salmon availability in spring was tightly correlated with whether adult bald eagles laid eggs in a given year, and also influenced the timing of egg-laying. As with other salmon consumers, bald eagles affect the ecosystems within their range by distributing MDNs in their excretions.

Direct or indirect interactions between shorebirds and salmon are not well-documented. Some shorebird species are observed to consume dead salmon and salmon eggs. No studies have been conducted to deduce the contribution of salmon to the energetics of shorebird populations; however, the abundance of invertebrates in the intertidal zone is very likely due in part to MDN from salmon that die on the coast and in the rivers feeding Bristol Bay. Shorebirds play a role in distributing MDNs into the terrestrial system, especially during the migratory period, but this has not been quantified. Some of the longest migrations known for birds involve shorebird species (bar-tailed godwit) that use Bristol Bay intertidal areas in autumn. Such flights are possible not only due to the extreme abundance of intertidal invertebrates (polychaetes, crustaceans, gastropods, and bivalves) in the region, but also because the adjacent uplands are usually rich in

fruits of ericaceous plants or tubers that birds like plovers, whimbrels, and godwits, regularly feed on. Some species like whimbrel, Hudsonian godwit, and black and ruddy turnstones feed on herring roe, carrion (including salmon carcasses), and salmon eggs. Many shorebirds make use of freshwater invertebrates; small fish may be consumed by yellowlegs and phalaropes.

Landbirds also benefit from salmon carcasses when available. Aquatic invertebrate larvae feed on salmon carcasses, overwinter in the soil, and emerge in the spring as adults. These invertebrate adults become prey for a variety of landbird species in the spring, and serve as an important seasonal subsidy during a period when terrestrial invertebrate biomass is low. Salmon also benefit landbirds by increasing plant productivity due to MDN inputs, potentially resulting in an abundance of berries and seeds for avian consumption. Some birds, such as the American Dipper, directly consume salmon eggs, fry, and small bits of carcasses when available.

In summary, MDN from salmon cycle throughout the ecosystem of watersheds with healthy salmon runs, benefitting wildlife, increasing vegetation productivity, and promoting the production of periphyton, aquatic macroinvertebrates, resident freshwater fish, and juvenile salmon. This nutrient cycling is in turn dependent on interactions with wildlife, which distribute MDN into the terrestrial environment through both transport of carcasses and excretion of wastes. The loss of either salmon or key wildlife species may result in significant changes to the productivity, diversity and physical structure of the ecosystem, via mechanisms that extend beyond simple “food chain” interactions.

CONTENTS

ACKNOWLEDGEMENTS ii
EXECUTIVE SUMMARY iii
Background iii
The Importance of Marine-Derived Nutrients to Bristol Bay iii
LIST of FIGURES x
LIST of TABLES x
INTRODUCTION 11
METHODOLOGY 12
Geographic Scope of USFWS Evaluation 13
Selection of Wildlife Species for Characterization 13
The Characterization Process 15
CHARACTERIZATION OF WILDLIFE 15
Overview of Wildlife Species 15
Alaska- 15
Southwest Alaska Region- 16
The Importance of Marine-Derived Nutrients to Bristol Bay Watershed Ecosystems 16
Overview of Land Cover and Habitat Types 19
BROWN BEARS 21
Introduction 21
Habitat 21
Food Habits 22
Behavior 23
Interspecies Interactions 25
Mortality, Productivity, and Survivorship 25
Population 27
Human Use/Interaction/Management 28
Sport Hunting for Brown Bears 28
Game Management Unit 9- 28
Game Management Unit 17- 29
Subsistence Hunting for Brown Bears- 29
Bear Viewing- 30
Other Human-Bear Interactions 30

Local Residents and Bear-Human Conflicts- 30
Other Recreational Users and Bear-Human Conflicts- 30
MOOSE 31
Introduction 31
Habitat 31
Winter Habitat- 34
Food Habits 35
Behavior 37
Movements and Home Ranges- 37
Sexual Segregation and Grouping Behaviors- 40
Mating and Maternal Behaviors- 41
Activity Budgets- 42
Interspecies Interactions 43
Mortality, Productivity, and Survivorship 45
Population, Subpopulations, and Genetics 48
Human Use (Subsistence, Recreation)/Interaction/Management) 49
BARREN GROUND CARIBOU 51
Introduction 51
Population History of Caribou in the Upper Bristol Bay Region 51
Habitat 52
Seasonal Preference- 52
Food Habits 52
Spring- 52
Summer- 53
Fall- 53
Winter- 53
Behavior 53
Seasonal Range Use and Migrations- 53
Response to Disturbance- 54
Interspecies Interactions 55
Mortality, Productivity, Survivorship 55
Mortality- 55
Breeding- 55

Human Use/Interaction/Management 56
WOLF 58
Introduction 58
Habitat 58
Food Habits 58
Diet- 58
Salmon as a Food Source 59
Dispersal of Marine-Derived Nutrients (MDNs) by Wolves- 60
Behavior 61
Wolf Packs- 61
Range- 61
Dispersal (Emigration)- 62
Seasonal Movements- 63
Interspecies Interactions; Response to Change in Salmon Populations/ Distribution 63
Mortality, Productivity, and Survivorship 65
Population Estimates 66
Human Use/Interaction/Management 67
WATERFOWL 69
Introduction 69
Regional Overview- 69
History of Waterfowl Surveys- 70
Waterfowl Resources and Seasonal Occurrence 71
Estuaries and Inner Bristol Bay- 71
Bristol Bay Lowlands- 75
Inland Tundra/Taiga- 78
Nutrients, Trophic Relations and Foods 80
Nutrients and Habitat Productivity- 80
Food Habits- 81
Importance of Marine-Derived Nutrients (Salmon and Herring) to Waterfowl- 84
Populations, Subpopulations, and Genetics 85
Swans- 86
Geese- 86
Dabbling and Diving Ducks- 86

Sea Ducks- 86
Human Use 87
Nonconsumptive Uses- 87
Recreational Harvest- 88
Subsistence Harvest- 88
BALD EAGLES 91
Introduction 91
Habitat 91
Food Habits 93
Diet- 93
Significance of MDNs- 94
Foraging Methods- 95
Behavior 95
Territoriality- 95
Flocking- 96
Migration and Local Movements- 96
Interspecies Interactions 97
Breeding, Productivity, and Mortality 97
Breeding- 97
Productivity and Survivorship- 98
Mortality- 99
Population, Distribution, and Abundance 101
Human Use 102
SHOREBIRDS 104
Introduction 104
Habitat 106
Food Habits 108
Behavior (Movements) 109
Interspecies Interactions 110
Population, Subpopulations, and Genetics 112
Human Use and Threats 113
LANDBIRDS 114
Introduction 114

Habitat 114
Interspecies Interactions 115
APPENDIX 1: LIST OF AUTHORS AND REVIEWERS 117
APPENDIX 2: SOUTHWEST ALASKA TERRESTRIAL VERTEBRATE SPECIES 119
APPENDIX 3: LITERATURE CITED 128

LIST of FIGURES

Figure 1. Nushagak and Kvichak River watersheds and inner Bristol Bay. 12
Figure 2. National Land Cover Dataset, land cover types for the Nushagak River watershed and Kvichak River watershed. 19
Figure 3. Nushagak and Kvichak River watersheds and associated Alaska Department of Fish and Game, game management units. 29

LIST of TABLES

Table 1. Size of subbasins (sq. mi.) within the Nushagak and Kvichak River watersheds and percent of watershed or subbasin within each National Land Cover Database land cover type. . 20
Table 2. Mean (range) home range size (km2) for selected moose populations in Alaska. 39
Table 3. Moose activity budgets in winter[1] and spring/summer[2] in Denali National Park and Preserve (averages) 43
Table 4. Subsistence statistics for moose harvest in Alaska Dept. of Fish and Game, game management units (GMU) 9B, 17B, and 17C. 50
Table 5. Mulchatna caribou herd- estimated population size and harvest. 56
Table 6. Average territory sizes (km^2) of wolf packs in Alaska*. 62
Table 7. Total wolf harvests in GMUs 9, 10 and 17 reported to Alaska Department of Fish and Game. 67
Table 8. Average abundance indices and densities of species/groups recorded in late May on the Alaska Yukon Waterfowl Breeding Population Survey, Bristol Bay Lowlands (Stratum 8)..... 76
Table 9. General food habits and consumption of fish by duck species of Bristol Bay. 82
Table 10. Reported survival of bald eagle nestlings in Alaska. 100
Table 11. Summary of surveys for bald eagle nests in the Bristol Bay study area. 102
Table 12. Shorebirds found in the Bristol Bay Watershed. 105

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is conducting a watershed assessment in the Nushagak and Kvichak River watersheds of Bristol Bay, Alaska in response to requests from nine Tribal Governments and other interests. The tribes have requested that EPA take action to protect the Bristol Bay watershed from the adverse impacts of potential large-scale hard rock mining projects utilizing EPA's statutory authority, including Section 404(c) of the Clean Water Act (CWA). Section 404(c) allows EPA to prohibit or restrict discharges of dredged or fill material into waters of the United States, including wetlands, when it determines that such discharges would have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas), wildlife, or recreational areas. EPA has also received requests from two tribes and other interests to refrain from taking advance action and to wait for specific permit applications for mining projects to be reviewed by the U.S. Army Corps of Engineers (Corps) pursuant to Section 404 of the CWA and the National Environmental Policy Act (NEPA). EPA is conducting the Bristol Bay Watershed Assessment (BBWA) under its Clean Water Act Section 104(a) authority, which directs them to: *"...conduct and promote the coordination and acceleration of, research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of pollution."*

EPA requested that the U.S. Fish and Wildlife Service (USFWS) provide assistance in conducting the BBWA. The mission of the USFWS is to work with others to conserve, protect and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people. The USFWS works to protect a healthy environment for people, fish and wildlife, and helps Americans conserve and enjoy the outdoors and our living treasures. The USFWS has responsibility for fish and wildlife resources with specific emphasis on migratory birds, endangered plants and animals, certain marine mammals, and freshwater and anadromous fish. USFWS expects that this report will be useful to EPA in completing the BBWA, but it should also provide a comprehensive summary of wildlife information for others interested in southwest Alaska. These uses might include: completion of environmental documentation for oil and gas leasing or any development project; activities related to the Western Alaska Landscape Conservation Cooperative; the Southwest Alaska Salmon Habitat Partnership; or any land use planning effort.

The Bristol Bay watershed is comprised of six major drainages: the Togiak River, Nushagak River, Kvichak River, Naknek River, Egegik River, and Ugashik River. The Kvichak and Nushagak River watersheds are the principle Bristol Bay drainages that have lands open to large-scale development. Much of the rest of the region is within National Parks or National Wildlife Refuges and is protected from such development. EPA's analysis therefore, focuses on the Nushagak and Kvichak watersheds (Figure 1).

The objective of the BBWA process is to build a common understanding of both the fish and wildlife resources of Bristol Bay and the potential impacts to those resources from large-scale development and to identify possible options for protecting these resources. The overall assessment represents an integration of several types of evaluations. The first component is an assessment of the resources themselves, also called a characterization, which synthesizes current conditions within the Nushagak and Kvichak watersheds and compares those resources to other regional or reference areas. It's focus is determining if the resources in question, the wildlife of the

EPA-6363-000002969

Nushagak and Kvichak watersheds in the case of this report, represent an exceptional resource that might be worthy of special protection. For exceptional resources, the characterization identifies the environmental factors that contribute to the extraordinary nature of the resource. The characterization thus identifies what must be protected to retain an exceptional status. The second component of the evaluation is a predictive risk assessment, devoted, in this case, to estimating the effects of reasonably foreseeable large-scale development in the area on wildlife. It is organized on the established EPA frameworks for ecological and cumulative risk assessments. The potential development scenarios and the results of the predictive risk assessment include inherent uncertainties and cumulative risks.

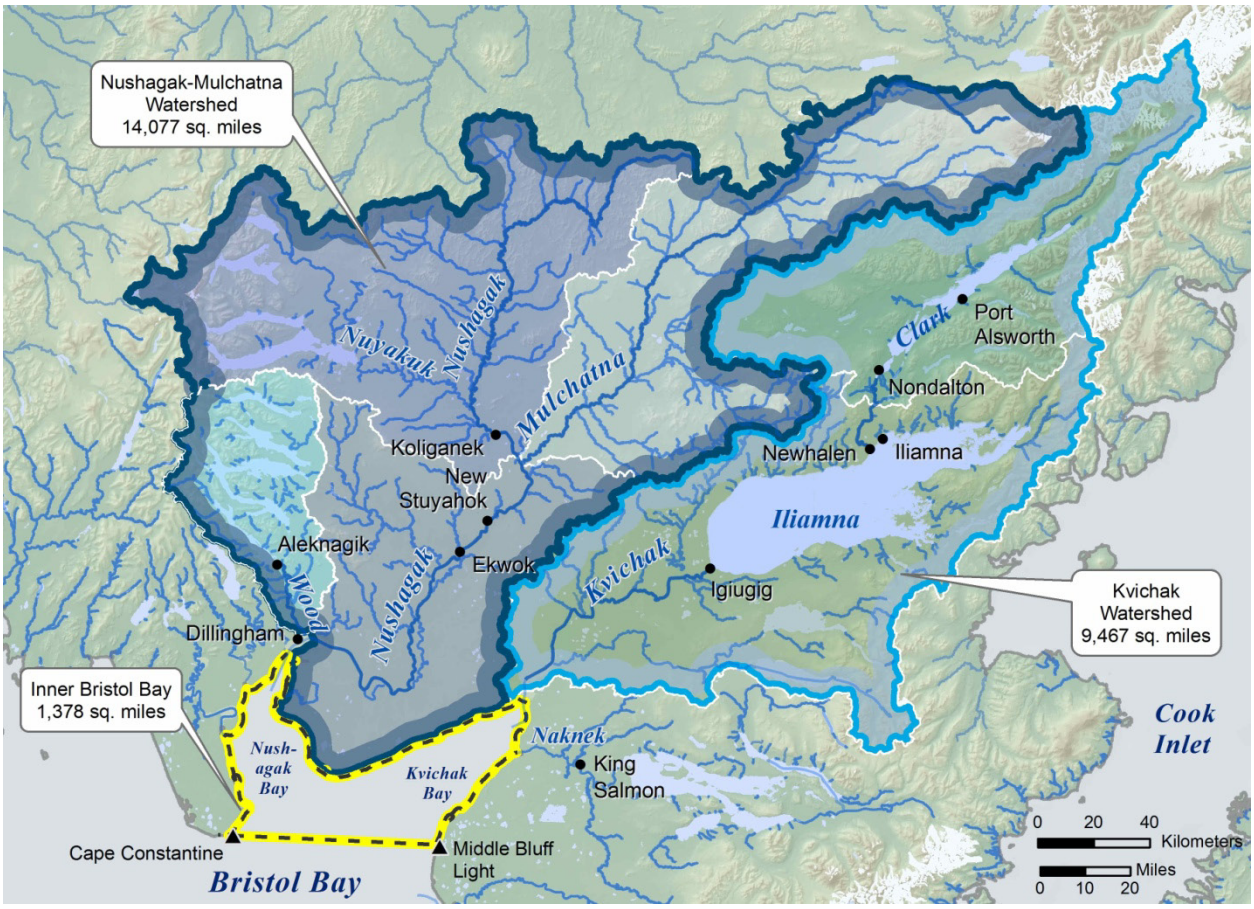

Figure 1. Nushagak and Kvichak River watersheds and inner Bristol Bay.

METHODOLOGY

There are two phases of the EPA BBWA: characterization and predictive risk assessment. Characterization is the review and documentation of relevant literature, interviews with knowledgeable agency staff and other experts on the ecological and economic significance of the fish and wildlife resources in the Nushagak and Kvichak watersheds. The goal of this review and documentation process is to describe the level of current scientific knowledge of fish and wildlife resources of Bristol Bay, and to answer the question "What is the ecological and economic significance of Bristol Bay fish and wildlife resources locally and around the North Pacific Ocean?" This USFWS report is primarily intended to provide information to EPA about wildlife resources in the Nushagak and Kvichak watersheds for their use in developing the BBWA but, it

could also be useful for other land use planning or project environmental review and permitting activities. EPA is preparing a separate report which characterizes fish in the Bristol Bay region.

Predictive risk assessment is the review and documentation of relevant literature, interviews with knowledgeable agency staff and other experts on the risks, threats and stressors associated with current and foreseeable human activity on the health, productivity, ecological integrity, and long-term sustainability of fish and wildlife resources of Bristol Bay. It includes review and documentation of mitigation practices used to abate threats and risks to fish and wildlife resources.

Based on the scope of the BBWA, USFWS formulated three objectives for this report to EPA. These are:

1. Describe significant, representative wildlife species in Bristol Bay and their importance to humans;
2. Describe the importance of marine derived nutrients to these wildlife species; and
3. Describe the role of these wildlife species in distributing marine derived nutrients throughout the ecosystem.

Geographic Scope of USFWS Evaluation

The primary geographic scope of the BBWA, and therefore this report, is the Nushagak and Kvichak watersheds. In addition to terrestrial mammal species, the USFWS is characterizing and assessing migratory birds, many of which use marine waters during some portion of the year. Therefore, we needed to determine the extent of freshwater influence from these river systems in the Bristol Bay marine environment. Data on the hydrography of the Bay is limited; however, an evaluation based on salinity differences, drift cards and fluorescent dye (Straty, 1977), indicates that the net seaward flow of lighter and less saline river runoff water from the Kvichak River (and the adjacent Naknek River to the south) moves in a counterclockwise direction along the northwest side of inner Bristol Bay, where it mixes with water from the Nushagak River. Data indicate that the mixture of Kvichak and Naknek river water remains relatively distinct as far as Cape Constantine. On the southeast side of the bay, the answer is less clear. However, Egegik River water does not appear to travel much further north than Middle Bluff Light. North of Middle Bluff Light water immediately along the shoreline is probably mostly Naknek River water, but by around 8 km off shore, Naknek River water is mixed with Kvichak River water. Therefore, to facilitate evaluation of migratory birds in marine waters, we are defining the area of freshwater influence as the area north of a line drawn from Cape Constantine east to Middle Bluff Light. We call this area inner Bristol Bay for purposes of this report. This area is marked with the yellow dashed line on Figure 1.

Selection of Wildlife Species for Characterization

EPA asked the USFWS for assistance in evaluating wildlife species that can be directly linked to salmon, due either to their direct dependence on salmon for survival (food) or to their role in distributing marine derived nutrients throughout freshwater aquatic or terrestrial ecosystems. The vast number of wildlife species in the Nushagak and Kvichak watersheds made it impractical to characterize each individual species. Additionally, staff resources available to the USFWS and time constraints imposed by the EPA BBWA process, also meant that there would be no new primary wildlife data collection and that our analysis would be based primarily on previously-collected data.

EPA-6363-000002971

The first step, therefore, was to identify a subset of wildlife species that represent major components of biodiversity in the region. Initially, the USFWS decided to use portions of an approach developed by The Nature Conservancy for ecoregional planning (Groves et al., 2000). This process was modified for use by the Mat-Su Salmon Habitat Partnership to develop a Strategic Habitat Action Plan and also by The Nature Conservancy in preparing the Alaska Peninsula and Bristol Bay Basin Ecoregional Assessment (The Nature Conservancy in Alaska, 2004). A simplified version was also used by the Southwest Alaska Salmon Habitat Partnership to develop a draft Strategic Habitat Conservation Action Plan. The USFWS is a member of both fish habitat partnerships and USFWS biologists were also involved with the Ecoregional Assessment, so we are familiar with ecoregional planning concepts.

Ecoregional planning, as described by Groves et al. (2000) is a complex, step-by-step approach with the goal of selecting and designing networks of areas of high biodiversity significance (conservation sites) that will conserve the diversity of species, communities, and ecological systems in an ecoregion. Since this is not the goal of the USFWS's work as part of the EPA BBWA, we used selected portions of the approach to help us identify wildlife species targets. Species-level targets facilitate identification of threats and development of strategies and actions to abate threats.

The USFWS selected key wildlife species for our contribution to the EPA BBWA based largely on professional judgment, and consultation with EPA, and members of the BBWA Intergovernmental Technical Team. Key species regulate energy flow and nutrient dynamics or they may be ecosystem engineers that modulate habitat structure (Davic, 2003). We define key species as being those we know from experience, have a direct link to salmon or are of special interest to local or Alaska residents. Additionally, migratory birds and bald eagles are considered key species because the USFWS has direct statutory authority for them under the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act.

The term "key species" should not be confused with the term "keystone species" which are those whose impact on a community or ecological system is disproportionately large for their abundance and biomass (Paine, 1995). Keystone species have spatial, compositional and functional requirements that may encompass those of other species in the region and they may play a critical role in maintaining the structure of an ecological community. They affect many other organisms in an ecosystem and help to determine the types and numbers of various other species in the community. They contribute to ecosystem function in a unique and significant manner through their activities. Their removal may initiate changes in ecosystem structure and often a loss of diversity (e.g., beaver, bison, prairie dog). Keystone species may also be wide-ranging and depend on vast areas for survival. These species include top-level predators (e.g., wolves, grizzly bear) as well as migratory mammals (e.g., caribou), anadromous fish and birds (The Nature Conservancy in Alaska, 2004). Keystone species regulate local species diversity in lower trophic levels (Davic, 2003).

The key species the USFWS selected for inclusion in the wildlife component of the BBWA are:

- brown bear;
- moose;
- barren ground caribou;

EPA-6363-000002972

- wolf;
- waterfowl (as a guild);
- bald eagle;
- shorebirds (as a guild); and
- landbirds (as a guild).

The USFWS also considered including species listed under the Endangered Species Act and seabirds but a preliminary assessment revealed there are no significant occurrences of either listed species or significant assemblages of seabirds in the Nushagak and Kvichak watersheds or inner Bristol Bay.

The Characterization Process

Staff from the Anchorage Fish and Wildlife Field Office (AFWFO) prepared initial drafts of all but two of the species accounts. The waterfowl species account was developed by a contractor and the shorebird account was drafted by a USFWS National Wildlife Refuge biologist. Species accounts were drafted based on a suggested outline provided by AFWFO. We circulated for review and comment initial draft species accounts to numerous experts from the USFWS, other federal and State agencies, and other knowledgeable individuals, many of whom are retired federal or State wildlife biologists. The USFWS then obtained assistance from expert wildlife biologists to revise the draft species accounts on brown bear, caribou, moose, and bald eagles. Finally, we circulated the revised draft species accounts for review and comment. A list of authors and reviewers for each species account is provided in Appendix 1**.** All completed species accounts are incorporated in this report.

Species accounts were largely developed using available published data and information, but in some instances we used unpublished information from species experts. Our preference was to use data specific to the Nushagak and Kvichak watersheds. However, we also used relevant information from other regions of Alaska or other parts North America.

CHARACTERIZATION OF WILDLIFE

Overview of Wildlife Species

Alaska- Many Alaskans depend on the State's diverse wildlife resources[1] for food and enjoyment. Traditional subsistence harvest and personal use, sport and guided hunting, as well as nonconsumptive uses of wildlife, such as wildlife viewing, are critical components of the Alaska economy and lifestyle (ADF&G, 2006). According to the Alaska Department of Fish and Game (ADF&G), the value of game species such as moose, caribou, and deer are well understood by most Alaskans(ADF&G, 2006). Historically, species not taken for subsistence, sport, or commercial use, were perceived as having little direct economic value. However, the contribution of nongame species to Alaska's economy is substantial, although difficult to quantify. According to ADF&G, basic biological information on life history, population levels, and other parameters is lacking for many species, but the majority of Alaska's wildlife resources are considered healthy.

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[1] ADF&G includes fish, reptiles, amphibians, and marine mammals (including whales) in the definition of wildlife in the Comprehensive Wildlife Strategy. Of the 1,073 vertebrate species known to occur in Alaska, there are 469 species of birds and 64 species of terrestrial mammals (ADF&G 2006; Jarrell et al 2004).

Southwest Alaska Region- Southwest Alaska, including the Nushagak and Kvichak watersheds, possesses intact, naturally functioning terrestrial ecosystems that still support their historic complement of species, including large carnivores. Such ecosystems, containing historic levels of biodiversity, are becoming extremely rare globally. Large terrestrial herbivore-predator interactions are an intrinsic property of intact functioning ecosystems and are a flagship ecological feature of southwest Alaska (Bennett et al., 2006; Jarrell et al., 2004; Nushagak-Mulchatna Watershed Council, 2007).

Based on a compilation of vertebrate species lists for Togiak National Wildlife Refuge (NWR) (USFWS, 2009b), Alaska Peninsula and Becharof NWR Bird List (USFWS, 2010b), and southwest Alaska national parks (Cook and MacDonald, 2005), there are 192 species of birds and 41 species of terrestrial mammals in southwest Alaska (Appendix 2). There is no comprehensive species list available for the Nushagak and Kvichak watersheds, but it is reasonable to assume that species in these watersheds are nearly identical to those in the larger region.

Of all the species described in this report, caribou, moose and waterfowl are probably the most important subsistence species to local residents. These species also provide significant recreational hunting opportunities for both nonlocal resident and nonresident hunters. Other wildlife species which provide subsistence food for local residents include black bears, beaver, ptarmigan, and porcupine. River otter, red fox, marten and wolverine are also important in the region. We have not identified any of these other wildlife species as key species for purposes of this report.

The Importance of Marine-Derived Nutrients to Bristol Bay Watershed Ecosystems

One of the most important ecological functions of salmon is to transfer large quantities of nutrients from the marine environment into terrestrial and freshwater ecosystems within the watersheds where adults return to spawn. Pacific salmon spend most of their lives feeding and growing at sea before returning to spawn and die in their natal streams or lakes, and approximately 95 to 99% of the carbon, nitrogen, and phosphorus in the adult salmon body are derived from the marine environment (Larkin and Slaney, 1997; Schindler et al., 2005). These nutrients are transported inland when salmon return to their natal streams or lakes to spawn. For oligotrophic Lake Iliamna, the annual nitrogen pool associated with the annual spawning migration is comparable in size with the dissolved nitrogen pool in the lake, indicating the importance of adult salmon to the lake's nitrogen budget (Kline et al., 1993). Marine-derived nutrients (MDN), in combination with other ecosystem features such as suitable spawning habitat and oceanic carrying capacity (Schindler et al., 2005), are essential for the survival and growth of the next generation of salmon, and also greatly benefit a number of other fish and wildlife species.

Brown bears within the Nushagak and Kvichak watersheds depend on the annual salmon runs as an excellent source of lipids. In several Alaskan brown bear populations, lipids obtained through the consumption of salmon contributed approximately 80% of the mass gained by bears prior to winter hibernation (Hilderbrand et al., 1999c). Accumulation of fat reserves is important for successful hibernation, and for female reproductive success (Farley and Robbins, 1995; Hilderbrand et al., 1999c).

EPA-6363-000002974

Wolves also consume salmon seasonally when available, and this marine-derived protein source can be a major component of the lifetime total diet of wolves in areas where the two species co-exist (Adams et al., 2010; Darimont et al., 2003; Szepanski et al., 1999). Salmon are not solely a food resource for coastal wolves, as some Pacific salmon spawning grounds are hundreds of miles from the ocean. A study in Interior Alaska documented the seasonal salmon consumption among wolves who lived more than 1,200 river miles from the coast (Adams et al., 2010).

Both brown bears and wolves play an important role in distributing MDN from streams to the terrestrial environment, both by transporting salmon carcasses prior to consumption and through excretion of wastes rich in salmon nutrients (Darimont et al., 2003; Helfield and Naiman, 2006).

As far as we can determine, there has been no research conducted on the MDN links between salmon and moose or caribou. However, we believe that while it is reasonable to assume that MDN transported to the Nushagak and Kvichak watersheds by salmon may be detectable in tissue of animals, especially those preferentially feeding in riparian areas (e.g. moose), this does not necessarily mean there would be any detectable benefit to these herbivores. In order for there to be a direct effect, salmon would have to have a strong fertilizing effect on forage, resulting in additional biomass on the landscape, and ungulates would have to be forage limited in order for the increased biomass to matter (Adams, personal communication). There have been anecdotal reports of ungulates (both deer and moose) feeding directly on salmon carcasses (Hilderbrand, personal communication).

Waterfowl benefit from salmon as both direct sources of prey and carrion and indirect nutrient drivers of aquatic systems. The large influx of nutrients to riverine and terrestrial systems strongly benefits waterfowl (Holtgrieve, 2009; Willson et al., 1998; Willson and Halupka, 1995). Of the 24 duck species that regularly occur in Bristol Bay, at least eleven species are known to prey on salmon eggs, parr, smolts, and scavenge on carcasses (Table 9). Of these, greater and lesser scaup, harlequin duck, bufflehead, common and Barrow's goldeneyes, and common and red-breasted mergansers exhibit directed foraging on salmon. Among dabbling ducks, mallards feed most on salmon because they are distributed across a diversity of summer habitats in spawning areas, and they are the principal wintering dabbling duck on the North Pacific coast where fall-winter salmon runs occur. Fish predators like mergansers feed extensively on salmon fry and smolts (Munro and Clemens, 1932; Munro and Clemens, 1937; Munro and Clemens, 1939; Salyer and Lagler, 1940; White, 1957; Wood, 1987a). Other duck species may prey on smolt incidentally. Salmon eggs are a seasonally rich food source for harlequin ducks, goldeneyes and scaup that frequent rivers and streams (Cottam, 1939; Dzinbal and Jarvis, 1984; Munro, 1923) and probably for other opportunistic ducks. Species ranging from dabbling ducks (mallard, green-winged teal) and diving ducks to sea ducks that inhabit spawning waters probably opportunistically scavenge easy protein-rich meals from salmon carcasses.

Spawned-out salmon carcasses provide an ideal food resource to bald eagles as they accumulate on stream banks, river bars, lake and ocean shores, and tidal flats (Armstrong, 2010). Salmon carcasses may provide food to eagles beyond the spawning season, as large numbers of carcasses may be frozen into river ice during the winter and become available for consumption by eagles the following spring (Hansen et al., 1984). The abundance of salmon affects bald eagle population size, distribution, breeding and behavior (Armstrong, 2010). In one studied population, salmon availability in spring was tightly correlated with whether adult bald eagles laid eggs in a given year, and also influenced the timing of egg-laying (Hansen et al., 1984). As with other salmon

EPA-6363-000002975

carcass consumers, bald eagles affect the ecosystems within their range by distributing MDNs in their excretions (Gende et al., 2002).

Direct or indirect interactions between shorebirds and salmon are not well-documented. Some shorebird species are observed to consume dead salmon and salmon eggs, but it is unlikely that shorebirds have an impact on salmon populations. No studies have been conducted to deduce the contribution of salmon to the energetics of shorebird populations; however, the abundance of invertebrates in the intertidal zone is very likely due in part to MDN from salmon that die on the coast and in the rivers feeding Bristol Bay. Shorebirds play a role in distributing MDNs into the terrestrial system, especially during the migratory period, but this has not been quantified. They frequently feed in the intertidal zone, but roost in the terrestrial zone, where they deposit their waste. In the spring, shorebirds need to acquire critical food resources, not only to fuel their migration, but also, for some species, to assure that they arrive on the breeding grounds with sufficient reserves to initiate nesting and egg production (Klaassen et al., 2006; Yohannes et al., 2010). Some of the longest migrations known to birds involve shorebird species (bar-tailed godwit) that use Bristol Bay intertidal areas in autumn (Battley et al., 2011; Gill et al., 2009). Such flights are possible not only due to the extreme abundance of intertidal invertebrates (polychaetes, crustaceans, gastropods, and bivalves) in the region, but also because the adjacent uplands are usually rich in fruits of ericaceous plants or tubers on which birds like plovers, whimbrels, and godwits, regularly feed (Elphick and Klima, 2002; Johnson and Connors, 1996; Paulson, 1995; Skeel and Mallory, 1996). Some species like whimbrel, Hudsonian godwit, and black and ruddy turnstones feed on herring roe, carrion, including salmon carcasses, and salmon eggs (Elphick and Tibbitts, 1998; Gill et al., 2002; Handel and Gill, 2001; Nettleship, 2000; Norton et al., 1990). Many shorebird species make use of freshwater invertebrates; small fish may be consumed by yellowlegs (Elphick and Tibbitts, 1998) and phalaropes (Rubega et al., 2000).

Landbirds also benefit from salmon carcasses when available. Aquatic invertebrate larvae feed on salmon carcasses (Wipfli et al., 1999), overwinter in the soil, and emerge in the spring as adults. These invertebrate adults become aerial prey for a variety of landbird species in the spring, and serve as an important seasonal subsidy during a period when terrestrial invertebrate biomass is low (Nakano and Murakami, 2001). Salmon also benefit landbirds by increasing plant productivity due to MDN inputs (Helfield and Naiman, 2001), potentially resulting in an abundance of berries and seeds for avian consumption (Christie and Reimchen, 2008). Some birds, such as the American Dipper, directly consume salmon eggs, fry, and small bits of carcasses when available. In one study of dippers, consumption of salmon fry was related to higher fledgling mass and lower brood reduction (Obermeyer et al., 2006).

In summary, MDN from salmon cycle throughout the ecosystem of watersheds with healthy salmon runs, benefitting wildlife, increasing vegetation productivity, and promoting the production of periphyton, aquatic macroinvertebrates, resident freshwater fish, and juvenile salmon (Helfield and Naiman, 2006). This nutrient cycling is in turn dependent on interactions with wildlife, which distribute MDN into the terrestrial environment through both transport of carcasses and excretion of wastes. The loss of either salmon or key wildlife species may result in significant changes to the productivity, diversity and physical structure of the ecosystem, via mechanisms that extend beyond simple “food chain” interactions (Helfield and Naiman, 2006).

Overview of Land Cover and Habitat Types

The National Land Cover Database (NLCD) 2001 is a Landsat-derived, 30-meter spatial resolution map that illustrates land cover for the United States, including Alaska (Homer et al., 2004) (http://alaska.usgs.gov/science/geography/nlcd.html). The NLCD dataset is a fairly broad level characterization and is the only dataset that covers the entire Nushagak and Kvichak watersheds. Therefore, we use the NLCD as a surrogate for a wildlife habitat-type map. Nineteen land cover types are described for Alaska: open water; perennial ice/ snow; developed, open space; developed, low intensity; developed, medium intensity; developed, high intensity; barren land; deciduous forest; evergreen forest; mixed forest; dwarf scrub; shrub/scrub; grassland/herbaceous; sedge/herbaceous; moss; pasture/hay; cultivated crops; woody wetlands; and emergent herbaceous wetlands (Selkowitz and Stehman, 2011; Talbot, 2010).

Figure 2 shows the land cover types present in the Nushagak and Kvichak watersheds. The NLCD does not describe wetlands in great detail and wetlands likely extend into other land cover types not specifically identified as such (e.g., sedge/herbaceous land cover, which may include wet tussock tundra, and evergreen forest, which may include wet black spruce bogs). Table 1 shows the total size of each watershed and sub-watershed, as well as the percentage of each NLCD land cover type in each.

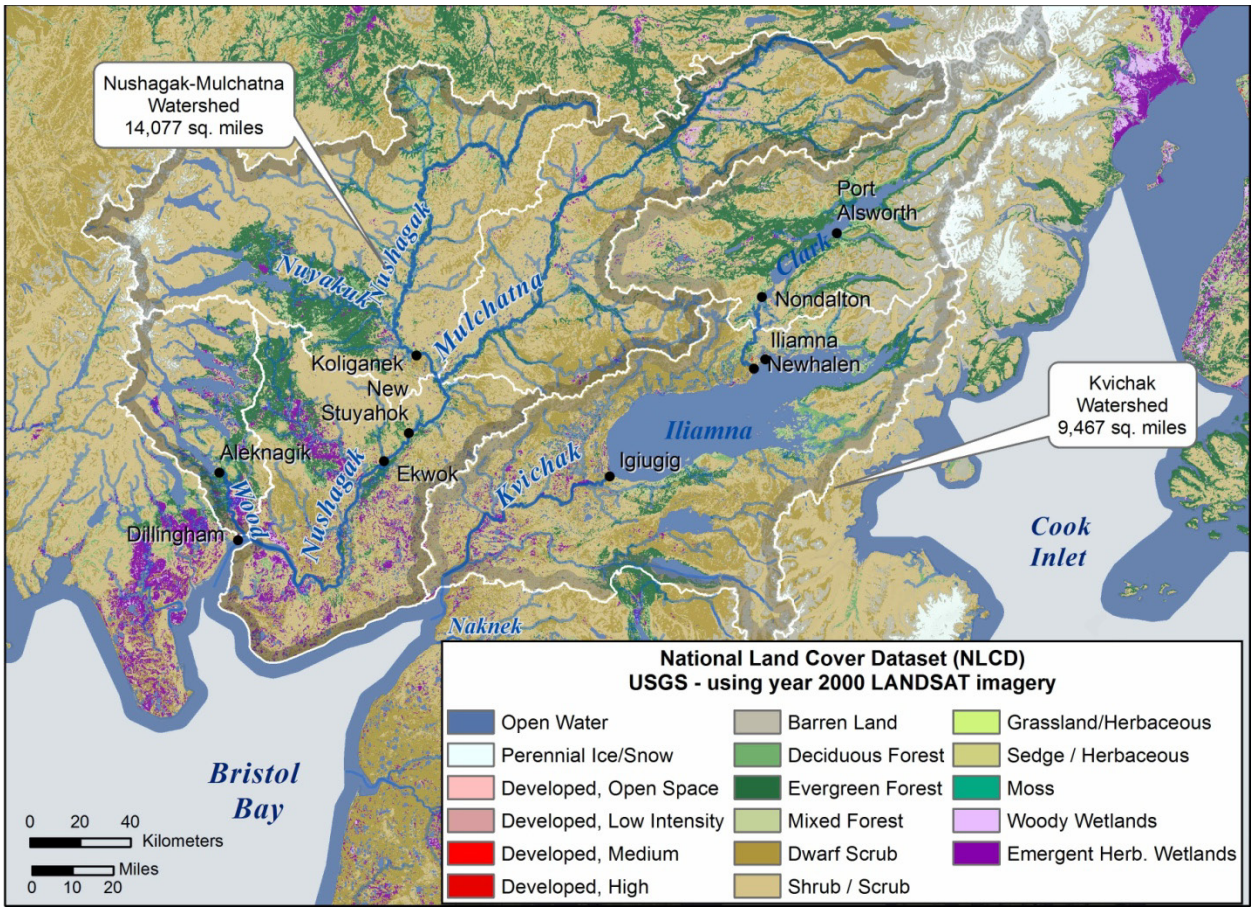

Figure 2. National Land Cover Dataset, land cover types for the Nushagak River watershed and Kvichak River watershed.

Currently, there is only one statewide ecosystem map available for Alaska (Nowacki et al., 2001). This map describes 32 ecoregional landscapes, but it is very coarse and not intended to provide specific habitat classifications for wildlife. This ecosystem map does not provide sufficient detail to be used for habitat type classification as part of this project.

Table 1. Size of subbasins (sq. mi.) within the Nushagak and Kvichak River watersheds and percent of watershed or subbasin within each National Land Cover Database land cover type.

	Kvichak River Watershed			Nushagak River Watershed					Total
	Lake Clark Subbasin	Lake Iliamna Subbasin	Sub-total	Mulchatna River Subbasin	Upper Nushagak River Subbasin	Lower Nushagak River Subbasin	Wood River Subbasin	Sub-total	
Size (Square Miles)	3,532	5,935	**9,467**	4,291	5,026	3,386	1,367	**14,077**	**23,537**
Land Cover Type	**Percent of Watershed**								
Open-Water	5.96	23.89	**17.20**	2.31	5.34	5.36	14.28	**5.29**	
Perennial Ice & Snow	6.51	0.38	**2.67**	0.39	1.61	0.00	1.32	**0.82**	
Developed, Low Intensity	0.02	0.01	**0.01**	0.00	0.00	0.00	0.00	**0.00**	
Barren Land	23.55	5.88	**12.47**	4.61	3.31	0.09	.36	**2.94**	
Deciduous Forest	2.92	2.79	**2.84**	1.94	3.63	2.15	4.36	**2.83**	
Evergreen Forest	15.51	5.34	**9.13**	10.04	11.86	9.63	13.81	**10.96**	
Mixed Forrest	4.45	3.20	**3.67**	2.30	5.08	2.99	5.47	**3.77**	
Dwarf Scrub	10.85	22.57	**18.19**	24.50	12.77	20.06	5.26	**17.24**	
Shrub Scrub	28.27	31.79	**30.66**	51.08	54.97	44.86	44.12	**50.23**	
Sedge Herbaceous	0.01	1.67	**1.05**	0.48	0.37	3.86	0.13	**1.22**	
Moss	0.01	0.02	**0.01**	0.00	0.02	0.09	0.34	**0.06**	
Woody Wetlands	0.64	0.19	**0.36**	1.28	0.16	0.74	1.24	**0.75**	
Emergent Herbaceous	0.81	2.28	**1.73**	1.53	1.05	10.17	6.32	**3.90**	

BROWN BEARS

Introduction

The purpose of this section is to characterize the brown bears that spend most of their lives in the Nushagak and Kvichak watersheds. Some of the general information comes from decades of research on this species in its entire cosmopolitan ranges. If variable facts are derived from study areas other than the Nushagak and Kvichak watersheds, it is so noted. However, owing to their interconnected home ranges and close genetic relationships, brown bears' habitat selection and behavior show a great degree of overlap wherever they occur (Schwartz et al., 2003).

In this section, we use the term "brown bears" to refer to all North American bears of the classification *Ursus arctos,* although bears in interior parts of North America traditionally have been referred to as grizzly bears and those on the coast, in salmon-rich areas, as brown bears. *Ursus arctos* on the Alaska Peninsula are commonly called brown bears.

Habitat

Brown bears are a wide-ranging species that, throughout the course of a year, use many different plant and animal communities. Habitat is defined here as the location or environment where an organism is most likely to be found. Habitats provide the food, water, and cover that a species needs to survive. Biologists describe individual bear's habitats as "home ranges." A home range is the normal area that an animal uses to carry out the activities of securing food, mating, and caring for young. Brown bears are generally solitary, food-maximizing individuals whose home ranges vary with the availability of their seasonal foods. When food is abundant, as is the case during salmon runs, home ranges of female bears may be smaller because of their ability to obtain sufficient energy to meet their nutritional needs. Conversely, home ranges may increase in order to take advantage of more widely dispersed food resources (McLoughlin et al., 1999).

On the Alaska Peninsula, brown bears emerge from their dens between early April and early June. Male brown bears tend to emerge before females. Females with cubs of the year are often the last to leave the den (Miller, 1990). Brown bears often spend June to mid-August in lowland and coastal areas, though probably not all bears in the Nushagak and Kvichak watersheds include coastal plains in their home ranges. A study conducted on Admiralty Island found that brown bears did not necessarily use rich coastal habitats as part of their home ranges, though the reason for these different patterns of habitat selection are not known (Schoen et al., 1986).

Brown bears typically spend July through mid-September near streams that support salmon runs (Schoen et al., 1986). The Nushagak and Kvichak watersheds contain at least 8,286 linear miles (13,335 linear kilometers) of anadromous fish habitat, not including lakes (Johnson and Blanche, 2011). As salmon begin to appear in the streams, bears move closer to them, sometimes congregating where shallow streams make preying on fish more efficient (Aumiller and Matt, 1994). Studies of bear predation on salmon in a series of streams in the Wood River system demonstrated that the probability a fish is killed by bear increases with decreasing stream size (Quinn et al., 2001).

Bears move to higher elevations in the fall, presumably to feed on berries and other food items (Collins et al., 2005). Some brown bears will continue to feed on fish until October, especially at

EPA-6363-000002979

shallow streams where dead and dying sockeye salmon are washing out of lakes after spawning (Fortin et al., 2007).

Dens are typically dug at higher elevations within bears' home ranges (Van Daele et al., 1990), on 20- to 50-degree slopes at between 300 and 1,600 meters in elevation. Most brown bears enter dens by early November, with a mean entrance date of October 14. In a study from the Nelchina area in south-central Alaska, brown bears spent an average of 201 days in winter dens (Miller, 1990).

Food Habits

Alaska Peninsula brown bears move within their home ranges in order to exploit seasonally available food sources (Glenn and Miller, 1980). During late summer and fall, brown bears gain weight rapidly, primarily stored as fat; peak body mass generally occurs in fall, just prior to hibernation (Hilderbrand et al., 2000). It is essential for bears to maximize weight gain prior to hibernation, since they metabolize only fat and muscle during that time and must rely on those stored energy reserves for reproduction and survival.

In the spring, after den emergence, bears commonly graze on early season herbaceous vegetation, such as cow parsnip (*Heracleum lanatum*), horsetails (*Equisetaceae*), lupine *(Lupinus spp.)*, false hellebore (*Veratrum viride*) and grasses (*Gramineae*) (ADF&G, 1985). They also search for and scavenge winter-killed carrion, as well as moose and caribou calves (Glenn and Miller, 1980). Bears with access to salt marshes commonly graze on sedges (*Carex* spp.), grasses (e.g., *Elymus* spp.), sea-coast angelica (*Angelica lucida*), and forbs (e.g., *Plantago* spp. and *Triglochin* spp.). Brown bears are also known to dig soft-shelled clams (*Mya arenaria*) and Pacific razor clams (*Siliqua patula*) on intertidal beaches (Smith and Partridge, 2004). Brown bears on the coast may also scavenge for dead marine life (Glenn and Miller, 1980).

In July through October, brown bears move to streams to take advantage of the predictable runs of salmon. The Nushagak and Kvichak Rivers provide natal homes to five species of Pacific salmon (*Oncorhynchus* spp.) and are part of the world's largest of run of salmon in Bristol Bay (Salomone et al., 2011). The abundance of salmon in the Nushagak and Kvichak watersheds makes them prime habitat for brown bears because salmon are an excellent source of lipids.

Lipids obtained through the consumption of salmon account for approximately 80% of the mass gained by bears (Hilderbrand et al., 1999b). More than other factors, the accumulation of fat determines whether brown bears will hibernate successfully, or in the case of females, produce cubs (Farley and Robbins, 1995). In addition, bigger, fatter adult females produce faster growing cubs that survive better than do cubs produced by smaller, leaner females (Ramsay and Stirling, 1988). Larger, fatter males also receive an advantage from their size. Dominance in males is necessary to win breeding opportunities and defend estrus females, and larger males tend to compete better for these opportunities than smaller males (Robbins et al., 2007).

Research conducted in Bristol Bay and Southeastern Alaska to determine factors that influenced consumption choice of salmon made by brown bears found that the availability, as well as the age and spawning status of the salmon, played a significant role in consumption choice (Gende et al., 2004). When salmon were not abundant, bears consumed more biomass of each fish, rather than just consuming body parts high in energy content. When salmon were abundant, bears ate parts of

the fish considered to be higher in energy such as roe and the brain. In addition, bears were found to consume ripe fish before fish that had spawned-out. Some bears were even observed catching and releasing fish that had spawned-out in order to consume only ripe fish with higher energy content (Gende et al., 2004).

Brown bears are also known to feed extensively on wild fruits, including crowberry (*Empetrum nigrum)*, lowbush cranberry (*Vaccinium vitis-idaea)*, and bog blueberry (*Vaccinium uliginosum)* (Fortin et al., 2007; Rode et al., 2006a; Rode et al., 2006b). The simultaneous ingestion of salmon and berries appears to benefit bears, in terms of growth rate, compared to the ingestion of one or the other alone (Robbins et al., 2007).

Fall foraging is especially important for brown bears. In the fall, brown bears seek out available meat sources including salmon, ungulates, rodents, and mice, as well as berries, in order to store as much fat as possible. The more efficiently bears forage, the more vital lipids they can store, thereby improving their ability to live long and reproduce often (Robbins et al., 2007).

Behavior

Brown bears have generalist life history strategies, extended periods of maternal care, and omnivorous diets. A generalist species is able to thrive in a wide variety of environmental conditions and can make use of a variety of different resources such as a varied diet. Brown bears travel comparatively long distances to find the amount and variety of food they need to flourish, despite six months of hibernation.

Movement patterns that define home ranges are influenced by important food resources, breeding, reproductive status, individual dominance status, security, and human disturbance (Schwartz et al., 2003). Differences in home range size between study areas are attributed to differences in habitat quality and distribution (McLoughlin et al., 2000). The larger ranges of adult males overlap several females (Schwartz et al., 2003). Female brown bears are generally faithful to their home ranges. Sub-adult females tend to stay close to or within the home range of their mothers. However, sub-adult males tend to disperse longer distances (Glenn and Miller, 1980). Brown bears searching for alternative foods outside their usual home ranges, in particular dispersing bears, often run into more conflicts with humans, and human-caused bear mortality increases (Schwartz et al., 2003).

Different study areas illustrate the range in size of brown bear home ranges relative to habitat quality. For example, in the Nelchina River basin of south-central Alaska, adult female home ranges averaged 408 km^2, while those of adult males averaged 769 km^2 (Ballard et al., 1982). In contrast, Collins et al. (2005) estimated 356 km^2 for adult females in the southwest Kuskokwim Mountains, west of the Nushagak watershed. On the relatively productive Alaska Peninsula, Glenn and Miller (1980) found an average seasonal range of 293 km^2 for adult females and 262 km^2 for adult males. The authors were unable to gather data from a comparable sample size for adult males (n=4 males vs. n=30 females), and therefore do not support a range size comparison based on these results. They mention other parameters that seem to contradict the small male seasonal range estimated from their small sample size. For example, the cumulative 6-year movements of 13 adult males were greater than those of 49 females. In addition, they found that seasonal range movement of subadult males (744 $km^{2)}$ was three times that of subadult females (249 km^2).

During winter months brown bears hibernate in dens and rely on stored energy reserves for survival. In hibernation, bears can go up to seven months without eating, drinking, defecating, or urinating (Schwartz et al., 2003). Generally, brown bears seek out remote, isolated areas and sites that will accumulate enough snow to insulate them from cold winter temperatures, often on steep slopes. Bears may prefer steeper slopes for denning sites, due to reduced potential for disturbance (Goldstein et al., 2010).

Female brown bears enter estrus beginning around late spring and, depending upon male availability, can still breed into August. However because males are rarely limiting in a population, most breeding occurs in May and June. After the eggs are fertilized development proceeds to the blastocyst stage and then halts. Embryo implantation is delayed until hibernation begins. It is possible that a litter could have multiple sires. Female brown bears that have successfully bred and have implanted embryos have an obligate denning requirement as the newborns are completely helpless at birth and remain so for several months. Most births occur in January and February after 6 to 8 weeks of gestation. All maternal care from fetal development through the first four months of lactation occur in the den and all nutrient reserves for the developing young are drawn from maternal body stores accumulated the previous summer/fall. Litters can range from one to four cubs; however, twins are the most common (Schwartz et al., 2003).

Brown bears in the Nushagak and Kvichak watersheds interact with humans around residences, recreational sites, and in the backcountry. The behavior of bears during these interactions depends on many variables (Herrero et al., 2005). Brown bears that have received food or garbage "rewards" while near humans or their habitations can become food-conditioned. Food-conditioning is a form of operant conditioning in which bears learn to associate sources of food with humans or their infrastructure (Matt, 2010). Food-conditioned bears are more likely to encounter humans in an aggressive manner, perhaps because they assertively seek foods where humans are found. Preventing access to anthropogenic foods keeps bears from being positively rewarded for close association with people (Herrero, 2002).

Habituation describes behavior that is different from food-conditioning (Aumiller and Matt, 1994; Herrero, 2002). A habituated bear has been repeatedly exposed to a neutral situation, such as a person observing it from a close distance. Bears will conserve energy by muting their reaction. Consequently, habituation often is assumed to have occurred when bears tolerate people at close distances. Habituation is not an all-or-none response and may vary widely among individual bears. Some bears habituate to certain human artifacts such as roads and other structures (Follman and Hechtel, 1990).

Today most brown bear attacks are associated with defensive behavior, such as females protecting cubs or incidents involving protection of a food cache such as an ungulate carcass (Herrero, 2002; Herrero and Higgins, 1999; Herrero and Higgins, 2003). Whether or not a bear charges or attacks a human in a defensive manner is dependent on many factors in the immediate environment, as well as the prior experience and individual behavior of both the human and the bear (Herrero et al., 2005). Historical records strongly suggest that brown bears have not been important predators on people, although rare incidences of predation may have occurred, as they still do today (Herrero, 2002).

Interspecies Interactions

Pacific salmon (*Oncorhynchus spp.)* and brown bears meet the basic criteria of "keystone species." The loss of either species results in significant changes in the productivity, diversity and physical structure of their communities, far beyond just their "food chain" interactions. By both consuming and transporting partially consumed salmon, brown bears distribute MDNs via decaying salmon carcasses and through excretion of wastes rich in salmon nutrients (Helfield and Naiman, 2006).

Pacific salmon spend most of their lives feeding and growing at sea before returning to spawn and die in their natal streams. Approximately 99% of the carbon, nitrogen, and phosphorus in their bodies when they return to freshwater is from the marine environment (Hilderbrand et al., 1999c). These nutrients are transported inland when salmon return to their natal streams to spawn. For example, sockeye salmon (*Oncorhynchus nerka*) are estimated to import approximately 12,700 kg of phosphorus and 101,000 kg of nitrogen back to the Wood River system each year (Holtgrieve, 2009).

Nitrogen, phosphorus, and carbon are among the most important MDNs. These nutrients cycle through the ecosystem, benefitting other forms of wildlife and vegetation, promoting the production of periphyton (e.g., algae), aquatic macroinvertebrates, resident freshwater fish, and juvenile salmon (Helfield and Naiman, 2006). Insects that directly benefit from decaying salmon include stoneflies (*Plecoptera* spp.), caddis flies (*Trichoptera* spp.), mayflies (*Ephemeroptera* spp.), midges (*Diptera* spp.: Chironmids (*Chironomidae* spp.), blackflies (Diptera: *Simuliidae*), and carrion beetles (Coleoptera: *Silphidae*) (Helfield, 2001).

As salmon enter freshwater streams in late July, and throughout August, brown bears become hyperphagic (consume abnormally large quantities of food) as they store energy for winter by consuming salmon which contain protein and fat (Hilderbrand et al., 1999b). Female brown bears are each estimated to consume 1,003 kg (SD ¼ 489 kg) of salmon each year and transport approximately 37.3 kg of MDNs to terrestrial ecosystems on the Kenai Peninsula (Hilderbrand et al., 2004; Hilderbrand et al., 1999a).

In one study, brown bears delivered 83 to 84% of marine-derived nitrogen found in white spruce trees near two Kenai Peninsula creeks (Hilderbrand et al., 1999a). In addition, Helfield and Naiman (2006) found Sitka spruce growth rates to be three times greater near salmon spawning sites than in areas lacking spawning sites. Other studies also show that "bears feeding on salmon increased soil ammonium concentrations three-fold and nitrous oxide (NO_3) flux by 32 fold" (Holtgrieve, 2009).

The level of MDNs transported by brown bear shows the significance of the abundance of salmon in areas with brown bears. It also shows that loss of either population would change the nitrogen budget "and, by extension, the productivity and structure of the riparian forest" (Helfield and Naiman, 2006). The potential loss of this nitrogen source would also greatly affect other organisms throughout the food chain and ecosystem (Helfield, 2001).

Mortality, Productivity, and Survivorship

Brown bears have one of the lowest reproductive rates among mammals. This low rate is mainly due to their relatively late age of first reproduction, small average litter size, and long interval

between litters. Their low reproductive rate makes brown bears particularly susceptible to impacts from humans (Schwartz et al., 2003). On the Alaska Peninsula, the mean age is 4.4 years at first reproduction for female brown bears (Miller and Sellers, 1992). The earliest that a brown bear female might breed is in the late spring at 4.4 years. If the female is of adequate size and nutritionally healthy, the fertilized ova develop into a blastocysts that stop developing until they implant in the uterus in late November. Following 6 to 8 weeks of gestation, tiny cubs are born within a den. The female would then emerge from her den with her surviving cubs in the late spring at 5.4 years. If cubs are raised until the typical age of weaning (2.4 years), the female's age of second breeding likely would not occur until she was 7.4 years (Schwartz et al., 2003). Therefore, during the first ten years of her life, a female grizzly bear is capable of producing only two litters.

Age at first reproduction, litter size and intervals between litters vary among populations and individuals. Litter sizes vary from one to four cubs, with twins being the most common. Females are capable of breeding in the same spring that they wean their cubs; however, they do not always wean them at 2.4 years and may keep them until the cubs are 3.4 years. Evidence shows that the average interval between litters is generally between three and six years (Schwartz et al., 2003). In a ten-year study in southwest Alaska, there was great variation in reproductive intervals (Kovach et al., 2006), although when compared to other studies in Alaska, the southwest population had one of the highest production rates of offspring, yet the lowest number of female offspring weaned per year.

Adult female brown bears that eat meat (mostly salmon) in the fall gain approximately 80% fat mass (Hilderbrand et al., 1999b). Deposited fat is more important than lean body mass in producing cubs during winter dormancy (Farley and Robbins, 1995). While late summer and fall salmon are a critical resource on their own, it is the likely the availability of both fall berries and salmon, together, enable brown bears to accumulate body reserves important for reproduction and hibernation (Hilderbrand et al., 1998; Robbins et al., 2007). While it seems logical that productivity (independent of mortality) would be higher in populations with access to salmon in the fall, Kovach et al. (2006) found that, in southwest Alaska, females had only slightly higher productivity than the figures reported for Yellowstone National Park and the Selkirk Mountains, where salmon are not present (Kovach et al., 2006).

The age and sex structure of brown bear populations is dynamic. Many variables, such as habitat conditions, time of year of observations, and hunting make generalizations difficult. However, in one study of a hunted population on Kodiak Island, the population structure of brown bears was 26% cubs, 22% yearlings, 27% sub-adults, and 25% adults (Troyer and Hensel, 1964). The number of cubs born varies from year to year, and the proportion of cubs in any brown bear population is a function of both reproductive rate and early mortality. Cub survival rates, based on observation of den emergence from the first year to the second year, were estimated for two areas on the Alaska Peninsula. At Black Lake, cub survival was an estimated 57%, while cub survival in Katmai National Park was an estimated 34% (Miller et al., 2003).

Survival of adult males varies among populations, but is generally lower in hunted populations. In 1985, in the middle Susitna River basin study area in south-central Alaska, there was an estimated 82% annual survival for adult males (Miller et al., 2003). Ten years later, in 1995, Miller et al. estimated only 71% annual survival for adult males, due to increased hunting pressure. Female survival rates are generally higher than males. In the middle Susitna study, Miller et al. (2003)

estimated 90% annual survival for adult females in both 1985 and 1995. In their study of female survivorship in a hunted population in the southwest Kuskokwim Mountains, midway between Dillingham and Bethel, Alaska, Kovach et al. (2006) found mean annual survival estimates of 90.1 to 97.2% for radio collared females aged five years or older.

Due to the difficulty of observing entire life histories of brown bears, the causes of natural mortality are not well known. While it is known that adult males kill juveniles and that adults kill other adults, there are insufficient data to fully assess the effects of predation on younger bears by adult bears (Schwartz et al., 2003). Brown bears are exposed to more dangers during some life stages than others. Survival rate estimates for cubs during their first year of life shows particular vulnerability. In the middle Susitna study, survival for cubs of the year was estimated at 67% (Miller et al., 2003). Kovach et al. (2006) reported survival rates of 48.2 to 61.7% for cubs of the year.

In the latter study, researchers estimated survival rates of 73.3 to 83.8% for one- and two-year-old offspring, combined. Dispersing sub-adults may be forced to choose marginal home ranges or areas near human habitation that are dangerous to their survival (Servheen, 1996). Brown bears can be afflicted with parasites and diseases that may contribute to their demise from other causes such as starvation. However, there are no known instances of parasites or diseases causing major die-offs within populations (Schwartz et al., 2003).

In many brown bear populations, human-caused mortality is higher than natural mortality. The rate of human-caused mortality varies greatly in Alaska, where contact between bears and humans is a function of human population density, activities of both species, and hunting regulations. Servheen (1996) lists the following categories of human-caused mortality, in order of frequency: direct human/bear confrontations (hikers, backpackers, photographers, hunters, etc.); attraction of grizzly bears to improperly stored food and garbage associated with human habitations and other sources: careless livestock husbandry, including the failure to properly dispose of dead livestock; inadequate protection of livestock; loss of bear habitat; and hunting, both lawful and illegal.

Population

Brown bear population abundance is usually measured in terms of density, since it is widely considered to be the most biologically meaningful measure of abundance. Two methods for estimating bear population density, capture-mark-recapture, and aerial line-transect survey, have been used recently in Alaska. Both estimates survey in the early spring, prior to leaf growth on deciduous shrubs and trees.

Alaskan brown bear populations vary significantly in density depending on the availability and distribution of food (Miller et al., 1997; Schwartz et al., 2003). Brown bear populations achieve maximum densities in areas where the populations have access to multiple runs of Pacific salmon (Hilderbrand et al., 1999c; Miller et al., 1997). Based on a modified capture-mark-recapture method for estimation, the Pacific Coast of the Alaska Peninsula has the highest documented brown bear density in North America, at 551 bears (representing all ages) per 1,000 km^2 (Miller et al., 1997). The North Slope of Alaska has the lowest estimated density at 3.9 bears of all ages/1,000 km^2 (Reynolds, 1976).

While population density estimates for the entire Nushagak and Kvichak watersheds are not currently available, recent aerial line-transect studies in portions of the watersheds and in nearby watersheds can give some idea about brown bear densities. Using the double observer aerial line-transect method, brown bear density in the Lake Clark National Park and Preserve portion of the Kvichak watershed was estimated at 39 bears/1000 km^2 (1999 E. Becker personal communication). Recent aerial line transects in the remainder of the inland Kvichak watershed reveal an estimated 47.7 bears of all ages/1000 km^2 (Becker, 2010). In the nearby northern Bristol Bay area (Togiak NWR and Bureau of Land Management Goodnews Block), brown bear population density was 40.4 bears/1,000 km^2 (Walsh et al., 2010). The later study included both coastal and inland habitats.

As expected, surveys that include coastal habitat have higher population density estimates during spring. Researchers using the same line-transect survey method as in the above studies, estimated brown bear density at 124 bears/1,000 km^2 in Katmai National Park, an area that included both coastal and inland brown bear habitat. Along the coast of Lake Clark National Park and Preserve (NPP), brown bear density was estimated at 150 bears/1,000 km^2.

When inferring the distribution of brown bears from density estimates, it should be noted that brown bears move long distances across the landscape. Bears that are counted in coastal areas in the spring may move inland and upstream in the summer and fall to take advantage of pre- and post-spawning salmon. It is common to see brown bears in interior Lake Clark NPP feeding on post-spawning salmon in September and October, and less commonly, in December (Mangipane, personal communication). Fortin et al. (2007) recorded brown bears feeding on salmon into October on the Kenai Peninsula.

Human Use/Interaction/Management

Major human "uses" of brown bears in the Nushagak and Kvichak watersheds include sport hunting, subsistence hunting, and bear viewing. Besides these uses, there are many other interactions between brown bears and humans, including both residents and non-residents visiting the area for purposes other than seeking encounters with brown bears.

Sport Hunting for Brown Bears

Game Management Unit 9- The Alaska Board of Game has placed a high priority on maintaining a quality hunting experience for the large brown bears of the Alaska Peninsula in Game Management Unit (GMU) 9, which includes the Kvichak watershed (Figure 3). Due to relatively easy aircraft access and the high quality of bear trophies in the unit, an active guiding industry for the area developed during the 1960s. Non-resident sport hunters are required to use a guide for brown bear hunting throughout Alaska, and to have their harvest inspected and sealed by ADF&G. The ADF&G management program strives to maintain stable guide and client numbers over time. As of 2007, approximately 75% of the GMU 9 brown bear harvest came from guided hunts (ADF&G, 2009).

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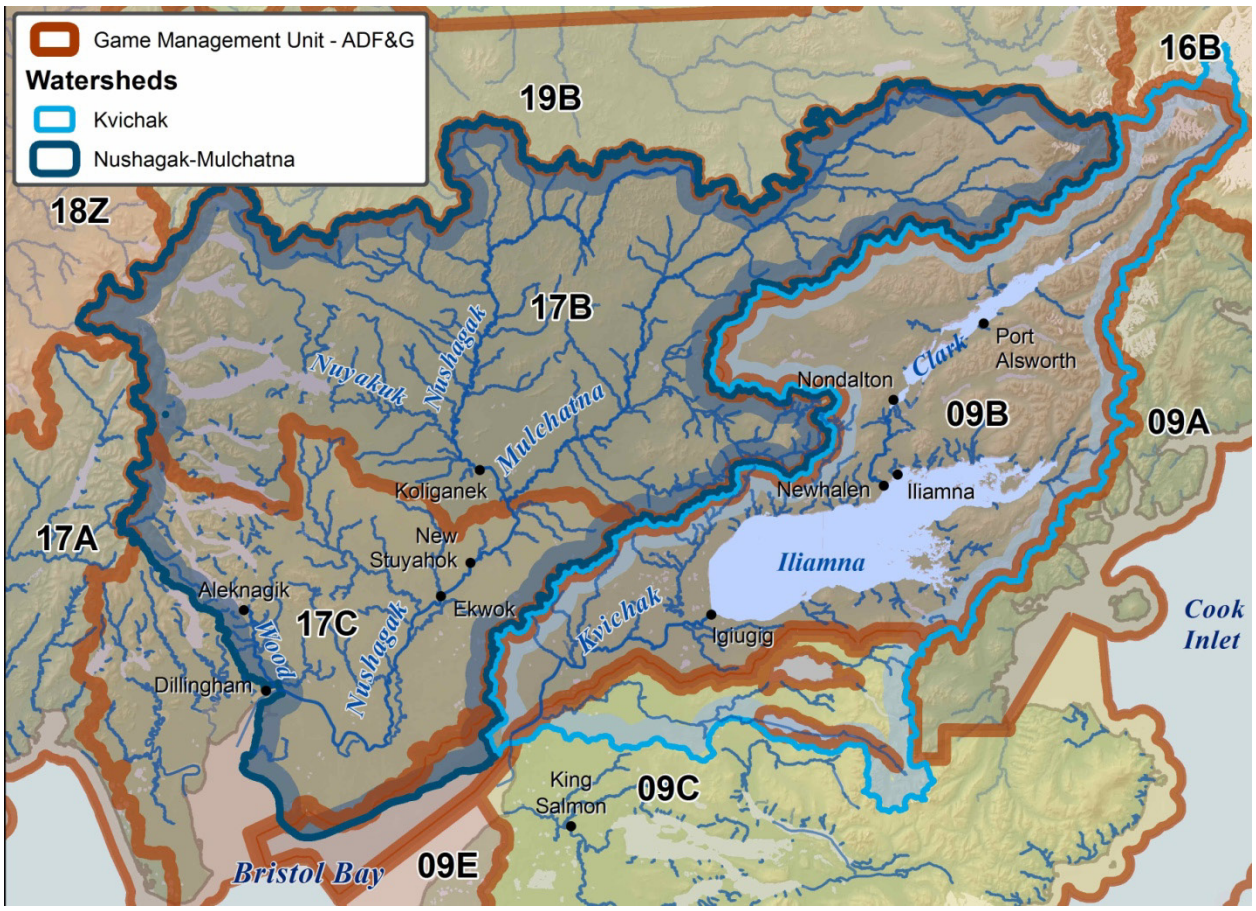

Figure 3. Nushagak and Kvichak River watersheds and associated Alaska Department of Fish and Game, game management units.

The current brown bear management objective for GMU 9 is to maintain a high bear density with a sex and age structure that will sustain a harvest composed of 60% males, with 50 males aged eight years or older taken during the combined fall and spring seasons. In GMU 9, in the 2007 Regulatory Year (July 1, 2006 through June 30, 2007), results reported to ADF&G revealed a harvest of 621 bears (72% male and 28% female).

Game Management Unit 17- In GMU 17, which includes the most of the Nushagak River watershed, brown bears are neither as abundant nor, usually, as large as those found on the Alaska Peninsula. GMU 17 has not received much hunting pressure in the past. However, interest in hunting brown bears in many parts of Alaska is increasing, and bear hunting in GMU 17 has increased substantially since the mid-1990s. As of 2007, the brown bear population objective for GMU 17 was to maintain a brown bear population that will sustain an annual harvest of 50 bears composed of at least 50% males (ADF&G, 2009).

Subsistence Hunting for Brown Bears-
On non-federal lands in GMUs 9b and 17, subsistence brown bear hunters must obtain a subsistence registration permit for bears to be taken for food. In addition to requiring a registration permit, the subsistence brown bear hunting regulations establish a hunting season of September 1 to May 31, limit take to one bear/regulatory year, and prohibit take of cubs and sows with cubs (ADF&G, 2011a). Salvage of the hide and skull is optional and the hide and skull need not be sealed, unless they are removed from the Western Alaska Brown Bear Management Area, in

which case they must be sealed by an ADF&G representative and their trophy value destroyed. All edible meat must be salvaged for human consumption. On federal lands within GMUs 9 and 17, residents must consult the Federal Subsistence Management Program Regulations, available at http://alaska.fws.gov/asm/law.cfml?law=2&wildyr=2010. There are some differences between federal and State subsistence hunting regulations. For example, on federal lands in GMU 9B, there is a federal registration permit harvest quota of four females or ten bears and the season closes as soon as the first quota is reached.

Bear Viewing-
Within the Kvichak watershed there are specific destinations for recreational visitors to view brown bears. Lodges on Lake Clark, Kukakluk Lake, Nonvianuk Lake, and Battle Lake offer brown bear viewing in addition to fishing expeditions. Several guides and air taxis take brown bear viewers to Funnel Creek and Moraine Creek on day trips.

The 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation reported that 491,000 Alaskan residents and non-residents participated in wildlife watching as a primary activity (USFWS and US Department of Commerce Census Bureau, 2006). Bear viewing is now the leading recreational activity in Lake Clark NPP. The incidental "use" of bears has spatiotemporal impacts to the bear use (Rode et al., 2007; Tollefson et al., 2005).

Other Human-Bear Interactions

Local Residents and Bear-Human Conflicts- In both GMU 9 and 17, the number of bears killed annually includes both legally harvested bears and reported non-hunting mortalities. Villages with open landfills attract bears during the spring, summer, and fall. Residential garbage, dog food, and fish drying racks also bring bears close to humans. Incidences of local residents killing bears in defense of life and property near villages and fishing sites are not uncommon. Although reporting rates seem to have improved in recent years, most non-hunting mortalities of bears are reported either indirectly or not at all; as such, any conclusions based solely on harvest data or reported non-hunting mortalities should be viewed with caution (ADF&G, 2009).

During the 2007 regulatory year, in GMU 9, ADF&G received 17 reports of bears killed by people in defense of life and property; however, wildlife managers estimated that the number of unreported brown bear killings in the unit might be over 50 when considering unreported data. During the same period in GMU 17, ADF&G received 5 reports of defense of life and property mortalities; however wildlife managers assumed there were more unreported brown bear killings (ADF&G, 2009).

Other Recreational Users and Bear-Human Conflicts- In Lake Clark NPP, park managers analyzed 171 bear-human incidents over 24 years. They found that, in 46% of the incidents, brown bears received food as a result of the encounter. Bears were killed in 23% of the incidents (Wilder et al., 2007). Managers were concerned about the large number of food-conditioning incidents, given that food-conditioned bears are responsible for the majority of human injuries from bears in national parks (Herrero, 2002; Wilder et al., 2007). Food-conditioned bears have been found to be 3 to 4 times more likely to be killed by humans than non-food conditioned bears (Mattson et al., 1992). Wilder et. al. (2007) also noted that casual bear photographers at private recreational cabins at Telequana Lake, may have contributed to the high number of bear-human incidents, saying "that individuals repeatedly fed bears in this area to facilitate photography."

MOOSE

Introduction

Moose, the largest member of the deer family (*Cervidae*), have a circumpolar distribution in the northern hemisphere (ADF&G, 2011d; Telfer and Kelsall, 1984), occupying a broad band of boreal forest dominated by spruce, fir, or pine trees. Fire is a major force that shapes these vegetative communities (Odum, 1983; Telfer and Kelsall, 1984). Moose occur in northern forests of North America, Europe, Russia, and China (Karns, 2007). The association between moose and the northern boreal forest is unique, as there are no counterparts in the southern hemisphere (Shelford, 1963). There are four recognized subspecies of moose in North America (Hundertmark et al., 2003; Peterson, 1952; Peterson, 1955); the one found in the study area (Nushagak and Kvichak watersheds) is the Alaska-Yukon subspecies (*Alces alces gigas*) (Miller, 1899). This subspecies is often referred to as the "tundra moose," since it is often found in and near tundra areas (Bubenik, 2007). However, it also inhabits the boreal forest, low elevation riparian and delta habitats, and mixed deciduous forest areas. The Alaska-Yukon subspecies is generally larger than the other subspecies in body size and antler development. In Alaska, moose are found in suitable habitats throughout the mainland portion of the State, except on the northernmost coastal plain (LeResche et al., 1974), ranging from the Stikine River in southeast Alaska to the Colville River on the Arctic Slope (ADF&G, 2011d). Moose are ruminants, with a four-chambered stomach, and are classified as browsers based on their foraging strategy (Hoffman, 1973). These herbivores consume mainly tree and shrub leaves and woody twigs during winter (Renecker and Schwartz, 2007). Due to their large body size and the volume of vegetation consumed, moose play an important role in plant productivity and nutrient cycling in ecosystems where they occur (Molvar et al., 1993).

Here we characterize moose that inhabit the Nushagak and Kvichak watersheds, but we provide substantial information accumulated from decades of research on this species from across North America. Since moose are a generalist species, much of this information is relevant to moose in the Nushagak and Kvichak areas. We borrow heavily from the work of a distinguished group of moose biologists, which provides a near complete summary of moose biology and management (Franzmann and Schwartz, 1998; Franzmann and Schwartz, 2007) and have attempted to cite them when appropriate. We also relied on a separate, condensed version of these data with more recent updates (Bowyer et al., 2003).

Habitat

Both stable and transitory habitats are important in the evolution of moose (Geist, 1971). Permanent habitats are those that persist through time without alteration in character or condition, such as riparian willow/poplar communities and high-elevation shrub/scrub communities that do not succeed to different kinds of vegetation (Peek, 2007). Telfer (1984) characterized the full range of moose habitats to consist of boreal forest, mixed forest, large delta floodplains, tundra subalpine shrubs, and stream valley/riparian zones. According to Peek (2007), boreal forest habitats are considered fire-controlled and likely represent the primary environments in which moose evolved (Kelsall and Telfer, 1974; Peterson, 1955). As noted by Peek (2007), delta floodplains are expected to have the highest density of moose, followed by shrub/shrub habitats, boreal forests, mixed forests, and stream valley/riparian zones. A study in the Copper River Delta supported the finding that large deltas and floodplains are the most productive of these five major habitat types for moose (MacCracken et al., 1997b). Boreal forest habitats are the least stable

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through time, whereas stream valley/riparian zones are the most stable. In Alaska and the Northwest Territories, the climax tundra and subalpine shrub communities at higher latitudes and elevations are more stable in time and space than the alluvial and riverine habitats (Viereck and Dyrness, 1980).

Transitory habitats of moose include boreal forests where fire creates successional shrub communities that provide extensive forage. Geist (1971) hypothesized that islands of permanent habitat found along water courses and deltas, and in the high elevation dwarf shrub communities, serve as refugia where moose populations persist and from which they disperse into transient habitats created by fire. The common occurrence of fire in boreal forests is considered sufficient to promote adaptations favoring dispersal of yearling moose to newly created habitats (Peek, 2007). The dominant land cover types in the study area consist of high elevation dwarf shrub, shrub/scrub and tundra habitats, with lower elevation boreal forests (deciduous, evergreen and mixed) and riparian habitats (woody wetlands) along water courses (Table 1). All of these cover classes represent high-quality moose habitat.

Habitat selection by moose is influenced by availability of food, predator avoidance, and snow depth (Dussault et al., 2005). Peek (2007) advanced the view that moose select habitat primarily for the most abundant and highest quality forage. Since these resources are unequally distributed in space and time, moose habitat may be considered as a series of patches of different kinds and sizes, with the value of each patch varying through the year. However, the total year-round value of a diverse habitat should be emphasized even if each part is only critical at one season or another. Peak (2007) further stated that the caveat to this general proposition was that sufficient size of both overall habitat, and possibly each patch of any given habitat, must be accessible to make an area most suitable for occupation by moose. As a corollary, if a certain critically important community, such as shrub/scrub vegetation type, is unavailable in sufficient quantity, then the ability of an overall habitat to support moose may be reduced even if it contains a highly diverse set of other plant communities.

The typical annual pattern of moose habitat selection includes open upland and aquatic areas that provide the best forage in early summer, followed by more closed canopy areas that provide the best forage as summer progresses and plant quality changes. In autumn, after the rut and into winter, moose intensify use of open areas with the highest biomass of dormant shrubs, where the remaining major source of palatable forage occurs. Closed canopy areas are used in late winter when forage is naturally at its lowest value and quantity for the year. The nature of the cover used at this time will provide the best protection available from wind and cold, and may range from tall shrub communities to tall closed canopy conifer stands (Peek, 2007). Metabolic activity in moose generally corresponds to this pattern, being highest in summer and lowest in winter (Regelin et al., 1985). Alaskan moose generally do not use areas > 1,220 m in elevation (Ballard et al., 1991). Also, in Alaska, because forage quantity and quality (nutritional value) in summer and winter can differ by orders of magnitude, winter habitat availability is often the ultimate limit on moose abundance (Stephenson et al., 2006). Spatial heterogeneity of habitat on a relatively small scale ($\leq$ 34 km^2) enhances habitat quality for moose (Maier et al., 2005), probably because it enables moose to respond to rapidly changing conditions such as climate (Stephenson et al., 2006).

Moose benefit from early successional stages of vegetation, which provide the woody browse biomass that moose require (Schwartz, 1992). A disturbance regime that provides persistent shrub communities, distributed in a diverse mosaic on the landscape, is essential to high moose density

EPA-6363-000002990

(Stephenson et al., 2006). In Alaska, this disturbance can be provided by fire (LeResche et al., 1974; Maier et al., 2005), glacial outwash, and earthquakes (Stephenson et al., 2006). On the Kenai Peninsula, forest succession following fire provided the most abundant forage for moose 20 years post-burn (Bangs et al., 1985; Schwartz and Franzmann, 1989; Spencer and Chatelaine, 1953; Weixelman et al., 1998). Schwartz and Franzmann (1989) reported that, after the 1969 fire, moose abundance peaked about 15 years after the burn, when browse plants reached maximum productivity. The increase was attributed to high production and low mortality, with some initial shifting of home ranges from adjacent high-density populations. Where fire was absent for 25 years, moose densities on the Kenai Peninsula were sufficiently high to cause the forage base to shift from a multispecies complex to a much less diverse community dominated primarily by white birch (Oldemeyer et al., 1977). In the boreal forest, the optimum successional stages for moose are 11-30 years after burning (Kelsall et al., 1977).

In Game Management Unit (GMU) 17 in northern Bristol Bay, moose habitat is enhanced primarily by the scouring of gravel bars and low-lying riparian areas by ice and water during the spring thaw (Woolington, 2008). Willows and other plants quickly regenerate after bank scouring and subsequent deposit of river silt (Woolington, 2004). This disturbance mechanism is particularly important for the Nushagak and Mulchatna Rivers and for the lower reaches of the major tributaries to those rivers (Woolington, 2008). Major river systems with large riparian zones, like the Nushagak and Mulchatna Rivers, represent alluvial habitats that support an abundant moose population, because they feature an abundance of nutritious food, primarily in the form of regenerating willow stands. Deciduous shrubs proliferate in these areas because of the annual influx of nutrients from waterways, sufficient soil moisture, and changing river channels. Lightning-caused wildfires also occur occasionally in GMU 17 (Woolington, 2008), and provide disturbance that enhances moose habitat. Moose habitat has not been formally assessed for GMUs 17B and 17C. Much of GMU 17 is wet or alpine tundra, and moose are located mostly along the riparian areas (Woolington, 2008).

In interior Alaska, habitat characteristics and female moose densities were evaluated using a spatial linear model (Maier et al., 2005). The densest moose populations occurred closer to towns, at moderate elevations, in areas with greatest amounts of riparian habitat, and in areas where fire occurred between 11 and 30 years prior. Moose avoided non-vegetated areas. Female moose preferred areas with patch richness, indicating their need for a diverse habitat with both food and availability of concealment. It was postulated (Maier et al., 2005) that moose might have preferred to be near towns either because human disturbance of vegetation provides high-quality foods for moose, or because predators such as wolves and grizzly bears tend to avoid human-inhabited areas.

On the Copper River Delta, open tall alder-willow and low sweetgale-willow habitats were used most by moose, and use of closed tall alder-willow habitat was intermediate (MacCracken et al., 1997b). Aquatic and woodland spruce habitats were used the least by Copper River Delta moose. Aquatic plants were used seasonally by Copper River Delta moose during the period from April through August, and were used primarily for foraging by both sexes (MacCracken et al., 1993).

In northwest Alaska during March and April, moose occurred at stands of felt-leaf willow (*Salix alaxensis*) 85.0 % of the time, followed by other willow (*Salix*) (6.4 %), riparian areas (3.9 %), gravel bars (2.5 %), and upland areas (1.3 % of the time) (Gillingham and Klein, 1992).

Winter Habitat- The influence of snow on moose habitat use patterns has received considerable attention. In severe winters, snow depth can be a limiting factor for moose populations. Deep snows can reduce browse availability by burying it, and travel through deep snow increases energy expenditure (Ballard et al., 1991). Snow characteristics of ecological significance include temperature, density, hardness and depth (Peek, 1986). Since the temperature of snow fluctuates less than ambient temperatures and never gets as low as the air temperature, snow provides insulation for moose against temperature extremes (Peek, 2007). Density and hardness influence the ability of an animal to travel across or through the snowpack. Under some conditions, snow density can be sufficient to support the mass of a wolf, but not a moose. Under these circumstances wolf predation on moose tends to be high (Ballard and Van Ballenberghe, 2007). It has been shown for other cervids (mule deer and elk) that energy expenditure while moving through snow increases exponentially with increasing snowpack maturation through the winter. Hardness and density affect sinking depth, and snow level at front knee height has been suggested as a threshold parameter (Parker et al., 1984). Applying the same principals and relationship to moose, a snow depth beyond 50-60 cm would result in a relatively large increase in energy expenditure for movement (MacCracken et al., 1997a). Snow depths ranging from 70–100 cm have been shown to limit the travel of moose (Des Meules, 1964; Kelsall, 1969; Kelsall and Prescott, 1971). When snow depths approach 97 cm, moose have been confined to areas where forest canopies are dense (Kelsall and Prescott, 1971).

The distribution of snow within the forest influences moose habitat use patterns. Snow depth is nearly always greater in open areas until late winter, when snow exposed directly to the sun melts more rapidly than snow protected by tree canopies. Snow falling on tree branches of fine-needled conifers, such as spruce, tends to be retained in the canopy and produces a lower snow depth immediately beneath the tree canopy in areas called a tree well (Pruitt, 1959). When this snow sheds from the tree branches to the ground, it tends to produce a hard dense surface, which provides more support for moose traveling beneath the canopy (Peek, 2007). In some geographic locations with deep winter snow, mature coniferous forests can provide zones of shallow snow accumulation that benefit moose survival (Balsom et al., 1996). In deep snow habitats where conifers are absent, such as in shrub/scrub tundra or riparian communities, moose still use the best microsites offered by combinations of shrub canopies and topographical situations that reduce snow depths. However, the principal adaptation simply is to reduce energy expenditure (Peek, 2007).

Severe winters have been associated with high moose calf mortality from starvation (Ballard et al., 1991). In Quebec, females with calves had a greater preference for habitats providing protection from predators, while solitary adult females preferred habitats with moderate food abundance, moderate protection from predators, and substantial shelter against deep snow (Dussault et al., 2005). In Denali National Park and Preserve (DNPP) during the severe winter of 1986, large males were the only moose able to remain in the Jenny Creek unit, which had a higher forage biomass but deeper snow than other units (Miquelle et al., 1992). Moose are very tolerant of cold temperatures, but are susceptible to heat stress. The upper critical temperature range for moose during winter is -5 to 0°C; during the summer upper thermal limits are 14 to 20°C (Renecker and Hudson, 1986).

Food Habits

The moose diet is comprised mainly of leaves, twigs and bark of woody plants (Schwartz, 1992; Van Ballenberghe et al., 1989). Renecker and Schwartz (2007) reviewed the diet items consumed by moose. They list more than 221 plant genera/species, with willow (Salix), birch (Betula), and alder (Alnus) predominating across North America. Daily patterns of moose use of time and space explain how the animal satisfies hunger, remains fit, avoids thermal stress, maintains security from predators, and reproduces. Since many of an individual moose's life cycle needs interact daily, tradeoffs often occur, because most requirements are more critical at certain times than at others. The day-to-day needs of moose for food and thermoregulation are most often preempted in favor of other activities that accommodate fitness and mating. However, the survival instinct is satisfied most on a daily basis by optimizing food consumption at minimal risk and effort. In this regard, a basic constraint for most moose is an abundant food supply of low quality (Renecker and Schwartz, 2007).

Digestive strategies of wildlife species vary significantly. Moose are ruminants, with a four-chambered stomach. In ruminants, browse, forbs, and grass are held in the large-chambered rumen of the stomach until adequate nutrients are extracted from the fibrous materials and the plant particles are small enough to pass through to the omasum and true stomach. On the basis of feeding habits, specialization and design of the digestive anatomy, ruminants are classified into three main groups (Hoffman, 1973): browsers that eat mainly shrubs and trees, grazers that eat mainly grass, and mixed or intermediate feeders that eat a mixture of grass, forbs, and browse. The moose is a browser and has been classified as a seasonally adaptive concentrate selector (Hofmann, 1989). Concentrate selectors have a relatively small ruminoreticular chamber and must search for high-quality foods that will pass rapidly through the digestive system. Moose consume plant species and parts (twigs and foliage) high in cell-soluble sugars that ferment rapidly in the rumen. They generally avoid plants that are fibrous and require extensive breakdown in size before passage from the rumen. Moose have a relatively narrow muzzle, prehensile lips and tongue that allow them to select high-quality plant parts (Renecker and Schwartz, 2007). Moose ferment (digest) mostly the soluble components of their food, and propel digesta rapidly through their digestive system (Schwartz, 1992). Their digestive efficiency is regulated by forage selection, rumination, gut morphology, and mechanisms controlling the rate of passage of food (Schwartz, 1992). Moose can ingest and process high-quality foods more rapidly, (e.g., aquatic plants eaten in summer), because both passage and digestion rates are enhanced (McArt et al., 2009).

In the range of moose, plant species respond to seasonality by growing during the short summers and entering a state of dormancy during long the winters. As plants change seasonally so does their nutrient quality. Plants begin their growth phase in early spring, long before actual green-up occurs. In general, spring and summer foods are 1.5 to 3 times more nutritious than winter foods, depending on which constituent is examined (Schwartz and Renecker, 2007). Summer diets contain excess digestible energy and protein, whereas winter diets generally are insufficient to meet maintenance requirements (Renecker and Hudson, 1989; Schwartz et al., 1988; Schwartz et al., 1987). As a result, feeding habits of moose vary by season, via a complex interaction of internal physiological regulators and the external environment. There is an annual cycle of food selection and intake, fat metabolism, metabolic rate, and body mass dynamics that is not driven simply by food quality and availability (Schwartz, 1992). The gastrocentric hypothesis predicts that large male moose will eat large amounts of low quality, fibrous foods, while smaller-bodied

EPA-6363-000002993

females will consume smaller amounts of higher-quality forage to meet the demands of reproduction and lactation (Oehlers et al., 2011). Both sexes reduce food consumption and metabolic rates in the winter, and operate at a net energy deficit by utilizing fat reserves (Miquelle et al., 1992; Schwartz, 1992).

Protein and energy are considered the major limiting nutrients within the environment (Schwartz, 1992). Summer protein intake is critical for lactating female moose (McArt et al., 2009). Tannins have a negative influence on forage quality, because they quantitatively reduce protein availability (Robbins et al., 1987). In two areas of Alaska, browse quality differences were consistent with observed differences in moose reproductive success (McArt et al., 2009). In recent years, the productivity of DNPP moose has been significantly higher than that of moose in the Nelchina Basin. A study of browse quality in the two areas found that, on average, nitrogen levels were 9% lower and tannin levels 15% higher in Nelchina than in DNPP, resulting in a digestible protein differential of 23%. The researchers concluded that the Nelchina moose population was nitrogen-limited. In both systems, browse quality declined significantly as summer progressed, with nitrogen levels decreasing and tannin levels increasing in all species of browse studied. In comparison with early-summer forage, digestible protein had decreased by an average of 35% by mid-summer and 70% by late summer (McArt et al., 2009).

High-quality summer forage, particularly near wetlands, allows nursing cows to regain body condition and calves to grow so they can better escape predators and survive their first winter (ADF&G, 2011d). During the spring-summer period, moose feed in aquatic habitats. In the Copper River Delta, aquatic habitats produced about four times more forage than terrestrial habitats, and the forage was more digestible (MacCracken et al., 1993). While some researchers have linked the summer consumption of aquatic plants by moose to a craving for sodium (Jordan, 1987), the Copper River Delta data did not support that hypothesis. Those data suggested that moose selecting aquatic forage were switching from an energy-maximizing to a time-minimizing strategy (MacCracken et al., 1993). This is because aquatic plants are high in water content and although a moose can fill it's rumen quickly, the relative quantity of dry matter consumed is less than when eating the same amount of terrestrial vegetation, such as leaves. Although a relatively small part of the wild moose diet, another forage type selected seasonally by moose is bark. Bark stripping occurs mostly in winter, when there are a lesser number of twigs available due to snow depth (MacCracken et al., 1997b). In DNPP, female moose also stripped bark in aspen-spruce forests in May and June, coincident with birth and lactation (Miquelle and Van Ballenberghe, 1989). Studies have also identified certain plant species that moose avoid because of low palatability due to chemical defenses in plants, such as black cottonwood (*Populus balsamifera trichocarpa*) on the Kenai Peninsula (Weixelman et al., 1998) and white spruce (*Picea glauca*) both on the Kenai and in other parts of Alaska (Weixelman et al., 1998).

Moose in the Copper River Delta consume three different diets that vary among the seasons of winter, spring/early summer, and late summer/fall (MacCracken et al., 1997b). Willow dominated all three diets; the differences were related to the amounts of sweetgale (*Myrica gale*), marsh five-finger (*Potentilla palustris*) and graminoids in the diet. Winter diets included sweetgale and alder (*Alnus* spp.), which are both nitrogen-fixers, leading to relatively higher protein content. Spring/early summer diets were most diverse, due to the increased use of emergent aquatic plants such as marsh five-finger. Late summer/fall diets were least diverse, consisting almost entirely of willow leaves and twigs (MacCracken et al., 1997b).

EPA-6363-000002994

Moose diets in DNPP were also found to vary by season. In the summer, seven species of willow comprised a total of 81.5% of the diet (Van Ballenberghe et al., 1989). In that study, diamond-leaf willow (*Salix planifolia*) was eaten more than any other plant species in summer (45.7% of diet). In contrast, willow comprised over 94% of the total diet of DNPP moose in winter (Risenhoover, 1989).

Moose can influence the composition and productivity of the terrestrial plant community through browsing (Bedard et al., 1978). In DNPP, moose initiated positive feedback loops on their environment through browsing (Molvar et al., 1993). Willows exhibited a growth response to moose herbivory; specifically, leaf area was significantly greater at the site with high moose density than at the site with low moose density. Annual biomass productivity per growing point on willow stems increased with increasing browsing intensity on the plant as a whole, via release from apical dominance. Moose also increase rates of nutrient cycling, as their urine and feces transfer nutrients to soil. The organic content of soil can also be enhanced by moose, in turn benefitting microbiota such as decomposers (Molvar et al., 1993). In a study in interior Alaska, twigs re-growing from two-year old willow stems that had been browsed by moose had larger diameters than those that had not been browsed in the previous year (Bowyer and Neville, 2003). Browsing on felt-leaf willow did not have an effect on nitrogen content, digestibility, or tannin content, which indicated that the willow did not exhibit a tannin-mediated inducible defense system in response to herbivory (Bowyer and Neville, 2003).

Marine derived nutrients (MDNs) carried upstream by spawning salmon have implications for nutrient flow into riparian habitats, and are thought to enhance growth and productivity therein (Quinn et al., 2009). While it is plausible that MDNs might contribute to increased plant productivity and thus benefit moose, evidence of this direct impact was not located in the scientific literature.

Moose density is often associated with food abundance (Eastman and Ritcey, 1987; Joyal, 1987; Oldemeyer and Regelin, 1987; Schwartz and Franzmann, 1989; Thompson and Euler, 1987). As reviewed by Renecker and Schwartz (2007), forage biomass varies with successional age of forests. In Newfoundland, available woody biomass increased from about 200 kg/ha in two-year-old clear cuts to more than 2,000 kg/ha by eight years, at which time it peaked and subsequently declined gradually (Parker and Morton, 1978). On the Kenai Peninsula, important browse species peaked about 15 years after fire (Spencer and Hakala, 1964). The biomass of important browse species in successional stands of forest has been estimated on the Kenai NWR; browse production measured at 3, 10, 30, and 90 years post-burn was 37, 1,399, 397, and 4 kg/ha, respectively (Oldemeyer and Regelin, 1987).

Behavior

Movements and Home Ranges- The ways in which moose use their environment both spatially and temporally are of great interest to resource managers (Hundertmark, 2007). The dynamics of animal movements and distribution in space and time are integral to behavioral, ecological, genetic, and population processes. Thus, the attributes of the space occupied by individual animals, both annually and seasonally (home ranges), patterns of movement within home ranges, establishment of new home ranges by young moose and colonization of new habitats (dispersal) and movements between seasonal ranges (migration) must be considered in comprehensive management programs.

The size of a moose home range varies with the sex and age of the animal, season, habitat quality, and weather. Two studies from Alaska generated the largest estimates of home range size, although one of these (Grauvogel, 1984) included migratory locations in the estimate of seasonal ranges, which can increase home range size significantly (Hundertmark, 2007). Moose in south-central (Ballard et al., 1991) and northwest Alaska had mean seasonal ranges > 92 km^2. With the exception of home ranges of non-migratory adults in the later study, total home range sizes exceeded 259 km^2. In contrast, estimates of annual ranges for moose in northwest Minnesota were ≤ 3.6 km^2 (Phillips et al., 1973).

Seasonal ranges, when they exist, represent partitioning of the environment based on behavioral and energetic constraints. Migratory moose (those that use separate winter and summer ranges) use distinct seasonal ranges because they attempt to optimize their nutrient intake on summer range, but winter conditions on these ranges may preclude occupation during some or all winters. Moose that remain on the same range during winter and summer are termed non-migratory, and do so because the environmental conditions permit their residence. A third seasonal range associated with mating, occurs in autumn, but many investigators define this as part of the summer range (Hundertmark, 2007). Breeding areas for tundra moose are typically in open habitats where visibility is good. This is likely for behavioral purposes so bulls and cows can see each other as they display. It may also afford some predator protection.

In several moose populations studied in Alaska, some individuals were non-migratory residents while other individuals migrated seasonally. In the Copper River Delta, 8 of 15 collared females were migratory, while two of five collared males were migratory (MacCracken et al., 1997b). Moose in that area exhibited greater fidelity to their summer range than their winter range (MacCracken et al., 1997a); winter severity influenced winter migratory behavior from year to year in the Copper River Delta (Stephenson et al., 2006). Moose populations in south-central Alaska (GMU 13, comprising the Nelchina and upper Susitna basins) also included both migratory and non-migratory individuals (Ballard et al., 1991). Those moose exhibited three seasonal periods of movement – autumn migration to wintering areas, spring migrations to calving areas or summer feeding grounds, and early fall migrations to rutting areas (Ballard et al., 1991). In the Togiak River drainage of the northern Bristol Bay area (GMU 17A, the), some collared moose were resident whereas others migrated seasonally (Woolington, 2008). During a population estimation survey in February 1995, 29 moose were documented moving westward from the upper Sunshine Valley in GMU 17C (the lower Nushagak watershed) into GMU 17A (Woolington, 2008).

Cows with new-born calves restrict their movements for the first few weeks, after which they gradually expanded their home range to approximate home range size of other adults (LeResche, 1974). In one study, cow-calf pairs had smaller summer home ranges than did other moose, and calf movements increased exponentially with age during the first six weeks of life (Ballard et al., 1980).

When differences in annual home range sizes are attributed to sex, males always are found to occupy larger areas. In south-central Alaska males had significantly larger home ranges than did females (Ballard et al., 1991). In northwestern Alberta researchers noted no difference between the sexes, but did note the tendency of bulls to occupy larger winter and spring home ranges (Lynch and Morgantini, 1984).

EPA-6363-000002996

The timing of seasonal migration has been observed to vary significantly among individuals from several moose populations in Alaska. In the Nelchina Basin of south-central Alaska, individual moose movements varied by months both in the initiation and the duration of winter migration (Van Ballenberghe, 1977). Snow depth was an important factor that influenced winter migratory behavior in that population. Cows with calves tended to migrate to wintering grounds earlier than did males and cows without calves (Van Ballenberghe, 1977). During spring in the Nelchina Basin, the initiation of migration varied substantially between individuals, but all individuals migrated quickly once they started moving (Van Ballenberghe, 1977). Individual moose in south-central Alaska (GMU 13) also initiated migration to wintering areas at very different times, ranging from mid-August to mid-February (Ballard et al., 1991). Moose in GMU 13 exhibited more variation in spring migration than Nelchina Basin moose did (Ballard et al., 1991). Dates of spring migration ranged from March through mid-July; during some years, moose remained on the winter range for calving. Subsequent movement to the summer range in mid-summer seemed related to plant development (Ballard et al., 1991).

Moose in different areas of Alaska were found to migrate different distances seasonally and have different annual home range sizes (Ballard et al., 1991; Gillingham and Klein, 1992; MacCracken et al., 1997b) (Table 2). Moose on the Seward Peninsula of northwest Alaska migrate up to 80 km seasonally (Gillingham and Klein, 1992). In south-central Alaska, the distance between winter and summer ranges of migratory moose averaged 48 km, and ranged from 16 to 93 km (Ballard et al., 1991).

Moose use of seasonal home ranges is traditional (Ballard et al., 1991). In south-central Alaska GMU 13, only one of 101 radio-collared female adults dispersed from their traditional home range during a 10-yr study period (Ballard et al., 1991). During the fall of 1978, that female relocated 177 km from her previous location (Ballard et al., 1991).

In the northern Bristol Bay region, some moose collared in GMU 17A since 2000 have moved westward within GMU 17A and into the southern part of GMU 18 (Woolington, 2008). This is thought to be part of a continued westward expansion into previously unpopulated moose habitat (Woolington, 2008).

Table 2. Mean (range) home range size (km2) for selected moose populations in Alaska.

Study area	Migratory status	Age/Sex	Mean home range size (km^2)			Reference
			Total	Winter	Summer	
Kenai Peninsula	M	Adult/M	137 (56–185)			(Bangs et al., 1984)
	N	Adult/M	52 (34–64)			
	N	Adult/F	127 (25–440)	63 (13–184)	36 (2–152)	(Bangs and Bailey, 1980)
Seward Peninsula	M	Adult	938 (236–1,932)	311 (36–1,393)	324 (41–1,323)	(Grauvogel, 1984)
	N	Adult	218 (91–350)	98 (36–223)	93 (44–150)	
	I	Adult	339 (205–593)	122 (21–334)	210 (60–559)	
South-central	N	F	290 (111–787)	113 (10–430)	103 (23–456)	(Ballard et al., 1991)
	M	F	427 (274–580)	147 (15–375)	263 (60–622)	
Southeast	N	Adult/F	28 (9–51)	11 (3–30)	14 (2–30)	(Doerr, 1983)

Migratory status: M = migratory, N= nonmigratory, and I = intermediate. Data from Hundertmark (2007).

EPA-6363-000002997

Sexual Segregation and Grouping Behaviors- Bowyer et al. (2003) provide a succinct discussion of sexual segregation in moose, and we paraphrase it here. Sexual segregation is the differential use of space by the sexes outside the mating season (Barboza and Bowyer, 2000) and often includes differential use of habitats and forages. Sexual segregation is especially pronounced in moose and plays a crucial role in their ecology (Bowyer et al., 2001; Miller and Litvatitis, 1992; Miquelle et al., 1992). In Alaska, male and female moose select habitats differently, leading to their spatial segregation throughout most of the year (Oehlers et al., 2011)). Spatial segregation occurs because adult males select habitats with greater forage abundance and females select areas with more concealment cover during winter (Bowyer et al., 2001; Miquelle et al., 1992), while cows with calves select denser cover and are more secretive than other age groups (Peek, 2007). In southeast Alaska, female moose selected habitat that maximized high-quality forage while minimizing predation risk, while male moose selected habitat that provided the highest forage intake (Oehlers et al., 2011). In DNPP, summer habitat selection by adult females also varied, depending on whether or not they had a calf (Miquelle et al., 1992). Females with calves remained solitary and preferred forested habitats, which provided better cover from predators. Such differences in habitat use between the sexes have implications for sampling of moose populations, because it can affect the accuracy of sex and age ratio information obtained by direct observation (Bowyer et al., 2002; Peek, 2007; Peterson, 1955; Pimlott, 1959).

The degree to which Alaskan moose segregate by gender varies by season. In DNPP, sexual segregation is most common in winter, when only 19% of all observed groups had both large males and females (Miquelle et al., 1992). Spatial segregation in that study was most extreme during a deep-snow winter, when only large males could access forage at higher-elevation Jenny Creek due to their larger body size (Miquelle et al., 1992).

The effect of habitat enhancement on sexual segregation was studied in interior Alaska after mechanical crushing of willow stands (Bowyer et al., 2001). In that study, males occurred predominantly on the more open, disturbed area during winter, whereas females and young used older stands of willow, where dense vegetation offered substantial concealment from wolves. Females and young faced a tradeoff between foraging on a greater abundance of food in the disturbed area and a reduced risk of predation in the mature stand (Bowyer et al., 2001).

The way in which moose, either individually or in groups, partition their habitats and associate with other moose can be informative in determining the needs of the various segments of the population (Hundertmark, 2007). Moose have been referred to as "quasi-solitary," and large groups are uncommon (Houston, 1968). The tendency of moose to lead a solitary life or to occur in groups depends on their age, sex, and reproductive status, and varies by season. Molvar and Bowyer (1994) note that Alaskan moose are more gregarious than moose from Eurasia and suggest that the formation of social groups is a recently evolved adaptation in Alaska moose in response to a relative abundance of predators and to relatively open terrain. In DNPP, larger groups ventured farther from cover but were less efficient at foraging due to inter-individual aggression (Molvar and Bowyer, 1994).

Cows with calves are consistently the most solitary members of the population, probably because of predator avoidance (Hauge and Keith, 1981; Hundertmark, 2007; Miquelle et al., 1992). Alaskan female moose with calves are nearly always solitary at the time of birth (Miquelle et al., 1992; Molvar and Bowyer, 1994). Females without calves are more likely than males to be

EPA-6363-000002998

solitary during the early summer, but they become more gregarious as the summer progresses (Miquelle et al., 1992). In DNPP, during the summer, females without calves were seen alone only 23% of the time (Miquelle et al., 1992). During the months of June through August, male moose in DNPP were consistently gregarious (Miquelle et al., 1992). When in a group, small males were more likely than large males to be in a group that included females, at all times except the rut and post-rut (Miquelle et al., 1992).

In south-central Alaska GMU 13, calves separated from their parents at an average age of 14 months (Ballard et al., 1991). In that study, 33% of yearlings and one two-year old were observed in one to six temporary re-associations with their mothers after their original dispersal. Calves were more likely to re-associate with their mother if she was not caring for a new calf (Ballard et al., 1991).

Mating and Maternal Behaviors- Moose in North America have two general forms of mating behavior. In the taiga of Canada, moose have a serial mating system, in which bulls search for cows in heat by traveling widely, while calling and thrashing their antlers (Bubenik, 2007). The bull digs shallow pit holes in which he urinates, but they are randomly located and seldom found on the same spot in successive years. For all cows to be bred during the short three-week mating season, the serial mating strategy requires a relatively high number of bulls. Bubenik (2007) concluded that due to differences in climatic conditions of the periglacial tundra, the tactic of serial mating was replaced by communal or harem mating in tundra moose. Toward the end of August, a prime tundra bull settles in a mating area of about 10 km^2. Rutting areas appear to be traditional (Bubenik, 2007). In early September, bulls begin scent-urinating on trails and in pit holes. Two prime bulls may share a harem when it contains eight or more cows. During the eight to ten days of breeding in the harem, a tundra bull probably can fertilize as many or more cows than the taiga bull does during the entire three-week rut because the tundra bull can mate with each female in his harem without traveling long distances to locate a new female.

Many mammals have evolved seasonal reproductive patterns that ensure adaptation to predictable annual changes in the environment. Moose exhibit marked seasonal changes in reproductive behavior that reflect adaptations to yearly fluctuations in food availability to ensure favorable conditions for rearing young (Schwartz, 2007). This means that moose do not reproduce all year long, but only during one season (autumn). By breeding in the fall, it insures calves are born in spring when forage is high in nutrient quality and the cow has a high probability of producing enough milk to successfully raise the calf. Day length may provide the clue to annual timing of the breeding season. Length of the breeding season is relatively short for moose. Since it is difficult to determine the exact date of breeding under natural conditions, few studies provide detailed information. Researchers with the most robust data sets each concluded that moose exhibit a very well-defined breeding season, as judged by conception dates and the spread of observed breeding (Crichton, 1992; Schwartz and Hundertmark, 1993; Thomson, 1991). The mean date of breeding in British Columbia ranged from October 5 to 10, with a standard deviation of five days (Thomson, 1991). The average day of breeding in Manitoba was 29 September and 93% of all females were bred by 12 October (Crichton, 1992). The average breeding date in Alaska was 5 October, with a range from 28 September to 12 October. There was very little difference among years in all studies, suggesting that photoperiod, rather than weather influences rut timing. Synchrony of the rut has also been observed in DNPP. Over a twelve-year interval, rutting consistently occurred during the brief period from 24 September through 5 October (Van Ballenberghe and Miquelle, 1993).

Moose cows across North America give birth during a relatively short period of time. The peak birthing period occurs from about 15 May through 7 June (Schwartz, 2007). In DNPP, timing of birth in moose was consistent from year to year, despite variation in climate between years (Bowyer et al., 1998). Birth timing exhibited "extreme synchrony" and Bowyer et al. (1998) hypothesized that moose were tracking long-term patterns of climate in the area to time reproduction. Hence, there is concern that moose will be vulnerable to climate change even before extensive changes to vegetation occur (Bowyer et al., 1998).

In DNPP, the primary drivers influencing birth site selection were microclimate, forage abundance and quality, and risk of predation (Bowyer et al., 1999). Birth sites were not re-used, and some females appeared to behave unpredictably shortly before giving birth, perhaps in an attempt to thwart predators (Bowyer et al., 1999). Proximity to human development did not influence birth site selection. Moose preferred birth sites with abundant willow, high visibility to detect predators, and a southeasterly exposure that would be warmer and drier (Bowyer et al., 1999). Bark stripping was common around birth sites, because females seldom travelled more than 100 m from their young and hence rapidly depleted the birth site's forage (Bowyer et al., 1999).

Activity Budgets- Moose spend most of their active life foraging. Seasonal rates of forage intake tend to mimic the cyclic nature of energy metabolism in moose (Regelin et al., 1985), with higher rates of activity and intake in spring and summer and reduced rates during winter. Activity budgets tend to follow a similar pattern. Activity budgets have been studied for DNPP moose during winter (Risenhoover, 1986) and spring/summer (Van Ballenberghe and Miquelle, 1990). DNPP moose exhibited low activity levels from January through April, when they were active, on average, only 27.3% of the time (6.5 h/d) (Risenhoover, 1986). Risenhoover (1986) found that activities associated with resting and foraging constituted 99.3% of the time of DNPP moose in winter. In contrast, Miquelle et al. (1992) found that small males in DNPP spent some of their active time engaged in social behavior during winter. In winter and early spring in DNPP, moose exhibited a polyphasic pattern alternating between foraging and bedding, with about six cycles per 24 hours (Risenhoover, 1986).

Following their relative inactivity in winter, DNPP moose increased their metabolic rate in April, as evidenced by the onset of antler development in males and increased mobility of cows (Risenhoover, 1986). Activity increased during May to a peak in early June, then began to decline until mid-August (Van Ballenberghe and Miquelle, 1990). DNPP moose were active 12.8 h/d at the peak, and activity had declined to 9 h/d by late summer (Van Ballenberghe and Miquelle, 1990). In summer DNPP moose spent about equal amounts of time feeding, resting and ruminating during each 24-h period (Van Ballenberghe and Miquelle, 1990). When comparing winter activity budgets (Risenhoover, 1986) to summer activity budgets (Van Ballenberghe and Miquelle, 1990) in DNPP, large differences were observed (Table 3).

Table 3. Moose activity budgets in winter[1] and spring/summer[2] in Denali National Park and Preserve (averages)

Activity Parameter	Winter	Spring/Summer
Total active time/day (hr)	6.5	10.1
Total resting time/day (hr)	17.5	13.9
# Activity bouts/day	5.7	8.2
Duration of activity bouts (min)	68	73
Duration of resting bouts (min)	178	97
Foraging time/day (hr)	4.9	7.5
Rumination time/day (hr)	11.7	6.7

1= "Winter" is January through April; data from Risenhoover 1986
2="Spring/Summer" is 1 May through 15 August; data from Van Ballenberghe and Miquelle (1990)

On the Seward Peninsula of northwestern Alaska, moose winter activity time allotments were 43.2% feeding, 42.8% bedding, 8.4% walking, 4.4% standing, and 1.2% other (Gillingham and Klein, 1992). Walking time was far greater than reported during winter in DNPP (< 1%) (Risenhoover, 1986). Gillingham and Klein (1992) attributed this difference to Seward Peninsula moose using the Kuzitrin River as a feeding and movement corridor during winter. The use of a narrow, linear feature, such as a river bottom, means that a moose needs to travel farther up and down the river to obtain food, as opposed to feeding in a large, non-linear area. There are at least two other differences between DNPP moose and Seward Peninsula moose. While there is an abundance of predators in DNPP (wolves and bears), there are no predators of moose on the Seward Peninsula in winter (Gillingham and Klein, 1992). Also, moose activity was highly synchronized during mid-afternoon in late April on the Seward Peninsula; presumably due to heat stress (Gillingham and Klein, 1992). In contrast, there was no significant correlation between mean daily temperature and daily activity level in DNPP during winter (Risenhoover, 1986).

On the Copper River Delta, inactive bout duration of moose was shortest on the west delta, which had the highest estimates of forage abundance and quality among the three areas studied (MacCracken et al., 1997a). It was suggested that the relative duration of inactive bouts might be useful as an index of habitat quality for moose.

Interspecies Interactions

Boer (2007) provided an excellent review of the interspecific relationships between moose and other species. Interspecific interactions between moose and other species take on one or more of the following general forms: competition, parasite-mediated competition, predation, and commensalism (Boer, 2007). Due to the diversity of habitats, species combinations, and abundance of sympatric species, a variety of competition mechanisms operate throughout moose range. Of the interspecific interactions possible, competition is the most obvious one influencing moose habitat use and distribution (Boer, 2007). Throughout their North American range, moose compete with an array of other ungulate species. However, in the Nushagak and Kvichak watersheds, caribou are the only other ungulate species abundant enough to consider. Direct competition between moose and caribou appears limited and insignificant (Davis and Franzmann, 1979). Food preferences of moose and caribou coincide to some degree, but the diet of caribou appears to be more specialized. Caribou consume forbs and deciduous vegetation and lichens in

winter (Darby and Pruitt, 1984; Servheen and Lyon, 1989). Moose primarily consume browse, but also use forbs and deciduous vegetation during summer (Dodds, 1960; Eastman and Ritcey, 1987).

As reviewed by Boer (2007), in multi-prey systems, moose and caribou populations may influence each other indirectly. Increasing moose numbers in western and central portions of DNPP have resulted from increased availability of caribou as alternate prey for wolves (Singer and Dalle-Molle, 1985). In the eastern section of that park, migrating caribou were available as prey for only a brief period of time, and therefore, they were not a particularly important factor of the area's prey base. In that area, moose populations have declined. Moose are the primary prey of wolves in other areas of Alaska as well (Gasaway et al., 1983), although others have attributed an increase in moose numbers in northern Alaska to a preference by wolves for caribou (Coady, 1980).

Interspecies population dynamics have been studied in several areas of Alaska with multiple predators and multiple prey species. These relationships can be quite complex and can vary based on both abiotic and biotic factors within the ecosystem. None of the formal scientific interspecies studies reviewed here were conducted in the Nushagak and Kvichak watersheds.

In Alaskan ecosystems with multiple predators, bears were responsible for more moose calf kills than were wolves. Black bears can be significant predators of moose calves (Franzmann et al., 1980). Of 47 radio-collared neonatal calves on the Kenai Peninsula, black bears killed 34%, whereas brown bears and wolves each killed 6% (Franzmann et al., 1980). In the western Interior, near McGrath, black bears were also the dominant source of predation mortality of calves during six out of seven years studied; wolves and brown bears were secondary predators in that system (Keech et al., 2011). In contrast, brown bears were the primary predators of moose calves in a south-central Alaska study, causing 73% of calf mortality (Ballard et al., 1991). Brown bears were also the primary predator in east-central Alaska (GMU 20E), where 79 to 82% of radio-collared moose calves died by the age of eleven months (Gasaway et al., 1992). In that study, 52% of moose calves were killed by brown bears, 12 to 15% of calves by wolves, and 3% by black bears.

Several studies have compared the causes of calf mortality in the nutritionally unproductive 1947 burn and in the productive high-quality habitat of the 1969 burn on the Kenai Peninsula, Alaska (Franzmann and Schwartz, 1986; Schwartz and Franzmann, 1989; Schwartz and Franzmann, 1991). Black bears killed 34 and 35% of the calves, respectively, whereas wolves and brown bears killed 5 to 13%, respectively. Total calf mortality from all causes ranged from 51 to 55%. Moose densities were four times greater in the 1969 burn area (370/100 km^2) and the population was increasing, whereas the population in the 1947 burn was about 100/100 km^2 and declining. The investigators concluded that habitat quality had a significant impact on reproductive rate and population growth. The moose population in high-quality habitat (1969 area) was capable of sustaining this level of predation and continued to grow, whereas the population in poor habitat (1947 area) was not.

Wolves appeared to select for moose calves in some areas and seasons in Alaska, but not in others. In south-central Alaska, moose calves were taken in proportion to their abundance in the overall population during May through October (Ballard et al., 1987). In contrast, during November through April in that study, wolves preyed on moose calves selectively. During those months calves were only 12 to 20% of the moose population, but they consisted of 40% of moose kills by wolves (Ballard et al., 1987). During autumn in northwest Alaska, wolves displayed a lack of selectivity for moose calves, which were killed in proportion to their relative abundance within the

population (Ballard et al., 1997). On the Kenai Peninsula, wolves killed mostly moose calves (47%), yearlings, and older adults (Peterson et al., 1984). Half of moose adults killed by wolves during that study were more than twelve years of age. Wolf predation on moose calves was highest during the winter with deepest snow, and calves killed after 1 January were commonly malnourished, with bone marrow fat content ≤10%.

In east-central Alaska (GMU 20E), predation was the primary cause of non-hunting deaths for yearling and adult moose (Gasaway et al., 1992). Of 46 such moose that died from 1981 through 1987, 89% were killed by brown bears or wolves, 9% died from antler wounds or locked antlers, and 2% drowned. Peterson et al. (1984) examined the incidence of debilitating conditions among 109 wolf-killed adult moose on the Kenai Peninsula. They found that 20 such moose had moderate or severe periodontitis, 14 had arthritis, one had a broken leg, and one had a leg wedged between trees. Of 40 wolf-killed adult moose assessed for bone marrow fat content, four had levels ≤20%, indicating severe malnutrition (Peterson et al., 1984).

Wolves in different regions in Alaska displayed different relative preferences for moose and caribou as prey. In south-central Alaska, moose were the primary prey of wolves, constituting 38% of observed kills, while caribou was the second most important prey at 21% (Ballard et al., 1987). In northwest Alaska, caribou was the preferred prey of wolves (Ballard et al., 1997). In January through April 1988, when caribou were abundant, 92% of observed ungulates killed by wolves were caribou. In contrast, in 1989 and 1990 when caribou were less abundant, they constituted 11% and 48% of observed ungulate kills, respectively (Ballard et al., 1997).

Estimated kill rates for wolf packs on the Kenai Peninsula varied from one moose/3.1 days to one moose/21.4 days (Peterson et al., 1984). The average kill interval in winter for Kenai wolf packs with more than two members was 4.7 days. In 38 wolf-moose encounters observed on the Kenai Peninsula, wolves succeeded in killing only two of the moose (Peterson et al., 1984).

Ballard et al. (1997) speculates that the recent occurrence of moose (since the 1940s) in northwest Alaska has altered the historical migratory patterns of wolves in that area. There is evidence that wolves in northwest Alaska used to migrate with the caribou herds, but now they do that only when alternate prey (moose) numbers are insufficient.

Mortality, Productivity, and Survivorship

Understanding the dynamics of a population requires knowledge of how many individuals it contains, how fast it is increasing or decreasing, its rate of production of young, and its rate of loss through mortality (Van Ballenberghe and Ballard, 2007). Moose populations increase by the addition of calves born to the population each year and decrease by the loss of animals. Death can occur from the moment of birth. Moose die from a variety of causes including hunting, predation, starvation, accident, drowning, vehicle collision, parasites, and disease. Mortalities are generally divided into two major categories: human-caused or natural. Moose populations are adaptable to artificially disturbed habitats, and therefore are often found in close proximity to roads, major highways, and railways. But this association is far from compatible (Child, 2007). In populated areas of Alaska a large number of moose are killed each year by collisions with motor vehicles and trains (Bowyer et al., 2003; Child, 2007). For example, from 1963 to 1990, 3,054 moose were killed on the Alaska Railroad, with annual losses ranging from seven to 725 (Modafferi, 1991). In the severe winter of 1989–1990, deep snow caused more moose to travel on roads and railroads

EPA-6363-000003003

and fatalities thereon exceeded the previous record by more than 100 animals. In the Willow-Talkeetna area during the same winter, the number of railroad kills represented a 70% loss from the resident population (Schwartz and Bartley, 1991). Other sources of mortality include sport and subsistence hunting and poaching (Woolington, 2004).

Prime adult moose tend to have very high rates of survival because they are not as vulnerable to natural causes of mortality when compared to younger (calves) and older age classes. Survival rates are generally estimated by radio collaring individuals and following them for some period of time (Van Ballenberghe and Ballard, 2007). Ballard et al. (1991) provided data on mean annual survival rate from a sample of radio-collared adult female moose during a ten-year period. From 25 to 80 moose per year were followed in a study area where hunting of cows was prohibited. Annual survival rates were estimated at 94.8%. Data from yearling females spanned four years with two to 22 individuals per year collared, and annual survival rates averaged 95.1%. Annual survival of yearling and adult males averaged 75.4 and 90.9% respectively, with hunting the major mortality factor. On the Kenai Peninsula, researchers followed 51 radio-collared females for six years and reported a 92% annual survival rate (Bangs et al., 1989). Survival of cows aged 1 to 5 years was estimated at 97% and 84% for females aged 16 to 21 years. Hunting was not a significant cause of mortality of the study population. As reported by Van Ballenberghe and Ballard (2007), various other studies using radio-collared moose have reported annual survival rates of adults ranging from 75 to 94%, depending upon the extent of human hunting. In general, starvation and wolf predation during severe winters causes the greatest mortality in older age classes (Ballard et al., 1991; Bowyer et al., 2003); moose weakened from starvation are particularly vulnerable to wolf predation. Bull moose occasionally wound each other during the rut and die from these wounds (ADF&G, 2011d).

As reviewed by Van Ballenberghe and Ballard (2007), hunting is a major limiting factor of many moose populations throughout the world. In fact, hunting pressure can reduce moose population density (Crete et al., 1981). In Quebec, where natural mortality apparently was low, harvest rates as high as 25% were reported (Crete, 1987). Moose harvest rates ranging from 2 to 17% have also been reported for various other parts of North America (Crete, 1987). In concert with other factors, including severe winters, high harvest rates have contributed to moose population declines in Alaska (Gasaway et al., 1983). In addition, hunting can significantly reduce the number of bulls, perhaps sufficiently to reduce the level of first-estrus conception (Bishop and Rausch, 1974). When, due to heavy hunting pressure, there are fewer than ten bulls per 100 cows, some cows simply may not encounter a bull early in the mating season. Breeding early in the mating season means the rut would be synchronous and calving would therefore be synchronous. If a cow mates late in the breeding season, the result would be later calving in the spring. In some European environments, where severe winters, predation and nutritional stress are absent, moose harvest as high as 50% of the winter population is sustainable (Cederlund and Sand, 1991). Most North American moose populations harvested at this rate would decline sharply. In nearly all areas where hunting is legal, harvest is managed under sustainable principals, so hunting mortality seldom results in unintended population declines (Timmerman and Buss, 2007).

Within the Nushagak and Kvichak watersheds both hunter numbers and moose harvest have increased. Correlated to a four-fold increase in moose hunters in GMU 17 from 1983 to 2006 (from 293 to 1,182), reported moose harvest tripled (from 127 to 380). In GMU 17B (the upper Nushagak watershed), the reported harvests for the past five years, when data were available, ranged from 113 to 183, with a mean annual harvest of 149 moose. In GMU 17C (the Togiak

watershed), the five-year mean annual harvest was 224, with a range of 193 to 251 (Woolington, 2008). Hunters must harvest moose with antler spreads of no less than 50 inches. The largest antlers reported exceeded 69 inches.

Juvenile moose tend to die at higher rates than adults. Calves are typically the most vulnerable age class. Calf moose mortality can be divided into two general time periods when mortality is highest: from birth to about six months of age, and from about nine months to one year of age (Van Ballenberghe and Ballard, 2007). These periods correspond roughly to particular vulnerabilities, specifically, to bear and wolf predation in the first period and hunting (in some areas), wolf predation, and winter starvation in the second period. According to Van Ballenberghe and Ballard (2007), neonatal mortality varies greatly, depending on several factors, most notably the extent of predation. Several studies of radio-collared moose calves have documented that predators may account for up to 79% of newborn deaths and that survival during the first eight weeks of life may be as low as 17% (Ballard et al., 1981; Ballard et al., 1991; Franzmann et al., 1980; Gasaway et al., 1992; Larsen et al., 1989; Osborne et al., 1991). Further losses during the first year of life may result in annual survival rates as low as 10% (Van Ballenberghe and Ballard, 2007). In south-central Alaska, Ballard et al. (1991) observed that brown bears caused the majority of natural death of calves younger than five months of age, whereas, on the Kenai Peninsula, Franzmann et al. (1980) documented that black bears were the greatest cause of moose calf mortality.

Moose breed in late September to early October (Van Ballenberghe and Miquelle, 1993) and adult females give birth to one or two (twin) calves in late May–early June each year (Schwartz, 2007; Testa et al., 2000). Production of moose calves is the result of a complex chain of biological processes including estrus cycles, rutting behavior, fertilization, gestation, pre-partum events and birth (Boer, 1992; Schwartz, 2007; Van Ballenberghe and Ballard, 2007). Fecundity, or productivity of individual moose, is related to sexual maturation and a broad array of ecological factors affecting food supply, forage quality, and weather that affect the physiological status of females. These factors influence ovulation, pregnancy rates, litter size, and fetal sex ratios. Ultimately, fecundity and subsequent survival of young determines recruitment rates and population trends, which are important factors in moose population dynamics.

Reproductive tract studies have shown that female moose do not ovulate during the mating season in the first year of life and therefore do not produce calves as yearlings. Cows may or may not breed in their second year, depending on body mass (Saether, 1987). Most cows are sexually mature at around 28 months of age and females continue to breed to the end of their life span at around 18 years of age (ADF&G, 2011d; Schwartz, 2007). Litter size in moose ranges from one to three (Peterson, 1955), but litters greater than two are rare (Coady, 1982). Body condition of female moose (as influenced by habitat quality) has correlated strongly with twinning rates in several diverse moose populations (Franzmann and Schwartz, 1985). In an area known to contain abundant high-quality food resources on the Kenai Peninsula, up to 70% of cows with calves one year had twins the next year. This contrasts to other populations, in which twinning rates as low as 5% were reported (Houston, 1968; Markgren, 1969; Pimlott, 1959), but some of the estimates may have considered post-natal mortality. The data suggest that twinning rates exceeding 40 to 50% are uncommon for moose populations strongly limited by nutrition. Twinning frequency is a good indicator of cow health condition and habitat quality (Dodge et al., 2004). Calves that survive predation from bears in the summer wean in August, but will remain with their mother until the

EPA-6363-000003005

next calf is born the following spring (Schwartz, 2007), or for an additional year if no new calf is born (Testa, 2004).

Population, Subpopulations, and Genetics

The number of animals in a population is one measure of abundance, but is only useful when the geographic boundaries of an area are well defined, because that allows biologists to estimate density (the number of individuals per unit area), which is a more robust parameter. Moose population densities were compared by Gasaway et al. (1992) over very large areas (>2000 km^2) of generally continuous moose habitat across a broad area of Alaska and the Yukon Territories. They noted that smaller sites exhibited high variability in prey and predator densities and in habitat quality, making it more difficult for realistic comparisons. They focused their comparisons on the post-hunt, early winter season thereby enhancing comparability further. The mean density of moose from 20 populations was estimated at 0.148/km^2 (range 0.045–0.417/ km^2) in areas where predation was thought to be a major limiting factor of moose. Densities of 16 other populations in the same area, where predation was not limiting, averaged 0.66 moose/km^2 (Van Ballenberghe and Ballard, 2007). Ballard et al. (1991) provided 29 moose density estimates from Alaska, including some populations studied by Gasaway et al. (1992); they ranged from 0.05 to 1.24/ km^2.

ADF&G estimates the total population of moose in Alaska at 175,000 to 200,000 animals (ADF&G, 2011d). The 2004 population estimate for the study area of the Nushagak and Kvichak watersheds was 8,100 to 9,500 moose (Butler, 2004; Woolington, 2004). This estimate was based on population data from ADF&G GMUs 17B, 17C, 9B and less than half the area of GMU 9C, outside the Katmai National Park (Figure 3).

Moose are relatively new inhabitants in the Bristol Bay area, possibly having migrated into the area from middle Kuskokwim River drainages during the last century (Woolington, 2004). Moose were either not present or were sparse in the northern Bristol Bay area until the turn of the twentieth century, and even then the moose population did not increase until three decades ago (Butler, 2004; Woolington, 2004). Suspected reasons for low moose populations in the Bristol Bay region are heavy hunting pressure, particularly on female moose in the western part, and bear predation in the eastern part (Butler, 2004; Woolington, 2004). Over the last 25 years, managed harvesting, predator control, an increase in caribou herds as an alternative predator food source, and consecutive mild winters have led to an increase and expansion of the moose population westward (Butler, 2004; Woolington, 2004).

The largest moose population in the study area is in the Nushagak drainage; the upper watershed (GMU 17B) has an estimated 2,800 to 3,500 moose, while the lower drainage (GMU 17C) has an estimated 2,900 to 3,600 moose (ADF&G, 2011d). These moose comprise about 73% of the total moose in the Nushagak and Kvichak watersheds. The Nushagak drainage has large, healthy areas of riparian habitat, a major component of which is felt-leaf willow, a preferred browse species (Bartz and Naiman, 2005). The number of moose in the Kvichak watershed was estimated at 2,000 in GMU 9B, and less than 400 moose in the portion of GMU 9C outside Katmai National Park (Butler, 2008).

Fall trend counts have been notoriously unreliable in providing consistent data on moose populations in GMU 17 (Woolington, 2008). Suitable survey conditions, including complete snow

coverage, light winds and moose movements onto winter range rarely occur before antler drop. Regular population estimation surveys of portions of the unit during late winter provide the best population information; unfortunately they do not provide reliable information on sex and age composition.

Moose population estimates in the northern Bristol Bay area are produced by a spatial statistics stratification model, which uses harvest ticket data from sport and subsistence hunters (Butler, 2004; Woolington, 2004). The ADF&G, Division of Subsistence suspects there is a considerable unreported subsistence harvest as well as illegal harvest occurring in some regions of Alaska (ADF&G, 2011d). Illegal harvest of moose in Unit 17 was probably more of a problem in the past than during recent years. Unit residents used to actively pursue moose with snow machines during the winter and spring, when both male and female moose were taken. Attitudes have changed following considerable efforts by State and federal management agencies, working with local communities to help hunters see the benefits of reducing illegal moose kills. It is now common to see moose near local villages throughout the winter (Woolington, 2008).

Human Use (Subsistence, Recreation)/Interaction/Management)

In Alaska 7,400 moose were harvested in 2007. Residents harvested 6,750 moose and 685 were taken by non-resident hunters (ADF&G, 2011d). The harvest of 7,400 moose yields approximately 3.5 million pounds (1,587,573 kg) of meat.

Harvest records from ADF&G for 1983 to 2002 indicate that GMU 9 and 17 provided 7% of the total moose harvest in Alaska (BLM 2007). According to ADF&G, Division of Subsistence (http://www.adfg.alaska.gov/sb/CSIS/) local subsistence hunters from King Salmon, Naknek, and South Naknek harvested 19 moose in GMU 9B in 2007; total meat harvested was estimated at 10,206 pounds (4,629 kg). In unit 17B, local residents from Igugig, Koliganek, and New Stuyahok harvested 88 moose in 2005 (last year of available data); total meat harvested was estimated at 48,208 pounds (21,867 kg). Likewise, residents from Naknek and South Naknek harvested 4 moose from unit 17C with a total of 5,357 pounds (2,430 kg) of meat. In total, subsistence moose meat accounted for 63,771 pounds (28,987 kg) of meat with an average of 128 pounds (158 kg) harvested per household (Table 4).

Moose are an important subsistence food species for people residing in the area served by the Bristol Bay Area Health Corporation (Ballew et al., 2004). In a survey about traditional food consumption conducted in 2002, 86% of respondents from that region reported consumption of moose meat within the past year, at a median per capita consumption rate of five pounds (2.3 kg) per year (Ballew et al., 2004). Moose was the third greatest subsistence source of meat to residents of that region; residents reported eating more salmon and caribou than moose. Subsistence statistics (Table 4) also suggest that, on average, a high percentage of individuals from villages in the area (38%) attempted to harvest a moose, with about 20% succeeding. Additionally, about 24% of individuals reported sharing their moose with others, while 44% received meat from others.

In addition to being a source of subsistence meat, moose also contribute to the local economy, through jobs created as a result of non-resident hunters seeking a remote fly-in or boat-in experience to take a trophy moose.

Table 4. Subsistence statistics for moose harvest in Alaska Dept. of Fish and Game, game management units (GMU) 9B, 17B, and 17C.

GMU	Community name	Study year	Using (%)	Attempted harvest (%)	Successfully harvested (%)	Shared meat (%)	Received meat (%)	Reported harvest (#)	Estimated harvest (#)	Reported harvest lbs	Estimated harvest lbs	Mean harvest/ household (#)
09B	King Salmon	2007	33	31	10	10	24	5	9	2,700	4,849	55
09B	Naknek	2007	48	23	5	5	47	4	10	2,160	5,357	29
09B	South Naknek	2007	29	24	0	0	29	0	0	0	0	0
17B	Igiugig	2005	100	50	42	75	67	6	6	3,240	3,510	270
17B	Koliganek	2005	86	68	50	54	46	16	24	8,640	12,960	309
17B	New Stuyahok	2005	94	65	51	43	65	30	58	16,200	31,738	331
17C	Naknek	2007	48	23	5	5	47	4	10	2,160	5,357	29
17C	South Naknek	2007	29	24	0	0	29	0	0	0	0	0
Total										35100	63771	
Mean			58	38	20	24	44					128

(Data are from 2005 or 2007 and represent the most recent information available.) (http://www.adfg.alaska.gov/sb/CSIS/)

BARREN GROUND CARIBOU

Introduction

Alaska is currently home to 31 herds of wild caribou (*Rangifer tarandus granti*), with a combined population of approximately 760,000. Caribou herds are defined by their traditional and predictable use of calving areas that are separate and distinct from the calving grounds of other herds (Skoog, 1968). Use of other seasonal ranges is variable and less traditional. Caribou from different herds may overlap on seasonal ranges other than calving areas (Cameron et al., 1986). Historically, most caribou herds have fluctuated widely in numbers and in use of range (Skoog, 1968).

Adult bull caribou in southwestern Alaska usually weigh between 350 and 450 lbs (159 to 182 kg), while females weigh between 175 and 225 lbs (80 to 120 kg) (ADF&G, 1985). Body weight can vary with environmental and nutritional conditions (Cameron, 1994; Valkenburg et al., 2003). Caribou are the only members of the deer family in which both males and females grow antlers. Bulls begin to shed the velvet on their antlers between late August and early September, marking the start of breeding season. The largest bulls begin shedding their antlers in late October, with smaller bulls losing their antlers later in the winter. Females shed velvet in September (Skoog, 1968). Pregnant females usually keep their antlers until the calving season in the spring, while non-pregnant females lose their antlers about a month before calving begins. Some females never grow antlers (Whitten, 1995). Caribou populations throughout the Bristol Bay region have declined recently and body weights and antler sizes are now relatively low. In the past the area produced large-bodied animals with record book antlers (Valkenburg et al., 2003).

Population History of Caribou in the Upper Bristol Bay Region

Historical accounts from the early 1800s indicate that caribou were plentiful in the Bristol Bay region. There may have been a large herd that ranged from Bristol Bay across the Kuskokwim and Yukon deltas all the way to Norton Sound. By the late 1800s caribou throughout this area had declined dramatically. Caribou numbers may have increased in the early 1930s, but were declining again by the late 1930s. Domestic reindeer were brought to the Bristol Bay region in the early 1900s, but by the 1940s, reindeer herds were widely neglected and either died out or were assimilated into wild caribou populations (Skoog, 1968; Woolington, 2009a). Caribou in the Nushagak drainage remained relatively scarce into the 1970s, at about 10,000-15,000 animals (Woolington, 2009a).

Over the past thirty years, caribou herds in southwest Alaska have continued to undergo significant changes in population numbers. The Nushagak and Kvichak drainage basins are now used primarily by caribou from the Mulchatna herd. The Mulchatna herd grew rapidly during the 1980s and 1990s, from a population of about 18,600 animals in 1981 to a peak of approximately 200,000 in 1997. By 1999 the Mulchatna herd had declined to 175,000 and it continued to decline, to approximately 30,000 in 2008 (Valkenburg et al., 2003; Woolington, 2009a). As the Mulchatna herd grew, it overlapped with and eventually assimilated the much smaller Kilbuck (or Qavilnguut) herd that formerly ranged infrequently into the western part of the Nushagak

EPA-6363-000003009

drainage. By the late 1990s the Kilbuck herd had ceased to function as a distinct population (Woolington, 2009a).

The Northern Alaska Peninsula herd recovered from a population low of about 2,000 in the late 1940s to about 20,000 in 1984. The population remained at about 15,000 to 19,000 through 1993, but has since declined steadily to about 2,000 to 2,500 today (Butler, 2009a). For the most part, caribou of the Northern Alaska Peninsula herd remain well south of the Kvichak drainage. However, from 1986 to 2000 many caribou from the Northern Alaska Peninsula herd wintered in the Kvichak drainage, south of Lake Iliamna (Butler, 2009a). In the late 1980s and early 1990s, the Kvichak drainage was also used by far greater numbers (up to 50,000) of Mulchatna caribou (Woolington, 2009a). The two herds always returned to their traditional calving and summer ranges and remained distinct (Butler, 2009a; Hinkes et al., 2005; Woolington, 2009a).

The Nushagak Peninsula herd is a small population that was established in 1988, when caribou from the Northern Alaska Peninsula herd were translocated to the Nushagak Peninsula south of the Nushagak River delta, on the west side of upper Bristol Bay. The Nushagak Peninsula had been unoccupied by caribou for approximately 100 years (Hotchkiss, 1989; Paul, 2009). The Nushagak Peninsula herd grew rapidly after its introduction, from 146 caribou to over 1,000 caribou in 1994. Growth continued at a slower rate to about 1,400 caribou in 1997. Population density peaked at approximately 1.2 caribou per km^2. During the next decade, calf recruitment and adult female survival decreased and the population declined to 546 caribou in 2006 (Aderman, 2009). The population remained at about 550 caribou until 2009 and then increased to 801 by 2011 (Aderman and Lowe, 2011).

Habitat

Seasonal Preference- Spring calving grounds tend to be in open tundra areas or high and rugged mountains. Predator densities are often lower in such areas, but large caribou herds can also calve at high densities in sparsely forested terrain, where their sheer numbers and synchronized timing of births can swamp the effects of predators (ADF&G, 1985; Skoog, 1968).

During summer (mid-June to mid-August), caribou feed in open tundra, mountain, or sparsely forested areas. To avoid harassment from mosquitoes and other insects, caribou often gather on windswept ridges, glaciers, lingering snow drifts, gravel bars, elevated terrain, cinder patches, and beaches. Caribou near the coast may also avoid insects by standing head down and motionless on mudflats (ADF&G, 1985; Skoog, 1968).

In winter caribou often feed in forested areas, especially where there are spruce-lichen associations. In addition to forested areas, caribou can also be found along ridge tops, on frozen lakes and in bogs during winter (ADF&G, 1985; Skoog, 1968).

Food Habits

Spring- From mid-April to mid-June, caribou usually eat catkins of willow (*Salix alaxensis, S. planifolia spp. S. pulchra, and S. glauca*), grasses and sedges (*Carex bigelowii*, *C. membranacea*, *C. podocarpa*, and *Eriphorum vaginatum*). They also consume fruticose lichens, resin birch (*Betula glandulosa*), dwarf birch (*B. nana*), and horsetails (*Equisetum* spp.)(ADF&G, 1985; Skoog, 1968).

Summer- From mid-June to mid-August, caribou typically consume willow leaves, resin birch, and dwarf birch, as well as sedges and grasses, especially grasses from the genera *Alopecurus*, *Arctagrostis*, *Dupontia*, *Festuca*, *Poa*, *Puccinellia*, *Calamagrostis*, and *Hierochloe*. They also eat horsetails, legumes (*Astragalus umbellatus*, *Lupinus arcticus*, *Hedysarum alpinum*, and *Oxytropis nigresens*), and forbs such as *Gentiana glauca*, *Swertia perennis*, *Sedum roseum*, *Antennaria monocephala*, *Artemisia arctica*, *Epilobium latifolia*, *Pedicularis* spp., *Petasites frigidus*, *Polygonum bistorta*, *Rumex arcticus*, and *Saxifraga* spp. (ADF&G, 1985; Skoog, 1968).

Fall- Caribou feed on grasses, sedges, and lichens throughout the fall. They also feed on willow and water sedge (*Carex aquatilis*), if they are available (ADF&G, 1985). Caribou also feed on mushrooms, when available (Skoog, 1968).

Winter- Caribou winter diets consist primarily of lichens (especially *Cladonia* spp. and *Cetraria* spp.), with smaller amounts of sedges and grasses, as well as horsetails, and the tips and buds of willows and dwarf shrubs (e.g., *Vaccinium uliginosum*). They may consume vegetation in muskrat pushups during winter, as well as aquatic vegetation in poorly drained coastal plains (ADF&G, 1985; Skoog, 1968).

Behavior

Seasonal Range Use and Migrations- Some caribou herds travel long distances between summer and winter ranges, in order to find adequate sources of food and bear their calves in areas relatively free of predators (Bergerud, 1996; Griffith et al., 2002; Skoog, 1968; Whitten et al., 1992). Physical features on the landscape influence caribou migration routes. Caribou must negotiate around open seawater, large lakes, swift rivers, rivers with floating ice, rocky regions in high mountains, volcanic cinder patches, glaciers, and burns. Features such as frozen lakes and rivers, as well as ridge tops, eskers, streambeds, and hard-surfaced snow drifts aid caribou during winter migration (ADF&G, 1985). Since the 1980s, calving areas, other seasonal ranges, and migration routes of the Mulchatna herd have varied widely. The Mulchatna herd has ranged extensively throughout most of the Nushagak and Kvichak watersheds, but caribou from this herd also spend much of their time to the north in the Kuskokwim River drainage (Woolington, 2009a).

In contrast to most other migratory caribou herds, the Mulchatna herd does not use the same traditional calving ground annually, although its calving areas have remained distinct from those of any other herds. The Mulchatna herd calved in the Bonanza Hills area of the upper Mulchatna River watershed during the 1980s. In 1992, calving shifted west to the Mosquito River drainage in the upper Mulchatna watershed. From 1994 to 1999 calving generally occurred in the upper Nushagak River watershed. From 2000 to 2002 calving was split between the lower Nushagak watershed and the South Fork of the Hoholitna River, in the Kuskokwim drainage. In 2003 and from 2005 to 2008, calving occurred near Kemuk Mountain in the Nushagak drainage, as well as near the South Fork of the Hoholitna in the Kuskokwim drainage. In 2004 calving was widespread, from Dillingham in the Nushagak watershed, north to the Holitna and Hoholitna Rivers in the Kuskokwim drainage (Woolington, 2009a).

The Mulchatna herd often ranges widely across the Nushagak drainage during summer and fall, but also frequently uses areas to the north and west, in the Kuskokwim Mountains. During the 1980s much of the Mulchatna herd wintered north and west of Lake Iliamna, in the Kvichak drainage. In the 1990s most wintering shifted to the Kuskokwim Mountains. For the past decade part of the herd has wintered in the Nushagak and Mulchatna watersheds while part of the herd has wintered in the Kuskokwim watershed. In 2006/2007 and 2007/2008, up to 20,000 Mulchatna caribou wintered in the lower Nushagak and Kvichak valleys, with some going as far south as the Naknek valley in 2006/2007 (Woolington, 2009a).

Mulchatna caribou are often widely dispersed during movements between seasonal ranges. In accordance with the highly variable locations of seasonal ranges, migration tends not to follow the same routes from year to year (Woolington, 2009a).

Historically, the Northern Alaska Peninsula herd has spent most of its time in areas from the Naknek drainage to the south, far removed from the Kvichak and Nushagak watersheds. From about 1986 through 2000 many caribou from the Northern Alaska Peninsula herd did winter in the Kvichak drainage, south of Lake Iliamna, but since 2001, only a single radio-collared caribou from this herd has wintered north of the Naknek River (Butler, 2009a).

Like many small caribou herds, the Nushagak Peninsula herd is sedentary and spends the entire year on the Nushagak Peninsula, although a few caribou from this herd have made short forays off the Peninsula (< 20 km and for < 1 month) (Aderman and Woolington, 2001). So far, there has been no overlap between the Nushagak Peninsula herd and much larger migratory Mulchatna herd.

Response to Disturbance- Industrial activities impact caribou by hindering or altering their movements or displacing them from preferred habitats. Barren-ground caribou on the North Slope of Alaska have avoided development such as exploration wells (Fancy, 1983) and linear developments such as roads and pipelines (Dau and Cameron, 1986) by distances of 2 to 5 km. Establishment of extensive, densely packed development with interconnecting road networks, high levels of traffic, aircraft activity, and ongoing construction or production activity around the Prudhoe Bay oilfields has resulted in general displacement of caribou from some areas (Griffith et al., 2002). Avoidance and displacement are most prevalent among females with young calves (Cameron and Whitten, 1980; Cameron et al., 1979; Griffith et al., 2002). Similarly, woodland caribou in Canada typically avoided areas near mining sites by 1 to 5 km (Weir et al., 2007). Mining activities had the highest impact on caribou during calving season. Larger groups and females with young typically avoided mining sites more often than smaller groups and caribou without young (Weir et al., 2007). Weir et al. (2007) identified corridors such as roads and seismic lines as the greatest development impact on caribou because they increase the chance of encounters with humans and predators. The large Red Dog Mine in northwestern Alaska has had only limited and localized effects on caribou movements and distribution, in part because the mine occupies only a tiny fraction of the Western Arctic Caribou herd's otherwise pristine range. Also, mine operators and workers have implemented policies to minimize conflicts between traffic and caribou along the road from the mine to the port site (Dau, 2009). In Norway movement patterns and range use by wild reindeer have been disrupted by combinations of highways and railroads, as well as by large hydroelectric developments (Nellemann et al., 2001;

Nellemann et al., 2003). Impacts of any development tend to be less when they occur on non-critical seasonal range, in areas or at times when caribou are at low density relative to available range, or when similar habitats are available nearby (Griffith et al., 2002).

Interspecies Interactions

The interrelationships of wolves, caribou, and moose populations have been studied extensively in Alaska (Gasaway et al., 1983; Mech et al., 1998; National Research Council, 1997). In large areas of interior Alaska, moose tend to persist for long time periods at low densities, with population size regulated by high rates of predation by wolves and bears (Gasaway et al., 1992). In contrast, caribou are able to periodically escape regulation by predators and at least temporarily achieve high densities (Davis and Valkenburg, 1991; Valkenburg, 2001). Such a pattern is consistent with caribou population dynamics in the Nushagak and Kvichak watersheds. Predation by wolves does not appear to be a major factor in regulating the Mulchatna herd, possibly due to rabies outbreaks that periodically reduce the wolf population (Valkenburg et al., 2003; Woolington, 2009a). Large migratory caribou herds like the Mulchatna may also avoid predation by moving seasonally to areas with few resident predators or by erratic and unpredictable use of seasonal ranges. Wolves in the Nushagak and Kvichak drainages are not known to follow migratory caribou (Woolington, 2009a).

Mortality, Productivity, Survivorship

Mortality- Caribou populations are influenced by the availability and quality of forage plants, predation, weather, climate, disease, and hunting (Valkenburg, 2001). Winter severity, accidents, and insect harassment can also affect caribou numbers (Hinkes et al., 2005). Rapid growth of the Mulchatna herd from 1980 to 1995 indicated that predation pressure was not a limiting factor on the herd at that time. During its continued decline from 1997 to the present, this herd has been strongly limited by nutrition. Poor nutrition has also been associated with high levels of bacterial pneumonia, hoof rot (*Spherophorous necrophorous*) and high parasite loads (Valkenburg et al., 2003; Woolington, 2009a).

Predation by wolves and bears is now limiting calf survival and recruitment in the Northern Alaska Peninsula herd, but lowered productivity due to nutritional stress is also a problem (Butler, 2009a). Calf recruitment in the Nushagak Peninsula Herd has been lower, as the herd declined in recent years, but causes are not well known. Depletion of lichens on winter range may have contributed to poor nutrition (Valkenburg et al., 2003).

Breeding- Rutting occurs during fall migration and on wintering grounds. Females tend to breed at 28 months of age, but age at first breeding can vary from 16 to 41 months, depending on health (Hinkes and Van Daele, 1996). Females in good nutritional condition have a pregnancy rate of 80% or more, but pregnancy rates may drop dramatically when cows are in poor condition, due to severe weather effects on grazing, or in some cases, due to overgrazing of range when caribou are at high densities. Gestation typically takes 225 to 235 days. Calving occurs in late May or early June and females usually have one calf per year (Skoog, 1968). Birth rates in the Mulchatna, Northern Alaska Peninsula, and Nushagak Peninsula herds all dropped after these herds reached peak population levels and then began to decline (Valkenburg et al., 2003).

Human Use/Interaction/Management

Nearly all caribou harvested in the Nushagak and Kvichak watersheds are from the Mulchatna herd. Caribou are an important subsistence food species for people residing in the area served by the Bristol Bay Area Health Corporation (Ballew et al., 2004). In a survey about traditional food consumption conducted in 2002, 88% of respondents from that region reported consumption of caribou meat within the past year (Ballew et al., 2004). Caribou was second only to salmon as a subsistence source of meat for residents of the region. Caribou are also harvested by non-local residents, who fly into the area to hunt. Harvest levels for all hunters are highly dependent on caribou distribution during the fall and winter, as well as weather and snow cover conditions that affect hunter access to caribou (Woolington, 2009a). Harvest is also generally correlated with population size, with historically high harvests occurring when caribou have been most abundant. Reported harvest of Mulchatna herd caribou from 1991 to 1999 ranged from 1,573 to 4,770 (Table 5); although those totals include Mulchatna caribou taken in areas outside the Nushagak and Kvichak drainages (Woolington, 2009a). Estimates of total harvest from the Mulchatna herd during this period were roughly twice as high (3,770 to 9,770)(Valkenburg et al., 2003). However, harvest probably never exceeded 5% of the annual population and did not limit herd growth or range expansion or cause the decline of the population (Woolington, 2009a). As the Mulchatna herd declined in numbers after 1999, reported harvest steadily dropped to a low of 767 in 2007/2008 (Table 5). Lower harvests reflect generally reduced availability of caribou (Woolington, 2009a). Also, long hunting seasons, high bag limits (five caribou), and same-day-airborne hunting that were allowed during the 1990s and early 2000s have since been replaced by more restrictive regulations.

Table 5. Mulchatna caribou herd- estimated population size and harvest.

Regulatory Year	Estimated Herd Size	Reported Harvest
1991-1992	90,000	1,573
1992-1993	115,000	1,602
1993-1994	150,000	2,804
1994-1995	180,000	3,301
1995-1996	190,000	4,449
1996-1997	200,000	2,366
1997-1998	N/A	2,704
1998-1999	N/A	4,770
1999-2000	175,000	4,467
2000-2001	N/A	4,096
2001-2002	N/A	3,830
2002-2003	147,000	2,537
2003-2004	N/A	3,182
2004-2005	85,000	2,236
2005-2006	N/A	2,175
2006-2007	45,000	921
2007-2008	N/A	767

(Woolington, 2009)

EPA-6363-000003014

Hunting for Nushagak Peninsula Herd caribou is managed under regulations set by the Federal Subsistence Board. From 1995 to 2011, a total of 673 caribou were reported harvested from this herd. Reported harvests were < 12.3% of the population annually during this period (Aderman and Lowe, 2011), but there may have been additional unreported harvest (Valkenburg et al., 2003). Factors other than hunting (e.g., depletion of lichens on winter range) may have been involved in the decline of the Nushagak Peninsula Herd after 1999 (Valkenburg et al., 2003). Nevertheless, it was clear that the herd could no longer support the high levels of harvest seen during the 1990s. Harvest quotas were reduced and the herd is now increasing again.

With the Northern Alaska Peninsula herd now at very low population levels, the herd no longer extends as far north as the Kvichak drainage. Overall harvest of the herd is greatly restricted, and none occurs in the Nushagak and Kvichak watersheds.

EPA-6363-000003015

WOLF

Introduction

The gray wolf (*Canis lupus*) is the largest wild extant canid (Paquet and Carbyn, 2003). The historic distribution of wolves once covered most of North America, but as the contiguous United States were settled during the past two and one-half centuries, the wolf was widely persecuted due to its tendency to prey on livestock and pets (Mech, 1995). By the 1970s, wolf populations in the contiguous United States were decimated, which led to their protection under the Endangered Species Act. The gray wolf is currently listed as "endangered" in most of the Lower 48 states, except in Minnesota, where it is "threatened," in the northern Rocky Mountains where the species was recently de-listed as "recovered," and for several experimental populations in Wyoming and the southwest United States (USFWS, 2011).

Habitat

Wolves are habitat generalists and their home ranges can encompass a variety of diverse habitats (Mech, 1970; Mladenoff et al., 1995; Paquet and Carbyn, 2003). Historically, gray wolves were distributed throughout the northern hemisphere in every habitat where large ungulates were found (Mech, 1995). Prey abundance and availability strongly influence habitat use by wolves (Paquet and Carbyn, 2003). Male and female wolves do not differ in habitat selection, and the pack maintains their territory throughout the year.

Wolf pups are born, protected, fed, and raised in natal and secondary den sites, a series of rendezvous sites, and surrounding areas (Paquet and Carbyn, 2003). Dens provide shelter and are often located in a hole, rock crevice, hollow log, overturned stump, abandoned beaver lodge, or expanded mammal burrow (Paquet and Carbyn, 2003). Rendezvous sites are areas where pups are left while pack members forage (Theberge, 1969).

Decades ago, it was commonly thought that wolves needed wilderness to survive. More recent studies have shown that wolves do not need wilderness, but they do require adequate prey and a relatively low rate of mortality caused by humans (Mech, 1995; Mladenoff et al., 1999). The presence of roads has a complex impact on habitat selection by wolves. Roads benefit wolves by easing their travel and access to prey, but conversely roads are associated with human contact and increased wolf mortality through either intentional or accidental killing (Houle et al., 2010; Mladenoff et al., 1999). Near the Kenai NWR in Alaska, wolves preferred a gated pipeline road, presumably because it offered an easy travel corridor with little human use (Thurber et al., 1994). In that study, wolf absence from human-settled areas and heavily travelled roads seemed to be caused by wolf behavioral avoidance rather than direct human-caused mortality of wolves in those areas.

Food Habits

Diet- Wolves are obligate carnivores whose use of prey depends largely on the availability and vulnerability of ungulates (Weaver, 1994). Dietary habits such as preferred prey species and prey switching tactics vary substantially among wolf packs in different locations, in response to local ecological relationships.

EPA-6363-000003016

Wolves can be flexible and shift to non-ungulate prey species when ungulate prey are scarce (Forbes and Theberge, 1996) or to take advantage of seasonally abundant, nutritious alternate prey species such as salmon (Darimont et al., 2008). Some wolf packs require dietary supplementation during the summer, in order to meet the high energetic demands of reproduction (Paquet and Carbyn, 2003). Dietary supplementation by alternate prey species is also important for wolf packs in northwestern Alaska that rely on migratory caribou, which move seasonally to calving grounds inaccessible to wolves (Ballard et al., 1997).

Beavers and snowshoe hare are important to the winter diet of wolves in Algonquin Park in Ontario, as are scavenged moose carcasses (Forbes and Theberge, 1992; Forbes and Theberge, 1996). Other animals such as lemmings, voles, muskrat, and a variety of birds (especially waterfowl) and their eggs also supplement the wolf diet (Kuyt et al., 1981), while fish and berries are consumed seasonally, where available (Darimont and Paquet, 2000; Kohira and Rexstad, 1995).

Coastal wolves also consume marine mammal carcasses, mussels, crabs, and even barnacles (Darimont and Paquet, 2000). The Ilnik wolf pack on the Alaska Peninsula was found to preferentially utilize coastal habitat along Bristol Bay, where it was frequently observed consuming marine mammal carcasses that had washed ashore (Watts et al., 2010). In the winter, when Bristol Bay was frozen, the pack was documented using offshore sea ice, and wolves killed sea otters (*Enhydra lutris kenyoni*) near the coastline when the otters were trapped above the sea ice (Watts et al., 2010).

Wolves on the Kenai Peninsula of Alaska were found to rely heavily on moose during the summer (Peterson et al., 1984). Moose comprised an estimated 97% of ingested prey biomass in summer, which was largely scavenged from old kills; only 16% of moose carcasses found with summer wolves were fresh kills. In contrast, 80% of moose consumed during the winter were fresh wolf-kills (Peterson et al., 1984). Kenai Peninsula wolves also ate snowshoe hare and beaver during the summer, and minor quantities of small rodents, birds, vegetation and other prey (Peterson et al., 1984). Scat from wolves in south-central Alaska confirmed reliance on moose; beaver and snowshoe hare were also commonly consumed (Ballard et al., 1987). Wolves in south-central Alaska also eat caribou, muskrat, squirrel, voles, vegetation, and a variety of other dietary items (Ballard et al., 1987).

Salmon as a Food Source*[2]*- Preying on salmon may have considerable adaptive value for wolves regardless of ungulate density. Foraging theory predicts the avoidance of dangerous ungulate prey in favor of less dangerous alternatives such as salmon (Stephens and Krebs, 1986). Salmon also offers superior nutritive value; in one study pink salmon contained more than four times as much energy per 100 g of meat than raw black-tailed deer (Darimont et al., 2008). Behavioral observations suggest that wolves may have a broad history of seasonal consumption of salmon in areas where the two species co-exist (Darimont et al., 2003).

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[2] Ongoing research in LCNPP and the Alaska Peninsula and Becharof NWRs is providing new information on the relationship of wolves to salmon. The results of this research have not yet been analyzed or published, but preliminary results show that wolves rely on salmon, when available, for a significant portion of their diets. This information is cited as a personal communication in this section.

Wolves have often been observed consuming only the head of salmon instead of the whole fish (Darimont et al., 2003). There are several possible explanations for this behavior. Wolves may be consuming only the most energetically valuable part of the prey item, or they may be targeting specific micronutrients such as omega-3 fatty acids (Gende et al., 2001). Wolves may also be selecting head tissue to minimize their exposure to parasites such as *Neorickettsia helminthoeca*, which can infect salmon and can be fatal to canids (Darimont et al., 2003).

Wolf packs that seasonally utilize salmon can reap benefits during the fall and winter seasons. The consumption of salmon in the fall may improve pup survivorship during weaning (Person, 2001). Winter snow can preserve salmon carcasses buried underneath, enabling use by wolves and other scavengers for the rest of the winter (Carnes 2004). Carnes (2004) compared scat across different packs in the Copper and Bering River deltas, and noted that wolf consumption of salmon increased in winter relative to other seasons; he hypothesized this might be related to the relative lack of seasonal availability of moose in those areas.

Several studies in Alaska have examined the importance of salmon to wolves from various parts of the State. In the Copper and Bering River Deltas, late summer rendezvous sites for wolves were typically located alongside shallow spots in spawning areas or at bends where gravel bars extended out into streams (Carnes 2004). Researchers observed wolves, especially pups at these spots, waiting for spent salmon carcasses to float by (Carnes 2004). In southeast Alaska marine protein composed 18% of the lifetime total diet of Alexander Archipelago wolves; most of the marine contribution was likely salmon, but other marine organisms were probably also consumed (Szepanski et al., 1999). In southwest Alaska's Togiak NWR, wolves have been observed delivering intact salmon carcasses to their pups at rendezvous sites (Walsh, 2011). Similar foraging behaviors have been observed among wolves on the Alaska Peninsula (GMUs 9C and 9E, extending from the Naknek River drainage through Port Moller), where wolves often transport captured salmon to den or rendezvous sites (Watts, personal communication).

Salmon are not solely a food resource for coastal wolves. Some Pacific salmon migrate long distances inland, returning to spawning grounds that may be hundreds of miles from the ocean (Quinn, 2004). A study within DNPP, in Interior Alaska, documented substantial seasonal salmon consumption among wolves who lived more than 1,200 river km from the coast (Adams et al., 2010). Wolves with ranges in areas where salmon were seasonally abundant and ungulates occurred at low densities ate the most salmon; salmon averaged 17% of their total long-term diet (Adams et al., 2010). Preliminary data from LCNPP indicates that wolves use salmon from the time the fish enter streams, through the fall, and then again after late-winter ice out (Mangipane, personal communication).

Dispersal of Marine-Derived Nutrients (MDNs) by Wolves- The influences of salmon on terrestrial systems are largely dependent on predators that remove salmon from streams, consume a portion, and leave the remains behind (Hilderbrand et al., 1999a; Reimchen, 2000). Abandoned salmon carcasses contribute to ecosystem processes, as scavenging, decomposition, and fecal-urinary deposition provide MDNs to terrestrial systems that are typically nitrogen- and phosphorus-limited (Ben-David et al., 1998; Hilderbrand et al., 1999a; Reimchen, 2000; Willson et al., 1998).

Wolf behavior further influences the pattern of distribution of MDNs to terrestrial ecosystems, as wolves often transport caught salmon some distance rather than consuming it in the stream or immediate vicinity. In British Columbia wolves were observed to consume caught salmon on grass next to the river 70% of the time (Darimont et al., 2003). However, in LCNPP, preliminary data indicate that wolves move considerable distances over several days to feed on salmon. In 2009, in LCNPP, an individual wolf was documented travelling up to 64 km from a den site to feed on salmon and carry ingested remains back to feed pups. In 2010 and 2011, the same individual travelled up to 24 km and 40 km to feed on salmon (Mangipane, personal communication). In some locations, wolves consume only the salmon head, leaving the remainder of the carcass behind (Darimont et al., 2003), whereas bears often consume eggs, muscle and other body parts of salmon, especially when salmon density is not high (Gende et al., 2001). In LCNPP wolves have been observed feeding on fish carcasses frozen into lake ice, and the backbones and heads left from human subsistence fishing (Mangipane, personal communication; Spencer, personal communication).

Behavior

Wolf Packs- Gray wolves are territorial and social carnivores that typically live in packs of about six to eight animals but packs may include >20 wolves (Mech and Boitani, 2003). Wolf packs typically consist of a single breeding pair, pups of the year, and their older siblings (Mech and Boitani, 2003). Mating occurs during late January to March and gestation is usually 63 days. In each pack, a single litter of pups is born in a den during late April to May. Nonetheless, multiple litters have been observed within some packs occurring in Alaska (Ballard et al., 1987; Meier et al., 1995). Litter sizes range from one to 12 pups but usually four to six pups are born (Fuller et al., 2003). Dens in coastal temperate rainforests are located within the root wads of living or dead trees (Person and Russell, 2009). In boreal forest or tundra, dens are located in sandy areas or gravel eskers (Ballard and Dau, 1983; McLoughlin et al., 2004). Wolves and their pups occupy dens between late April and early July, and then move to rendezvous sites where sequestered pups are fed by pack members until September or early October when they are sufficiently large to move with the pack (Mech et al., 1998; Packard, 2003; Person and Russell, 2009). Pup mortality during summer is affected strongly by availability of food (Fuller et al., 2003). Wolves usually remain within their natal packs until they reach sexual maturity at 22 to 24 months. At that age, some may disperse from their packs to find mates and establish their own packs. However, researchers reported dispersers ranging in age from 10 months to 5 years (Mech and Boitani, 2003). Abundant prey may induce some wolves to defer dispersal until they are older and thus packs may grow to large size (Fuller et al., 2003; Mech and Boitani, 2003). Dispersing wolves may travel hundreds of kilometers and traverse very difficult terrain before settling (Mech and Boitani, 2003) and they are able to cross large bodies of water. For example, in southeastern Alaska, dispersing wolves were documented swimming 3 to 4 km in open ocean to move between islands (Person and Russell, 2008).

Range- Resident wolf packs occupy extensive territories that they attempt to defend from other wolves. Wolf territories tend to be smaller in summer, when packs remain closer to dens and home sites (Mech, 1977), and are larger in winter, when the pack resumes nomadic travelling as pups mature. In south-central Alaska, the average distance between dens of neighboring packs was 45 km (Ballard et al., 1987).

Territories of wolf packs tend to be much larger in Alaska than in the remainder of the United States, due to the relatively low density of prey in Alaska. Home ranges and pack sizes largely are influenced by availability of prey (Mech and Boitani, 2003). For example, when prey is abundant, home ranges tend to be small and pack sizes large and the opposite is true when prey are scarce. In Alaska, ungulates such as moose, caribou, and Sitka black-tailed deer (Odocoileus hemionus sitkensis) are the most important prey (Gasaway et al., 1992; Kohira and Rexstad, 1997). In general, wolf territory size is inversely related to the density of available prey (Fuller et al., 2003). Average territory sizes of wolf packs from different regions of Alaska were consistently larger in winter than in summer (Table 6) (Adams et al., 2008; Ballard et al., 1997; Ballard et al., 1998; Ballard et al., 1987; Burch et al., 2005; Peterson et al., 1984). Each of these studies of Alaska wolf packs documented territory sizes much larger than those of wolves from north-central Minnesota, where small winter territory size (average 116 km^2) and high wolf density (39/1,000 km^2 in mid-winter) were attributed to an abundant white-tailed deer population (Fuller, 1989). Preliminary analysis of recent data from LCNPP has shown annual ranges from 1,155 km^2 to over 5,000 km^2. One pack in this study had ranges of 2,214 km^2, 2,189 km^2, and 1,834 km^2 from 2009 to 2011 (Mangipane, personal communication).

Table 6. Average territory sizes (km^2) of wolf packs in Alaska*.

Region	Summer	Winter	Annual	Reference
Northwest	621	1,372	1,868	Ballard et al., 1997
Denali National Park	--	--	871	Burch et al., 2005
Central Brooks Range	--	--	358–2,315[a]	Adams et al., 2008
Kenai Peninsula	--	--	466-864[b]	Peterson et al., 1984
South-central	--	--	1,644	Ballard et al., 1987

a - Range of territory sizes estimated for wolf packs over the four-yr study period
b - Range of average annual territory sizes during study period
-- not determined
* This table does not include data from an ongoing study in LCNPP.

Dispersal (Emigration)- Several studies in Alaska have documented emigration as a vital factor influencing the population dynamics of wolves (Adams et al., 2008; Ballard et al., 1997; Ballard et al., 1987; Peterson et al., 1984). Individuals may leave a pack and strike out on their own in response to low prey densities (Messier, 1985). High rates of infectious disease (Ballard et al., 1997), social stress within the pack, or a lack of opportunity to achieve the high social status needed to successfully breed (Peterson et al., 1984) may also cause wolves to disperse to new territories.

Dispersal is a key mechanism that wolves use to colonize new habitats that become available. Dispersing wolves experience a high rate of mortality, but when successful, they are able to establish a new pack (Peterson et al., 1984) or join an existing pack (Mangipane, personal communication). Successful colonization of new territory requires both a vacancy of suitable habitat and bonding with a mate (Rothman and Mech, 1979).

Seasonal Movements- Wolves in south-central Alaska do not follow migratory movements of moose or caribou outside their pack areas, but do follow elevation movements of moose within their pack areas (Ballard et al., 1987). In a study in northwest Alaska, wolf packs usually did not follow migratory caribou from the Western Arctic herd, but rather, switched to moose for prey during the winter and maintained year-round resident territories (Ballard et al., 1997). However, in years when moose densities were low, up to 17% of radio-collared wolf packs in northwest Alaska followed migratory caribou and then returned to their original territory for denning (Ballard et al., 1997).

In Bristol Bay, there is no evidence that wolf packs follow the Mulchatna caribou herd, although wolves are occasionally seen with the herd as it moves throughout the region (Woolington, 2009b). However, recent information in LCNPP shows that wolves (in most cases, lone yearling wolves) were following caribou herds for all or a portion of the year (Mangipane, personal communication). Packs are more likely to have established territories and take advantage of caribou when they move through those territories.

Daily distances traveled within a pack's territory range from a few kilometers up to 200 km (Mech, 1970). On Ellesmere Island, Northwest Territories, mean travel speed of wolves during summer, on barren ground, was 8.7 km/hr for regular travel and 10.0 km/hr when returning to a den (Mech, 1994). In south-central Alaska, a wolf pack followed for 15 days in the spring moved an average of 24 km per day (Burkholder, 1959). In LCNPP, all packs and age classes of wolves have been documented travelling up to 34 km in 15 hours (Mangipane, personal communication).

Wolves in general are good swimmers; coastal wolves are particularly adept at swimming and are able to swim distances as far as 13 km between islands (Darimont and Paquet, 2002). However, wolves may be unwilling to swim in pursuit of large ungulates. On the Kenai Peninsula, wolves ceased pursuit of moose that entered ponds or lakes and swam away from shore (Peterson et al., 1984). However, as soon as waterbodies freeze, wolves travel across them freely (Spencer, personal communication).

Interspecies Interactions; Response to Change in Salmon Populations/ Distribution

In coastal regions and along major river systems salmon are important seasonal prey for wolves (Adams et al., 2010; Kohira and Rexstad, 1997). Indeed, in some coastal areas, salmon may seasonally decouple the dependence of wolves on ungulate prey (Darimont et al., 2008). Salmon is a particularly important food for Alaskan wolf packs in some areas and changes in salmon abundance may have effects on the alternate prey species of these wolves. In DNPP, salmon were found to be a particularly important food item for wolves in areas with low ungulate density but high salmon abundance (Adams et al., 2010). The availability of salmon had a strong impact on the numerical abundance of wolves in the northwestern flats area of DNPP; wolves were only 17% less abundant in that area compared to the rest of the study area, even as ungulate densities were 78% lower. The higher wolf population density facilitated by the availability of salmon was thought to result in increased overall predation pressure on ungulates in that system (Adams et al., 2010). Moose were the predominant ungulate in the northwestern flats, occurred at densities

EPA-6363-000003021

approaching the lowest in North America (Gasaway et al., 1992), and appeared to be limited by predation rather than nutritional constraint (Adams et al., 2010).

Some wolves in Alaska eat salmon carcasses throughout the winter, as cold winter temperatures and snowfall effectively preserve this food resource. In one study of wolf scat, salmon consumption was observed to increase in the winter relative to other seasons (Carnes, 2004). A shortage of available salmon might result in a reduced winter food supply for such wolves, which could lead to either increased predation pressure on alternate prey species or reduced wolf survival if alternate foods were not available.

In Alaska, ungulates such as moose, caribou, and Sitka black-tailed deer are the most important prey (Gasaway et al., 1992; Kohira and Rexstad, 1997). Under some circumstances, predation by wolves may limit or regulate ungulate populations, sometimes suppressing their numbers at very low densities (top-down forcing) (Gasaway et al., 1992). In other cases, ungulate populations are influenced mostly by carrying capacity of the range regardless of wolf predation (bottom-up effects) (Ballard et al., 2001). Nonetheless, the relative effects of top-down and bottom-up factors can shift over time depending on habitat changes, weather conditions, and anthropomorphic disturbances (Bowyer et al., 2005).

The interrelationships of wolves, caribou and moose populations have been characterized in several ecosystems. Alterations in moose densities can have a major influence on caribou populations, through their effect on wolf predation rates. In southeastern British Columbia, wolf population numbers can be suppressed due to a lack of available food in winter, when moose numbers are low, particularly when caribou over-winter in areas inaccessible to wolves (Seip, 1992). Elevated moose densities may cause a concomitant rise in wolf numbers. If moose numbers later decline, wolves in the area will turn to caribou as an alternative food source, potentially causing a profound effect on the caribou population. Industrial development can exacerbate this effect by increasing wolves' access to caribou, via the creation of new linear corridors, such as roads and pipelines (James et al., 2004). These interrelationships may not be applicable to the southwest Alaska ecosystem, which has barren-land caribou herds, in contrast to the low-density woodland caribou herds from the Canadian studies. In LCNPP, when the Mulchatna caribou herd was at high numbers, wolves fed on caribou and moose numbers were high. When the herd size declined, wolves fed more on moose and moose numbers declined by 50 percent (Mangipane, personal communication).

Wolves are coursing predators that actively pursue prey rather than passively ambushing them (Mech, 1970; Mech et al., 1998). Consequently, in much of Alaska, they typically select open or sparsely forested habitats that enable detection and pursuit of prey. Deep snow that hinders movement of ungulate prey or restricts them to small, forested patches often facilitates predation by wolves (Mech and Peterson, 2003). For large ungulate prey such as moose, wolves often focus predation on calves, which tend to be the most vulnerable. In interior Alaska, wolves are most effective hunting in flat or rolling terrain covered with sparse boreal forest or tundra. In coastal rainforests, prey tend to be most vulnerable to predation by wolves in open muskeg heaths at low elevations (Farmer et al., 2006).

Mortality, Productivity, and Survivorship

Annual mortality in unexploited wolf populations in Alaska and Yukon ranges from 16 to 27% and is linked strongly with abundance of prey (Fuller et al., 2003). Mortality results from accidents, disease, and intra- and inter-pack strife. Where wolves are hunted and trapped, human exploitation often is the overwhelming source of mortality (Fuller et al., 2003; Person and Russell, 2008). In a heavily exploited population in south-central Alaska average annual mortality was 45% of which most (36%) was human caused (Ballard et al., 1987). Human-caused mortality can be compensatory with respect to other sources of natural mortality (Fuller et al., 2003). Resident pack members usually have higher survival than nonresident dispersing wolves because dispersers may be traveling through unfamiliar or unsuitable terrain, and are subject to attacks by resident wolves (Fuller et al., 2003).

Wolves can live for up to 13 years in the wild (Mech, 1988), typically dying as a result of starvation, accidents (Mech, 1977), intra-specific fights (Ballard et al., 1987), disease (Ballard et al., 1997; Woolington, 2009b), or human-related causes (Paquet and Carbyn, 2003; Woolington, 2009b). Starvation and disease are often co-occurring, but the nature of that relationship has not been fully established (Paquet and Carbyn, 2003). When wolves attempt to take down large prey, such as moose or caribou, they risk injury or death (Mech, 1970; Paquet and Carbyn, 2003). Human-related causes of wolf mortality include legal hunting for sport, subsistence or predation control (Ballard et al., 1997; Ballard et al., 1987; Woolington, 2009b).

Wolves have prolific reproductive potential (Ballard et al., 1987; Boertje and Stephenson, 1992), and pups generally experience high survival rates through their first autumn (Adams et al., 2008; Ballard et al., 1987). These pulsed increases in pack size each year must be compensated for by a combination of mortality and emigration, if the population size is to remain roughly constant over time (Adams et al., 2008). The relative contribution of emigration, natural mortality, and human-caused mortality in wolf packs has varied substantially in different parts of Alaska.

In the central Brooks Range in northern Alaska, during the period 1987 to 1991, the resident wolf population increased by 5% per year while experiencing a 12% annual harvest rate (Adams et al., 2008). Harvest and natural causes were each responsible for half the annual mortality in radio-collared wolves. Causes of natural deaths in those wolves, when distinguishable, were wolves killing other wolves (n=6), avalanche (n=1), and old age (n=1) (Adams et al., 2008). Pups constituted about half the wolf population each autumn, and young wolves emigrated from the study area at high rates as yearlings (47%) and two-year-olds (27%).

In northwest Alaska, during the period 1987 to 1992, the annual survival rate averaged 55.2% for radio-collared wolves (Ballard et al., 1997). Hunting was responsible for 69% of known mortalities. Rabies was also a significant cause of death in this population (21% of mortalities) during the period 1989 to 1991. Twenty-one wolves (25%) dispersed from their original territory during the study, with the highest rates of dispersal occurring during the rabies outbreak.

In south-central Alaska, in GMU 13 (the Nelchina and upper Susitna basins), wolf population levels were highest at the beginning of one study period (1975) and declined each year through the end of the study (1982), due to aircraft-assisted ground shooting and state-managed wolf control (Ballard et al., 1987). Litter sizes in this wolf population ranged from two to nine pups,

with an average of six pups. Natural mortality accounted for only 20% of total wolf mortality in that study. That wolf population could sustain a mortality rate of 50% from all sources before experiencing a population decline. Human harvests in excess of 40% of autumn wolf numbers caused population declines. Wolf control practices were effective at reducing wolf numbers, but when wolf control ceased the wolf population rebounded quickly.

Wolves re-established on the Kenai Peninsula by natural immigration in the 1960s, after being absent since the early 1900s. That wolf population was studied during the period 1976 to 1981, and population changes were documented (Peterson et al., 1984). Wolf density in the winter of 1976/1977 was 11 wolves/1,000 km^2; density increased to 16 in 1978/1979, dropped to 11 to 12 in 1980/1981, and increased back to 18 to 19 in 1981/1982. Annual survival rate for radio-collared wolves declined during each year of the study, from 100% in 1976/1977 to 44% in 1980/1981. Harvest was responsible for the majority of mortality. Reported harvest averaged 30% annually, and annual mortality of radio-collared wolves was 32%. Dispersal was found to play a key role in wolf population dynamics during this study. Dispersing wolves were highly vulnerable to harvest (the annual survival rate for dispersing adults was only 38%, compared to 73% for resident adults), but those dispersers who survived to reproduce were critical to the maintenance of population densities in spite of increased mortality rates (Peterson et al., 1984).

In LCNPP 17 wolves were radio collared in a three-year period (2009 to 2011). Of the 17 wolves collared, eight died during that time. Three were harvested, two died in intra-specific fights, one drowned, and two died from unknown causes. Annual survival for all age classes for each year of the study was 75%, 63%, and 75%. Of five dispersing wolves in LCNPP, survival was estimated at 60%, but this is likely a high estimate (Mangipane, personal communication).

Population Estimates

There are between 7,000 and 11,000 gray wolves in Alaska. The highest densities occur on the islands associated with the southeastern panhandle where deer (are the principle prey and the lowest densities occur in mountainous areas where prey consists mostly of Dall sheep or mountain goats (Fuller et al., 2003; Person et al., 1996). Two genetically distinct wolf populations are recognized within Alaska, those occupying the coastal zone of southeastern Alaska and those inhabiting the rest of the state (Weckworth et al., 2005). During 2000 to 2009, 1,200 to 1,600 wolves, about 14 to 16% of the estimated population, were reported harvested annually in Alaska. It is estimated that wolf populations can usually sustain 30 to 40% total annual mortality (Fuller et al., 2003).

Wolf population numbers have not been well studied in the Nushagak and Kvichak watersheds. Better regional wolf population estimates, gathered using scientifically rigorous methods, are needed to improve understanding of wolf populations in the study area. Wolf populations are highly dynamic, so population estimates must be conducted on a relatively frequent basis. Additionally, wolf population numbers in this area are difficult to obtain due to vegetation and inconsistent snow conditions. Dense vegetation and sparse or inconsistent snow make sighting of wolves from the air challenging.

No population estimation surveys for wolves have been conducted in the Nushagak watershed (GMUs 17B and 17C; Figure 3) (Woolington, 2009b). ADF&G impressions of wolf population

status in GMU 17 (the Nushagak and Togiak watersheds, west to Cape Newenham) are based on observations of wolves and tracks, reports from the public, bounty records from 1962 through 1971, mandatory sealing records from 1972 to present, and an annual trapper questionnaire program initiated in 1988 (Woolington, 2009b). Based on these data, ADF&G biologists conclude that wolf density in GMU 17 peaked from 1974 to 1977 and then declined sharply by 1980. Wolf densities seemed to increase again until 1989, when a rabies outbreak affected canid populations in GMU 17. Wolf populations began to increase again in 1992, and wolves are now thought to be "abundant" throughout GMU 17 (Woolington, 2009b). Woolington (2009) provided current wolf population estimates for GMU 17, but these were considered too speculative to rely on for this assessment and are not repeated here.

The Kvichak watershed, the other large drainage in the study area, is located in GMU 9, which extends from LCNPP to False Pass. Wolf population estimates for the region are available, but they should be used with caution for several reasons. ADF&G has grouped GMUs 9 and 10 (the Aleutian Islands) for statistical purposes, so those wolf population estimates include lands outside the study area. Also, wolf population dynamics have been studied only lightly in the region, and only limited descriptions of methods and results are available (Butler, 2009b). Methods consisted of monitoring ten wolf packs using radio-collar tracking, monitoring trends through observations during other fieldwork, reviewing reports from hunters and guides, and collecting responses to annual trapper questionnaires. Using these data, ADF&G estimated a total population of 350 to 550 wolves in GMUs 9 and 10 (Butler, 2009b). Biologists concluded that wolf densities in GMU 9 and 10 are low to moderate, but wolf numbers in GMU 9 appear to have increased since the 1990s, despite a decline in caribou populations. Possible explanations hypothesized for this increase in wolves included an abundance of alternate prey such as marine mammal carcasses, salmon or snowshoe hares, a population rebound following a high period of mortality from a rabies outbreak, or wolf immigration from surrounding areas (Butler, 2009b). Data are not available to directly evaluate these hypotheses. Estimated wolf densities in GMU 9E (the Alaska Peninsula south to Port Moller) and the southwestern portion of GMU 9C (the Naknek watershed outside Katmai NPP) are 6 to 7 wolves per 1000 km^2 (Watts, personal communication).

Human Use/Interaction/Management

Reporting of wolf harvest in Alaska is mandatory, but reporting compliance is suspected to be weak in some areas (Ballard et al., 1997). The degree of reporting compliance within the Nushagak and Kvichak watersheds is unknown. The reported wolf harvest in GMUs 9, 10 and 17 for the period 2003 to 2008 are summarized in Table 7.

Table 7. Total wolf harvests in GMUs 9, 10 and 17 reported to Alaska Department of Fish and Game.

Year	GMU 9 and 10[a]	GMU 17[b]
2003-04	119	141
2004-05	64	60
2005-06	120	62
2006-07	85	79
2007-08	110	73

a= Butler 2009; b=Woolington 2009

Alaska harvests of wolves vary widely due to fur prices, hunter access to wolf habitat, predator control policies and practices, and population changes in response to prey populations. Hunter access is influenced by winter travel conditions (Woolington, 2009b), including snow depth and fuel prices. Wolves in the Bristol Bay area are typically hunted and trapped by local residents, but are also harvested opportunistically by non-local hunters.

Trappers from southwest Alaska indicated that wolf was the fourth most important species they targeted (as defined by the trappers themselves), behind otter, beaver and fox (in that order) (ADF&G, 2010). State trapping regulations do not distinguish between different types of use, such as "subsistence," "recreational," or "commercial" (ADF&G, 2011b). Most rural Alaska communities are supported by a mixed subsistence-cash economy (Wolfe, 1991). Trapping is one of many traditional subsistence activities that can provide a modest income for participants. Some harvested furs are sold to dealers, but others are used locally. Furs are often made into hand-crafted items, which are more valuable than the raw pelts (Wolfe, 1991). Items commonly crafted with furs include mitts, coats, boots, fur ruffs, and slippers. In some rural areas, households use most of their harvested wolf pelts locally for ruffs, hats, and lining for winter gear, because imported materials are considered inferior (Wolfe, 1991).

EPA-6363-000003026

WATERFOWL

Introduction

The purpose of this report is to provide a characterization of waterfowl resources (Anatidae) in the Nushagak and Kvichak watersheds. The waterfowl family includes swans, geese, and ducks (dabbling, diving, and sea). This overview is not a comprehensive account of the status, ecology, and life history of all species of waterfowl that regularly occur in the Bristol Bay region. Instead, this section briefly summarizes the prominent species, general habitat associations and their seasonal occurrence by subregion; highlights some primary ecological relationships between waterfowl and sources of nutrients, particularly salmon, that support habitats and food resources; and describes human values and uses of waterfowl from Bristol Bay. Waterfowl data and other biological information are from currently available sources.

Waterfowl information in this report has been organized by geographic subregions (Estuaries and Inner Bay, Lowlands and Inland Tundra/Taiga) because of substantially different species composition, seasonal use patterns, ecological settings, and extent of available biological information. To a large extent, information in this report is constrained to the Nushagak and Kvichak watersheds, a subset of the greater Bristol Bay region that has been interpreted as widely as the area from Cape Pierce to the end of the Alaska Peninsula.

Regional Overview-

The Bristol Bay region hosts 34 regularly occurring species of waterfowl (Appendix 2). The diverse wetlands and other aquatic habitats of the region include boreal forest and taiga lakes and ponds inland near Lake Clark, river basin wetlands and lakes along the Mulchatna, Nushagak and Kvichak valleys, tundra ponds and lakes of the lowlands, and coastal tide flats and estuaries. The diversity and extensiveness of these habitats provide habitat for many species of waterfowl as breeding birds, migrants during the summer molt, fall and spring migrants, and wintering birds.

Geographically, the Bristol Bay region is positioned as a major northern spring staging area for waterfowl destined to breed in western and northern Alaska, Russia, and Arctic Canada. At the southern extent of Bering Sea ice, the rich estuaries of Bristol Bay provide food and resting areas for migrants that are advancing north in spring (King, 1982). Spring aggregations include swans, geese and ducks arriving from Mexico and the western U.S.; sea ducks from the Pacific coast of North America (Baja Mexico, British Columbia, southeast and Gulf Coast of Alaska); and emperor geese (*Chen canagica*) and sea ducks from the Aleutian Islands.

During summer, the estuaries of Bristol Bay and Kuskokwim Bay to the north serve as traditional molting areas for large numbers of scoters that gather from the Bering Sea and western Arctic regions. These shallows provide food-rich and secure habitats at a time when these birds are nutritionally stressed and flightless. Molting occurs from July through September, varying among subadults and adults, males and females.

Bristol Bay is an important fall staging area for waterfowl migrating south from northern and local breeding areas. Fall migration tends to be faster and more direct to staging areas than spring migration. From mid-August through early October, ducks, Canada (*Branta canadensis*) and

EPA-6363-000003027

greater white-fronted (*Anser albifrons*) geese move overland through the passes of the Alaska Range to Cook Inlet coastal marshes (Redoubt Bay, Trading Bay, Susitna Flats, and Palmer Hay Flats). Large numbers of ducks and geese orient to the rich lagoons and coastal tundra on the north side of the Alaska Peninsula west to Izembek Lagoon. Canada, cackling (*Branta hutchinsii*) and white-fronted geese; brant (*Branta bernicla*); and most dabbling ducks depart by early November, either eastward along Alaska's south coast or directly across the Gulf of Alaska to points between British Columbia and Mexico. Most dabbling and diving ducks from western Alaska orient to wintering areas in the Pacific Flyway west of the Rocky Mountains, but some greater scaup (*Aythya marila)* and other ducks cross the continent to the Gulf of Mexico and Atlantic Coast (King, 1973; King and Lensink, 1971). Some sea ducks, an increasing number of Pacific brant (Ward et al., 2009), and even a small population of tundra swans (*Cygnus columbianus*) winter along the Alaska Peninsula, while others and emperor geese move into the Aleutian Islands.

History of Waterfowl Surveys-

Much of the quantitative data on waterfowl numbers and distribution in the greater Bristol Bay region are derived from surveys conducted over different areas. In many respects, the distributions and habitat use patterns of waterfowl in the Nushagak and Kvichak watersheds intergrade with habitats west of the Nushagak Peninsula and down the Alaska Peninsula to Izembek Lagoon. Information summarized in this report focuses, as much as possible, on the inner bay, lowlands, and inland subregions of the Nushagak and Kvichak watersheds.

Osgood (1904) provides a broad and detailed description of habitats and wildlife of the Bristol Bay region from his 1902 reconnaissance survey, mostly by canoe, starting from Cook Inlet and travelling to Iliamna Lake and Lake Clark, then up the Chulitna River and down the Koktuli, Mulchatna, and Nushagak Rivers to Bristol Bay. His trip continued by schooner to Egegik, over the Alaska Peninsula at Becharof Lake, and then by rowboat to Cold Bay. Hurley (1931; 1932 records bird observations in the Bristol Bay region. Murie (1959) summarized the environment, habitats and wildlife of the Aleutian Islands and Alaska Peninsula, with some coverage of Kvichak and Nushagak Bays, from his 1936-37 boat-based expedition. Both Osgood and Murie provide species accounts of waterfowl, reviewing records of earlier observers. Gabrielson (1944) compiled general records of birds on his extensive trip in summer 1940, including travel up the Kvichak River, across Iliamna Lake and portage to Cook Inlet. Hine (1919) and Cahalane (1944) described birds of the nearby Katmai region. Gabrielson and Lincoln (1959) provided the most thorough compilation of bird records of their day in *The Birds of Alaska*, including information on migration patterns, ecological zones and detailed species accounts. Gill et al. (1981) describe the waterfowl and other birds of the north-central Alaska Peninsula.

Quantitative surveys of Bristol Bay waterfowl were established in the 1950s to monitor ducks and geese on prime lowland nesting habitats as part of the annual North American breeding population survey (Hodges et al., 1996). Interest in oil and gas exploration and other resource development stimulated more extensive surveys of waterfowl in coastal areas (Bartonek and Gibson, 1972; King and McKnight, 1969). The Coastal Zone Management Act of 1972 provided funding to states to synthesize information and establish cooperative wildlife resource inventories in coastal areas (Timm, 1977). In 1974, the Outer Continental Shelf Environmental Assessment Program (OCSEAP) stimulated many surveys and research projects related to

waterfowl in the Gulf of Alaska, Bering Sea, and Beaufort Sea. This program greatly expanded the amount of information on waterfowl and other birds in Bristol Bay (Arneson, 1980). Information on waterfowl and other wildlife resources in the region have been reviewed broadly by Timm (1977); USFWS (1976); and USFWS (1983).

The longest-term and most consistent waterfowl surveys in the Bristol Bay region are part of the Alaska-Yukon Waterfowl Breeding Population Survey (AYWBPS), flown annually by USFWS since 1957 as part of a North American duck survey program (Mallek and Groves, 2010). This survey was designed to index breeding dabbling ducks during the early egg-laying period (late May) to provide annual status data and long term trends. Bristol Bay (Stratum 8 in this statewide survey) is composed of 11 transects in 23 segments, sampling an area of 25,641 km^2 (9,900 mi^2) usually flown in late May.

From 1989 through 1997, USFWS conducted a series of experimental expanded surveys of major tundra waterfowl areas to assess means of providing more reliable annual estimates of abundance (Conant et al., 2007). The expanded waterfowl surveys flown by Platte and Butler (1995) over the Bristol Bay region in 1993 and 1994 covered a much broader area (49,890 km^2) than the traditional AYWBPS, extending west to Togiak Bay and Togiak River drainage, covering more a northerly band from Wood-Tikchik Lakes eastward to Port Alsworth, and southwest on the Alaska Peninsula to include Port Heiden and the Seal Islands. The data from this experimental survey reflect a much wider range of habitats and duck densities than the traditional AYWBPS survey (Conant et al., 2007).

Coastline and estuarine waterfowl surveys of Bristol Bay, focusing on emperor geese, have been conducted annually in spring (1981-2011) (Dau and Mallek, 2011) and fall (1980-2011) (Mallek and Dau, 2011). Steller's eider are the focus of Bristol Bay surveys conducted since 1992 (Larned and Bollinger, 2011).

Waterfowl Resources and Seasonal Occurrence

Estuaries and Inner Bristol Bay-

Bristol Bay estuaries and nearshore waters are important to waterfowl year round, during spring and fall migration, summer molting, and as winter range for some species. King and McKnight (1969) made a first attempt to estimate the number of birds in Bristol Bay during October, flying transects from the high tide line offshore to 12 miles (19.3 km). Their survey covered over 20,700 km^2 of coast from Cape Constantine south and west to Unimak Island, and included lines in outer Kvichak and Nushagak Bays.

During the early 1970s, Bristol Bay became a focal area of the OCSEAP studies, including offshore transect surveys of birds from Kvichak Bay south along the Alaska Peninsula (Bartonek and Gibson, 1972; USFWS, 1976). Most of the survey coverage was over the outer bay beyond the BBWA area, but it provides insights to the seasonal use of Bristol Bay nearshore waters.

Additional coastal bird surveys were flown for OCSEAP between October 1975 and August 1978 (Arneson, 1980). These 33 surveys from the Gulf of Alaska through the Aleutian Islands were designed to assess seasonal bird densities and distributions in littoral/nearshore waters, describe coastal habitats, and document migration. The North-Bristol Bay region was surveyed

in spring (May) by fixed-wing aircraft, helicopter, and boats. Sections 1-6 of the study area covered the coast of Kvichak Bay to Cape Constantine within the BBWA study area.

Habitats- The estuaries and nearshore waters of Bristol Bay provide diverse aquatic habitats for waterfowl and other waterbirds (Michel et al., 1982; Selkregg, 1976). Arneson (1980) classified over 30 types of coastal habitats, ranging from intertidal flats and salt marshes to open waters, to document seasonal usage by birds. He found about 80% of waterbirds on protected delta habitats and exposed inshore waters. Dabbling ducks and geese preferred mudflats and delta habitats; diving ducks and sea ducks were found mostly in exposed inshore and bay waters. A large proportion of Nushagak and Kvichak Bays has water depths of < 10 m (Schamber et al., 2010), which provides very accessible benthic habitats for diving and sea ducks that feed largely on invertebrates.

Geese- Most of the Pacific (black) brant population and the world population of emperor geese migrate through the greater Bristol Bay and Alaska Peninsula regions during spring and fall. Pacific brant breed mostly on the Y-K Delta and also along the Arctic Coasts of Alaska, northeast Russia, and Canada (Pacific Flyway Council, 2002; Reed et al., 1998). During April, Bristol Bay and the Alaska Peninsula serve as staging areas for birds assessing snowmelt and Bering Sea ice conditions. Chagvan and Nanvak Bays near Cape Newenham hold about 50,000 brant during spring, but only small numbers of brant use Nushagak or Kvichak Bays. From late August through mid-September, most brant leave breeding areas and move south along western Alaska directly to the Alaska Peninsula and eventually to Izembek Lagoon where the entire population stages until early November. Most brant depart the Peninsula *en masse* across the Pacific to wintering grounds from British Columbia to California, but most settle in the large bays of Baja Mexico (Dau, 1992; Pacific Flyway Council, 2002). Since the mid-1970s, milder conditions have allowed up to one-third of Pacific brant to winter along the western end of the Alaska Peninsula (Ward et al., 2009).

Emperor geese breed almost entirely on the coastal zone of the Y-K Delta, with a few in Russia (Pacific Flyway Council, 2006; Petersen et al., 1994). They winter from the outer Alaska Peninsula westward into the Aleutian Islands. Like brant, emperor geese migrate in spring and fall through the greater Bristol Bay area and eastern Bering Sea coast. They stage and migrate mainly through bays to the west of the Nushagak Peninsula, but a few emperor geese occur in inner Bristol Bay. During fall large numbers of emperor geese cross Bristol Bay to the large lagoons on the north Alaska Peninsula, particularly the Seal Islands, Nelson Lagoon, and Izembek Lagoon (Petersen et al., 1994).

Ducks- The nearshore waters of Bristol Bay host a large variety of ducks, including most of the common dabbling and diving duck species that use an array of habitats from intertidal marshes to offshore waters. During spring surveys in 1976-77, diving duck densities were 10-100/km^2 along the north side of Kvichak Bay and around Nushagak Bay (Arneson, 1980). Data from Kvichak Bay indicated 259 birds/km^2, mostly shorebirds, dabbling ducks (81/km^2), and diving ducks on tide flats. In south and east Nushagak Bay, high densities (171/km^2) of scaup (*Aythya spp*.) were concentrated along Flounder Flats, mixed with flocks of black scoters (*Melanitta americana*).

Deeper more open waters are used by diving ducks and sea ducks. Relatively high densities of sea ducks (26/km^2) were recorded during surveys on the east side of the Nushagak Peninsula (Arneson, 1980), composed of 10% long-tailed ducks (*Clangula hyemalis*) and 12% harlequin ducks (*Histrionicus histrionicus*). The majority of ducks in exposed waters and areas out to > 10 m deep were greater scaup, scoters, and eiders (see below). During spring and fall, smaller numbers of long-tailed ducks, harlequin ducks, and goldeneyes (*Bucephala* spp.) occur in the inner Bay. Up to 48,000 long-tailed ducks have been recorded in greater Bristol Bay during April (Larned and Bollinger, 2011) on their way inland or northward for breeding; few long-tails occur during fall (Mallek and Dau, 2011). Harlequin ducks use the bay before and after breeding inland and on their way west to winter in the Aleutian Islands. Mallek and Dau (2011) counted 3,300 harlequins along the Bristol Bay and Alaska Peninsula coast during spring 2010 (peak count 6,114 in 1992) (USFWS, 1976).

<u>*Scoters*-</u> Bristol Bay, especially Kvichak Bay, is an important staging and molting area for black, surf (*Melanitta perspicillata*), and white-winged (*M. fusca*) scoters spring through fall. Early surveys often did not accurately record scoters by species, but over the past ten years, focused surveys have produced species estimates, especially for black scoters.

Spring OCSEAP surveys along more pelagic transects tallied over 253,000 scoters in May 1972 and 216,000 scoters in April 1973 (USFWS, 1976). Arneson (1980) estimated that black scoters comprised 97% of all scoters counted during spring surveys in 1976 and 1977. More recent spring estimates also have documented large number of scoters in the inner bay, including up to 45,000 black scoters (Larned, 2008).

Scoters gather in Bristol Bay during the wing molt from July through September. OCSEAP surveys counted 180,000 in July 1973 (Dau, personal communication; USFWS, 1976). A high proportion of 77 satellite-marked black scoters from several wintering areas gathered in northeast Bristol Bay where they spent an average of 15-20 days from June through September (Schamber et al., 2010).

Though King and McKnight (1969) did not provide bird distribution data, they documented about 181,000 scoters during October staging, including approximately 140,000 black scoters. On the more pelagic OCSEAP surveys, over 285,000 scoters were estimated in the outer bay during October 1974 (USFWS, 1976). Larned and Tiplady (1998) found about 20,000 black scoters in the bay during late September. Few scoters are thought to winter in upper Bristol Bay (Bellrose, 1980; Schamber et al., 2010); most probably disperse westward along the Alaska Peninsula.

Satellite telemetry indicates that black scoters from widely separate wintering areas (British Columbia, Kodiak, and Dutch Harbor) all used Bristol Bay from spring through fall (Bowman et al., 2007). Analysis of cumulative satellite locations throughout the year indicates that black scoters mostly use specific areas of shallow (< 3 m) waters along the north side of Kvichak Bay, western Nushagak Bay, and Egegik Bay to the south (Schamber et al., 2010).

<u>*King Eiders*-</u> King eiders (*Somateria spectabilis*) in North America breed across the Alaska North Slope and Arctic Canada, but inner Bristol Bay waters are important to king eiders as both

a wintering area and as a major spring staging area (Suydam, 2000). Spring, OCSEAP surveys estimated that about 280,000 king eiders were in outer Bristol Bay in May 1972, and over 1.8 million were found in April 1973 (USFWS, 1976). Arneson (1980) estimated eider composition was about 45% king, 36% common (*S. mollissima*), and 19% Steller's (*Polysticta stelleri*) during spring coastal surveys in 1976 and 1977.

In the late 1990s, king eiders marked with satellite tags guided aerial surveys to document staging and molting areas (Larned and Tiplady, 1998). During April surveys for Steller's eiders, Larned (2008) estimated over 570,000 king eiders in Kvichak Bay in 2008; an average of 194,000 king eiders were estimated from these surveys from 2000 to 2009 (Larned and Bollinger, 2011).

Bristol Bay has been documented as one of a few important molt areas for king eiders; other areas include the northeast Russian coast and St. Lawrence Island (Phillips et al., 2006). Based on satellite tracking, Bristol Bay molters arrive from Alaska's North Slope (Phillips et al., 2006) and Arctic Canada (Dickson et al., 2001). Molt periods vary by sex and age of birds, but extend from August to October.

During fall, smaller numbers of king eiders have been recorded in the bay; as many as 20,000 were estimated in late September (Larned and Tiplady, 1998). Southwestern Alaska, especially inner Bristol Bay, is considered one of three main wintering areas of king eiders breeding in western North America, though these birds may move considerably within the region between October and April (Oppel et al., 2008).

Schamber et al. (2010) assessed the distribution of king eiders in Bristol Bay from year-round locations of satellite-marked birds. Across seasons, king eiders used most of the inner bay between the Nushagak Peninsula and Egegik Bay (averaging 10.6 km offshore), including areas with water depths of > 20 m, but they particularly frequented defined areas off Etolin Point, Half Moon Bay, and Egegik Bay where water depths were < 10 m.

Steller's Eiders- Bristol Bay coastal waters host Steller's eiders mostly in spring and fall, but they are not thought to breed in the region. The historical breeding range of the species in Alaska extends from the Y-K Delta into northwest Alaska and the western North Slope (Fredrickson, 2001). Along with a large number of Steller's eiders that breed west to the central Siberian coast, the Alaska birds are part of a Pacific (Russia-Alaska) population that probably numbers between 130,000 (Hodges and Eldridge, 2001; USFWS, 1999) and 150,000 (Fredrickson, 2001). Though historical data are not quantified, the number of Steller's eiders breeding in Alaska declined sometime between the 1940s and 1960s, especially on the Y-K Delta (Kertell, 1991). Based on estimates that there were perhaps fewer than 3,000 birds breeding over a substantially reduced range in Alaska during the 1990s, the USFWS listed the Alaska-breeding component of the population as threatened under the Endangered Species Act in 1997 (USFWS, 2002).

The primary wintering grounds for the Pacific population extends from the central Alaska Peninsula westward into the Aleutian Islands (Fredrickson, 2001). Thus, most birds transit Bristol Bay in spring and fall. Surveys have been conducted to assess the Pacific population during spring migration (April-early May) since 1992, including survey sections between Cape

Constantine and the Naknek River (Larned and Bollinger, 2011). In general, spring staging Steller's eiders were concentrated along the Alaska Peninsula south of Egegik and west of the Nushagak Peninsula; very few birds used inner Bristol Bay. Coastal emperor goose surveys flown in late April show similar minimal occurrence of Steller's eiders in Nushagak and Kvichak Bays (Dau, personal communication; Dau and Mallek, 2011).

After breeding on more northern nesting areas, a large proportion of Pacific Steller's eiders begin to return to southwest Alaska in late June, in advance of the wing molt (Petersen, 1981). Few of these birds use inner Bristol Bay as they concentrate in the lagoons along the Alaska Peninsula (Dau, personal communication; Mallek and Dau, 2011). Molt migration progresses by sex and age classes, and the actual molt period extends from late July for subadults to October for adult females (Petersen, 1981). Bird numbers increase during fall staging, mainly in Nelson Lagoon and Izembek Lagoon, before moving westward to winter in the Aleutian Islands.

Bristol Bay Lowlands-

Habitats- The Bristol Bay lowlands are characterized by old glacial deposits with moraine lakes and ponds, glacial outwash and riverine deposits along floodplains, and mixed marine deposits near the mouths of the Nushagak and Kvichak Rivers. Landcover is mostly moist and wet tundra between Nushagak and Kvichak Bays, and in a broad region of the upper Mulchatna drainage. Tundra merges into lowland spruce-hardwood forest between the lower Nushagak River and the Wood-Tikchik Lakes, and in the Kvichak Valley to Iliamna Lake (Selkregg, 1976). This subregion has a wide diversity of freshwater lakes and ponds, as well as numerous floodplain wetlands.

Stratum 8 of the AYWBPS generally defines the "lowlands," including the area southwest of Iliamna Lake to the Nushagak Peninsula and extending southwest from Naknek River to Cinder River. Table 8 indicates the average indices and densities of 30 groups (32 species) of waterfowl recorded on aerial surveys flown annually in late May.

Swans- Most swans in the Bristol Bay region are tundra swans that comprise 10-15% of the Western Population which breeds from Kotzebue Sound to the outer Alaska Peninsula and winters from British Columbia to central California (Ely et al., 1997; Pacific Flyway Council, 2001). The most recent ten-year average index of swans from Bristol Bay (AYWBPS Stratum 8) is 15,400 (0.6/km^2). Tundra swans arrive as early as mid-March and numbers peak in late April (Wilk, 1988). The majority of swans move north to the Y-K Delta region, but those that breed in Bristol Bay initiate nests in early May and young hatch in early- to mid-June. Because Bristol Bay has an earlier spring thaw, the phenology of local breeding swans is 2-4 weeks earlier than those nesting on the Y-K Delta and northern Alaska. Wilk (1988) provides indications that earlier nesting in Bristol Bay supports larger average brood sizes and higher productivity.

Table 8. Average abundance indices and densities of species/groups recorded in late May on the Alaska Yukon Waterfowl Breeding Population Survey, Bristol Bay Lowlands (Stratum 8)

Species/Group	Long-term Average 1957-2011	Average Index 2002-2011	10-Yr Average Birds/km^2
Mallard	33,100	68,100	2.68
Gadwall	1,400	2,000	0.08
American Wigeon	25,200	55,300	2.16
Green-winged Teal	30,600	71,800	2.80
Blue-winged Teal	0	200	0.01
Northern Shoveler	13,300	33,500	1.30
Northern Pintail	57,300	82,100	3.20
Redhead	0	0	0.00
Canvasback	200	200	0.01
Scaup (Lesser, Greater)	79,800	94,000	3.67
Ring-necked Duck	400	0	0.00
Goldeneye (Common, Barrow's)	4,200	1,600	0.06
Bufflehead	500	300	0.01
Long-tailed Duck	13,700	5,200	0.20
Unidentified Eider	900	500	0.02
Common Eider	0	100	0.00
Spectacled Eider	0	0	0.00
Steller's Eider	0	0	0.00
King Eider	0	0	0.00
Unidentified Scoter	79,400	36,800	1.43
Surf Scoter	n/a [a]	400	0.01
White-winged Scoter	n/a [a]	2,300	0.09
Black Scoter	n/a [a]	37,600	1.47
Merganser (Common, Red-breasted)	2,700	5,300	0.21
TOTAL DUCKS	**346,500**	**497,000**	**19.38**
White-fronted Goose	5,100	5,300	0.21
Canada/Cackling Goose	2,400	2,300	0.09
Emperor Goose	0	0	0.00
(Pacific) Brant	0	100	0.00
TOTAL GEESE	**7,600**	**7,700**	**0.30**
Swan (Tundra, Trumpeter)	12,100	15,400	0.60
Sandhill Crane	3,300	5,300	0.20

[a] Scoters have been recorded by species only since 1993.

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Geese- Long-term average indices of geese in the region have been relatively stable over the past 30 years (Table 8), averaging 7,700 geese (0.3/km^2) during 2002-11, with greater white-fronted geese over twice as abundant as Canada geese (AYWBPS). Platte and Butler (1995) tallied 4,255 geese (0.09/km^2) over a survey area farther inland and estimated composition as 55% white-front and 45% Canada geese. Bristol Bay white-fronts currently comprise only a small portion of the Pacific Flyway population which breeds mostly on the Yukon-Kuskokwim (Y-K) Delta and numbers over 600,000. During the late 1970s and early 1980s, when Pacific white-fronts were overharvested and declined more than 80% (Pacific Flyway Council, 2003; Pamplin, 1986), Bristol Bay white-fronts made up about 15% of the population.

White-fronted geese from Bristol Bay have been shown to be slightly larger than most Pacific Flyway white-fronts from the Y-K Delta (Ely et al., 2005; Orthmeyer et al., 1995) though they are not considered taxonomically separate. Bristol Bay white-fronts also migrate south earlier than others in fall, passing through the Klamath Basin of Oregon and California in September, and overflying the Sacramento Valley where most Pacific white-fronts winter. Bristol Bay birds press further south to winter in the northern highlands of Mexico (Ely and Takekawa, 1996).

The Canada/cackling geese that breed in the Bristol Bay region include Taverner's cackling geese (*Branta hutchinsii Taverneri*) and lesser Canada geese (*Branta canadensis parvipes*), the former found closer to the coast. Taverner's geese breed extensively along the western and northern coastal regions of Alaska, and lesser Canada geese are found throughout Interior Alaska and Yukon Territory, but the breeding ranges of these two populations have not been delineated and there are no reliable population indices (Pacific Flyway Council, 1994). In fall, most lesser Canada geese migrate through Cook Inlet and along the Alaska coast to winter from British Columbia into Washington and Oregon while Taverner's geese staging on the western Alaska Peninsula make a direct migration across the Gulf of Alaska to wintering areas. During winter, most Taverner's and Lessers aggregate with over 250,000 other white-cheeked ("Canada") geese in southwest Washington and western Oregon. They also are found in the upper Columbia River Basin and east of the Cascade Mountains. Intermingling of populations precludes accurate winter inventories.

The smallest subspecies of cackling Geese (*B. h. minima*) migrates through the region en route to and from the Y-K Delta coast where they breed. Cackling geese are assessed annually on their breeding grounds, with survey results indicating substantial increases from a low of <30,000 in 1984 to 150,000-200,000 since 1997. During fall, nearly all of these cacklers historically staged along the Alaska Peninsula near Pilot Point and Cinder River (Sedinger and Bollinger, 1987). Since recovery from a major population decline from overharvest through the early 1980s (Pamplin, 1986), fall staging of cacklers has been more dispersed westward along the Alaska Peninsula (Gill et al., 1997) from which they migrate across the Gulf of Alaska. Prior to the 1980s, cacklers wintered in Central California, but now the majority of cacklers winter in the Willamette Valley of western Oregon and near the Lower Columbia River in southwest Washington (Pacific Flyway Council, 1999).

Brant and emperor geese move through Bristol Bay coastal habitats in spring and fall (see Estuaries and Inner Bristol Bay), but the lowlands are not considered a breeding area. Lesser

snow geese (*Chen caerulescens*) are occasionally seen in Bristol Bay during migration to and from Wrangel Island in Russia.

Ducks- Indices of duck abundance generally have been higher than long-term averages since 1995, as measured by the AYWBPS; the most recent ten-year average is about 497,000 ducks (19.4 ducks/km^2) (Table 8). The most prevalent duck species include greater and lesser scaup (*Aythya marila* and *A. affinis*; 3.7/km^2), northern pintail (*Anas acuta*; 3.2/km^2), green-winged teal (*A. crecca*; 2.8/km^2), mallard (*A. platyrhynchos*; 2.7/km^2), and American wigeon (*A. americana*; 2.2/km^2).

In their expanded survey area, Platte and Butler (1995) estimated averages of 355,200 ducks (7.12/km^2). Duck species composition was similar to the AYWBPS, with the highest average densities ranked as scaup (1.9/km^2), northern pintail (1.1/km^2), green-winged teal (1.0/km^2), and mallard (0.9/km^2). Gadwall (*A. strepera*), wigeon and shoveler (*A. clypeata*), at lower densities, were more prevalent south along the Alaska Peninsula. High to medium densities of scaup were recorded west of Iliamna Lake near the upper Kvichak and Alagnak Rivers.

Scaup- Greater and lesser scaup cannot be differentiated on aerial surveys, but most of the scaup breeding in tundra regions are assumed to be greater scaup (Hodges et al., 1996). The relatively high densities of scaup in the Bristol Bay lowlands recorded on the AYWBPS and expanded surveys suggest that this region hosts a substantial portion of the breeding greater scaup in North America. About 80% of greater scaup migrate across the continent in fall, stopping in the Great Lakes, and wintering along the northeast Atlantic Coast (Kessel et al., 2002). Others winter from south-central Alaska down the Pacific Coast.

Black scoters- Bristol Bay is recognized as one of the most important breeding areas for the western (Pacific) population of black scoters that occupies Alaska and western Canada. The Pacific population may number 200,000-400,000 birds (Bordage and Savard, 1995). The AYWBPS does not provide reliable indices for breeding scoters because it is flown before nest initiation, which is later (June) than other ducks, and because scoters also are found in taiga and boreal habitats outside traditional survey areas. Also, in the past, scoters were not identified to species level during AYWBPS surveys.

Through the Sea Duck Joint Venture, USFWS has been conducting additional aerial surveys designed for scoters in Alaska since 2007 to improve population estimates (Stehn et al., 2010; Stehn et al., 2006), particularly for black scoters that have shown historic declines (Bordage and Savard, 1995). The new surveys have produced recent estimates of 173,000 black scoters on all western Alaska tundra breeding areas (Stehn et al., 2010). Bristol Bay is an important breeding area, containing 46,100 black scoters (0.92/km^2), about 15% of surveyed ducks, in their expanded survey area (Platte and Butler, 1995). Densities were highest in a band from western Kvichak Bay to Lake Iliamna, and also along the western Alaska Peninsula between Egegik and Ugashik Bays.

Inland Tundra/Taiga-

Habitats- The inland subregion of Bristol Bay is underlain by glacial deposits that are interspersed with bedrock formations in the upper Kvichak and Mulchatna drainages. Bedrock

dominates in the montane areas south and east of Lake Clark. Vegetation communities represent a transition from moist tundra to the west into tall shrub habitats and upland spruce hardwood forest; alpine tundra rises into the Aleutian Range (Selkregg, 1976). The subregion has abundant aquatic habitats from alpine lakes and glacial lakes to wet tundra wetlands and floodplain basins along rivers.

Williamson and Peyton (1962) reviewed the characteristics and historical ecological classifications of the Iliamna Lake region, concurring with previous observers that the region's dominant feature is transitional communities where the interior/arctic, southcentral coast forest, and western tundra ecotypes meet. They indicate that neither the dissected Aleutian Range to the east nor the open plateaus to the west serve as barriers for avifauna. These authors describe 12 ecological formations (habitat types) and their associated birds species. Generally, Williamson and Peyton (1962) recorded strong associations of 15 waterfowl species to open lakes and ponds, secondary preferences for streams and rivers by most species, and use of freshwater marshes by dabbling ducks.

Aside from less detailed historical accounts, information on waterfowl distribution and abundance is found in Williamson and Peyton (1962), some aerial survey coverage by Platte and Butler (1995), and a few observations in montane habitats by Ruthrauff et al. (2007).

The most current waterfowl surveys for the inland/Iliamna region are from contract projects for Pebble Limited Partnership (PLP). They include aerial surveys for waterbirds from 2004 to 2006 north of Iliamna Lake during spring staging, breeding/brood surveys, and fall. Some surveys focused on harlequin ducks and tundra swans. Overall, 22 species of breeding waterfowl were recorded (including scaup, goldeneye, mallard, green-wing, pintail), averaging 10 ducks/km^2. Only very general summary information has been made available on the PLP website and in public presentations (Pebble Partnership, 2011).

<u>Swans-</u> Trumpeter swans (*Cygnus buccinator*) are found in the eastern portion of the Bristol Bay region, associated with the forested and taiga habitats typical of the boreal zone. This area abuts temperate coastal forest and coastal marshes occupied by trumpeter swans in Cook Inlet. As their name suggests, tundra swans are primarily birds of open tundra. They have an extensive breeding distribution from the Alaska Peninsula and Bristol Bay coast inland to the Iliamna Lake and Lake Clark regions. The Pacific Coast Population of trumpeter swans has been increasing, including breeders on the Kenai Peninsula, Cook Inlet lowlands and upper Kuskokwim valley. There is increasing evidence that trumpeters are expanding their range westward into tundra swan habitats (Pacific Flyway Council, 2008).

<u>Geese-</u> Lesser Canada geese (*B.c. parvipes*) are found throughout southcentral Alaska and interior portions of southwest Alaska. Though survey data and descriptions of geese are not readily available, it is possible that some Taverner's cackling geese (*B.h. taverneri*) may breed in the inland subregion. The ranges of these similar medium-sized geese have not been delineated. Canada/cackling geese are listed as common in Lake Clark National Park (National Park Service, 2011) and in the Kvichak River valley. Greater white-fronted and snow geese occur during spring and fall migrations to and from Cook Inlet, and brant have been recorded rarely.

Ducks- The densities of dabbling ducks are only moderate in the inland subregion, with mallards, northern pintail and green-winged teal as the most common. Aerial surveys suggest pockets of spring duck habitat near the head of the Kvichak River and the upper portions of the Chulitna and Mulchatna drainages (Platte and Butler, 1995). American wigeon and northern shovelers were less abundant. Scaup and black scoters associated with boreal habitats also occurred in the same general areas, with densities in some up to >8 birds/km^2. Among sea duck species, long-tailed duck, surf scoter, white-winged scoter, common goldeneye (*Bucephala clangula*), Barrow's goldeneye (*Bucephala islandica*), red-breasted merganser (*Mergus serrator*) and common merganser (*Mergus merganser*) were distributed more sparsely and at low densities. Harlequin ducks are found in low densities throughout the Bristol Bay region, using clear high-gradient streams during the breeding season. Harlequins are difficult to detect on aerial surveys due to the habitat they use and are often underestimated.

Nutrients, Trophic Relations and Foods

For waterfowl, body condition, reproductive success, and survival are dependent on the quantity and quality of foods available throughout their annual cycle. Waterfowl typically experience the greatest energetic demands before and during migrations; in the pre-breeding period when resources are needed for egg-laying, incubation, and territory defense; and during summer molt when feather replacement taxes reserves. Though stored reserves (body fat and protein) may be used during migration and incubation, waterfowl need to select habitats that have abundant food resources, be able to efficiently exploit specific foods, and be mobile to optimize seasonal foraging strategies.

Nutrients and Habitat Productivity-

In Alaska, the most productive waterfowl habitats are those that have dynamic nutrient systems that produce seasonally rich plant and animal foods for birds. For example, the mixing of marine nutrients from upwellings and terrestrial nutrients from rivers and streams enrich the productivity of coastal estuaries and lagoons. Large river deltas (Stikine, Copper, Yukon-Kuskokwim, Colville, etc.) are the best examples of complex interfaces of marine and terrestrial nutrients in a matrix of low-lying depositional wetlands, and they support high densities of breeding waterfowl. The estuaries and nearshore waters of Nushagak and Kvichak Bays are enriched by such nutrient mixing (Straty, 1977) in coastal marshes used by swans, geese, and dabbling ducks, and abundant benthic invertebrates for diving and sea ducks.

The productivity of waterfowl habitats in inland-interior regions are also based on dynamic nutrient systems mostly associated with river basin wetlands and floodplains. Within the extensive watersheds of large rivers, nutrient flux (largely nitrogen and phosphorus) is driven by upstream erosion, in-stream transport and seasonal flooding. In forested areas, mosaic patterns of wild fires can also be sources of nutrients for wetlands (Bayley et al., 1992). In the Bristol Bay region, Selkregg (1976) notes a long history of wild fires in the Mulchatna Valley; upland spruce-hardwood forests are found in the upper drainages of the Mulchatna and Nushagak Rivers. Seasonal nutrient inputs refresh and subsidize primary productivity and development of aquatic invertebrates in floodplains and large wetland basins associated with valleys (Heglund, 1992). In the Nushagak and Kvichak River systems, the large volume of sockeye and other salmon species is a significant source of imported nutrients throughout these watersheds (see below).

Food Habits-

The waterfowl of Bristol Bay exhibit a wide diversity in foraging strategies and food habits; some species tend to be specialists and some are generalists, but nearly all adapt seasonally to different foods. Among swans, geese and ducks during the breeding season, some species defend territories that are selected for sufficient food supplies for nesting adults and growing young; others adapt more social and mobile strategies to take advantage of temporarily abundant foods. During non-breeding periods (migration, molt and winter) waterfowl often aggregate and exhibit fidelity to habitats and sites with reliable food resources.

In general, swans and geese are primarily vegetarians, although adults and young feed opportunistically on insects, aquatic invertebrates and other animal foods especially during breeding and brood-rearing season. Both trumpeter and tundra swans feed on submergent and emergent vegetation year round. The development of cygnets to fledging often extends into fall when their freshwater habitats begin to freeze and they may move to aquatic beds in flowing waters and coastal shallows prior to migration (Limpert and Earnst, 1994.; Mitchell and Eichholz, 2010).

Geese are primarily vegetation grazers, although adults and goslings opportunistically feed on insects and invertebrates. Canada, cackling, and white-fronted geese consume shoots and stems of graminoid plants in typical moist and wet tundra breeding areas. In coastal areas, broods are often brought to wetland basins, tide flats and salt marshes where foods are abundant. During fall staging, Canada and white-fronted geese often frequent uplands to feed on berries. Canada geese, emperor geese and brant are associated with coastal habitats where they rely on salt marsh vegetation, eelgrass beds (*Zostera marina*) in estuaries, and some marine algae (Petersen et al., 1994; Reed et al., 1998).

The three tribes of ducks that use Bristol Bay have very diverse foods habits (Table 9). Dabbling ducks (Anatini) are generally omnivorous, feeding on seeds and aquatic invertebrates, and focusing on high protein foods prior to breeding. Diving ducks (Aythyini) are also omnivorous, but they feed in more open waters for benthic invertebrates and focus on animal foods during staging and wintering on coastal waters. Sea ducks (Mergini) consume mostly animal foods year round, feeding on freshwater benthic invertebrates during breeding and a wide variety of marine invertebrates during staging and wintering on saltwater.

Table 9. General food habits and consumption of fish by duck species of Bristol Bay.

Common Name	General Food Habits	Consumption of Fish
Dabbling Ducks		
Gadwall	Primarily plant foods with some invertebrates during pre-breeding	Unknown
American Wigeon	Strongly vegetarian with some invertebrates during pre-breeding	Spring herring eggs Oregon coast (Bayer, 1980)
Mallard	Omnivorous, mostly plant seeds and invertebrates, increasing animal foods during pre-breeding	Incidental fish; fall and winter use of salmon eggs and flesh in spawning lakes and coastal waters (Gleason, 2007; Munro, 1943)
Northern Shoveler	Small invertebrates and seeds strained at the surface	Trace of fish in winter
Northern Pintail	Omnivorous, mostly grain and plant seeds with more invertebrates during pre-breeding	Unknown
Green-winged Teal	Omnivorous, mostly plant seeds and invertebrates, increasing animal foods during pre-breeding	Use of salmon eggs and salmon flesh in spawning streams (Gabrielson and Lincoln, 1959)
Diving Ducks		
Canvasback	Omnivorous, mostly plant buds, tubers, root stock and invertebrates, increasing animal foods in pre-breeding	Incidental small fish (Cottam, 1939); alewife fingerlings on fall migration in New York. Spring herring eggs Oregon coast (Bayer, 1980). Salmon flesh Washington coast (Dawson and Bowles, 1909)
Redhead	Omnivorous, mostly plant leaves and stems, invertebrates; increasing animal foods during pre-breeding	Spring herring eggs Oregon coast (Bayer, 1980). Largemouth bass eggs in freshwater (Jarvis and Noyes, 1986). Incidental small fish (Cottam, 1939)
Ring-necked Duck	Omnivorous, mostly plant seeds and invertebrates; increasing animal foods during pre-breeding	Incidental small fish (Cottam, 1939)
Greater Scaup	Omnivorous with varied local and seasonal focus on mollusks, crustaceans, insects	Incidental small fish (Cottam, 1939); fall and winter use of salmon eggs and flesh in coastal streams and lakes (Munro, 1941). Spring herring eggs (Bayer, 1980; Munro, 1941)
Lesser Scaup	Omnivorous with tendency toward animal foods, insects, mollusks, crustaceans	Light use of 8 species of fish and salmon eggs (Cottam, 1939); 3 species of fish during fall in Minnesota (Afton et al 1991); winter scavenging flesh of shad and sunfish (Christopher and Hill, 1988); Spring herring eggs Oregon coast (Bayer, 1980)
Sea Ducks		
Steller's Eider	Mostly animal foods; insect larvae on freshwater; crustaceans, mollusks, other invertebrates on saltwater	Low occurrence of small fish, probably incidental to benthic feeding (Cottam, 1939).
King Eider	Mostly insects and crustaceans with some plant foods on freshwater;	Spring use of lumpfish eggs in Norway; small amounts of sculpins and fish eggs

EPA-6363-000003040

Common Name	General Food Habits	Consumption of Fish
	mollusks, crustaceans and diverse marine invertebrates on saltwater.	in Alaska during winter (Cottam, 1939)
Common Eider (Pacific)	Mostly animal foods, mollusks, crustaceans and benthic marine invertebrates	Spring use of herring eggs (Cantin et al., 1974); scarce use of sculpins and sculpins roe in winter (Cottam, 1939)
Harlequin Duck	Foods almost entirely animal; freshwater invertebrates during nesting; diverse mollusks, crustaceans and other marine invertebrates during most of the year	Herring eggs in spring (Munro and Clemens, 1931; Vermeer, 1983); occasional freshwater fish and eggs; fry of char (Kistchinski, 1968); high use of salmon roe in streams in late summer (Dzinbal and Jarvis, 1984); salmon carcasses in streams and estuaries (Vermeer and Levings, 1977)
Surf Scoter	Mostly animal foods, insects and clams on freshwater; mollusks, crustaceans and other invertebrates on saltwater	Minor use of fish, but more than white-winged or black scoters. Herring eggs in spring (Bayer, 1980; Vermeer, 1981)
White-winged Scoter	Mostly animal foods; insects, clams and some plant material on freshwater; mollusks, crustaceans and other invertebrates on saltwater	Minor use of fish on fresh and saltwater; coastal herring eggs in spring (Bayer, 1980; Cottam, 1939; Munro and Clemens, 1931)
Black Scoter	Mostly animal foods; insects,, crustaceans and some plant foods on freshwater; mollusks and crustaceans on saltwater	Some use of freshwater fish eggs (Bengtson, 1971). Spring herring eggs (Bayer, 1980; Munro and Clemens, 1931)
Long-tailed Duck	Mostly animal foods; insects, crustaceans and some plant foods on freshwater; mollusks and crustaceans on saltwater	Some use of freshwater fish (Peterson and Ellarson, 1977). Herring eggs in spring (Munro and Clemens, 1931) and some bottom fish on saltwater in winter (Cottam, 1939; Sanger and Jones, 1984)
Bufflehead	Mostly animal foods with some plant material seasonally; insects and crustaceans on freshwater; crustaceans and mollusks in saltwater	Minor use of fish on freshwater; salmon eggs in coastal streams; fall and winter use of small fish; herring eggs in spring (Bayer, 1980; Munro, 1942; Vermeer, 1982)
Common Goldeneye	Mostly animal foods; insects, mollusks and crustaceans on freshwater; crustaceans and mollusks in saltwater	Diverse small fish and roe in freshwaters and saltwater (Cottam, 1939; Jones and Drobney, 1986); salmon eggs and flesh on coastal lakes and rivers (Taverner, 1934); herring eggs in spring (Munro and Clemens, 1931; Vermeer, 1982)
Barrow's Goldeneye	Mostly animal foods; insects, mollusks and crustaceans on freshwater; crustaceans and mollusks in saltwater	Herring eggs in spring (Munro and Clemens, 1931; Vermeer, 1982); small numbers of sculpins taken; salmon eggs and parr on freshwater (Fitzner and Gray, 1994; Munro, 1923); salmon flesh (Cottam, 1939)

Common Merganser	Primarily small fish, also insects, mollusks, crustaceans, and small vertebrates	Very diverse fish prey. Salmon are most important in some regions (Munro and Clemens, 1932; Munro and Clemens, 1937; Salyer and Lagler, 1940)
Red-breasted Merganser	Primarily small fish, also insects, mollusks, crustaceans, and small vertebrates	Diverse fish prey. Salmon are important in some regions (Munro and Clemens, 1939; White, 1957). Also take herring and roe

Information obtained primarily from species accounts in the Birds of North America (A. Poole, Ed.). Cornell Lab of Ornithology, Ithaca, NY. Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/

Importance of Marine-Derived Nutrients (Salmon and Herring) to Waterfowl-

Waterfowl benefit from salmon as both direct sources of prey and carrion and indirect nutrient drivers of aquatic systems (i.e., supporting invertebrate prey species and riverine plant communities). Roughly 30-40 million salmon spawn annually in the Kvichak and Nushagak systems (Hilborn et al., 2003; Ruggerone et al., 2010), importing perhaps 20 million kg (44 million pounds) of nutrients throughout the watersheds. The fate of these nutrients (primarily nitrogen and phosphorus) is divided among the breakdown of carcasses (Cederholm et al., 1989; Cederholm et al., 1999) and deposition in drainages, the outmigration of smolts (Crawford, 2001; Moore and Schindler, 2004), and discharge into estuaries. This large influx of nutrients and net gain to riverine and terrestrial systems strongly affects a wide variety of plants and animals, including waterfowl (Gende et al., 2002; Holtgrieve, 2009; Willson et al., 1998; Willson and Halupka, 1995).

Of the 24 duck species that regularly occur in Bristol Bay, at least eleven species are known to prey on salmon eggs, parr, smolts, and scavenge on flesh of spent carcasses (Table 9). Of these, greater and lesser scaup, harlequin duck, bufflehead, common and Barrow's goldeneyes, and common and red-breasted mergansers exhibit directed foraging on salmon. Among dabbling ducks, mallards feed most on salmon because they are distributed across a diversity of summer habitats in spawning areas, and they are the principal wintering dabbling duck on the North Pacific coast where fall-winter salmon runs occur.

From early May through June, salmon smolts emigrate from Bristol Bay rivers, providing abundant prey (325 million smolt in the Kvichak) (Crawford, 2001) for fish predators like mergansers (Munro and Clemens, 1932; Munro and Clemens, 1937; Munro and Clemens, 1939; Salyer and Lagler, 1940; White, 1957; Wood, 1987a; Wood, 1987b). Other duck species may prey on smolt incidentally.

From late June through early September, salmon eggs are readily available on and downstream of spawning beds. These eggs are a seasonally rich food source for harlequin ducks, goldeneyes and scaup that frequent rivers and streams (Cottam, 1939; Dzinbal and Jarvis, 1984; Munro, 1923) and probably for other opportunistic ducks.

From mid-July through September, salmon carcasses are abundant in streams, rivers and spawning lakes. Though the scientific literature is scarce on this subject, species ranging from

dabbling ducks (mallard, green-winged teal) and diving ducks to sea ducks that inhabit spawning waters opportunistically scavenge easy protein-rich meals (Table 9).

Harlequin ducks offer an example of a waterfowl species that utilizes salmon in all life stages. Harlequins breed in high gradient streams in the upper reaches of drainages (Robertson and Goudie, 1999), and they forage in portions of rivers and streams occupied by salmon. In the Kolyma Highlands in Russia, harlequins focused on fry of Dolly Varden (*Salvelinus malma*) and white-spotted char (*S. leucomaenis*) (Kistchinski, 1968). Gudmundsson (1971) noted a relationship between harlequin duck nesting areas and Atlantic salmon (*Salmo salar*) spawning areas in Iceland, but thought that ducks and salmon fry preyed on the same insect larvae. Dzinbal and Jarvis (1984) demonstrated that harlequins breeding in the short streams of northern Prince William Sound depended heavily on the dislodged eggs of pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon in the lower stream reaches from the first week of July to early August. In their study, the drifting biomass of salmon eggs exceeded the biomass of invertebrates in late July and early August. Harlequin ducks also scavenge from salmon carcasses from August through September (Vermeer and Levings, 1977). Winter diets did not include notable occurrence of fish (Fischer and Griffin, 2000; Vermeer, 1983).

Spring spawning of Pacific herring (*Clupea pallasi*) along Alaska coasts provides abundant food for waterfowl and many other waterbirds in need of energy during migration, and sea ducks follow the progressive spawning northward (Lok et al., 2008). Though the waters of inner Bristol Bay are turbid and not conducive to herring spawning, small concentrations may be found. The region's center of herring activity is the Togiak district west of Cape Constantine from Kulukak Bay to Cape Pierce (ADF&G, 2011c). Sixteen of Bristol Bay's duck species feed on herring and herring roe during spring (Table 9; (Bayer, 1980; Lok et al., 2011; Lok et al., 2008; Munro and Clemens, 1931; Vermeer, 1983)).

Populations, Subpopulations, and Genetics

Among waterfowl, the designation of subspecies, populations, and subpopulations has been applied through increasing research on genetic diversity and relatedness; a long history of morphological measurements; and evaluation of cohesiveness, philopatry, and annual distributions of birds from traditional banding and marking studies. Overall, few population units below the species level have been established for swans, geese, and ducks, probably because their extensive migrations and mobility across broad ranges provide genetic homogeneity. The American Ornithologist's Union (AOU) no longer taxonomically designates subspecies (American Ornithologists' Union, 2011) because of the difficulty in differentiating valid subunits and the dynamic nature of evolving groups.

In some cases, subspecies and populations have been defined when genetic, morphological and observational data support designations that are practical for population management, yet are provisional in terms of taxonomy. Population units also have been designated for purposes of monitoring biodiversity by programs such as the Alaska Natural Heritage program (Alaska Natural Heritage Program, 2011), but under varying scientific standards that may be less rigorous than taxonomic determinations. In addition, populations may be defined and designated for protection under the Endangered Species Act without strict evidence of discreteness or

genetic distinction. Following is a summary of current understanding of population structuring in the principal waterfowl species of Bristol Bay.

Swans-

Few distinctions have been made among trumpeter or tundra swans across their ranges. Trumpeter swans in Alaska are part of the Pacific Coast Population (PCP) that constitutes over 80% of the species in North America. Recent genetic studies (Oyler-McCance et al., 2007) indicate that PCP birds are distinguishable from Rocky Mountain Population (RMP) trumpeters that range from Yukon Territory south to Wyoming and Utah, but within Alaska trumpeters are fairly homogenous through the Interior and Cook Inlet. Copper River Delta breeders were somewhat unique because of their geographic isolation. Samples were taken from Susitna Basin and the Kenai Peninsula, but not from the eastern Bristol Bay region. Based on banding and marking studies, tundra swans in southwest Alaska are affiliated with the Western Population (WP) found wintering west of the Rocky Mountains (Pacific Flyway Council, 2001). The small non-migratory group on the end of the Alaska Peninsula is considered part of the WP, not a separate entity.

Geese-

The taxonomy of Canada geese has long been debated, but the recent species separation of cackling geese (*B. hutchinsii*) from Canada geese (*B. canadensis*) is based on extensive genetic studies (Paxinos et al., 2002; Scribner et al., 2003) that support divergence of three small subspecies (*hutchinsii*) from three larger subspecies (*canadensis*) during the last glacial period. The coastal Taverner's (cackling) goose and inland lesser (Canada) goose breeding in the Bristol Bay region, as well as the migrant Cackling (cackling) goose that passes through, have been managed somewhat separately for over 60 years. The extensive historical banding information and genetic evidence, warrants recognition of these populations among six white-cheeked goose populations in Alaska.

As mentioned previously, white fronted geese breeding in Bristol Bay are slightly different in morphology and migration patterns from other Pacific white-fronts nesting on the Y-K Delta, but the differences do not rise to the level of taxonomic significance, nor can they practically be managed separately (Ely et al., 2005; Orthmeyer et al., 1995; Pacific Flyway Council, 2003).

Dabbling and Diving Ducks-

Historically, there has been little to support identification of distinct populations among dabbling ducks (tribe *Anatini*) and diving ducks (tribe *Aythyini*) largely because of their extensive mobility and exchanges across flyways. No population structure has been suggested among these ducks for the Pacific Flyway or Bristol Bay, though extensive genetics studies have not been conducted.

Sea Ducks-

Over the past 10 years, declining trends in most sea duck species (tribe Mergini) and the listing of spectacled and Steller's eiders under ESA have prompted research into the structure and diversity of sea duck populations. In general, sea ducks are known to be quite philopatric to breeding, molting and wintering areas, suggesting the potential for discrete population units. In addition, sea ducks from broad breeding ranges aggregate in winter, making winter a critical

period of social and genetic interchange. These unique characteristics are important for understanding the biology of sea ducks and adopting effective management regimes.

The biology and population dynamics of harlequin ducks are not well understood, but they breed in the upper high-gradient drainages of Bristol Bay and occur in the upper bay, Alaska Peninsula, and Cook Inlet during the non-breeding season. Though these birds are generally segregated by river drainage during breeding and they demonstrate fidelity to wintering areas (Esler et al., 2000), dispersal occurs across regions (Cooke et al., 2000). No evidence has been found to genetically distinguish wintering harlequins from Prince William Sound, Kodiak and Katmai areas (Lanctot et al., 1999). This suggests that gene flow likely has occurred across broad areas and regionally discrete populations have not developed.

In a study of genetic structure among king eiders, samples were analyzed from Holarctic breeding areas from northeast Russia east to Greenland, and wintering areas in the Pacific and Atlantic sides of North America (Pearce et al., 2004). Results showed little genetic structuring across the range, indicating that historical or current mobility among regions has not produced discrete populations, particularly in western North America including the aggregations of molting and wintering birds of Bristol Bay.

The population structure of Steller's eiders has been of great interest to assess the status and prospects of the threatened Alaska-breeding component, particularly the small group breeding near Barrow. In a study that genetically compared samples from breeding and wintering areas of the Atlantic population (Russia-Norway) and the Pacific population (Russia-Alaska), some differentiation was found between the two greater populations, but no sign of subpopulation structure (Pearce et al., 2005). Similar to the situation with king eiders, genetic differentiation could develop in the future if natural or anthropogenic factors provide isolation of breeding groups.

Human Use

Bristol Bay waterfowl provide viewing, educational and research values, and harvest opportunities to people in Alaska, Russia, Canada, the western U.S., and Mexico. As described above, Bristol Bay is uniquely positioned to host a great diversity of waterfowl that breed, winter, or pass through the region. This includes birds associated with Arctic breeding grounds, the Aleutian Islands, the exceptionally productive tundra habitats of western Alaska, and birds that winter as far south as Mexico and east to Chesapeake Bay. Though most of the common waterfowl species of North America occur in the region, species such as swans, emperor geese, and eiders are especially appreciated for their aesthetic, scientific and cultural values. The richness and abundance of waterfowl from the region supports significant subsistence and recreational harvests that are important economically and traditionally throughout western North America.

Nonconsumptive Uses-

Birds that breed in or pass through Bristol Bay are subjects of wildlife viewing opportunities throughout their annual cycles, from Alaska to Mexico. During spring and fall migration, and during winter, Bristol Bay birds stop at many local, state, and federal parks and wildlife areas featuring viewing and interpretive facilities. For some species, special community events revolve

around the occurrence of migrating birds. For example, there are brant festivals in British Columbia, Puget Sound, and northern California, and brant are an attraction with whale watchers in Baja California. Such events and numerous local viewing programs are also common for swans, aggregations of geese, and sandhill cranes that breed in the Bristol Bay lowlands.

Recreational Harvest-

Because Bristol Bay is an important breeding and staging area for ducks and geese, birds produced in or supported by the region comprise a notable contribution to fall and winter harvests in the Pacific Flyway from Alaska to Mexico. Waterfowl harvest data have been collected by USFWS in Alaska since the early 1960s through a national mail questionnaire survey (MQS) of federal duck stamp buyers. Species composition of the harvest was estimated from duck wings and goose tails from a Parts Collection Survey (PCS). From 1971 through 1997 ADFG also conducted a mail questionnaire survey of hunters. Since 1998, waterfowl harvests have been estimated by USFWS through the national Harvest Information Program (HIP), based on a sample of all registered migratory bird hunters. The objective of all these surveys was to produce reliable estimates of duck and goose harvests at the statewide level.

There are no reliable estimates of fall duck and goose harvests in the Bristol Bay region. Although the ADFG survey and federal MQS surveys collected harvest data by regions, the hunter sampling rates were not sufficient to provide more than a general sense of harvest across the state. Bristol Bay was only part of a large sampling region named "Alaska Peninsula" that extended west to Unimak Pass where ADFG data indicate that 4,000-5,000 ducks and 2,000 geese were harvested annually. Through the 1990s, this amounted to roughly 5% of Alaska's fall duck harvest and 20-25% of the goose harvest. There are no recent regional harvest data.

Beyond southwest Alaska, birds that use Bristol Bay for some part of their life cycle contribute an unknown portion of fall harvests in south-central and southeast Alaska, which typically represent 60-70% of the statewide duck total (~70,000) and 30-40% of the statewide goose harvest (~6,100) (USFWS, 2010a). There is no practical way to estimate the proportion of ducks and geese from Bristol Bay harvested in the western states or other jurisdictions. Waterfowl banding has not been sufficient in the Bristol Bay region to undertake analysis of harvest derivation for the Pacific Flyway.

Since 2001, a fall tundra swan season has been open in Game Management Unit 17, with registration permits required. The unit includes the Togiak, Wood, and Nushagak drainages inland to Lake Clark. On average, fewer than 60 permits have been issued annually, and reported harvest has been less than ten swans per year (ADFG, unpubl. data). A small number of tundra swans harvested in Montana, Utah, and Nevada are derived from Bristol Bay.

Subsistence Harvest-

Harvest of waterfowl and other birds has been an important component of Bristol Bay's traditional subsistence culture and economy. Although spring and summer hunting occurred historically and continues, it was largely illegal after passage of the Migratory Bird Treaty Act of 1918. Fall and winter hunting, beginning September 1, has been allowed under federal and state regulations. In 1997 the United States Senate ratified Protocols that amended the migratory bird treaties with Canada and Mexico. This action authorized the USFWS to open a legal, regulated

spring and summer subsistence season for migratory birds in Alaska during 2003, the first in over 80 years. The Alaska Migratory Bird Co-Management Council (AMBCC) was formed, composed of USFWS, ADF&G, and 12 regional representatives to establish a body of subsistence hunting regulations and undertake the vital task of assessing spring and summer subsistence harvests to meet intentions of the amended treaties.

During the 1980s, ADF&G worked with federal agencies, Alaska Native regional organizations, and village governments to conduct subsistence harvest surveys of 151 rural communities in Alaska and they characterized the levels and nature of migratory bird subsistence harvest in Alaska, including Bristol Bay (Wolfe et al., 1990). In response to an intensive goose conservation program on the Y-K Delta, cooperative village harvest surveys were initiated across the region and eventually expanded to Bristol Bay villages that harvested the same goose populations (Wong and Wentworth, 1999). These surveys, begun in 1995, gathered harvest data by subregions, including Togiak, Dillingham, Iliamna, and villages in the Nushagak drainage and on the Alaska Peninsula.

In a review of historical and recent harvest information, the AMBCC found the available data to be insufficient to address management needs, so it designed a comprehensive statewide survey protocol (Alaska Migratory Bird Co-Management Council, 2003), including Bristol Bay communities on a rotating basis. Statewide subsistence harvest surveys were implemented annually from 2004 to 2009, although they were not fully funded and implemented to full performance standards.

In general, the seasonal harvest of migratory birds in the Bristol Bay region is most prevalent in spring, with a few species taken in summer, and increased hunting during fall migration and winter (Wolfe et al., 1990). The importance of the spring harvest reflects the abundance of birds during spring migration and traditional need for fresh meat after winter supplies have been depleted. For the Bristol Bay/Iliamna region (not including Alaska Peninsula), Wolfe et al. (1990) estimated annual harvests in the late 1980s of about 8,800 ducks, nearly 2,000 geese, 100 swans, and 1,100 waterfowl eggs. About 70% of households used birds; waterfowl provided 3.4 lbs of meat per capita.

Conservation concerns in the late 1980s prompted a statewide assessment of harvests for Pacific brant, emperor geese, and eider species (Wolfe and Paige, 1995). This study characterized harvest of these species circa the early 1990s and presented harvest estimates by regions (including North Bristol Bay, South Bristol Bay, and Lake Iliamna-Nushagak) and some communities from ADFG and USFWS surveys during 1983-94. Harvest estimates for Bristol Bay subregions provide totals for relative comparisons to other parts of the state, but also reflect the seasonal availability of species within the region.

Brant harvest was highest (~300) in the North Bristol Bay area where spring staging is concurrent with seal hunting (Schichnes and Chythlook, 1988), but was low in South Bristol Bay because most brant bypass that part of the Alaska Peninsula. Brant were rare inland in the Iliamna-Nushagak region. Emperor geese, which are closely tied to the coast in transit to and from the Aleutian Islands, provided harvest for North (~300) and South (~200) Bristol Bay, but were rare inland. Because of diminished numbers, all hunting of emperor geese was closed in

EPA-6363-000003047

1986. Eiders were harvested most in North Bristol Bay (~850) where king eiders are abundant during spring and molt in Nushagak and Kvichak Bay, and common eiders stage during migrations. Eider harvest was low in South Bristol Bay where king and common eiders are more transient. Only common eiders (~250) were recorded for the Iliamna-Nushagak region, probably representing either inland migrant birds from lower Cook Inlet or inland households hunting in coastal areas.

Harvest data from 1995-2005 were collected by subregion, including Dillingham, Nushagak River and Iliamna subregions (Wentworth, 2007; Wong and Wentworth, 1999). Estimated annual harvests included ~10,000 ducks (mostly dabbling ducks, with ~600 scoters, 100-200 eiders, and up to 190 harlequin ducks); 2,500-2,900 geese (up to 1,000 white-front, 800 Canada/cackling, 180-230 brant); up to 300 tundra swans; and fewer than 500 waterfowl eggs.

As part of the statewide AMBCC harvest survey program, Bristol Bay communities were sampled during 2004 to 2008, including a Southwest Bristol Bay Subregion from Togiak south to Port Heiden covering King Salmon and 20 villages in the Nushagak and Kvichak drainages, and a Dillingham Subregion sampled every other year. Recent harvest estimates and seasonality of species harvests are found in Naves (2010a, b). Approximate five-year average harvests for the villages are: ducks – 10,200 (includes 600 scoters, 1,600 eiders); geese – 5,200 (includes 2,700 Canada, 1,300 white-fronts, 1,100 brant); swans – 270; and waterfowl eggs – 800. Dillingham was surveyed on a rotational schedule (2005, 2007, 2008); results indicated estimated harvests of 1,000-5,000 ducks, 500-800 geese, up to 50 swans, and less than 100 waterfowl eggs (Naves, 2010a; Naves, 2010b).

It is difficult to precisely characterize subsistence harvest of waterfowl in the Nushagak and Kvichak watersheds and the greater Bristol Bay region because of subregional differences in the geographic diversity and seasonal availability of waterfowl species and other wildlife resources, as well as differences in cultural preferences and practices (Wright et al., 1985). In addition, local and regional harvests of migratory birds vary considerably year-to-year because of variations in bird abundance; timing, rates, and patterns of migrations; and seasonal hunting conditions (Wolfe et al., 1990). Assessments of changes or potential changes to subsistence uses of migratory birds will rely on updated status information for migratory bird populations, review of data from the AMBCC community harvest survey program (Naves, 2010b), and compilation of historic and current harvest data for subregions and communities (Behnke, 1982; Fall et al., 2006; Fall et al., 1986; Schichnes and Chythlook, 1988; Schichnes and Chythlook, 1991).

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BALD EAGLES

Introduction

Bald eagles (*Haliaeetus leucocephalus*) range across North America, but are most abundant in Alaska, where approximately half of the world population occurs. During the first half of the 20th century in Alaska, the abundance of bald eagles and their attraction to human food sources made them easy prey for bounty hunters (Hodges and Robards, 1982). Since even before the end of the bounty days, however, they have been valued by Americans for their stately appearance, and especially for their intrinsic association with wilderness (King, 2010). Bald eagles and their nests receive extra protection above and beyond that afforded to other migratory birds by the Migratory Bird Treaty Act (16 U.S.C. §§ 703–712). The Bald and Golden Eagle Protection Act (16 U.S.C. 668-668c), enacted in 1940 and amended several times since then, establishes federal responsibility for the protection of bald and golden eagles and requires consultation with the USFWS to ensure activities do not adversely affect bald eagle populations. The Act prohibits anyone, without a permit issued by the Secretary of the Interior, from "taking" bald eagles, including their parts, nests, or eggs. It provides criminal penalties for persons who "take, possess, sell, purchase, barter, offer to sell, purchase or barter, transport, export or import, at any time or any manner, any bald eagle ... [or any golden eagle], alive or dead, or any part, nest, or egg thereof."

A large apex predator, as well as an opportunistic scavenger, the bald eagles is a key species of most of the regional food webs across coastal Alaska, from the Aleutians to Southeast. Bald eagles were proposed as a management indicator species (MIS) for all National Forest lands in Alaska (Sidle and Suring, 1986) and selected as a MIS for the Tongass National Forest (USFS, 2008). They are also included as a "vital sign"[3] for long-term monitoring in the southwest Alaska national parks (Bennett et al., 2006). The purpose of this paper is to provide a characterization of bald eagles in the Nushagak and Kvichak watersheds, with particular emphasis on their ecological relationships with MDNs.

Habitat

Bald eagles are well-known for their association with water. In the Pacific Northwest most nests are within 1.6 kilometers of large waterbodies (Anthony et al., 1982) and in Alaska they are almost always found within 200 meters of a stream, lake, or ocean shoreline (Hodges and Robards, 1982; Stalmaster, 1987; Swaim, personal communication). In the Bristol Bay watershed they inhabit the spruce and mixed spruce/broadleaf forests along major rivers, streams, and lakes of the Bristol Bay Lowlands, upper Alaska Peninsula, and Lime Hills eco-regions (ADF&G, 2006), as well as coastal areas of Bristol Bay.

Throughout most of their range, bald eagles nest in forested habitat associated with riparian and beach areas (Buehler, 2000; Stalmaster, 1987). The significance of shoreline nest sites appears to be strongly related to foraging opportunities these areas provide (Armstrong, 2010). Commonly

[3] Defined as "a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values."

used foraging areas are open sites where prey or carrion can be seen and accessed by these large birds. These are often areas that provide prey aggregations, accessible to many bald eagles at once. In Alaska, these areas include lakes, rivers, oceans, and their shorelines, beaches, and bars (Stalmaster, 1987). On the Kenai NWR, nests are located near clear, relatively shallow streams with spring and fall fish runs (Bangs et al., 1982a). While bald eagle nest sites are positively correlated with water, they tend to be negatively correlated with lands impacted by timber harvest and other human uses (Anthony and Isaacs, 1989; Livingston et al., 1990).

In Alaska, where suitable trees are present, bald eagles build their enormous nests near the tops of live trees, typically in one of the tallest of the stand (Bangs et al., 1982a; Ritchie, 1982; Stalmaster, 1987). Where large trees are absent, they nest on ridges, hillsides, small islets, or sea stacks (Savage, personal communication; Suring, 2010). Around Lake Clark and its drainages, most nests are reported to be in balsam poplar and spruce trees (Wright, 2010). Monitoring in LCNPP since 1992 identified black cottonwood as the predominant substrate for coastal nests; interior nests were more equally divided between cottonwood and spruce (from Witter and Mangipane 2011, in preparation). Of the 165 known bald eagle nest sites on Togiak NWR, most (~86%) are in balsam poplar trees; 8% are in spruce and 6% are located on the ground (Swaim, personal communication).

On Kodiak NWR, one-third of bald eagle nest sites are not located in trees (Zwiefelhofer, 2007). In the Bristol Bay area, at least one ground nest has been noted on an islet in Tikchik Lake (Wright, 2010) and one on an islet in Katmai NPP (Savage, personal communication). At least two ground nests have been documented on Flat Island, in interior LCNPP, although each was occupied for only one year (one was successful and the other failed). Also, there are multiple years of data on two coastal ground nests near Tuxedni Bay in LCNPP. A third coastal ground nest was found near Difficult Creek in 2011 and was successful that year (Witter, personal communication). Besides nest platforms, bald eagles need perches and, often, communal roosts. In Alaska, bald eagles commonly perch in large spruce or cottonwood trees, often with a good view of foraging waters. Bald eagles often perch for 90% of the daylight hours (Stalmaster and Gessaman, 1984), with these locations serving as sites for resting/loafing, foraging/hunting, feeding, look-outs/sentry posts, displaying (territoriality), and thermal regulation (heating or cooling) (Stalmaster, 1987).

The extent of communal roosting is not well-known for the Nushagak and Kvichak watersheds. In general, though, breeding bald eagles roost at the nest tree or on other large trees within their territory. Non-breeding bald eagles often retire to communal roosts at night, usually in large spruce or cottonwoods trees. They may be near a foraging area, but are not as closely associated with shorelines as perches and nest trees (Stalmaster, 1987). Non-breeding bald eagles also regularly feed, rest, and roost along gravel bars and gravel shorelines (Hansen et al., 1984). On the Naknek River in March and April, communal roosts are located on hillsides with shrubs and some balsam poplars (Savage, personal communication). These are often on south-facing slopes that overlook the river.

An abundant, readily available food supply in conjunction with one or more suitable night roost sites is the primary characteristic of winter habitat. The majority of wintering bald eagles are found near open water, where they feed on fish, marine invertebrates, and waterfowl and

seabirds, often taking dead, crippled, or otherwise vulnerable animals (Buehler, 2000). Over-wintering on the breeding grounds may provide a competitive edge in territory selection and with early initiation of nesting (Ritchie and Ambrose, 1987).

The proportion of bald eagles that over-winter in the Nushagak and Kvichak watersheds is not well-understood, and potential links between over-wintering and open water or winter prey accessibility remain to be studied. Ritchie and Ambrose (1987) reported that records of bald eagles over-wintering in northern boreal forests are rare and that one reason for this fact is that water bodies are frozen. They observed bald eagles in winter along the Tanana River in Interior Alaska, where open water probably provides access to spawning salmon and waterfowl. Bald eagles often congregate along the ice/open water interface on the Naknek River, where wintering common mergansers (*Mergus merganser*) and common goldeneyes (*Bucephala clangula*) are often found. The 1986 to 2010 King Salmon–Naknek Christmas bird counts reported from zero to up to 48 adult bald eagles (average 18) (Savage, personal communication). Some over-wintering occurs in Dillingham and the surrounding area, but in much lower densities than found in summer. Some of those over-wintering eagles obtain human garbage at the city dump (Swaim, personal communication).

Food Habits

Diet- Bald eagles are primarily fish eaters (Armstrong, 2010). They do, however, have a variable diet that can include birds, mammals, and crustaceans, and, as noted above, even human garbage (Anthony et al., 1999; Knight and Knight, 1983) (also see Stalmaster 1987 and Armstrong 2010 for summaries).

Food habits vary spatially according to specific prey availability and abundance at the site. Bald eagles nesting near and foraging at seabird colonies during the summer may take primarily bird prey (DeGange and Nelson, 1982). In the Pacific Northwest, diet varied among sites, with bird prey items found under nests generally out-numbering fish items (Knight et al., 1990).[4] Birds likely also out-number fish as prey at some sites on Togiak NWR, including Cape Peirce and Cape Newenham, which support high densities of breeding seabirds (Swaim, personal communication).

The diet of bald eagles tends to vary temporally, as well, depending on prey availability and abundance. Nesting bald eagles rely primarily on the availability of salmon resources (Hansen, 1987). Inland bald eagles whose nests are close to spawning streams have higher nesting success than those with more distant nests (Gerrard et al., 1975). When salmon resources are scarce during late winter and early spring, coastal populations of bald eagles often shift their diet to birds (Isleib, 2010; Wright and Schempf, 2010). In one study, birds averaged nearly 20% of stomach contents by volume over the course of a year, but could range up to 86% and be especially high during the colder months (Imler and Kalmbach, 1955). In other areas, mammalian prey may be utilized in winter, because it is as available, or more available, than birds. For example, on the Kenai NWR, bald eagles may seasonally shift from a diet of primarily fish to snowshoe hare (*Lepus americanus*) or mammalian carrion (Bangs et al., 1982a).

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[4] Note that fish and other soft-boned or bodied prey may be commonly under-counted in both stomach-content and under-nest methodologies (Ritchie 1982, Knight et al. 1990).

Specific information regarding bald eagle diet variability in the Nushagak and Kvichak watersheds is generally not available. Eagles in the Bristol Bay watershed area eat all five species of Pacific salmon (Savage, personal communication). Bald eagles in the winter along the Naknek River have been observed to take small fish, which may include eulachon (*Thaleichthys pacificus*) (Savage, personal communication). Pacific herring (*Clupea pallasi*) may also be an important resource for bald eagles in the Togiak area. In early spring Savage has also observed bald eagles catching large rainbow trout (*Oncorhynchus mykiss*). Bald eagles in Bristol Bay may also scavenge dead marine mammals (Savage, personal communication).

Independent of prey availability, energy requirements may influence prey selection at some level as well. During the breeding season many bald eagles choose large fish over small fish (Jenkins and Jackman, 1994). Diets of nesting bald eagles are much more variable than those of non-breeders (Hansen et al., 1984; Hansen et al., 1986). Non-breeders are able to range farther for preferred food items (e.g., in late fall birds may leave the Chilkat Valley in southeast Alaska to go to British Columbia and Washington, where salmon may still be available). Feeding of young is, as Stalmaster (1987) says, "an enormous chore" and breeders may exploit a variety of food resources within their home range.

Significance of MDNs- Fresh salmon and salmon carcasses provide an ideal food resource for bald eagles, because they are large fish that become available in great numbers when they enter shallow water to spawn. Shallow water increases the likelihood that living fish will be available to bald eagles because the limited depth of water brings fish closer to the surface (Livingston et al., 1990). Returning salmon die after spawning in natal streams, providing a significant seasonal pulse of MDNs, including nitrogen and phosphorous, to the generally oligotrophic streams and lakes of northern Pacific watersheds (Hilderbrand et al., 2004; Naiman et al., 2002b; Willson et al., 1998). Spawned-out salmon carcasses accumulate on stream banks, river bars, lake and ocean shores, and tidal flats (Armstrong, 2010). Although spawned-out salmon are low in fat and considered a relatively low-energy food source (Christie and Reimchen, 2005), their large size, availability, sheer numbers, and other factors (even cold air temperatures, which can increase the efficiency of digestion of some prey (Stalmaster and Gessaman, 1982)), contribute to their value. Salmon are approximately 79% edible flesh, compared to 71% for hares and 68% for ducks (Stalmaster, 1981). Although metabolizable energy is lower for salmon than for hares or ducks, their greater size means that a bald eagle would require only 57 salmon in one year, compared to 87 hares, or 135 ducks (Stalmaster, 1981; Stalmaster and Gessaman, 1982).

Armstrong (2010) reported that several studies have correlated bald eagle abundance with the abundance of spawned-out salmon. Simply put, bald eagles in southeast Alaska, the Kenai NWR, and many other parts of their range likely depend on salmon (Armstrong, 2010; Bangs et al., 1982b). The nature of the relationship that bald eagles have with salmon, however, is complex (Hansen et al., 1986). The variable nature of salmon (and other bald eagle food sources) apparently causes bald eagles to be limited by food availability (Stalmaster and Gessaman, 1984). The abundance of salmon affects not only bald eagle population and distribution, but also breeding and behavior. Bald eagles, in turn, affect the riparian ecosystem and other areas where they may range by distributing the MDNs in their excretions (Gende et al., 2002).

Bald eagles in Alaska also congregate to feed on other species of anadromous and shallow-water spawning fish, particularly Dolly Varden (*Salvelinus malma malma*), Pacific herring, and eulachon (Armstrong, 2010). Armstrong (2010) also summarized the importance of Pacific sand lance (*Ammodytes hexapterus*) to bald eagles and other marine-associated birds and mammals.

Foraging Methods- Bald eagles are opportunistic foragers that exhibit rather complex social feeding behaviors. They use a variety of methods to obtain food, including active hunting and killing, scavenging of carcasses, and theft (pirating or kleptoparasitizing) from other eagles or species (Stalmaster, 1987). They are visual predators that locate their prey by sight. Foraging methods chosen by bald eagles vary according to both complex relationships among other eagles and with other predators or competitors, as well as seasonal variability of food sources. Bald eagles may search for prey themselves or follow other birds, or even mammals, to a concentrated food source (Harmata, 1984; Knight and Knight, 1983; McClelland et al., 1982). Also, as summarized in Armstrong (2010), bald eagles will not only steal fish or force other predators away from fish, but will also exploit fish injured or driven to the surface by others, and scavenge crippled or dead fish or fish parts left by other predators such as humans or bears. Bald eagles in the Chilkat Valley of southeast Alaska typically competed amongst themselves for salmon (Hansen et al., 1984). Dominance in bald eagles may be based on several conditions, but often includes age and size (Garcelon, 1990; Stalmaster, 1987).

Salmon returning to spawning streams are a relatively easy food source for bald eagles, because the fish are found either in shallow waters, swimming or floating near the surface, or washed up or stranded on streambanks (McClelland and McClelland, 1986). Besides their size, abundance, and availability in shallow water, other unique aspects of salmon life history may contribute to their importance to bald eagles. For example, large numbers may be frozen into river ice in the winter, becoming available as food sources again in spring (Hansen et al., 1984). Brown bear pull salmon from holes too deep for eagles to access, often transporting and discarding portions of carcasses to other locations, where eagles then scavenge them (Armstrong, 2010). Armstrong (2010) stressed what he believes to be a particularly important relationship with bears (*Ursus* spp.), which scoop salmon out of deep pools, where they may be inaccessible to bald eagles, and then often eat only the brains and eggs, leaving a significant proportion of the salmon flesh for the birds.

According to Stalmaster (1987), bald eagles, in general, appear to prefer stealing of food over scavenging, and scavenging over hunting. Hansen et al. (1984) observed higher frequencies of stealing over scavenging of salmon carcasses in the Chilkat Valley in southeast Alaska, even though the cost and benefits of both may be equal. However, others have found that, when food is scarce, bald eagles will choose scavenging over stealing, if both methods are available (Knight and Skagen, 1988). Wright and Schempf (2010) state that during seasons of food scarcity, feeding strategy may switch to more active hunting, particularly of large gulls and waterfowl, and some bald eagles may steal ducks from hunters or scavenge in garbage dumps.

Behavior

Territoriality- During the nesting period, breeding bald eagles occupy and defend territories (Mahaffy and Frenzel, 1987). A territory includes the active nest and may include one or more inactive nests, which the eagles may maintain, even when not in use for nesting in a given year

(Hansen et al., 1984). They maintain the same territory year after year, using the same nest or an alternate nest within the same territory (Steidl et al., 1997).

The defended territory contains not only the nest trees, but also favored perches and roost(s). Territories have been reported to range from 0.2–4.2 km^2 (Garrett et al., 1993), but size varies according to site and other parameters (Stalmaster et al., 1985). The territory is within a larger home range. Bald eagles, unlike many other birds, do not necessarily use a territory to monopolize food, but commonly range out of their territory to obtain food communally at a site where it is abundant (Stalmaster, 1987).

In any given year, not all territories will be occupied, and not all occupants will attempt to reproduce (Stalmaster, 1987). During the non-breeding season, or if not breeding, bald eagles generally do not defend territories (Armstrong, 2010), although a pair may remain close to their nest or return to their territory regularly over the winter (Gende, 2010). Information is not currently available on characteristics of bald eagle territories (e.g., size, use patterns, average number of nests, variability according to habitat type, etc.) in the Nushagak or Kvichak watersheds.

Flocking- When a food resource is concentrated, bald eagles will often forage in large flocks (Stalmaster, 1987). This is true not only for scavenging and stealing, as can occur when carrion is present, but also for hunting, when there are large aggregations of forage fish like eulachon or sandlance (Stalmaster, 1987; Stalmaster and Gessaman, 1984; Willson and Armstrong, 1998).

In the winter, when food availability is limited (e.g., by iced-over rivers or limited daylight), bald eagles aggregate in large flocks and become very aggressive, often pirating food from other birds. An available food source will initially draw bald eagles to a site, and the presence of large numbers of bald eagles will attract additional birds.

At night, non-breeding and wintering bald eagles may congregate in communal roost areas (Hansen et al., 1980). The same roost areas are used for several years. Roosts are often in locations that are protected from the wind by vegetation or terrain, providing a favorable thermal environment. The use of these protected sites helps minimize the energy stress encountered by wintering birds. Communal roosting may also assist bald eagles in finding food. The use of communal roosts is poorly documented in Alaska, however (USFWS, 2009a).

Migration and Local Movements- The extent to which bald eagles are migratory or non-migratory varies with breeding site and the severity of its climate (particularly in winter), whether the individual is adult or sub-adult, and year-round food availability (Buehler, 2000). Bald eagles breeding in coastal Alaska typically remain in the vicinity of their nest sites throughout the year. For example, the southeast Alaska adult population is mostly non-migratory, remaining in its rainforest habitat year-round (Sidle et al., 1986). Adults in Aleutian Island populations are generally resident as well (Sherrod et al., 1976). Wintering grounds for migratory Alaska bald eagles are not well understood, but it is suspected that Interior bald eagles winter in the Intermountain West and Pacific Northwest (Ritchie and Ambrose, 1996).

Diurnal and tidal cycles affect the daily activity patterns of fish, as well as enhancing or inhibiting hunting conditions for bald eagles (Hansen et al., 1986).Variations in these daily patterns lead to local movements of bald eagles.

Even though the population of bald eagles in southeast Alaska is non-migratory, individuals will leave their territories to visit foraging areas for several days at a time (Kralovec, 1994). Southeast pairs also return to their breeding territory periodically over the course of the winter.

Local movement patterns, the extent of over-wintering and migration, and how each may vary with age, food availability, or other factors are poorly understood for the Bristol Bay watershed. It is known that at least some adults and sub-adults over-winter in Bristol Bay (Wright, 2010).

Interspecies Interactions

Prey availability has a strong influence on bald eagle reproduction, habitat use and territorial behavior in Alaska. The studies of Hansen et al. (1984) suggest that salmon availability in spring is tightly correlated with if and when adult bald eagles will lay eggs in a given year, although this has not been studied in the Bristol Bay watershed. Bald eagles preferentially select nest sites near stable food supplies (e.g., salmon in the Chilkat Valley). These studies also indicate that food (salmon) availability during the nesting period regulates the survival rate of offspring. Hansen et al. (1984) further determined that, while breeding adults commonly defended feeding territories, they did not do so when salmon became overabundant. Fall and winter habitat use is often correlated with salmon availability, too. Hansen et al. (1984) clearly demonstrated this in the Chilkat Valley and is likely true in Bristol Bay as well.

Bald eagles defend vulnerable young against predators (Stinson et al., 2001). Otherwise they do not tend to be as aggressive with other species as they are with other eagles, with which antagonistic interactions regularly occur during feeding and territory defense. One exception is osprey (*Pandion haliaetus*), which bald eagles commonly keep from nesting nearby (Stalmaster, 1987), although this behavior has not been investigated in the Bristol Bay area. Great horned owls (*Bubo virginianus*), which nest earlier than bald eagles, and osprey, which nest later, each may occupy bald eagle nests in southwest Alaska (Savage, personal communication). Bald eagles steal and scavenge food from a variety of bird and wildlife species, including river otter (*Lutra canadensis*) and sea otter and many others (Stalmaster, 1987).

Breeding, Productivity, and Mortality

Breeding- As with other birds, the timing of bald eagle nesting varies by latitude; in Alaska it begins with courtship and nest building as early as February and ends when the young fledge in late August to early September. In the Bristol Bay watershed, initiation may not be until mid- to late March (Savage, personal communication). The young are attended by the adults near the nest for several weeks after fledging (Buehler, 2000). A pair's territory frequently contains more than one nest (Haines and Pollock, 1998), although a pair uses only one nest in a given breeding year and does not necessarily breed every year (Hansen and Hodges, 1985). The territory (and pair bond) is usually maintained for life (Jenkins and Jackman, 1993).

Whether or not bald eagle pairs breed in a given year and how early they may initiate nesting in a given year appear to be related to food availability (Hansen, 1987), particularly in spring

(Hansen et al., 1984). These studies suggest that there may be a natural long-term population cycle, at least in southeast Alaska's Chilkat Valley, resulting from a saturated breeding habitat and surplus of non-breeders, who then compete for food and cause productivity to decline. The decline may result in less recruitment into the non-breeding population, less competition, and ultimately increased productivity. Annual occupancy rates at known nest sites within Togiak NWR varied from 45 to 88% between 1986 and 2006 (Swaim, personal communication). The lowest occupancy rate occurred in 2006, when spring break-up was particularly late. Occupancy rates, relationships with food availability and seasonal variability, and other details of bald eagle breeding are not well understood for the Nushagak and Kvichak watersheds.

Even well-established nesting bald eagles are highly sensitive to disturbance, particularly during the phases of early courtship and territory establishment, incubation, and the first two weeks after hatching (Buehler, 2000). As with many birds, a constant level of nest attendance is required during incubation and brooding. Bald eagles in newly established territories are highly sensitive to disturbance and prone to abandon nest sites during the courtship and nest-building stage (Gende et al., 1998). Occasionally, a pair will establish and maintain a territory in urban or semi-urban areas where some, usually predictable level of, disturbance already occurs (Zwiefelhofer, personal communication).

Females are larger than males (Buehler, 2000). Both sexes incubate eggs, brood young, and deliver prey to chicks, sharing the duties more than many other raptor species, although females still undertake these tasks a greater percentage of the time than males (Cain, 1985).

Productivity and Survivorship- Productivity varies among sites according to prey abundance and availability, habitat quality, weather, breeding-season length, nesting density, and human disturbance (Gende et al., 1997; Hansen, 1987; Savage, 1997; Steidl et al., 1997). Measures of annual productivity include number and percentage of occupied nests, successful nests, and young produced. Some local information about bald eagle productivity in the Bristol Bay area can be gleaned from National Park Service nest surveys in Lake Clark and Katmai NPPs. Average nest success (percentage of occupied nests that produced at least one young) for interior LCNPP was about 55% between 1992 and 2009, falling to 48% in 2010 (Mangipane, 2010). Nest success for the Naknek Lake and major associated drainage areas of Katmai NPP varied from 31 to 65% in the years 1992 through 1997, although the sample size was relatively small (Savage, 1997).

Dates vary, but generally egg-laying begins in mid- to late April in Alaska (Savage, personal communication; Swaim, personal communication). Clutch sizes range from one to three eggs. Successful pairs usually raise one or two young, or rarely, three per nest (Table 9). Bald eaglets make their first unsteady flights about 10 to 12 weeks after hatching, and fledge (leave their nests) within a few days after that first flight. The time between egg-laying and fledging is approximately four months. However, young birds usually remain in the vicinity of the nest for several weeks after fledging and depend on their parents for food until they disperse from the nesting territory approximately six weeks later. The entire breeding cycle, from initial activity at a nest through the period of fledgling dependency, is about six months (Buehler, 2000).

Numbers of young produced overall in the Nushagak and Kvichak watersheds is unknown. Annually, Alaska bald eagles may produce roughly 4,200 fledglings, although that figure varies considerably according to site and year (Schempf, 1989). In Alaska, both inter-annual and site-specific variability in productivity can be significant (Schempf, 1989) and neither has been comprehensively studied for the Nushagak and Kvichak watersheds. Productivity appears to be most commonly related to site-specific habitat features and prey (fish) availability in early spring during egg-laying and incubation (Anthony, 2001; Gende et al., 1997; Steidl et al., 1997). Availability of fish increases survivorship of bald eagle offspring, and therefore can cause bald eagle productivity to fluctuate widely (Hansen et al., 1984). Variability in food availability appears to be the cause of variability in fledging rates in southeast Alaska (Hansen, 1987). Productivity can be affected by human disturbance, as well (Fraser and Anthony, 2010; Stalmaster, 1987).

Mortality- Full-grown bald eagles have few natural enemies, and the most frequently reported causes of premature adult bald eagle mortality are human-related (Franson et al., 1995; Harmata et al., 1999; Stalmaster, 1987). Shooting, electrocution, trapping, and collisions cause about two-thirds of reported deaths. Bald eagles also die from ingesting pesticides and contaminated carrion used for predator control. Historically, bald eagles experience decreased reproduction and survival from both intentional and unintentional effects of a wide range of pesticides and environmental contaminants (Buehler, 2000). Poisoning from a wide variety of sources accounted for 16% of all deaths in bald eagles necropsied between 1963 and 1994 at the National Wildlife Health Center (Franson et al., 1995).

Top-level predators, such as bald eagles, are believed to be especially vulnerable to many contaminants and can be used as sentinel species for contaminated areas (Holl and Cairns, 1995; Welch, 1994). Eggs from bald eagles in the Aleutian Islands, for example, contained elevated levels of organochlorine pesticides, but concentrations of these contaminants and mercury were significantly higher in eggs from Kiska Island than in eggs from the other islands (Anthony et al., 1999). In contrast, polychlorinated biphenyl (PCB) concentrations were higher in eggs from Adak, Amchitka, and Kiska islands than in those from Tanaga Island. The most likely source of these contaminants in bald eagles was their diets, which were spatially and temporally variable. A similar study found that contaminant concentrations in Aleutian bald eagle eggs were influenced more by point sources of contaminants and geographic location than by the trophic status of eagles among the different islands (Anthony et al., 2007).

Mean cadmium, chromium, mercury, and selenium concentrations in bald eagle tissues from Adak Island were consistent with levels observed in other avian studies and were below toxic thresholds (Stout and Trust, 2002). However, elevated concentrations of chromium and mercury in some individuals may warrant concern. Furthermore, although mean PCB and *p,p*'-dichlorodiphenyldichloroethylene (DDE) concentrations were below acute toxic thresholds, they were surprisingly high, given Adak Island's remote location.

Table 10. Reported survival of bald eagle nestlings in Alaska.

Site and year(s)	Average number of young raised to near [a] fledging per successful nest	Source
Interior LCNPP (1992–2011)	1.00–1.87 [b]	Witter and Mangipane (2011, in preparation)
Coastal LCNPP(1992–2011)	1.09–1.82 [b]	Witter and Mangipane (2011, in preparation)
Pacific Coast of the Alaska Peninsula (1989–1995)	1.55–1.71	(Dewhurst, 1996)
Port Moller (1976)	1.90 [b]	R. Gill, unpublished data reported in Wright (2010)
Togiak NWR (1986–1988)	0.95–1.90	L Hotchkiss and D. Campbell, unpublished data, as reported in Wright (2010)
Togiak NWR (1986–2006)	1.33–2.00 [b]	M. Swaim, personal communication
Togiak NWR (2006)	1.72	(MacDonald, 2006)
Togiak NWR (1999–2005)	1.62	(MacDonald, 2006)
Katmai NPP (1976–1979)	1.2–1.8 [b]	W. Toyer, unpublished data reported in Wright (2010)
Katmai NPP (1992-1993)	1.45–1.67	(Savage, 1993)
Kodiak NWR (1963 and 2002)	1.66	(Zwiefelhofer, 2007)
Petersburg area (1967–1969)	1.50–1.65	(Corr, 1974)
Gulkana River (1989–1994)	1.29–1.65	(Steidl et al., 1997)
Copper River (1989–1994)	1.34–1.64	(Steidl et al., 1997)
Chilkat Valley (1979–1983)	1.32	(Hansen et al., 1984)
Prince of Wales Island (1991–1993)	1.10	(Anthony, 2001)

[a] Nests are normally surveyed just before fledging to assess success and it is assumed that nests are successful if young are observed. This is because once young fledge and leave the nest it is impossible to determine if they survived. [b] Successful nests with three young have been reported in Lake Clark and Katmai NPPs and Port Moller (L. Witter, personal communication, and as reported in Wright [2010]). Also, 3% of nests on Togiak NWR between 1986 and 2006 had three young (M. Swaim, personal communication).

Non-human causes of mortality include starvation, fights with other bald eagles, and incidental diseases and infections (Stalmaster, 1987). When food is limited, mortality rates are probably higher among sub-adult than adult bald eagles (Stalmaster and Gessaman, 1984). Other causes of mortality include loss of nests (eggs and nestlings) to spring storms, parental desertion or death, and predation by gulls, black bears (*Ursus americanus*), and other predators (Stalmaster, 1987). Although eggs tend to have a higher mortality rate than nestlings, nestlings also kill each other in fights, die from starvation when more aggressive nest mates receive the majority of feedings from the parent, and fall prematurely from nest trees.

Population, Distribution, and Abundance

Bald eagles are one of the most abundant raptors in Alaska, with a population estimated at >58,000 (Hodges, 2011). Most Alaskan bald eagles occur in the vicinity of the southern coast (from Dixon Entrance to Bristol Bay) and secondarily along interior rivers and lakes (Schempf, 1989). An estimated 2,775 adult bald eagles were present along the Alaska Peninsula Gulf Coast in 2005 (Savage and Hodges, 2006).

Surveys of nests and calculations of nest densities and occupancy rates are commonly conducted to contribute to bald eagle population information, although nesting rates have considerable temporal and spatial variability. Nesting density is considered to be generally correlated with food availability (Dzus and Gerrard, 1993), although density of breeding bald eagles in Saskatchewan was found to be correlated with mean April temperatures (Leighton et al., 1979). Densities of nests in inland river areas of southeast Alaska are highly variable among sites and years. This may be correlated with food abundance and weather conditions (Hodges, 1979). Nests in the Susitna watershed, though, are thought to be more uniformly distributed (Ritchie and Ambrose, 1996). For Interior Alaska populations, Ritchie and Ambrose (1996) surmise that densities are greatest in areas adjacent to abundant coastal populations and where weather is somewhat milder and prey more seasonally accessible and diverse.

Bald eagle densities have been extensively studied in southeast Alaska. A review of several nesting density investigations in various southeast Alaska locations revealed densities ranging from 0.33 to 0.50 (perhaps greater on Admiralty Island) active nests per kilometer of coastline and 0.25 to 0.38 active nests per river kilometer (Hansen et al., 1984; Hodges, 1979; Robards and King, 1966). There were 0.01 to 0.08 active nests per river kilometer at an Interior location (Gulkana River) (Byrne et al., 1983). Population and nesting density is also high on Kodiak NWR, where almost 1,000 nests were located within an area of about 8,000 square kilometers in 2002 (Zwiefelhofer, 2007).

A comprehensive survey has not been published for bald eagles or their nests in the Bristol Bay watershed. The data that we do have appears to indicate that nest density may be almost as high in portions of the region as anywhere outside of the highest known densities in southeast Alaska and Kodiak. The USFWS Bald Eagle Nest Database has accumulated approximately 230 nest records for the study area (Table 10). Approximately one-quarter (61) of those records, however, are from the 1970s and 1980s, and those nests may not persist on the landscape. The remaining 169 records were collected between 2003 and 2006. In 2006, a fixed-wing survey of adult bald eagles was conducted by the USFWS along main-stem portions of some Alaskan rivers. During that survey, 50 bald eagle nests were incidentally recorded along portions of the Nushagak,

Mulchatna, and Kvichak Rivers. Of those 50, approximately one-half (24), were identified as active. Database records for 2004 and 2005 are from a project contractor survey (not flown for the USFWS Database) that was conducted along the north side of Lake Iliamna. The 2004 and 2005 surveys recorded 75 total nests in this area (Lewis, personal communication). This appears to be a relatively high nesting density, although we do not know which or how many of those nests were active, nor therefore, the density of active territories in this area. Data from 2003 are for only three nests, one active and one empty nest in the lower Nushagak drainage and one of unknown status on an islet off the north shore of Iliamna Lake.

Table 11. Summary of surveys for bald eagle nests in the Bristol Bay study area.

Survey	Survey dates and results	
USFWS bald eagle nest surveys (recorded in USFWS bald eagle nest database)	1970–1990 61 nest records	2003–2006 169 nest records
Nushagak and Mulchatna Rivers survey by USFWS	2006 50 nest records (24 active)	
North side of Lake Iliamna survey by contractor	2004–2005 75 nest records	

Regarding numbers of individual bald eagles observed, some site-specific surveys have been conducted in portions of southwest Alaska. For example, summer activity surveys for Katmai NPP identified between 50 and 87 individuals in the Naknek Lake drainage between 1991 and 1997 (Savage, 1997). Systematic efforts have not been made to identify fall bald eagle congregation sites in the Bristol Bay area (Wright, 2010). Such sites are known to exist in surrounding areas (e.g., Port Moller, Savonoski River), however, and are believed to be related to late-spawning sockeye salmon, fall runs of coho salmon, and fall-staging waterfowl. While bald eagle densities are undeniably greatest overall in southeast Alaska, salmon also appear to be a major driving force for the Bristol Bay watershed population of bald eagles, so some comparisons may be inferred. In the Chilkat Valley, fall and winter bald eagle densities in habitats adjacent to foraging areas may be ten times those of the same habitats (e.g., gravel bars, cottonwood stands) located distant from food sources (Hansen et al., 1984).

Human Use

Historically, bald eagles have been important to Native Americans and continue to be so at present. Bald eagle parts have been of particular importance for rituals and many other spiritually related uses (Stalmaster, 1987). The Bald and Golden Eagle Protection Act exempts Native Americans from the prohibition against purposeful take, although a permit is required.

Other humans have not used bald eagles historically for any significant intrinsic purpose. Humans, however, are the greatest source of the bird's mortality, both directly and indirectly. At least 128,000 birds, and probably many more, were taken during the bounty years (1917 to 1952) in Alaska. Bald (and golden) eagles are now protected by law in the United States, with only a

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minimal number of permits for indirect take (incidental to an otherwise lawful activity) allowed. Take is authorized only when it is consistent with the goal of maintaining stable or increasing bald eagle populations.

Despite legal protection, illegal direct take still occurs, most commonly when bald eagles are shot, trapped, or poisoned based on a belief that the birds prey on human-valued resources. Unpermitted indirect take is probably the greatest source of bald eagle mortality today. Leading causes of indirect take include pesticides, entanglement in fishing or trapping gear, collisions with power lines or buildings, ingestion of poisoned prey, plastics or lead shot, and disturbance or loss of nesting habitat (Buehler, 2000).

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SHOREBIRDS

Introduction

Shorebirds are a diverse group, with members occurring on every continent and in all habitats ranging from sea level to the highest mountains. They generally are associated with water, particularly intertidal and estuarine environments, and thus are fairly visible to humans. Due to their broad geographic distributions, their seasonal migrations are remarkable, regularly spanning continents and frequently hemispheres. Several species engage in long, nonstop flight, but most rely on a series of sites where they stop to "refuel" for subsequent legs of their migrations. Alaska intertidal areas, particularly Bristol Bay estuaries, serve two functions in this regard. First, during late summer through autumn, the majority of the shorebird population that nests in western Alaska moves to the benthic-rich intertidal communities of Bristol Bay, where ample food supports them while they complete their molt and fatten for autumn migrations. Winter destinations include sites throughout the Americas, the Central Pacific, and Australasia. Secondly, during spring, hundreds of thousands of shorebirds that staged on the Copper River Delta and estuaries of Cook Inlet migrate to their western Alaska breeding grounds, through a broad lowland corridor (the Lake Iliamna corridor) at the base of the Alaska Peninsula, linking Kamishak Bay in lower Cook Inlet to upper Bristol Bay. In most years, the migration through this corridor is direct, but in years with late spring or adverse weather conditions, birds stop in large numbers at Bristol Bay estuaries until conditions improve farther west (Gibson, 1967; Gill and Handel, 1981; Gill and Tibbitts, 1999). Two major estuaries in the area, Nushagak and Kvichak bays, have been recognized as Western Hemisphere Shorebird Reserve Network sites (Western Hemisphere Shorebird Reserve Network, 2011).

Over 70% of the shorebird species or subspecies (30 of 41) that regularly occur in Alaska each year (Alaska Shorebird Group, 2008) can be found in the Bristol Bay watershed; 21 of these 30 (70%) regularly nest there (Table 12). Shorebird populations worldwide are showing steady declines (Stroud et al., 2006), with causes most often attributed to loss or alteration of habitats and environmental contamination. Fourteen species that regularly occur in the Bristol Bay watershed have been ranked by the Alaska Shorebird Working Group (2008) as being of high conservation concern.

The Bristol Bay region has had a long history of studies that reported in part on shorebirds. Several of these studies date to the late 19th and early 20th centuries, but few shorebird-specific studies emanated from this region until the initiation of the Outer Continental Shelf Environmental Assessment Program (OCSEAP) in coastal Alaska in the early 1970s (Arneson, 1978; Gill et al., 1977; Gill et al., 1978). At that time, there was also increased interest in declining populations of waterfowl throughout Alaska and considerable information on shorebirds was collected in conjunction with waterfowl studies, such as annual spring and fall emperor goose aerial surveys (Mallek and Dau, 2011). There have also been multiple studies detailing shorebird activities during the breeding season and migration in the adjacent Kilbuck and Ahklun Mountains and coastal areas from Kuskokwim Bay to Togiak (Petersen et al., 1991). Breeding activities of several shorebird species in the Iliamna Lake area have also been reviewed (Williamson and Peyton, 1962).

Table 12. Shorebirds found in the Bristol Bay Watershed.

Species	Scientific name	Breeding[1]	Current Trend[2]	Conservation Priority[3]
Black-bellied Plover	*Pluvialis squatarola*	Yes	Declining	3
American Golden-Plover	*Pluvialis dominica*	Yes	Declining	4
Pacific Golden-Plover	*Pluvialis fulva*	Yes	Declining	3
Semipalmated Plover	*Charadrius semipalmatus*	Yes	Stationary	2
Spotted Sandpiper	*Actitis macularius*	Yes	Stationary	2
Wandering Tattler	*Tringa incana*	Yes	Stationary	3
Greater Yellowlegs	*Tringa melanoleuca*	Yes	Stationary	3
Lesser Yellowlegs	*Tringa flavipes*	Yes	Declining	4
Whimbrel	*Numenius phaeopus*	Yes	Declining?	4
Bristle-thighed Curlew	*Numenius tahitiensis*		Stationary	5
Hudsonian Godwit	*Limosa haemastica*	Yes	Stationary	4
Bar-tailed Godwit	*Limosa lapponica*	Yes	Declining	4
Marbled Godwit	*Limosa fedoa*		Unknown	4
Ruddy Turnstone	*Arenaria interpres*		Unknown	3
Black Turnstone	*Arenaria melanocephala*	Yes	Stationary	4
Surfbird	*Aphriza virgata*	Yes	Declining	4
Red Knot	*Calidris canutus*		Declining	4
Sanderling	*Calidris alba*		Declining	4
Semipalmated Sandpiper	*Calidris pusilla*		Declining	3
Western Sandpiper	*Calidris mauri*	Yes	Declining?	4
Least Sandpiper	*Calidris minutilla*	Yes	Declining	3
Baird's Sandpiper	*Calidris bairdii*		Stationary	2
Pectoral Sandpiper	*Calidris melanotos*	Yes	Declining	2
Sharp-tailed Sandpiper	*Calidris acuminata*		Stationary	2
Rock Sandpiper	*Calidris ptilocnemis*	Yes	Stationary	4 ort 3
Dunlin	*Calidris alpina*	Yes	Declining	4
Short-billed Dowitcher	*Limnodromus griseus*	Yes	Declining	4
Long-billed Dowitcher	*Limnodromus scolopaceus*		Stationary	3
Wilson's Snipe	*Gallinago delicata*	Yes	Declining	3
Red-necked Phalarope	*Phalaropus lobatus*	Yes	Declining	3

[1] Breeding status of "Yes" requires a record of breeding evidence (nest, eggs, or recently fledged young on or within 150 km of the Bristol Bay Watershed.
[2] Current trends were reproduced from Morrison et al. 2006, Table 1: Estimates, Current trend.
[3] Conservation Status scores were reproduced from Alaska Shorebird Plan 2008, Table 2, Conservation Category. Species in Categories 4-5 are of high concern and in category 2-3 are of low to moderate concern.

In more recent years avian surveys have been conducted by the National Park Service in Lake Clark and Katmai NPPs (montane surveys including the upper Nushagak and Kvichak drainages)

EPA-6363-000003063

(Ruthrauff et al., 2007); by the USFWS (targeting lowland areas of the northern Alaska Peninsula) (Savage and Tibbitts, In prep); by the Pacific Shorebird Migration Project (including satellite tracking of godwits (*Limosa* spp.), bristle-thighed curlew (*Numenius tahitiensis*), and whimbrel (*N. phaeopus*)) (Gill et al., 2009); using color banding (whimbrels) (Tibbetts, personal communication); and using radio tracking and attachment of geo-locators (plovers (*Charadriidae*)) (Johnson et al., 2004; Johnson et al., 2001; Johnson et al., 2011; Johnson et al., 2008). These surveys have provided additional understanding of the importance of this region to various stages of shorebird life history. A deficiency in information for upper Bristol Bay during the early spring still exists, but information for nearby Egegik (Fernandez et al., 2010) and Nanvak bays (Fernandez et al., 2010; Petersen et al., 1991) are relevant to this characterization. The paucity of information for the early spring stems in part from the winter-like conditions that frequently persist in the Bristol Bay region until early May, affecting, if not the birds' use of the area, then at least the ability of biologists to access it.

The Bristol Bay/Alaska Peninsula lagoon system, of which the Nushagak and Kvichak River deltas are part, is one of the most important migratory shorebird stop-over areas in the state. Only the Copper River Delta and the Yukon-Kuskokwim Delta are likely more important (Gill and Handel, 1990; Isleib and Kessel, 1973; Senner, 1979). The entire set of lagoons supports thousands of individuals, representing numerous shorebird species, that undertake post-breeding migrations to the Pacific coast of North America and across the Pacific Ocean to Australia, Southeastern Asia, and Oceania. For species that migrate directly across the ocean to Hawaii or other South Pacific islands (e.g. bar-tailed godwit (*Limosa lapponica*), ruddy turnstone (*Arenaria interpres*)), these lagoons provide the last stopover before their long overwater flights. Western sandpiper (*Calidris mauri*), dunlin (*C. alpina*), and long-billed dowitcher (*Limnodromus scolopaceus*) use the peninsula's lagoons to replenish energy reserves before departing non-stop for British Columbia and points south. The Bristol Bay lagoons are also used by shorebirds as they migrate north in spring, providing an essential refueling location that enables species not only to succeed in reaching their breeding grounds, but also to begin breeding shortly thereafter. The relative importance of each lagoon/delta, including the deltas of the Bristol Bay region, is likely to vary annually and by species, and the loss of any one site might have a devastating effect on a species' ability to successfully migrate and consequently might add another factor to already declining populations.

Habitat

The geomorphology of upper Bristol Bay is shaped by the interaction between the shallow basin of the Bay and the twice-daily tidal fluctuation in excess of 10 m. These features interact with the numerous river deltas, including the Nushagak, Kvichak, and Naknek, to form an expansive intertidal zone dominated by unvegetated sand and mudflats. The intertidal zone also includes vegetated substrate at Nushagak Bay. These intertidal areas, the Bristol Bay estuary itself, and other nearby river mouths with extensive mudflats along the Alaska Peninsula characterize the estuarine portions of the region. Approximately 530 km^2 of intertidal habitat is found at Kvichak Bay and 400 km^2 at Nushagak Bay (Gill et al.; Western Hemisphere Shorebird Reserve Network, 2011). In winter, substantial shore ice forms along the coast and sea ice moves through the area with the tides. The supralittoral (splash) zone varies from gradually sloping unvegetated or sparsely vegetated shore, to sand and morainal bluffs up to 20 m in height. Beyond the shore zone, the region is characterized by a mosaic of wetland and tundra habitats, punctuated with low

and tall shrub communities, located primarily along drainages. At higher elevations are spruce, mixed spruce, birch or cottonwood forests that give way to ericaceous dwarf shrub or sparsely vegetated substrates in the alpine zone.

Shorebirds inhabit the Bristol Bay watershed primarily during two phases of their annual life cycle: migration and breeding season. During each phase they make use of geographically distinct parts of the watershed. Shorebirds use the expansive intertidal and adjacent supralittoral areas during both spring and fall migrations. In spring, the mouths of major rivers including the Naknek, Kvichak and Nushagak, are often the first areas to become ice-free, and provide critical feeding habitat in the littoral zone (Gill and Handel, 1981). Shorebirds actively forage in the intertidal zone, often moving toward the declining water level as the tide drops. During high tide and at night, birds move into the adjacent supralittoral zone to continue foraging or to roost. Although information for these specific bays is sparse for the spring period, we can make inference from observations in nearby areas. Beginning in late April through mid-May, the predominant species to use the Bristol Bay region (western tip of Unimak Island north to Cape Newenham, as defined in Gill and Handel, 1981) include: bar-tailed godwit (several thousand), western sandpiper (a few thousand), rock sandpiper (*C. ptilocnemis*; a few thousand), dunlin (a few thousand), black-bellied plover (*Pluvialis squatarola*; hundreds to thousands), Pacific golden-plover (*P. fulva*; several hundred), black turnstone (*Arenaria melanocephala*; several hundred), red-necked phalarope (*Phalaropus lobatus*; several hundred), Hudsonian godwit (*Limosa haemastica*; a few hundred), and short-billed dowitcher (*Limnodromus griseus*; a few hundred)(Gill and Handel, 1981). Other species are found in lesser numbers.

Beginning in mid- to late June, shorebirds return to Bristol Bay in larger numbers and remain for protracted periods along the intertidal zone. This general shift between terrestrial habitats and the littoral zone is observed throughout the region (Gill and Handel, 1981; Gill and Handel, 1990; Gill et al., 1977; Gill et al., 1978) and Alaska (Connors, 1978; Taylor et al., 2011). Shorebirds also make use of the supralittoral zone and terrestrial habitats near the coast during high tides and at night for feeding and for roosting (Gill and Handel, 1981; Gill et al., 1981). Initially, the primary birds present in the region are those nesting locally, but as the season progresses, populations swell with birds moving into the region from nesting areas in western and northern Alaska and as far away as eastern Russia (Gill et al., 1994). By early August it is not uncommon to find hundreds of thousands of shorebirds on intertidal areas of upper Bristol Bay. Species composition and abundance in fall is similar to the spring migration except for additional species and increased numbers: bar-tailed godwit (thousands to ten thousands), dunlin (several ten thousands), red-necked phalarope (several ten thousands), and red phalarope (several ten thousands), western sandpiper (a few ten thousands), rock sandpiper (a few ten thousands), short-billed dowitcher (a few ten thousands), black-bellied plover (a few thousands), Pacific golden-plover (a few thousands), whimbrel (a few thousands), ruddy turnstones (a few thousands), black turnstones (a few thousands), sanderlings (a few thousands), long-billed dowitcher (a few thousands), greater yellowlegs (hundreds to thousands), semipalmated plover (several hundreds), Hudsonian godwit (a few hundreds) (Gill and Handel, 1981; MacDonald, 2000; MacDonald and Wachtel, 1999). Populations awaiting storms to help carry them to Australasia and the west coast of North America may extend their period of use into October (e.g., dunlin) (Gill et al., 1978) or early November (e.g., bar-tailed godwit) (Gill et al., 2009).

Shorebirds breeding in the Bristol Bay watershed use different habitats in the terrestrial areas of the watershed, from the supralittoral zone (Gill and Handel, 1981; Gill et al., 1981) to elevations of 1,300 m (Ruthrauff et al., 2007), based on their species' preferences. Many species (e.g., greater yellowlegs, dunlin, Wilson's snipe (*Gallinago delicata*), and short-billed dowitcher) prefer mesic to wet herbaceous vegetation, while many of the plovers or montane breeders (e.g., American golden-plover (*Pluvialis dominica*), semipalmated plover, surfbird (*Aphriza virgata*), rock sandpiper), prefer dwarf shrub/lichen vegetation or even barren areas for nest sites. Several species are highly dependent on lake or river shores (e.g., spotted sandpiper (*Actitis macularius*), wandering tattler (*Tringa incana*)) (Petersen et al., 1991). A few species (semipalmated plover, marbled godwit (*Limosa fedoa*), black turnstone, dunlin, and short-billed dowitcher) prefer the coastal fringe (Gill and Handel, 1981; Gill et al., 2004). All of these shorebirds may feed in marine intertidal zones during breeding, depending on their proximity or their preference for feeding in these environments.

Food Habits

The shorebird group derives its name from the fact that many species spend migration, and often winter, associated with shore environments. In many cases, these are marine shores. Food is likely the most important factor controlling the movements of shorebirds throughout the Bristol Bay region. Use of Nushagak and Kvichak Bays during shorebird migration is undisputed. In the spring, shorebirds need to acquire critical food resources, not only to fuel their migration, but also, for some species, to assure that they arrive on the breeding grounds with sufficient reserves to initiate nesting and egg production (Klaassen et al., 2006; Yohannes et al., 2010). Beginning mid-summer and continuing into early autumn, shorebirds in Alaska must again find food-rich areas to support the process of partial or complete molt (a few species) and to fuel extended migration (all but a few species). Indeed, some of the longest migrations known to birds involve shorebird species (bar-tailed godwit) that use Bristol Bay intertidal areas in autumn (Battley et al., 2011; Gill et al., 2009). Such flights are possible not only due to the extreme abundance of intertidal invertebrates (polychaetes, crustaceans, gastropods, and bivalves) in the region, but also because the adjacent uplands are usually rich in fruits of ericaceous plants or tubers that birds like plovers, whimbrels, and godwits, regularly feed on (Elphick and Klima, 2002; Johnson and Connors, 1996; Paulson, 1995; Skeel and Mallory, 1996). For species like bar-tailed godwit and sharp-tailed sandpiper, individuals can gain up to 6% of their lean body mass per day while feeding prior to migration (Gill et al., 2005; Lindstrom et al., 2011). Other species acquire their fuel at a different trophic level. Rock sandpiper, for example, often eat the gonads of tide-stranded jellyfish medusae, while species like whimbrel, Hudsonian godwit, and black and ruddy turnstones feed on herring roe, carrion and salmon eggs (Elphick and Tibbitts, 1998; Gill et al., 2002; Handel and Gill, 2001; Nettleship, 2000; Norton et al., 1990). During the breeding season terrestrial and freshwater environments provide the bulk of the food sources and a wide variety of animal and vegetable resources are consumed. Most shorebird species make use of terrestrial invertebrates or their larvae or eggs, and many make use of freshwater invertebrates; small fish may be consumed by yellowlegs (Elphick and Tibbitts, 1998) and phalaropes (Rubega et al., 2000). Detailed summaries for each species are found in *The Birds of North America* (Cornell Lab of Ornithology, 2011).

Shorebirds play a role in distributing MDNs into the terrestrial system, especially during the migratory period, but this has not been quantified. They frequently feed in the intertidal zone, but

EPA-6363-000003066

roost in the terrestrial zone, where they frequently deposit their waste. In addition, they are prey items for many larger predators that subsequently cycle the nutrients into the terrestrial system.

Behavior (Movements)

Shorebirds move at multiple temporal and spatial scales that are usually associated with specific phases of their annual cycle, but within each, there can also be movement driven by more random events such as weather and opportunistic feeding. The most obvious movements are associated with migration, a phenomenon that occurs twice a year in most shorebirds. Spring migration in Alaska is an end to a process that began months prior and often continents away and is driven by the pending nesting season and the need for birds to establish territories and produce young. As such, it is characterized as rapid and direct (Gill and Handel, 1981), with little use made of intertidal areas once birds leave penultimate staging sites such as the Copper River Delta (Isleib, 1979; Iverson et al., 1996; Senner, 1979).

Spring conditions in Bristol Bay vary greatly from year to year. Shore bound and riverine ice can vary considerably with regard to magnitude and timing of melt, depending on the severity of the winter, amount of snow cover, and the onset of spring conditions. Currently, no formal measure of shore ice is conducted in this region; however remote sensors such as MODIS (Moderate Resolution Imaging Spectroradiometer) could be used to describe and monitor spring conditions (Spencer, 2006). Informal observations indicate that breakup may begin as early as late March or be delayed until early May. The ice conditions may change within a week or may linger for four to six weeks. Shorebirds make use of the Bristol Bay tidal flats as they become ice-free, typically beginning in mid- to late April and peaking in early May; the length of their stay depends in part on conditions in the nearby breeding grounds or further north on their migratory route.

Spring shorebird surveys are limited for this area and most information comes from surveys targeting other taxa. With that in mind, note that peak numbers for single aerial surveys along the margins of the two bays range from approximately 7,000 to 10,600 small to medium shorebirds (Arneson, 1978; King and Dau, 1992). Arneson (1978) conducted several surveys in one spring and mentions that spring shorebird densities can change dramatically over a short time span. Although spring migration is abbreviated, variation in migration timing by sex is known for some species with males generally arriving earlier (Senner et al., 1981).

Once established on the breeding grounds, most shorebirds exhibit territorial behavior. Movements are driven by the need to defend territories, attract mates, establish and defend nests and young, feeding, and the need to find shelter from weather and predators. Once young fledge, or when nesting attempts fail, many species move to coastal habitats; such movement may be driven by deteriorating food supplies on the nesting grounds or increased availability of food in the littoral habitats (Gill and Handel, 1981).

Shorebirds return to the coastal zone beginning in mid-June, with some remaining until early November. Summer and fall food resources in Bristol Bay are diverse and abundant, as evidenced by the diversity and numbers of shorebirds, waterfowl and seabirds that are attracted to the area during this time (Gill et al., 1981). A clearly attractive attribute of Bristol Bay is the short distance birds must move between various components of its large system of interconnected mudflats and bays, all containing concentrated food resources. In the context of

EPA-6363-000003067

post-breeding shorebird use, Nushagak and Kvichak Bays cannot be separated from the context of the greater Bristol Bay/Alaska Peninsula complex. Rich food resources are in demand, because adult birds are recovering from the energetic stress of breeding and beginning the energy-demanding molt. Ground and aerial surveys conducted in Nushagak Bay (MacDonald, 2000; MacDonald and Wachtel, 1999) and other Alaska Peninsula lagoons (Gill et al., 1977; Gill et al., 1978) provide insight on the seasonality, and duration of use by at least 25 shorebird species. The magnitude of shorebird use has been captured on single-day aerial surveys in the later part of the season; for these two bays, high counts range from 20,000 to 67,000 (Gill and King, 1980; Gill and Sarvis, 1999; Mallek and Dau, 2004). Late summer and fall shorebird use is likely greater than spring, due to the addition of juveniles in the population, longer residence times, different pathways of migrants during different times of the year, or different use patterns of individual species.

The autumn migration is broken into phases based on species, age, sex, and individual breeding success. Species-specific use patterns have been reported for Nelson Lagoon, on the central Alaska Peninsula (Gill and Jorgensen, 1979) and patterns for other species common to the Bristol Bay watershed are reported from studies on the Yukon Delta (Gill and Handel, 1981; Gill and Handel, 1990). In general, black turnstones, western sandpipers and short-billed dowitcher move through the area the earliest; black-bellied plovers arrive later and rock sandpipers, dunlin and sanderlings may arrive at similar or later dates, but remain longer into the fall. Failed breeders move to the coastal zone sooner than successful breeders (Gill et al., 1983; Handel and Dau, 1988). On the Y-K Delta, Gill and Handel (1990) observed three age-based patterns of intertidal use through the late summer. In the most common pattern, demonstrated by western sandpipers, adults arrived first, followed by a period in which adults and juveniles occurred together, and finally juveniles appeared alone. In the second pattern (bar-tailed godwits, dunlin, and rock sandpipers), adults appeared first, followed by a long period of use by both adults and juveniles. The third pattern was demonstrated by plovers, in which only juveniles used the intertidal zone in late summer. In addition, some species demonstrate a sex-specific pattern: female western sandpipers depart before males (Gill and Jorgensen, 1979), but in pectoral sandpipers (*Calidris melanotos*), males depart before females (Pitelka, 1959). The specific migration patterns demonstrated by individual shorebirds, with regard to micro- and macro-habitat use and timing, will become clearer as researchers continue to deploy satellite transmitters and geo-locators.

Interspecies Interactions

Shorebirds act as an intermediate link in the food web between primary producers (berries, seeds, and tubers of plants) /consumers (invertebrates and small fish) and predatory species. Especially during migration, when birds are concentrated, their effect on invertebrate populations in feeding areas can be extensive (Jensen and Kristensen, 1990; Quammen, 1984; Sanchez et al., 2006; Wilson, 1989). The response of the invertebrate prey varies with time of year, substrate, presence of other predators, presence of other prey, and age-related factors of the prey items. Any negative effect on prey abundance is assumedly short-term, however, as these areas are revisited by shorebirds on the next tide and the next season on a daily and annual schedule. Shorebirds may compete intra-specifically or inter-specifically for resources during migration as well, as demonstrated by inter-specific aggressive interactions (Burger et al., 1979).

Shorebird adults, young, and eggs provide food for a wide variety of predatory birds including jaegers, gulls, raptors, owls, corvids, and shrikes. Avian predation has long been hypothesized to be the dominant force in flocking behavior (Lack, 1954); the relationship between the benefits (predator avoidance) and costs (feeding competition) has been explored (Stinson, 1980). Nocturnal avian predators alter shorebird use of feeding and roosting areas (Piersma et al., 2006). The increase in raptor populations following the removal of DDT appears to be altering how much time shorebirds spend in marine intertidal areas; this threat of danger is potentially forcing the birds into a trade-off between good food locations and the potential of being eaten (Ydenberg et al., 2004). In the Bristol Bay ecosystem potential mammalian predators of shorebirds, particularly eggs and chicks, include canids (especially foxes), lynx, weasels (including otter), and some rodents. Shorebirds may play a role as prey in multi-species predator-prey cycles known throughout the Arctic (Underhill et al., 1993).

Direct and indirect interactions between shorebirds and salmon are not well-documented. As mentioned above, some shorebird species are observed to consume dead salmon and salmon eggs, but it is unlikely that shorebirds have an impact on salmon populations. No studies have been conducted to deduce the contribution of salmon to the energetics of shorebird populations; however, the abundance of invertebrates in the intertidal zone is very likely due in part to nutrients from salmon that die on the coast and in the rivers feeding Bristol Bay.

Breeding, Productivity, and Survivorship

Using information from studies in and adjacent to the Bristol Bay watershed, approximately 21 shorebird species are known to breed in this area. Most shorebird species form monogamous pairs, with both sexes defending breeding territories and incubating eggs; however, spotted sandpipers and red-necked phalaropes will engage in polyandry if conditions are favorable. Individuals, and especially males, commonly demonstrate site fidelity to breeding territories. Nesting begins in early to mid-May in the Bristol Bay area (Petersen et al., 1991). Territorial defense is usually strongest during the early part of the breeding season and lessens as chicks hatch (Lanctot et al., 2000). All shorebirds nesting in the Bristol Bay watershed, except solitary sandpiper (*Tringa solitaria*), nest on the ground. Shorebirds usually produce four eggs per clutch. After a nest is depredated or lost due to environmental factors, re-nesting may be attempted in some species, but generally the season is long enough for only one complete nesting cycle (laying, incubation, and brood-rearing). Incubation may take from 18 to 28 days, depending on species; chicks can move to forage in habitats outside of the nesting territories within a few days of hatching. Adults generally brood young for several days or more, until they are thermally independent, and provide defense against predators for two to three weeks. The time from hatch to fledging takes from 17 to 45 days depending on species shorebird. Individual breeding behaviors are discussed at length in the species accounts of the *Birds of North America* (Cornell Lab of Ornithology, 2011).

Alaska is known as a nursery ground for shorebirds; however the Bristol Bay watershed has not been inventoried for breeding shorebird distribution or abundance. Studies from montane areas in adjacent Katmai and Lake Clark NPPs and the Kilbuck and Ahklun Mountains and from lowlands of the northern Alaska Peninsula provide some basis for distribution of breeding species, but cannot be used to estimate breeding densities. For montane areas in Katmai and Lake Clark, the most common species found during May (breeding season) were semipalmated

EPA-6363-000003069

plover, spotted sandpiper, wandering tattler, greater and lesser (*Tringa flavipes*) yellowlegs, surfbird, least sandpiper (*Calidris minutilla*), and Wilson's snipe (Gill and Sarvis, 1999; Ruthrauff et al., 2007). Ruthrauff et al. (2007) extended the breeding range of several alpine shorebirds (wandering tattler, surfbird, and Baird's sandpiper (*C. bairdii*)) and confirmed these and another three species (black-bellied plover, American golden-plover, Pacific golden-plover), previously only known as migrants, to be breeders in Katmai. In the area west of the Bristol Bay watershed, Petersen et al. (1991) found black-bellied plover, semipalmated plover, spotted sandpiper, greater yellowlegs, western sandpiper, rock sandpiper, dunlin, Wilson's snipe, and red-necked phalarope to be the most common breeding shorebirds. For lowland areas of the northern Alaska Peninsula, the most common shorebird species found during May were greater yellowlegs, least sandpiper, dunlin, short-billed dowitcher, Wilson's snipe, and red-necked phalarope (Savage and Tibbitts, In prep). Other species that breed in the area include whimbrel and Hudsonian godwit (Ruthrauff et al., 2007).

Shorebird productivity, survivorship, and mortality) are affected by many factors that may vary by species, region and annual conditions. Measures of these parameters do not exist specifically for the Bristol Bay watershed and may not exist at all for many species of shorebirds. Productivity may be affected by life history (e.g., age at first reproduction, annual participation in breeding), seasonal abundance of food resources, weather, flooding, predation, and other forms of disturbance. Productivity in birds is measured in various ways, including proportion of eggs hatched, proportion of successful nests, and proportion of young fledged. Shorebird pairs may produce, at most, four chicks per season. Most small and medium-sized birds, including shorebirds, suffer from high mortality during their first weeks and months of life. It is possible that some species may experience complete reproductive failure for a region in some years.

Survival may be affected by food availability, weather and climate, predation, and human-caused mortality (e.g., building strikes, domestic cat predation, and contaminated or degraded habitats); to date, human disturbance, including habitat degradation, is significantly greater along the migratory paths and wintering grounds of most shorebirds, than in the breeding grounds. Once birds reach adult age and have successfully navigated their first migration, survival is generally higher. The U.S. Geological Survey's Bird Banding Lab maintains longevity records for banded birds (USGS Bird Banding Lab, 2011). These records indicate that smaller shorebird species live from 6 to12 years, while some of the medium to larger species have been recorded to live 21 (Pacific golden-plover) to 23 (bristle-thighed curlew) years. The average age of the majority of the population is much lower and is not known for most species of shorebirds.

Population, Subpopulations, and Genetics

Shorebird populations throughout North America are experiencing declines (Alaska Shorebird Group, 2008). Although accurate population data are lacking for most shorebirds, of the 30 regularly occurring shorebird species in the Bristol Bay watershed, 17 are suspected to be declining and 11 are thought to be stationary; there is not enough information to make a determination for two species (Morrison et al., 2006). None of the species using the Bristol Bay watershed are known to be increasing in population.

Two species of shorebirds found in the Bristol Bay watershed may include two or more subspecies, especially during the migratory period. Of the two subspecies of dunlin that breed in

Alaska, it is most likely the *Calidris alpina pacifica* subspecies that migrates through Bristol Bay and not the *C.a. arcticola* subspecies. Subspecies status for this species is still under consideration (Warnock and Gill, 1996). Four to five subspecies of rock sandpiper are found in Alaska and the most likely subspecies to use the Bristol Bay watershed for breeding would be *Calidris ptilocnemis tschuktschorum;* use by *C. p. couesi*, or *C. p. ptilocnemis* during migration may also be possible (Gill et al., 2002).

Human Use and Threats

Shorebirds have been, and continue to be, used as human food. During the latter part of the 19th and early 20th century, shorebirds were harvested commercially, along with waterfowl, for human consumption. The overhunting of shorebirds and waterfowl and the killing of birds for the fashion industry in part led to the development of the Migratory Bird Treaty Act of 1918, and in North America, shorebirds are protected under its provisions. Shorebirds may still be hunted under regulations formulated for each state. In Alaska, Wilson's snipe may be harvested during the fall migratory bird season (1 September to 16 December in the Bristol Bay area). Sixteen shorebird species common to Bristol Bay during some part of their life cycle may be harvested during the Alaska Subsistence Spring/Summer Migratory Bird season (1 April to 14 June and 16 July to 31 August). A harvest survey is conducted in parts of southwest Alaska, with various areas assessed on rotating years; however, participation is voluntary and the reports likely represent minimum harvest levels (Naves, 2011). During the 2009 survey (included the Y-K Delta Region), 1,688 shorebirds and 1,835 shorebird eggs were reported harvested (Naves, 2011). In general, godwits, whimbrels and curlews are targeted, due to their larger size. The value of these shorebirds to the diet and thus economy of Native Alaskans, especially in western Alaska, should not be underestimated.

Non-consumptive uses of shorebirds mostly include shorebird-viewing and tourism associated with that activity. Other areas of Alaska such as Kachemak Bay, the Copper River Delta, and Cordova are developing this industry and depend on birds that will pass through the Bristol Bay watershed. There have been some initial attempts (http://www.visitbristolbay.com/visitor-guide/wildlife.html) to develop the birding tourist industry in the Bristol Bay area.

EPA-6363-000003071

LANDBIRDS

Introduction

Approximately 80 species, representing six orders and 27 families of landbirds breed in the areas in and adjacent to the Nushagak and Kvichak watersheds (USFWS, 2008; USFWS, 2010b). Published surveys of birds in this area include biological inventories from 1902 through 1959 (Gabrielson, 1944a; Gabrielson, 1944b; Hurley, 1931a; Hurley, 1931b; Hurley, 1931c; Hurley, 1932; Osgood, 1904; Williamson and Peyton, 1962). More recent work in this and adjacent areas include: inventories in the Kilbuck and Ahklun Mountains (Petersen et al., 1991), inventories in the montane regions of Lake Clark and Katmai NPPs (Ruthrauff et al., 2007), breeding bird surveys in Dillingham, Katmai, and King Salmon, and Christmas Bird Counts in Dillingham and King Salmon (National Audubon Society: http://audubon2.org/cbchist/count_table.html). "Landbirds" are species that are generally associated with terrestrial habitats: passerines (or "songbirds") and other species such as woodpeckers, owls, raptors, and gallinaceous birds (grouse and ptarmigan). Bald eagles are addressed separately in this document.

Landbirds common in the region during the summer breeding season include, but are not limited to, Swainson's thrush (*Catharus ustulatus*), American robin (*Turdus migratorius*), varied thrush (*Ixoreus naevius*), Arctic warbler (*Phylloscopus borealis*), orange-crowned warbler (*Vermivora celata*), and Wilson's warbler (*Wilsonia pusilla*) (USGS, 2011). Numerous other songbirds regularly nest here, including several other species of swallows (*Hirundinidae*), thrushes (*Turdidae*), warblers (*Parulidae*), sparrows (*Emberizidae*), and others. Year-round resident species include northern goshawk (*Accipiter gentilis*), great-horned owl, common raven (*Corvus corax*), gray jay (*Perisoreus canadensis*), black-billed magpie (*Pica pica*), black-capped and boreal chickadees (*Poecile atricapillus* and *P. hudsonicus*), American dipper (*Cinclus mexicanus*), common redpoll (*Carduelis flammea*), and snow bunting (*Plectrophenax nivalis*) (ADNR, 2008; USGS, 2011). Of the relatively common species occurring in the area, two (short-eared owl (*Asio flammeus*) and rusty blackbird (*Euphagus carolinus*)) are on the Continental Watch List. Twenty-six of the Bristol Bay landbird species are on the Continental Stewardship list for Partners in Flight, a multi-stakeholder partnership dedicated to the conservation of landbirds (Rich et al., 2004).

Habitat

Most species of landbirds occupy and defend individual breeding territories during the spring and summer. Few studies have focused on landbirds in the Nushagak and Kvichak watersheds and site-specific information is extremely sparse. Migratory species begin arriving in late April and may remain through late September (Savage, personal communication).

The Nushagak and Kvichak watersheds are within, albeit near the border of, the Arctic avifaunal biome, as described by Partners in Flight (Rich et al., 2004). The diversity, population, distribution, and densities of birds here are not well-understood. While no comprehensive studies have been published for these watersheds, land bird density and diversity, generally speaking, may be highest along the numerous riparian corridors of the region (Boreal Partners in Flight Working Group, 1999; Williamson and Peyton, 1962). Greater landbird densities in the riparian zone often occur in areas where the surrounding habitats have lower plant species or canopy layer diversity (Stauffer and Best, 1980; Wiebe and Martin, 1998). Riparian habitats in these

EPA-6363-000003072

watersheds include ribbons of tall shrub (willow/cottonwood/alder), as well as spruce, birch and mixed forests, which wind and branch across vast acreages of moist and wet tundra (ADF&G, 2006; Nushagak-Mulchatna Watershed Council, 2007).

From the sparse site-specific data available, we are able to collect the following information to begin a characterization of local species diversity. For the Western Alaska Lowlands/Uplands Bird Conservation Region 2 (BCR 2), which includes the Ahklun Mountains and Bristol Bay-Nushagak Lowlands, passerine diversity is thought to be greatest in riparian tall shrub habitats (Boreal Partners in Flight Working Group, 1999).[5] Sixteen species of passerines, one woodpecker species, and belted kingfisher have been recorded along the Alagnak River (Gotthardt et al., 2010), although proximity to the river and whether or not the records were associated with riparian habitats is unknown.

Mixed spruce-birch forests of the area may also have a relatively high species diversity, with 25 to 27 species noted by Williamson and Peyton (1962). Forty species were recorded in plots in LCNPP, within the upper Mulchatna and upper Kvichak watersheds; the survey area likely included some non-riparian areas (Ruthrauff et al., 2007).

No site-specific density information is available for the Bristol Bay watershed. Regarding potential densities, Kessel reported between 11.8 and 45.4 passerine/woodpecker breeding territories per 10-hectare plot (mostly riparian) in Interior Alaska, (Kessel, 1998). However, significantly wide ranges of variability in landbird breeding densities reduce any potential usefulness of these figures for the local area.

Landbird diet requirements vary by species and time of year; foods include: vegetation (seeds, berries), invertebrates (aquatic and terrestrial, as well as flying insects), and vertebrates (other birds, fish and mammalian carrion, juvenile fish, fish eggs). During the breeding season, adults face high demands, associated with producing eggs, feeding young, and molting; young birds require considerable food resources to grow and both young and adults must gain fat prior to migration. Even birds that consume a high proportion of seeds and other vegetative matter in the non-breeding season may switch to food in higher trophic levels during the breeding season. In general, the timing of hatch and the growth of young landbirds is directly related to the abundance of invertebrate food sources (Ehrlich et al., 1988). In fact, the abundance of emergent aquatic insects may be one of the reasons riparian habitats are often associated with greater avian abundance (Iwata et al., 2003; Murakami and Nakano, 2002). Foraging techniques for avian predators of invertebrates (e.g., foliage gleaning, ground foraging, aerial predating/flycatching) vary considerably among species, however, so landbirds can exploit a variety of riparian invertebrate prey types overall (Murakami and Nakano, 2001).

Interspecies Interactions

Regarding the importance of salmon to landbirds, recent studies have indicated that the abundance of many species of songbirds is related to the presence of salmon carcasses in

[5] BCR 2 includes most of the middle and lower areas of the Nushagak and Kvichak watersheds, but extends beyond them, from the Kuskokwim River to Unimak Pass.

freshwater streams (Christie and Reimchen, 2008; Gende and Willson, 2001; Willson et al., 1998). The relationship is complex and not yet fully understood (Christie and Reimchen, 2008; Gende et al., 2002). One primary component, though, appears to be the initial positive effect of the seasonal accumulation of carcasses on invertebrate populations (Helfield and Naiman, 2006). For example, masses of aquatic invertebrate larvae feed on salmon carcasses (Wipfli et al., 1999), over-winter in the soil, and emerge in the spring as adults, subsequently becoming aerial prey for songbirds, an important seasonal subsidy that becomes available during the same period when terrestrial invertebrate biomass is low (Nakano and Murakami, 2001). Terrestrial invertebrate (e.g., litter detritivore) populations may also increase as a result of salmon carcass abundance, providing another important food source for passerines (Gende and Willson, 2001). Passerines such as Pacific wren (*Troglodytes pacificus*) and other species also feed directly on fly larvae within dead salmon in the fall (Christie and Reimchen, 2008).

Other important relationships between salmon and landbirds include the effects of increased plant productivity, particularly in riparian areas, that appears to result from MDN input from salmon (Gende et al., 2002; Helfield and Naiman, 2001; Hilderbrand et al., 2004; Naiman et al., 2002a). This increased productivity, reflected, for example, in an abundance of berries and seeds, in turn provides an increased vegetative food source for landbirds such as Swainson's and varied thrushes (Christie and Reimchen, 2008). Another positive effect of spawning salmon on Alaska landbirds is indicated in the case of American dippers. Dippers feed primarily on aquatic invertebrates, which appear to increase in abundance with salmon carcasses, and females switch to salmon eggs, fry, and small bits of carcasses during the egg-laying period (Morrissey et al., 2010). In one study of dippers, there was an apparent positive correlation between consumption of salmon fry and higher fledgling mass and less brood mortality (Obermeyer et al., 2006).

As noted above, the trophic relationships among salmon, landbirds, invertebrate prey items, and other organisms are complex, and not yet well understood, particularly in relatively remote and undisturbed boreal regions, such as the Nushagak and Kvichak watersheds. However, these relationships are apparently significant to many aspects of landbird life history. In summary, abundance, distribution, productivity, habitat use, and foraging habits are some of the ways in which multiple species of landbirds may be affected by salmon. The temporal nature of the pulses of the abundant food source salmon provide is of particular interest. Several researchers have examined such seasonal resource subsidies in the riparian forest and it has been suggested (Takimoto et al., 2002) that seasonal productivity differences between spatially linked habitats help foster the stability of food web dynamics (Wiebe and Martin, 1998; Zhang et al., 2003).

EPA-6363-000003074

APPENDIX 1: LIST OF AUTHORS AND REVIEWERS

Species	Primary Author(s) (Affiliation)	Expert Reviewer (Affiliation)
Overall Report	• Phil Brna (USFWS/AFWFO) • Lori Verbrugge (USFWS/AFWFO)	
Land Cover	• Phil Brna (USFWS/AFWFO)	• David Selkowitz (USGS/ Alaska Science Center) • Jerry Tande (USFWS/NWI Program) • Julie Michaelson (USFWS/NWI Program) • Marcus Geist (The Nature Conservancy)
Brown Bear	• Colleen Matt (C.A. Matt; ADF&G/ Retired)	• Sterling Miller (ADF&G/Retired) • Sean Farley (ADF&G) • Grant Hilderbrand (NPS) • Cara Staab (BLM) • Susan Savage (USFWS/Alaska Peninsula-Becharof NWRs) • Patrick Walsh (USFWS/Togiak NWR) • Buck Mangipane (NPS/ Lake Clark NP) • Page Spencer (NPS/Retired) • Lem Butler (ADF&G/Wildlife Conservation) • Meghan Riley (ADF&G/Wildlife Conservation) • Jim Woolington (ADF&G/Wildlife Conservation)
Caribou	• Lori Verbrugge (USFWS/AFWFO) • Ken Whitten (ADF&G/Retired)	• Layne Adams (USGS/Alaska Science Center) • Dominique Watts (USFWS/Alaska Peninsula-Becharof NWRs) • Bob Tobey (ADF&G/Retired) • Andy Aderman (USFWS/Togiak NWR) • Buck Mangipane (NPS/Lake Clark NP) • Cara Staab (BLM) • Jeff Shearer (NPS/Lake Clark NP) • Lem Butler (ADF&G/Wildlife Conservation) • Meghan Riley (ADF&G/Wildlife Conservation) • Jim Woolington (ADF&G/Wildlife

EPA-6363-000003075

		Conservation) • Nick Demma (ADF&G/Wildlife Conservation) • Bruce Seppi (BLM)
Moose	• Lori Verbrugge (USFWS/AFWFO) • Chuck Schwartz (ADF&G and USGS/Retired)	
Wolf	• Lori Verbrugge (USFWS/AFWFO)	• Layne Adams (USGS/Alaska Science Center) • Buck Mangipane (NPS/Lake Clark NP) • Dominique Watts (USFWS/Alaska Peninsula- Becharof NWRs) • Ashley Stanek (UAA/ENRI) • Ken Whitten (ADF&G/Retired) • Bob Tobey (ADF&G/Retired) • Cara Staab (BLM) • Bruce Seppi (BLM) • Page Spencer (NPS/Retired)
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Species List	• Maureen de Zeeuw (USFWS/AFWFO) • Susan Savage (USFWS/Alaska Peninsula-Becharof NWRs)	

EPA-6363-000003076

APPENDIX 2: SOUTHWEST ALASKA TERRESTRIAL VERTEBRATE SPECIES

BIRDS
(Togiak NWR, Bird List 2006; D. Ruthrauff et al. 2007; Alaska Peninsula and Becharof NWR Bird List, 2010; with edits from S. Savage, M. Swaim, D. Ruthrauff)

The following species are thought to regularly occur in the Nushagak and Kvichak watersheds based on surveys and observations documenting their presence in adjacent federal land management areas. The species are marked as breeders if they are known to breed in the adjacent areas. Other species that may occur as accidentals are not included here.

Common Name	*Scientific Name*	Breeder
Waterfowl		
Greater White-fronted Goose	*Anser albifrons*	*
Emperor Goose	*Chen canagica*	*
Snow Goose	*Chen caerulescens*	
Brant	*Branta bernicla*	*
Cackling Goose	*Branta hutchinsii*	
Canada Goose	*Branta canadensis*	*
Trumpeter Swan	*Cygnus buccinator*	*
Tundra Swan	*Cygnus columbianus*	*
Gadwall	*Anas strepera*	*
Eurasian Wigeon	*Anas penelope*	
American Wigeon	*Anas americana*	*
Mallard	*Anas platyrhynchos*	*
Northern Shoveler	*Anas clypeata*	*
Northern Pintail	*Anas acuta*	*
Green-winged Teal	*Anas crecca*	*
Canvasback	*Aythya valisineria*	
Redhead	*Aythya americana*	
Ring-necked Duck	*Aythya collaris*	*
Greater Scaup	*Aythya marila*	*
Lesser Scaup	*Aythya affinis*	
Steller's Eider	*Polysticta stelleri*	
Spectacled Eider	*Somateria fischeri*	
King Eider	*Somateria spectabilis*	
Common Eider	*Somateria mollissima*	*
Harlequin Duck	*Histrionicus histrionicus*	*
Surf Scoter	*Melanitta perspicillata*	*
White-winged Scoter	*Melanitta fusca*	*
Black Scoter	*Melanitta americana*	*
Long-tailed Duck	*Clangula hyemalis*	*

EPA-6363-000003077

Common Name	*Scientific Name*	Breeder
Bufflehead	*Bucephala albeola*	*
Common Goldeneye	*Bucephala clangula*	*
Barrow's Goldeneye	*Bucephala islandica*	
Common Merganser	*Mergus merganser*	*
Red-breasted Merganser	*Mergus serrator*	*
Gallinaceous Birds		
Spruce Grouse	*Falcipennis canadensis*	*
Willow Ptarmigan	*Lagopus lagopus*	*
Rock Ptarmigan	*Lagopus muta*	*
White-tailed Ptarmigan	*Lagopus leucura*	*
Loons		
Red-throated Loon	*Gavia stellata*	*
Pacific Loon	*Gavia pacifica*	*
Common Loon	*Gavia immer*	*
Grebes		
Horned Grebe	*Podiceps auritus*	*
Red-necked Grebe	*Podiceps grisegena*	*
Tubenoses		
Northern Fulmar	*Fulmarus glacialis*	
Sooty Shearwater	*Puffinus griseus*	
Short-tailed Shearwater	*Puffinus tenuirostris*	
Fork-tailed Storm-Petrel	*Oceanodroma furcata*	
Leach's Storm-Petrel	*Oceanodroma leucorhoa*	
Cormorants		
Double-crested Cormorant	*Phalacrocorax auritus*	*
Red-faced Cormorant	*Phalacrocorax urile*	*
Pelagic Cormorant	*Phalacrocorax pelagicus*	*
Hawks, Eagles, Falcons		
Osprey	*Pandion haliaetus*	*
Bald Eagle	*Haliaeetus leucocephalus*	*
Northern Harrier	*Circus cyaneus*	*
Sharp-shinned Hawk	*Accipiter striatus*	
Northern Goshawk	*Accipiter gentilis*	*
Red-tailed Hawk	*Buteo jamaicensis*	*
Rough-legged Hawk	*Buteo lagopus*	*
Golden Eagle	*Aquila chrysaetos*	*

EPA-6363-000003078

Common Name	*Scientific Name*	Breeder
American Kestrel	*Falco sparverius*	
Merlin	*Falco columbarius*	*
Gyrfalcon	*Falco rusticolus*	*
Peregrine Falcon	*Falco peregrinus*	*
Cranes		
Sandhill Crane	*Grus canadensis*	*
Shorebirds		
Black-bellied Plover	*Pluvialis squatarola*	*
American Golden-Plover	*Pluvialis dominica*	*
Pacific Golden-Plover	*Pluvialis fulva*	*
Semipalmated Plover	*Charadrius semipalmatus*	*
Black Oystercatcher	*Haematopus bachmani*	*
Spotted Sandpiper	*Actitis macularius*	*
Solitary Sandpiper	*Tringa solitaria*	
Wandering Tattler	*Tringa incana*	*
Greater Yellowlegs	*Tringa melanoleuca*	*
Lesser Yellowlegs	*Tringa flavipes*	*
Whimbrel	*Numenius phaeopus*	*
Bristle-thighed Curlew	*Numenius tahitiensis*	
Hudsonian Godwit	*Limosa haemastica*	*
Bar-tailed Godwit	*Limosa lapponica*	*
Marbled Godwit	*Limosa fedoa*	*
Ruddy Turnstone	*Arenaria interpres*	
Black Turnstone	*Arenaria melanocephala*	*
Surfbird	*Aphriza virgata*	*
Red Knot	*Calidris canutus*	
Sanderling	*Calidris alba*	
Semipalmated Sandpiper	*Calidris pusilla*	
Western Sandpiper	*Calidris mauri*	*
Least Sandpiper	*Calidris minutilla*	*
Baird's Sandpiper	*Calidris bairdii*	*
Pectoral Sandpiper	*Calidris melanotos*	*
Rock Sandpiper	*Calidris ptilocnemis*	*
Dunlin	*Calidris alpina*	*
Short-billed Dowitcher	*Limnodromus griseus*	*
Long-billed Dowitcher	*Limnodromus scolopaceus*	
Wilson's Snipe	*Gallinago delicata*	*
Red-necked Phalarope	*Phalaropus lobatus*	*
Red Phalarope	*Phalaropus fulicarius*	

Common Name	*Scientific Name*	Breeder
Gulls and Terns		
Black-legged Kittiwake	*Rissa tridactyla*	*
Sabine's Gull	*Xema sabini*	*
Bonaparte's Gull	*Chroicocephalus philadelphia*	*
Mew Gull	*Larus canus*	*
Herring Gull	*Larus argentatus*	
Slaty-backed Gull	*Larus schistisagus*	
Glaucous-winged Gull	*Larus glaucescens*	*
Glaucous Gull	*Larus hyperboreus*	*
Aleutian Tern	*Onychoprion aleuticus*	*
Arctic Tern	*Sterna paradisaea*	*
Jaegers		
Pomarine Jaeger	*Stercorarius pomarinus*	
Parasitic Jaeger	*Stercorarius parasiticus*	*
Long-tailed Jaeger	*Stercorarius longicaudus*	*
Alcids		
Common Murre	*Uria aalge*	*
Thick-billed Murre	*Uria lomvia*	*
Pigeon Guillemot	*Cepphus columba*	*
Marbled Murrelet	*Brachyramphus marmoratus*	*
Kittlitz's Murrelet	*Brachyramphus brevirostris*	*
Ancient Murrelet	*Synthliboramphus antiquus*	
Parakeet Auklet	*Aethia psittacula*	*
Rhinoceros Auklet	*Cerorhinca monocerata*	
Horned Puffin	*Fratercula corniculata*	*
Tufted Puffin	*Fratercula cirrhata*	*
Owls		
Great Horned Owl	*Bubo virginianus*	*
Snowy Owl	*Bubo scandiacus*	
Northern Hawk Owl	*Surnia ulula*	*
Great Gray Owl	*Strix nebulosa*	*
Short-eared Owl	*Asio flammeus*	*
Boreal Owl	*Aegolius funereus*	*
Northern Saw-whet Owl	*Aegolius acadicus*	*
Hummingbirds		
Rufous Hummingbird	*Selasphorus rufus*	

EPA-6363-000003080

Common Name	*Scientific Name*	Breeder
Kingfishers		
Belted Kingfisher	*Megaceryle alcyon*	*
Woodpeckers		
Downy Woodpecker	*Picoides pubescens*	*
Hairy Woodpecker	*Picoides villosus*	
American Three-toed Woodpecker	*Picoides dorsalis*	*
Black-backed Woodpecker	*Picoides arcticus*	*
Northern Flicker	*Colaptes auratus*	*
Flycatchers		
Olive-sided Flycatcher	*Contopus cooperi*	
Alder Flycatcher	*Empidonax alnorum*	*
Say's Phoebe	*Sayornis saya*	
Shrikes		
Northern Shrike	*Lanius excubitor*	*
Crows, Jays, Magpies		
Gray Jay	*Perisoreus canadensis*	*
Steller's Jay	*Cyanocitta stelleri*	
Black-billed Magpie	*Pica hudsonia*	*
Northwestern Crow	*Corvus caurinus*	*
Common Raven	*Corvus corax*	*
Larks		
Horned Lark	*Eremophila alpestris*	*
Swallows		
Tree Swallow	*Tachycineta bicolor*	*
Violet-green Swallow	*Tachycineta thalassina*	*
Bank Swallow	*Riparia riparia*	*
Cliff Swallow	*Petrochelidon pyrrhonota*	*
Barn Swallow	*Hirundo rustica*	*
Chickadees		
Black-capped Chickadee	*Poecile atricapillus*	*
Boreal Chickadee	*Poecile hudsonicus*	*
Nuthatches		
Red-breasted Nuthatch	*Sitta canadensis*	*

EPA-6363-000003081

Common Name	*Scientific Name*	Breeder
Creepers		
Brown Creeper	*Certhia americana*	*
Wrens		
Pacific Wren	*Troglodytes pacificus*	*
Dippers		
American Dipper	*Cinclus mexicanus*	*
Kinglets		
Golden-crowned Kinglet	*Regulus satrapa*	*
Ruby-crowned Kinglet	*Regulus calendula*	*
Old World Warblers		
Arctic Warbler	*Phylloscopus borealis*	*
Thrushes		
Northern Wheatear	*Oenanthe oenanthe*	
Gray-cheeked Thrush	*Catharus minimus*	*
Swainson's Thrush	*Catharus ustulatus*	*
Hermit Thrush	*Catharus guttatus*	*
American Robin	*Turdus migratorius*	*
Varied Thrush	*Ixoreus naevius*	*
Watgtails and Pipits		
Eastern Yellow Wagtail	*Motacilla tschutschensis*	*
American Pipit	*Anthus rubescens*	*
Waxwings		
Bohemian Waxwing	*Bombycilla garrulus*	*
Longspurs and Buntings		
Lapland Longspur	*Calcarius lapponicus*	*
Snow Bunting	*Plectrophenax nivalis*	*
McKay's Bunting	*Plectrophenax hyperboreus*	
Wood Warblers		
Northern Waterthrush	*Parkesia noveboracensis*	*
Orange-crowned Warbler	*Oreothlypis celata*	*
Yellow Warbler	*Setophaga petechia*	*
Blackpoll Warbler	*Setophaga striata*	*

EPA-6363-000003082

Common Name	Scientific Name	Breeder
Yellow-rumped Warbler	*Setophaga coronata*	*
Wilson's Warbler	*Cardellina pusilla*	*
Sparrows		
American Tree Sparrow	*Spizella arborea*	*
Savannah Sparrow	*Passerculus sandwichensis*	*
Fox Sparrow	*Passerella iliaca*	*
Song Sparrow	*Melospiza melodia*	*
Lincoln's Sparrow	*Melospiza lincolnii*	*
White-crowned Sparrow	*Zonotrichia leucophrys*	*
Golden-crowned Sparrow	*Zonotrichia atricapilla*	*
Dark-eyed Junco	*Junco hyemalis*	*
Blackbirds		
Rusty Blackbird	*Euphagus carolinus*	*
Finches		
Gray-crowned Rosy-Finch	*Leucosticte tephrocotis*	*
Pine Grosbeak	*Pinicola enucleator*	*
Red Crossbill	*Loxia curvirostra*	
White-winged Crossbill	*Loxia leucoptera*	*
Common Redpoll	*Acanthis flammea*	*
Hoary Redpoll	*Acanthis hornemanni*	*
Pine Siskin	*Spinus pinus*	

MAMMALS
(Cook and MacDonald, 2005; USFWS, 2009b)

Common Name	Scientific Name
Terrestrial Mammals	
Shrews	
Masked shrew	*Sorex cinereus*
Pygmy shrew	*Sorex hoyi*
Tundra shrew	*Sorex tundrensis*
Alaska tiny shrew	*Sorex yukonicus*
Arctic shrew	*Sorex arcticus*
Montane shrew	*Sorex monticolus*
Northern water shrew	*Sorex palustris*

EPA-6363-000003083

Common Name	*Scientific Name*
Bats	
Little brown bat	*Myotis lucifigus*
Canids	
Arctic fox	*Alopex lagopus*
Coyote	*Canis latrans*
Wolf	*Canis lupus*
Red fox	*Vulpes vulpes*
Cats	
Lynx	*Lynx canadensis*
Weasels	
River otter	*Lutra canadensis*
Wolverine	*Gulo gulo*
Marten	*Martes americana*
Ermine	*Mustela erminea*
Least weasel	*Mustela nivalis*
Mink	*Mustela vison*
Bears	
Black bear	*Ursus americanus*
Brown bear	*Ursus arctos*
Ungulates	
Moose	*Alces alces*
Caribou	*Rangifer tarandus*
Dall sheep	*Ovis dalli*
Rodents	
Hoary marmot	*Marmota caligata*
Arctic ground squirrel	*Spermophilus parryii*
Red squirrel	*Tamiasciurus hudsonicus*
Beaver	*Castor canadensis*
Meadow jumping mouse	*Zapus hudsonius*
Northern red-backed vole	*Clethrionomys rutilus*
Northern collared lemming	*Dicrostonyx groenlandicus*
Brown lemming	*Lemmus trimucronatus*
Northern bog lemming	*Synaptomys borealis*
Meadow vole	*Microtus pennsylvanicus*
Tundra vole	*Microtus oeconomus*
Singing vole	*Microtus miurus*
Muskrat	*Ondatra zibethicus*
Porcupine	*Erethizon dorsatum*
Collared pika	*Ondatra collaris*

EPA-6363-000003084

Common Name	***Scientific Name***
Hares	
Snowshoe hare	*Lepus americanus*
Tundra hare	*Lepus othus*

EPA-6363-000003085

APPENDIX 3: LITERATURE CITED

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Appendix D

Traditional Ecological Knowledge and Cultural Characterization of the Nushagak and Kvichak Watersheds, Alaska

EPA-6363-000003120

TRADITIONAL ECOLOGICAL KNOWLEDGE AND CULTURAL CHARACTERIZATION OF THE NUSHAGAK AND KVICHAK WATERSHEDS, ALASKA

Submitted to the Bristol Bay Assessment:
Environmental Protection Agency

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Public Review Draft

EXECUTIVE SUMMARY

1. Voices of the People

…Salmon more or less defines this area. It defines who we are. When you look at our art, you will see salmon….It is who we are. When you listen to the stories and take a steam, even in the middle of winter, people talk about salmon. It is in our stories; it is in our art. It is who we are; it defines us. M-61, 9/16/11

…we are relying on EPA to give us a fair shake out here. If EPA is going to crap all over our people, then take out the checkbook, federal government, and start writing million dollar checks for these people to move to Anchorage because you are going to kill us culturally, economically and every other way. M-60, 9/16/11

But I wouldn't trade this place for anything. This is home; this is where I find clean water to drink. M-51, 8/20/11

We love the place; it's home. Moving is not an option to me. M-29, 8/17/11

…basically one of the main purposes of the Blessing of the Water is to make that Holy water…. When the Father blesses that particular river, that particular river becomes Holy. M-61, 9/16/11

I think with us, during potlatch times, during hard times, or Russian Christmas, or if we gather together, everybody brings out their dry fish or their jarred fish or their salt fish. Nobody goes hungry, there's always sharing. F-32, 8/18/11

We share with our families, or if anybody does not have fish, we give them fish also. F-27, 8/17/11

2. The Condition of the Indigenous Cultures of the Bristol Bay Region

This section of the Bristol Bay Assessment is based on 53 interviews in seven villages and an overview of previous research in the study area. The condition of the ecosystems, both riverine and lacustrine, on which the Yup'ik and Dena'ina depend for wild fish, mammals, and plants including the keystone species salmon, is nearly pristine. The cultures have proved to be sustainable in this region for thousands of years. Alaska Department of Fish and Game statistics indicate wild subsistence resources including salmon provide the Yup'ik and Dena'ina of the

study area with the bulk of their food resources. Wild foods provide critical nutritional elements in both quantity and quality in the diet, but subsistence also forms the core of the culture itself, including knowledge, attitudes, practices, and beliefs important to the Yup'ik and Dena'ina people in their daily lives.

The villages of the study area are predominantly Alaska Native and the population remains stable (United States Census, Alaska). The culture has a very high degree of homogeneity as represented by interviewees' responses to this set of questions revolving around the importance of salmon and streams in their lives. Interviews conducted in this project relating to the importance and significance of salmon and clean water resulted in 97% concurrence among Elders and culture bearers. The Yup'ik people of the region retain their language, and more than 40% of the population continues to speak it. The Dena'ina are undergoing a cultural renaissance through language revitalization programs and the emergence of culture camps. Both languages have a large number of words related to salmon and stream resources reflecting nuanced understanding developed over time.

Elders and culture bearers continue to instruct young people particularly at fish camps where not only fishing and processing techniques are taught, but also cultural values. The social system which forms the backbone of the culture, nurturing the young, supporting the producers, and caring for the Elders, is based upon the virtue of sharing the wild foods harvested from the land and waters. Sharing networks extend to family members living far from home. The first salmon catch of the year is recognized with a prayer of thanks and shared in a continuation of the ancient First Salmon Ceremony.

The Yup'ik and Dena'ina consider the land and waters to be their sacred homeland. They have traditionally considered the salmon as kin in the sacred web of life. The populations of both Yup'ik and Dena'ina have shown themselves to be spiritually tenacious, combining elements of traditional practices with those of Russian Orthodox and other Christian churches to create a rich syncretic religious heritage for their families. The rivers are blessed by priests annually in the Great Blessing of the Water at Theophany, celebrating the baptism of Christ. This ceremony, for Orthodox Yup'ik and Dena'ina, is the pure element of God expressed as sanctified nature. The holy water of the rivers derived from this ceremony is used to bless the homes, churches, and people and is believed to have curative powers.

3. The Status of the Resource Relative to other Salmon Culture Ecosystems Internationally

The Human Relations Area Files on-line cultural database (Human Relations Area Files, World Cultures Data Base. http://www.yale.edu/hraf/collections.htm) identifies 23 world cultures in which anadromous salmon are, or were, a chief component of subsistence. Only in Alaska are wild, non-farmed, non-hatchery spawned, non-bioengineered salmon abundant. The Yup'ik and Dena'ina of the study area are among the few remaining cultures to still rely on wild salmon as a chief source of nutrients and have an intact relationship with the landscape that supports them.

4. The Causes of the Unique Status of the Resource and the Vulnerability of the Resource

This area is among the last remaining truly viable cultural and ecologically interdependent human/salmon ecosystem in the world because it is an intact ecosystem largely due to the fact that it is remote, roadless, and until recently, not thought to contain natural resources of value

other than fish and game. In addition the unique Alaska State and United States Federal subsistence laws protect the indigenous people's right to harvest wild resources.

5. Vulnerabilities

The existing culture of the indigenous people of the study area is vulnerable to anything that would change the quantity or quality of wild salmon resources or the quantity or quality of water in the Nushagak or Kvichak watersheds. Negative impacts to salmon would leave the existing culture susceptible to destabilization and affect its present ability to cope with natural disasters. If significant negative impacts to salmon or streams occur, the cultural stability will be vulnerable to change in the following ways:

- Since the diet is heavily dependent on wild foods, particularly salmon, the diet would be significantly changed from a highly nutritious diet to one based on store-bought processed foods.
- Since the social networks are highly dependent on procuring salmon (fish camps) but also sharing salmon and wild food resources, the current social support system would be significantly degraded
- Since significant, meaningful family-based work takes place in fish camp or similar subsistence settings, transmission of cultural values and language learning would be impacted and family cohesion impacted.
- Since values and the belief system are represented by interaction with the natural world through salmon practices and clean water practices and symbolic rituals, core beliefs

would be challenged potentially resulting in a breakdown of cultural values, mental health degradation and behavioral disorders.

- Since Alaskan state and federal subsistence law currently rests on rural and urban designations, a significant increase in population potentially would result in loss of subsistence rights if an area were re-designated "urban."
- Since a yearly subsistence round rests on having time to harvest and process wild foods, a shift from part-time wage employment supporting subsistence to full-time wage employment would impact subsistence-gathering capabilities by restricting the time necessary to harvest subsistence resources.
- Since the area exhibits a high degree of cultural uniformity tied to shared subsistence practices, significant change could provoke increased tension and discord both between villages and among villagers.

Table of Contents

I. INTRODUCTION 9
A. Overview 9
B. Villages, Population, and Ethnicity 15
II. CULTURAL AND HISTORICAL BACKGROUND 20
A. Pre-Contact Bristol Bay 20
1. Voices of the People 20
2. Introduction 20
3. Pre-Contact Salmon Fishing Cultures 23
B. History and Culture of the Yup'ik Area 31
1. Voices of the People 31
2. Introduction 33
3. Pre-Contact Culture 33
4. Post-Contact History and Culture (A.D. 1791 to 1935) 35
C. History and Culture of the Dena'ina 41
1. Voices of the People 41
2. Pre-Contact Culture 42
3. Post-contact History and Culture 44
D. Traditional Yup'ik and Dena'ina Spirituality and Cosmology 47
1. The Yup'ik People 47
2. The Dena'ina People 52
E. The Yup'ik and Dena'ina Languages: Salmon and Streams 57
1. Voices of the People 57
2. Introduction 57
3. The Central Yup'ik Language 57
4. The Dena'ina Language 68

III. MODERN CULTURE 80
A. Interview Synopsis 80
B. Subsistence 85
1. Voices of the People 85
2. Introduction 87
3. Subsistence in Alaska 88
4. Scope of Subsistence 91
5. The Seasonal Subsistence Round 96
6. The Interplay of Subsistence and Wage Income 97
7. Subsistence as an Economic Sector 100
8. Subsistence and "Wealth" 103
C. Physical and Mental Well-being: the Role of Subsistence 105
1. Voices of the People 105
2. Introduction 107
3. Nutrition 109
4. Fitness 111
5. Disease Prevention 112
6. Local Wild Fish 114
D. Traditional Ecological Knowledge 116
1. Voices of the People 116
2. Introduction 117
E. Social Relations 124
1. Voices of the People 124
2. Introduction 127
3. Sharing and Generalized Reciprocity 127
4. Fish Camp 130
5. Steam Baths 131
6. Gender and Age Equity 132
7. Wealth 133
8. Suicide in the Study Area 134

F. Spirituality and Beliefs Concerning Water and Salmon 137
1. Voices of the People 137
2. Introduction 140
3. Great Blessing of the Water 141
4. Respect and Thanks 144
5. First Salmon Ceremony 145
G. Messages From the People 147
1. Voices of the People 147
IV. CONCLUSIONS 150
V. APPENDIX 1. METHODOLOGY and TRIBAL LETTER OF INTRODUCTION 154
VI. REFERENCES CITED 158

I. INTRODUCTION

A. Overview

The purpose of the Bristol Bay Cultural Assessment is to provide information to the Environmental Protection Agency on the status of the indigenous cultures of the Nushagak and Kvichak River watersheds and their dependence on and relationship to salmon and other stream-based natural resources of the region. The focus of the Bristol Bay Assessment is salmon and water and this part of the overall assessment portrays the human dimension of modern indigenous "salmon-cultures" of the region. The Human Relations Area Files on-line cultural database (http://www.yale.edu/hraf/collections.htm) identifies 23 cultures in which anadromous salmon are or were a chief component of subsistence. Wild Atlantic salmon populations have been decimated by high-seas fishing and dam building (Montgomery 2003:111-118) and consequently indigenous cultures such as the Sami of Fennoscandia, Micmac and Abnacki of northeastern North America and other cultures once dependent on Atlantic salmon have been forced to choose non-traditional options (cf. Lethola 2004: 72-84). In the Asian Far East wild salmon have likewise been decimated in Japan and Russia through overfishing and habitat destruction and cultures like the Ainu of Hokkaido and Nvkh of Sakhalin Island can no longer depend on wild salmon and cultural institutions based on salmon have been severely affected (cf. Iwasaki-Goodman and Nomoto 1998: 27-46). In the Pacific Northwest of North America hydroelectric dam building, overfishing, and habitat degradation have decimated wild salmon runs and the Northwest Coast cultures from California to British Columbia can no longer subsist on wild salmon as they once did (cf. Johnsen 2009). The Yup'ik of the Nushagak and Kvichak

River watersheds and the Dena'ina of the Lake Iliamna, Newhalen River and Lake Clark (also the Kvichak River watershed) are among the remaining cultures still relying on wild salmon as a chief source of nutrients. This reliance on salmon has lasted unbroken for 4000 years and salmon subsistence has shaped cultural patterning in multiple ways. Today modern technology is used but many beliefs, social practices and components of spirituality are part of this long history and form both Yup'ik and Dena'ina essential identity and provide the cultural basis for sustainability. To say they are the last wild salmon cultures is an overstatement, but they are certainly among the last. Part of the reason they remain is that Alaska in general, and Bristol Bay in particular, has become the world's last bastion of wild, non-farmed, non-hatchery raised, wild salmon.

This document contains five parts. First, this introduction contains information about the project and its methodology. Second, it consists of contextualization of relevant prehistoric, historic, linguistic, and cultural information obtained from anthropological, historical, and other publications and data bases. Third, this document includes the product of interviews in villages of the Nushagak and Kvichak River watersheds conducted in 2011, which constitutes original research on the peoples of the area. Fourth, this document contains conclusions about the vulnerability of the culture to loss of clean water and salmon resources in the Bristol Bay area. Between us (Boraas and Knott) we have 48 years of research, teaching, and collaboration with Alaskan tribes, and that experience is reflected in this study.

As a foundation for this research, all of the federally recognized tribes in the watersheds were contacted through the Environmental Protection Agency's Tribal Trust and Assistance Unit in Anchorage following government to government protocols. Since one of us, Alan Boraas, is an Honorary Member of the Kenaitze Indian Tribe, a letter of introduction from the Kenaitze

Tribe to village councils was included in the government to government packet following village protocols (See Appendix 1 which also includes the initial statement of methodology). We selected seven villages in which to conduct interviews: New Stuyahok, Koliganek, Curyung (Dillingham), Nondalton, Pedro Bay, Newhalen, and Iliamna. Time and funding prevented us from conducting interviews in Igiugig, Levelok and Ekwok. Kokanok and Port Alsworth did not respond to the government to government request to conduct interviews.

Table 1 Number of Interviews per Village.

Village	Males	Females	Total
Curyung (Dillingham)	7	0	7
Iliamna	1	3	4
Koliganek	5	5	10
Newhalen	5	6	11
New Stuyahok	5	2	7
Nondalton	4	6	10
Pedro Bay	2	2	4
Total	29	24	53

We interviewed 53 Elders and culture bearers, people whom the village councils or tribal governments recognize as authoritative sources of information about subsistence, traditional ecological knowledge, social relations and spiritual aspects of their culture. The village-selected interviewees consisted of 24 females and 29 males (see Table 1) and ranged in age from mid-twenties to a man reportedly in his nineties. Most, however, were in their forties or older due to the intentional weighting toward village-selected Elders and culture bearers. We were not consulted in the selection of specific interviewees and were assisted by a tribal employee or a village council member who arranged the time and place of the interview (see Appendix 1, Methodology). The interviews took place in public tribal or community centers or private homes

because from the standpoint of the interviewees they are safe, non-threatening places in which to discuss important cultural matters. We normally interviewed two to four individuals at any one time but some sessions included as many as six and one was a single interviewee. The interview session lasted about two hours with a short break. Interviews followed a standard semi-structured interview process in which a set of questions guided the interview but interviewees were free to add additional information or perspective, in some cases delving into topics not covered by the original question. The questions were specifically designed not to be answered briefly but to probe the subject and allow interviewees to describe cultural structures which for the most part were familiar and obvious to local villagers, but not commonly understood to others, particularly those outside the state. If a response was brief we would respectfully clarify or amplify upon the question to generate a more complete narrative. Interviewees were told they did not have to respond to a question if they chose not to, although none did. If an interview session exceeded two hours we occasionally eliminated some questions. If the topic of a question had already been covered in a previous discussion we eliminated the question. Consequently, not all interviewees responded to every question. Regularly one person would respond and others would nod agreement. Since the questions dealt with a cultural standard, there were few alternative points of view. Some of the interviewees chose to speak in Yup'ik, in which case an interpreter was present to translate the question into Yup'ik and the response into English. None chose to speak in Dena'ina. Many Elders "think" in their Native language which we encouraged because responding in the traditional language generates more accurate and nuanced responses to questions about culture.

Figure 1. Nondalton, August 17, 2011

We digitally recorded the interviews and, in the Kenai Peninsula College Anthropology Lab, made transcriptions from the recordings including both responses to our questions and additional perspective provided by the Elders or culture bearers.

The interview questions revolved around the theme of, "How are salmon and other stream-based resources and water important in your lives?" The questions involved the topics of nutrition, subsistence, social relations, spirituality and beliefs. In addition a final question was asked: "is there anything you would like to add, or is there anything you would like the Environmental Protection Agency to know about the situation in your village." The interview questions are listed in Section III.A.

The transcribed interviews were lumped into a single Microsoft Word document and the lumped document was searched for key words related to the sub-headings of this report using the powerful search feature of Microsoft Word 2010. In this way we were able to capture responses both to the theme of the question we asked and to that theme that might have been discussed by

interviewees in the context of a question related to a different topic. In this document responses of Elders and culture bearers titled "Voices of the People," reflecting both the consensus among those interviewed and the rare deviations from consensus appear in italics before the anthropological discussion of each section. By the standards of highly pluralistic modern America, the Yup'ik and Dena'ina villages of Southwest Alaska are culturally much more homogenous, consequently the narratives reflect that homogeneity. "Voices of the people" statements were selected through the search process described above because they were concise, clear, and reflected the intent of the speaker in the context of their broader narrative. The English response or translation is transcribed "as is" with no grammatical modification; readers must understand that for some, English is a second language and imperfect English grammar is not to be construed as imperfect or naive thinking. Following University of Alaska Institutional Review Board Standards, to protect individual identity of the interviewees, each Elder or culture bearer has been designated by a code, using an "M" or "F" for "male" or "female" and a number, along with the date of the interview.[1] Only we, the interviewers, know the names of the interviewees.

All deviations from consensus have been included in the qualitative "Voices of the people" responses. In addition, the entire 500 page typed narrative was assessed from a favorable/unfavorable or agree/disagree standpoint to give a sense of the degree of conformity to a response. These results, along with the interview questions, are portrayed in Section III.A. and

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[1] Funding for this project was administered as a contract through the University of Alaska Anchorage/Kenai Peninsula College and came under Institutional Review Board (I.R.B.) auspices since it involved human subjects. The UAA I.R.B. reviewed and approved the methodology, consent forms and research design of this project. I.R.B. stipulates protection of the identity of human subjects, consequently the names of the participants of this study and not revealed. Signed consent forms are held by the researchers.

referenced throughout this document to give a quasi-numerical sense of the culture standards of the Nushagak and Kvichak drainages.

B. Villages, Population, and Ethnicity

In the 2010 United States Census, the 13 communities of the study area had a total population of 4118. Table 2 describes the population characteristics of the 13 villages and towns located in the Nushagak and Kvichak River drainages.

Table 2. Census of the Towns and Villages of the Nushagak and Kvichak River Drainages, 1980 to 2010. (data from U.S. Census, Alaska; Alaska Community Database)

Watershed	Community	1980 Pop.	1990 Pop.	2000 Pop.	2010 Pop.	% Alaska Native, 2010	Ethnic Majority
Nushagak River	Dillingham	1563	2017	2466	2378	55.9	Yup'ik
	Ekwok	77	77	130	115	90.4	Yup'ik
	Koliganek	117	181	182	209	95.7	Yup'ik
	New Stuyahok	331	391	471	510	93.5	Yup'ik
	Portage Creek	48	5	36	2	50.0	Yup'ik
Kvichak River	Igiugig	33	33	53	50	40.0	Yup'ik, Alutiiq/ Caucasian
	Iliamna	94	94	102	109	54.1	Dena'ina
	Kokhanok	83	152	174	170	80.0	Yup'ik/Dena'ina/ Alutiiq
	Levelock	79	105	122	69	84.1	Yup'ik
	Newhalen	87	160	160	190	80.0	Yup'ik
	Nondalton	173	178	221	164	63.4	Dena'ina
	Pedro Bay	33	42	50	42	66.7	Dena'ina
	Port Alsworth	22	55	104	159	21.4	Caucasian
					4118 Total 2010 Population		

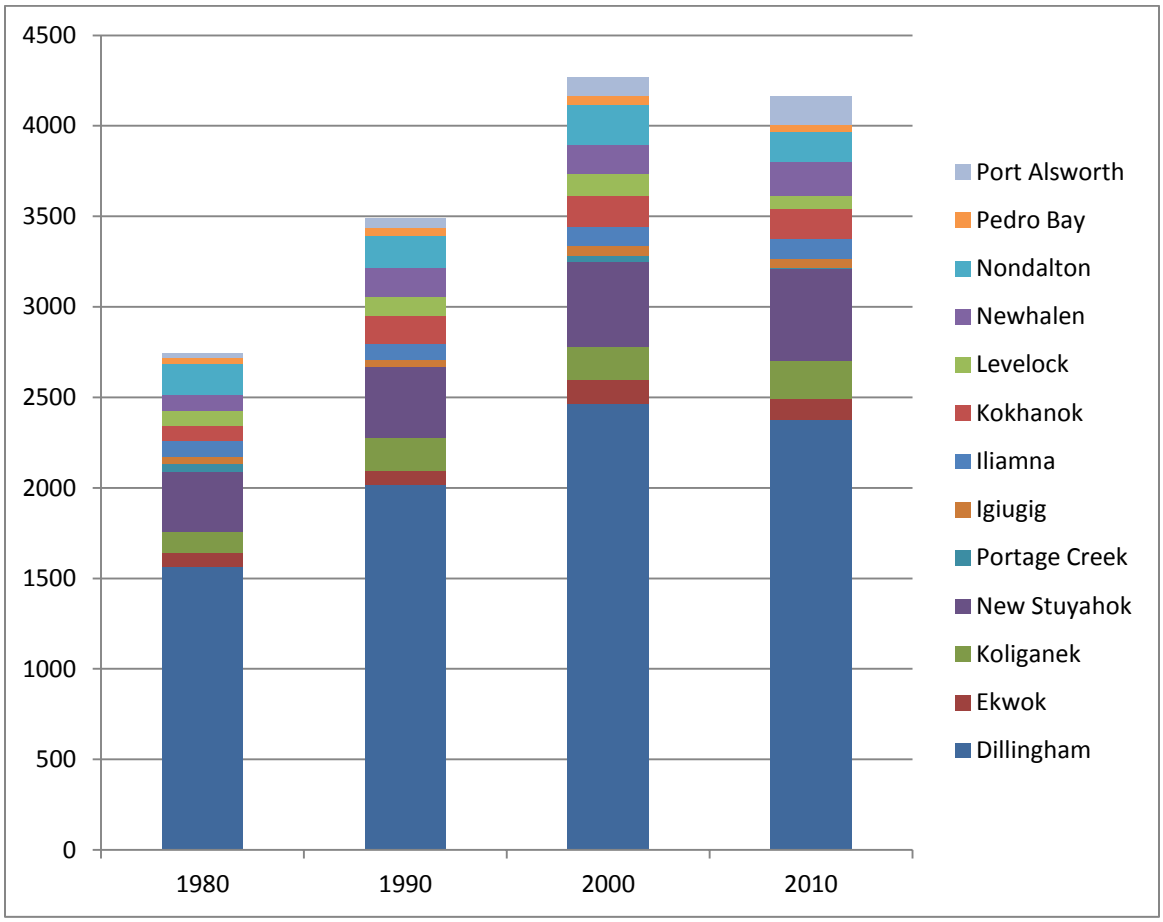

Figure 2. Population Change for the Study Area: 1980 to 2010. Data from U.S. Census.

Figure 2 indicates the population of the study area grew substantially from 1980 to 2000 and remained stable between 2000 and 2010. 1980 to 2000 village population growth is probably due to post-ANCSA changes in land-ownership and is related to a similar phenomenon throughout Southwest Alaska (Fienup-Riordan 1994:39). The population of individual communities can vary considerably; in small populations only a few large families moving in or out can change the overall population considerably. Of the 13 communities, four are anomalous: Dillingham, Port Alsworth, Igiugig, and Iliamna. Dillingham has, by far, the largest population

in the area (2,329 in 2010) and is a regional center with an economy based on the Bristol Bay commercial fishing industry, as well as government services, transportation, and professional and business services (Alaska Community Database). Dillingham has a small branch of the University of Alaska, a museum, and Alaska Department of Fish and Game (ADFG) offices, as well as several stores, churches, hotels, and other institutions typical of mid-sized Alaskan towns. Dillingham, however, is 55.9% Alaska Native—mainly Yup'ik—and the Curyung Tribe and Bristol Bay Native Corporation and associated agencies are a significant presence (Alaska Community Database).

Port Alsworth is only 21.4% Alaska Native and thus does not have the majority or near-majority Alaska Native population that other villages in the study area have. The non-Alaska Native population is primarily associated with two institutions. The Lake Clark National Park and Preserve, which surrounds Lake Clark, has its regional headquarters in Port Alsworth. Because of the park, a number of eco-tourism guides unaffiliated with the park but using its resources are headquartered at Port Alsworth. The Tanalian Bible Camp and associated ministries, loosely connected to Samaritan's Purse, a national fundamentalist Christian ministry directed by Rev. Franklin Graham, is also located at Port Alsworth. Yup'iks who relocated to the area in 1944 (Gaul, 2007:60-61)) account for most of the town's Alaska Native population and make up its ANCSA-based village corporation, Tanalian Inc. (Port Alsworth is well within traditional Dena'ina territory). Igiugig has a substantial number of guided sport fishing and sport hunting operations that have recently moved into the village or near the village which accounts for the relatively large non-Alaska Native percentage of the population. Iliamna, a traditional Dena'ina village located on Iliamna Lake, is also a growing center for guided sport hunting and

fishing. It has also become a staging area for exploration and other activities associated with proposed copper/gold porphyry mines in the area. Consequently, Iliamna has a proportionately larger non-Alaska Native population than most other villages in the area, although the Alaska Native population (54.1%; Alaska Community Database) outnumbers other ethnic groups, and is still the dominant ethnic group.

The remaining study area communities are Yup'ik or Dena'ina villages with close connections to traditional practices. They are relatively small, with populations ranging from 510 (New Stuyahok) to 42 (Pedro Bay) (Portage Creek, population 2, is reportedly seasonally occupied as of 2011, according to interviewee M-26), and from 93.5% Alaska Native (New Stuyahok) to 67% Alaska Native (Pedro Bay). Most have a single church (Russian Orthodox), a public school, a health clinic, an airstrip, a small general merchandise store, a post office, a tribal center or village corporation center, city or village corporation offices, a landfill, cemetery, and fuel storage tanks (Alaska Community Database and observations).

There are community health aides in the villages of Koliganek, New Stuyahok, Ekwok, Igiugig, Levelok, Kokhanok, Nondalton, and Pedro Bay (Bristol Bay Area Health Consortium, BAHC 2006) and some also have dental aides. The clinics are connected via internet to consulting physicians and the Alaska Native Hospital in Anchorage. New Stuyahok and Newhalen have completed the Rural Utility Business Advisor (RUBA) process in order to join the Alaska Rural Utility Collaborative (ARUC) and have a municipal water system (http://www.anthc.org/cs/dehe/sustops/). Many of the villages are being connected to high-speed fiber-optic internet connection. Nearly 100% of the population has access to some improved

sanitation, and 100% of the population has access to the abundant fresh, clean water of the rivers and lakes.

II. CULTURAL AND HISTORICAL BACKGROUND

A. Pre-Contact Bristol Bay

1. Voices of the People

Salmon and fresh water has been the lifeline of the people here for thousands of years. If you look at the water, that is why fish and game has survived so well here, because we have such clean water. M-62, 9/16/11

[If the salmon were to be impacted**],** *it would stop 10,000 years' plus tradition, culturally and spiritually for my people; not only my people, all the other communities and villages in this region will go away. We would cease to exist. We can't go anywhere. Where are we going to go?* M-33, 8/18/11

Freeze drying is not a new thing. That's been going on with my people for over 10,000 years, eating freeze dried food. M-33, 8/18/11

There's 10,000 cache pits [at the Kijik archaeological site on Lake Clark] *and they are still counting; over 200 houses, which are huge. So it was pretty big.* M-29, 8/17/11

My father, he usually keeps fresh salmon. He would dig a pit and take the topsoil off; dig it out lay some grass on the bottom and on the side. Then take the salmon, lay them in the pit until he filled it up. Then he would put grass on top of it. Then he would lay gravel right on top of it, and he would mark each corner for winter time. Put poles on each corner so he could find where he buried his salmon. And in the winter time, if he wanted salmon, he would take his axe and cut out a piece of the soil and dig from there. That was his freezer. That is how my dad would keep salmon. M-54, 8/20/11

2. Introduction

The pre-contact history (prehistory) of the Bristol Bay drainage is not as well documented as in other parts of Alaska. The archaeological work is largely due to five projects. In the 1960s James Van Stone conducted an archaeological survey of the Nushagak River as part of ethnohistoric research (VanStone 1967); B.I.A. archaeologists have conducted archaeological surveys in connection with Native Allotment assessments; Lake Clark National Park has

conducted various survey projects on the Mulchatna River and areas above tree line; the Pebble Partnership has contracted for archaeological surveys on the footprint of a proposed Pebble Mine site; and the Alaska Office of History and Archaeology has conducted or required pre-development archaeological surveys on proposed airstrips and other improvements and conducted town-site surveys. Within the study area there are a total of 228 historic and prehistoric sites listed on the Alaska Heritage Resources Survey (A.H.R.S.), the state's database for officially designated sites. To better understand the patterns of culture change and establish the time-depth of salmon use in the Nushagak and Kvichak River drainages one of us (Alan Boraas) generated a database of the 228 sites and from that developed a prehistoric cultural chronology of which the last 4000 years are depicted in Figure 3.

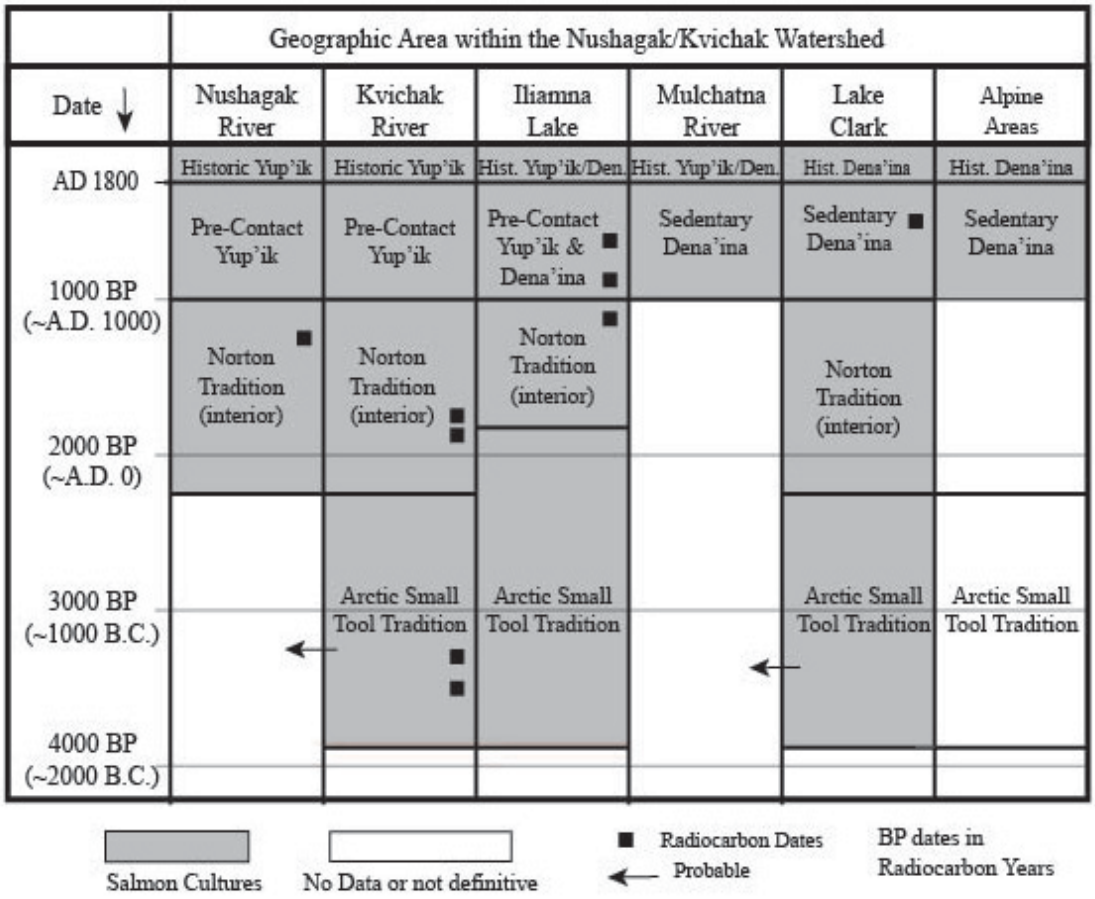

Figure 3. Cultural Chronology of Nushagak and Kvichak River Drainage Salmon-Based Cultures. From Alaska Heritage Resource Survey database. By Alan Boraas

The "BP" (Before Present) of the y-axis of Figure 3 is in uncalibrated radiocarbon years and an approximate B.C./A.D. date is indicated.[2] AHRS site data was assembled for six regions (Figure 3) within the Nushagak and Kvichak River drainages, including:

- The Nushagak River from its mouth to headwaters.
- The Kvichak River, including nearby archaeological sites in the Alagnak River drainage.
- The shoreline of Iliamna Lake and the lower Newhalen River.
- The Mulchatna River, upstream to Bonanza Creek.
- Lake Clark, Sixmile Lake, and the Upper Newhalen River.
- Alpine areas above tree line north of Iliamna Lake and west of Lake Clark.

3. Pre-Contact Salmon Fishing Cultures

The study area was occupied as early as 8,000 BP by core and microblade makers of the Paleoarctic tradition (with two Putu-like fluted points coexisting with microblades at one site, XHP-00430 extending the possible time range to 12,000 BP). Subsequently, archaeological cultures of the Northern Archaic and Ocean Bay traditions occupied the area. None involved intensive salmon fishing as indicated by AHRS records. The Paleoarctic and Northern Archaic sites are associated with Athabascans (Boraas 2007: 34-7) and establish a time-depth for the Dena'ina or proto-Dena'ina in the study area.

[2] The deviation between calibrated calendar years and uncalibrated radiocarbon years becomes significant before 1500 B.C. By 2000 B.C. uncalibrated radiocarbon years are ~ 400 hundred years old (http://www.radiocarbon.com/calendar-calibration-carbon-dating.htm).

As described below, archaeological records indicate Yup'ik or proto-Yup'ik people have been fishing for salmon for at least 4,000 years (Figure 3 and Table 3) and may be genetically related to earlier Siberian salmon fishers. Salmon fishing first appears with the Arctic Small Tool tradition (ASTt) (see Figure 3) and Table 3 is a list of ASTt sites in the study area. ASTt cultures are widespread in western and northern Alaska where the site data indicates the existence of interior nomadic hunters (primarily caribou) or coastal sea mammal hunters. In the Bristol Bay drainage, three village sites, evidenced by ASTt-style houses and artifacts, are found on the Kvichak River. Five alpine sites (artifacts only) indicate hunting above tree line. The houses are permanent structures, generally measuring four meters on a side, indicative of sedentary or semi-sedentary people and are located adjacent to salmon spawning streams. The ASTt site at Igiugig (ILI-00002), where the Kvichak River flows out of Iliamna Lake, is an example of such a site (Holmes and McMahan, 1996).

Table 3. Arctic Small Tool tradition sites in the Study Area. Compiled From Alaska Historic Resources Area Files

ARCTIC SMALL TOOL TRADITION AD 200 to 1800 BC			
Area	**AHRS Site**	**Characteristics**	**Houses**
Nushagak R.	NAK-00018, B	cores and microblades	
Iliamna Lake	ILI=00035	Lithic tools	
Alpine	ILI-00201	Microblade core	
Alpine	ILI-00205	Microblade core	
Alpine	ILI-00193	Lithic camp: microblades, side blades, end scrapers, knives.	
Alpine	ILI-00219	Microblade core	
Alpine	ILI-00218	Microblade core	
Kvichak	DIL-00088	Village, sedentary houses; C14 Date, 3580+/-150;	19
Kvichak	DIL-00170	Village; Brooks River Gravel Phase	2
Kvichak	ILI-00002	Cores, microblades, burins, notched stones, 4000 artifacts; Brooks River Gravel phase, ca. 1800 BC to 1100 BC 3350+/-60 BP radiocarbon date, possible Norton component	
Kvichak	ILI-00072	Microblades and other lithics	
Kvichak	ILI-00206	Village site	1

Anadromous salmon remains, while not common, occur in ASTt sites (Dumond, 1984), suggesting salmon were a significant subsistence human resource in riverine and lacustrine areas of southwest Alaska. The lack of abundant salmon bones in ASTt sites may be due to small populations of salmon, decomposition of the relatively delicate bones, or the practice of returning salmon bones to the water—similar to ethnographic Yup'ik and Dena'ina—thereby contributing to marine-derived nutrients important in salmon habitats. Further research is

necessary to clarify this point. The fact that one site (DIL-00088) contains 19 sedentary houses and is located along a salmon stream indicates salmon were a primary resource.

Analysis of human hair from a 4,000-year old ASTt site in Greenland places the mitochondrial DNA (mtDNA) in the D2c haplogroup reflecting Siberian origins (Gilbert et al., 2008). Today, haplogroup D2c is present, but haplogroup A is dominant among Yup'iks; haplogroup A also has Siberian origins where researchers place its origin as early as 7,000 years before present (Rubicz et al., 2003). Both haplogroups indicate that the time-depth of Yup'ik people in southwest Alaska is at least 4,000 years and that they derive from Siberian origins, where their ancestors were also potentially salmon fishers. As described in the section on nutrition (III.C.3.), evidence is building that Yup'iks are biologically adapted to salmon and 4000 years is the temporal context in which that evolution took place.

In all but the Mulchatna River and alpine areas where evidence has yet to be found, the Arctic Small Tool tradition is followed by a well-developed salmon culture, the Norton tradition, dating from ~300 B.C. to A.D. 1000 (see Figure 3; Table 4). Like ethnographic Yup'ik, the Norton tradition has both a coastal and interior subsistence orientation. The coastal Norton tradition is found in sites as far north as Cape Denbeigh and relied primarily on marine mammals (Dumond 1984: 99-101). The interior Norton tradition sites, such as those in the study area on the Nushagak and Kvichak Rivers and Lakes Iliamna and Clark, had a salmon-oriented subsistence culture based on the following evidence: archaeological features, mainly houses, similar to those at ethnographic Yup'ik salmon fishing sites: large sedentary villages, villages located adjacent to salmon fishing locations, and net fishing artifacts. Riverine Norton tradition sites are similar to ASTt sites in that they consist of large, permanent houses located on salmon

streams. One large Norton tradition site on the Kvichak River (DIL-00161) consists of 34 to 45 houses representing a population sustainable only through the availability of abundant resources such as anadromous salmon. In addition, the artifact inventory for the eight Norton village sites in the study area (see Table 4) contains notched stones that were used as net weights, similar to the lead line of a modern net (Dumond, 1987:11). In addition to dwelling houses, Norton sites in southwest Alaska contain large structures indicating a *kasheem* or *kazigi*, (local pronunciations vary), a men's house also found among pre-contact and early historic Yup'ik villages. These finds indicate that the Bristol Bay drainage Norton culture were Yup'ik or proto-Yup'ik speakers and relied on salmon as their primary subsistence food.

Table 4. Norton tradition sites in the study area. Compiled from Alaska Heritage Resources Survey data by Alan Boraas.

NORTON TRADITION AD 1000 TO 300 BC			
Area	**AHRS Site**	**Characteristics**	**House s**
Kvichak	DIL-00161	Prehistoric village (6100 artifacts) 1760+/-40 BP	34-45
Kvichak	DIL-00174	Two large house depressions; Smelt Creek Phase 1920+/-40	2
Kvichak	DIL-00175	Village site, artifacts, pottery; Norton Brooks River Weir and Brooks River Falls phases, 1830+/-40 BP	8
Kvichak	DIL-00229	Prehistoric Village	1
Kvichak	ILI-00073	Village site, Pottery,	4
Kvichak	DIL-00207	Village, 43 house depressions; lithics and ceramics	43
Iliamna Lake	ILI-00056	Village, C14 date 860+/-60	12-15
Iliamna Lake	ILI-00127	Pottery and stone beads	
Iliamna Lake	ILI-00128	Weir, Early Norton	
Iliamna Lake	ILI-00098	Village, cache pits no houses apparent on surface, fiber pottery	
Lake Clark	ILI-00012	Village	12
Lake Clark	XLC-00086	Bifaces, scrapers, sideblades, fiber pottery.	

It is not clear how long the Dena'ina have been salmon fishers, but about A.D. 1000, the Dena'ina of the Mulchatna River and Lake Clark areas developed a method to catch salmon using weirs and began storing salmon in underground cold storage pits called *elnen tugh* (Kenai dialect) that appear in the archaeological record (Boraas 2007). Salmon storage technology spread to Iliamna Lake, Cook Inlet, and the Susitna and middle Copper River areas (Boraas, 2007). A proliferation of Dena'ina sites—65 have been found to date far more than any other pre-contact period—occurs in the study area, dating to just after A.D. 1000 (Table 5 and Lynch,

1982). Forty-one sites are village sites (not necessarily occupied simultaneously) and the Kijik Site, XLC-00084 and associated sites, are among the largest in Alaska for the prehistoric period. We can conclude that weir fishing and the underground cold storage technology described in the pre-contact culture section (II.C.2.) below was an extremely successful adaptation.

Table 5. Pre-Contact or Early Contact Period Dena'ina Sites in the Study Area. Compiled from Alaska Heritage Resources Survey data by Alan Boraas.

SEDENTARY DENA'INA AD 1000 TO AD 1800			
Area	**AHRS Site**	**Characteristics**	**Houses**
Mulchatna River	XLC-00072	Village	1
Mulchatna River	XLC-00076	Village	2
Mulchatna River	XLC-00078	Cache pits	
Mulchatna River	XLC-00074	Village, Dena'ina	1
Mulchatna River	XLC-00075	Village, Dena'ina	1
Mulchatna River	TAY-00046	Cache pits	
Mulchatna River	TAY-00026	Cache pits	
Mulchatna River	TAY-00030	Cache pits	
Mulchatna River	TAY-00027	Cache pits	
Mulchatna River	TAY-00031	Cache pits	
Mulchatna River	DIL-00200	Cache pit	
Mulchatna River	DIL-00201	Cache pit	
Iliamna Lake	ILI-00029	Fish camp	
Iliamna Lake	ILI-00046 B	Village Complex	

Iliamna Lake	ILI-00019	Village site	3
Iliamna Lake	ILI-00135	Cache pit	
Iliamna Lake	ILI-00021	Village	nd
Iliamna Lake	ILI-00020	Village, houses undetermined	nd
Iliamna Lake	ILI-00001 A	Village	5
Iliamna Lake	ILI-00047	Cache pits	
Iliamna Lake	ILI-00049	Village	4
Iliamna Lake	ILI-00018 B	Village 560+/-60 BP	nd
Lake Clark	XLC-00048	Cache pits	
Lake Clark	XLC-00057 A	Prehistoric Village	30
Lake Clark	XLC-00102	Village	10
Lake Clark	XLC-00167	Village	5
Lake Clark	XLC-00166	Village	2
Lake Clark	XLC-00094	Village	19
Lake Clark	XLC-00165	Village	2
Lake Clark	XLC-00164	Village	2
Lake Clark	XLC-00155	Village	5
Lake Clark	XLC-00163	Village	1
Lake Clark	XLC-00162	Village	2
Lake Clark	XLC-00101	Village	11
Lake Clark	XLC-00100	Village	14
Lake Clark	XLC-00099	Village	2
Lake Clark	XLC-00084	Village (possibly two sites)	95
Lake Clark	XLC-00092	Village	13
Lake Clark	XLC-00090	Village; C14 BP 300+/-60	10
Lake Clark	XLC-00091	Village	4
Lake Clark	XLC-00093	Village	1
Lake Clark	XLC-00021	Cache pits	
Lake Clark	XLC-00020	Village	2
Lake Clark	XLC-00012	Village	2
Lake Clark	XLC-00013	Trapper cabin	
Lake Clark	XLC-00159	Village	3
Lake Clark	XLC-00158	Village	2
Lake Clark	XLC-00104	Village	1
Lake Clark	XLC-00157	Village	3
Lake Clark	XLC-00156	Village	12

Lake Clark	XLC-00105	Village	10
Lake Clark	XLC-00088	Cache pits	
Lake Clark	XLC-00083	Village	6
Lake Clark	XLC-00097	Village, 1 house	
Lake Clark	XLC-00098	Village	5
Lake Clark	XLC-00003	Cache pits	
Lake Clark	XLC-00004	Cache pits	
Lake Clark	XLC-00008	Village	4
Lake Clark	XLC-00250	Cache pit	
Lake Clark	XLC-00133	Village	3
Lake Clark	XLC-00134	Village	1
Lake Clark	ILI-00087	Cache pits	
Lake Clark	XLC-00096	Village	1
Lake Clark	XLC-00249	Cache pits	
Lake Clark	XLC-00107	Village	1
Mulchatna River	DIL-00150	Cache pits	
Iliamna Lake	ILI-00031	Village	5

B. History and Culture of the Yup'ik Area

1. Voices of the People

We want to give to our children the fish, and we want to keep *the water clean for them….It was a gift to us from our ancestors, which will then be given to our children.* F-69, 9/18/11

When I was a little girl they had no Snowgo's [snowmachines], *they had no Hondas* [Four-wheeler all-terrain vehicles]. *We live up river and they fished all the time. In wintertime they fished under the ice. They travel with dog teams. My Dad would take me out ice fishing. I used to be scared of those pikes. I don't know how old I was. That's the only thing they do is try to catch fish, summer time nets, and winter time they do ice fishing. That's how they pass it on down. They subsistence fish, usually they travel with dog teams, that's what they did, and that's how come those people were healthy. They walked, and walked, they worked from morning until they go to bed. That's how come they were healthy. They eat their fish, they go get wood with the dog team, they hunt with their dog teams, and they travel to village with their dog team.*

People walk and they eat that fish. That's what makes them live long and healthy, I noticed that. F-23, 5/18/11

All we have is use the salmon, salmon all the time. The old people tell us you guys have only one salmon season you guys got to catch it. If you don't catch it you won't have much in the winter, long winter. F-41, 8/19/11

*When you look at the map and where the old villages were they were there because of the salmon. You go to Igiugig and ?, and Port (?), Levelock, South Levelock and Dillingham… all those villages. Site selection of those communities was very important and it was because of the production of subsistence foods at each of those sites processed. Most of those produced salmon in addition to [*other foods*], for example you go to the village of Manokotuk, and it is rich in berries. If you go to the upriver villages they are rich in caribou and moose and other resources. Each village was selected by the folks…because of their subsistence resources.* M-61, 9/16/11

My father along with other people was very active in fisheries politics. Bristol Bay used to be controlled by Brindle which was a big cannery superintendent and what he said was law of the land. Fish and game used to listen to those big processors. One time my dad was talking to a group Truman Amberg, Joe McGill, Joe Clark from Clark's Point, saying we got to go on strike this year. I think it was Joe McGill said we're not going to get any more money [father's name]. Why are we going on strike? You know we are just going to end up sitting on the beach. Dad says we got to let the fish pass. What that meant was we needed more fish up the river spawning so we would have better seasons later. Then a group of locals said okay we're going to strike but don't tell the processors we aren't striking for more money. Tell them we want more money we know they're not going to give it but we will get more fish up the river because the Japanese decimated our runs in Bristol Bay in the '60's and 70's. We had to build our runs back up, M-60, 9/16/11

Like before, you know a lot of people used to put up a lot of fish 3000, 4000, 5000 fish. They used to have a lot of dogs while they were living that is how they try the tradition they have. They used to hook up their dogs and go wherever they wanted to go. They used to put up a lot of fish to eat. When they get moldy they just wipe it off and eat them. That is the way it was in my living days. Nowadays people when it is moldy they throw them away, that is the way of life now. You can't do that anymore. M-49, 8/20/11

2. Introduction

Perhaps as a result of the relatively recent occurrence of contact with non-Natives, the Yup'ik have retained their traditional culture and language, ecological knowledge and practices, social systems, and spirituality, to as great or a greater degree than any other Alaska Native populations. Where they have adopted non-Yup'ik traditions, such as Russian Orthodoxy, they have blended their own practices and beliefs with the introduced practices to create a new belief system that retains the Yup'ik culture as a whole.

3. Pre-Contact Culture

An Eskimo-speaking people have been living in the region for at least 4,000 years as a recognizable salmon culture, at least as far back as the Norton tradition and Arctic Small Tool tradition.

The Yup'ik of the Nushagak, Kvichak and lower Mulchatna Rivers historically were organized in bilateral extended families of up to about thirty people settled in permanent and semi-permanent villages. Many of the villages contain a *kashgee*, or men's house, and are relatively small, averaging five to six houses per village in the 12 pre-contact villages for which there is house data (see Table 5). Historic Yup'ik village sites, of which 21 are currently documented, average between 8- 9 houses per village. Today there are only four or five modern Yup'ik villages along the Nushagak River (Dillingham, Ekwok, Koliganek, New Stuyahok, and possibly Portage Creek; see also Table 1) and, except for seasonally occupied Portage Creek, they are much larger in population than their historic or pre-contact counterparts.

The wetland landscape is not easy to traverse, except by river, or in the depths of winter when all is frozen. The abundance of fish and game in the Bristol Bay region allowed the Yup'ik

to stay within a relatively fixed range, although they moved throughout their range seasonally from a base village, to hunt, gather, and participate in summer fish camps. The extended families practiced food sharing and generalized reciprocity, both within and between families. Most larger villages functioned as independent and self-sufficient social units, and people married within the village or nearby villages. Sometimes fluctuations in game or fish availability caused groups or individuals to travel from one region to another. Large disruptions to the population did not occur until epidemic diseases arrived with European explorers. These diseases devastated whole populations, decimated villages, undercut social distinctions, and wiped away some of the boundaries over which the earlier bow and arrow wars had been fought (Fienup-Riordan, 1994). These population changes resulted in shifts in salmon harvesting, when population remnants regrouped by joining other villages.

Historically, including after contact, in the winter villages the men and boys older than seven or eight lived in the *qasgiq*, the large communal men's houses, while women and girls lived in a smaller house called an *ena*, both built from sod and driftwood. During the winter, the community came together for dances and storytelling, but otherwise, men and women kept in their separate groups and worked to do gender-specific chores. Men, for example, repaired the tools for hunting, while women sewed clothes as well as waterproof raingear to protect everyone from harsh weather.

In the summer, everyone participated in harvesting salmon, whether net fishing, or processing the fish in fish camps. Women dominated the work of processing in the fish camps. Family groups might put up as much as 5,000 fish (personal communication to Catherine Knott, Lena Andree, Yup'ik Elder, Dillingham; July, 2011), including fish for their dogs.

The Yup'ik traveled to different subsistence sites either overland, by foot or dogsled, or on the water, in vessels that ranged from small kayaks to larger wooden boats. Traditional festivals during the year included the Bladder Festival, *nakaciuryaraq*, the Messenger Feast, *kevgiryaraq*, and the Seal Party, *uqiquryaraq.* Food exchanges played an important part in these festivals described below.

4. Post-Contact History and Culture (A.D. 1791 to 1935)

At the turn of the 19th century, the bilateral extended family, stretching over several generations, still formed the basis of Yup'ik villages (Fienup-Riordan 1994). Winter villages could be just one family, but ranged up to 150 to 300 people in some places. Families did not all live together in one house; the winter villages had one or more *qasgiq,* or communal men's houses, where men and boys over age 6 or 7 lived and worked together, telling stories, making tools, and preparing for subsistence activities. In the *ena,* women, girls, and the youngest boys lived in groups of up to a dozen, and the women taught the girls how to sew and cook. They cooked the meals there, either in the entryway, or in a central fireplace. Each winter, for three to six weeks, boys and girls would switch homes, and the men would teach girls survival and hunting skills, while the women would teach the boys how to sew and cook (Fienup-Riordan, 1990).

The *qasgiq* also functioned as the communal sweat bath for the men. They would open the central smoke hole, feed the fire until the heat was intense (possibly up to 300 degrees), then bathe. Men sat in the sweat house in the order of their social status. The *nukalpiaq*, or good provider, held a high social position and contributed wood for the communal sweat bath, as well as oil to keep the lamps lit; he also played an important role in midwinter ceremonial

distributions of food (Fienup-Riordan, 1994). There was competition between families to be the best providers.

Contact between the Yup'ik of the Bristol Bay area and Russians or Americans was later and more limited than in most of the rest of Alaska. The region was perceived to have few resources worth exploiting, and the marshlands were difficult to traverse. While some Russian explorers, traders, and missionaries persisted and made repeated contact with the Yup'ik throughout the nineteenth century, they did not settle in the area in any numbers until the twentieth century (VanStone 1967). As a result, the Yup'ik of this region, perhaps more than any other indigenous peoples in Alaska, have retained much of their language and cultural traditions to the present time.

When the Europeans came, they brought diseases, to which the Yup'ik and other Alaska Native populations had no immunity. The first epidemic known to have occurred in the Nushagak River region was before 1832, but there are no records of the number of dead. The 1838-1839 smallpox epidemic caused several hundred deaths in the Nushagak region and also occurred in the Dena'ina territory. Vaccines were introduced in 1838, and some Yup'ik received them, probably reducing the scope of the epidemic and subsequent outbreaks of smallpox. But each year, while not necessarily counted as an epidemic period, brought more death and illness to the region. Survivors were often weakened and succumbed later to other illnesses. VanStone states that during this period "The specter of ill health and death was continually present among the Eskimo population of all southwestern Alaska" (VanStone, 1967:100). The loss of population (especially Elders), the disruption of families, the plethora of orphans, and subsequent rearrangements of the social order created a social and cultural upheaval that the Yup'ik

struggled to overcome. The European visitors and settlers may not have understood that what they observed was not the way the Yup'ik had lived even a few short years before.

It is not certain when the first Russian visit to the Nushagak and Kvichak region occurred, but in the early 1790s Aleksey Ivanov of the Lebedev-Lastochkin Company made an overland journey to Iliamna Lake from Cook Inlet and then west into the Mulchatna and Nushagak drainage. His guide was apparently Dena'ina because the place names, including Dudna (spelled Tutna) the Dena'ina name for Yup'ik's (Downriver People), are Dena'ina, (Chernenko 1967:9-10). During this early period the region was not well known to outsiders, but the Russian-American company sent an expedition in 1818 to explore the territory north of Bristol Bay. In the same year, the company established a post at the mouth of the Nushagak River, the Alexandrovski Redoubt. Feodor Kolmakov, of mixed Russian and Native American ancestry, was in charge; he established trade relations with the Yup'ik and baptized some of them, spreading the influence of the Russian-American Company in several ways (VanStone, 1967:9).

In the summer of 1829, two minor Russian visits had major consequences for the Yup'ik. Ivan Filippovich Vasiliev led an overland expedition to ascend the Nushagak River, and the priest, Ivan Veniaminov, visited the redoubt. Veniaminov took away a permanent interest in the Bristol Bay region and in the Nushagak station which carried over even into his later position as Bishop. Vasiliev's exploration, in turn, established travel routes that were used by subsequent fur traders (VanStone, 1967:11).

Christianity was introduced in 1818, at the time that Alexandrovski Redoubt was built, but it was not until Veniaminov's arrival in 1829 that extensive missionary activity took off.

Veniaminov was flexible in his approach to the Yup'ik and their traditional religion and numerous conversions were registered in church documents. Veniaminov noted that "the Nushagak River was for them [Yup'ik] the River Jordan" (cited in Barsukov, 1887-1888, vol. 2:37). In 1832 Veniaminov visited again and had a small chapel built. By 1842 there were about 200 converts at Nushagak, and in 1844 Bishop Veniaminov had a new church built. The church, by 1879, was close to 2,400 members. Its success among the Yup'ik may have had much to do with the flexibility of Veniaminov's approach toward them. Yup'ik people were not required to fast and many indigenous customs were tolerated (VanStone, 1967:31).

Fur trading accompanied exploration, and sometimes incited it. By the 1840's contacts between the Kolmakovski Redoubt, on the Kuskokwim, and Alexandrovski at Bristol Bay were frequent. The company managers of the fur trade created *toyons,* designated local community leaders, and rewarded them with silver "United Russia" medals and incentive gifts. These *toyons*, motivated by their new prestige and the material rewards offered, then encouraged the members of their social networks to trap more furs for the Russians (Van Stone, 1967:56). The process of using village providers to convert the population into loyal company men and women to recruit fellow villagers into exploiting and extracting the resources of their own region for external benefit in a colonialist economic system has not changed in over a hundred years. The researchers observe the practice has helped to dismantle the traditional ecological knowledge and practices gained from the long indigenous history of subsistence-based culture.

Trade items included wool blankets, tobacco, beads, tent cloth, cast iron kettles, knives, iron spears, steel for striking a fire, needles, combs, pipes, etc. (VanStone, 1967:56). While these items did not immediately alter the deeper structures of the culture, the desire for them acted as a

change agent among the population. Where before, access to status had been open to all, through skills and responsible sharing with others, access to the time and materials for trapping, open to fewer individuals, had the potential to change the social dynamics of the Yup'ik. The companies allowed the Alaska Natives to purchase some items on credit; as debt mounted, some would be unable to repay for years. After the Alaska purchase, the powerful Alaska Commercial Company post at Nushagak maintained a trading post through the remainder of the nineteenth century engaging in about $10,000 in fur trades annually (VanStone, 1967:56),

In the nineteenth century gold mining occurred but was economically unimportant compared to other activities. In 1887-1888 the prospectors Percy Walker, Henry Melish, and Al King placer-mined for gold in the Koktuli and Nushagak Rivers, and there was also placer mining along the Mulchatna. In 1909 a group organized the Mulchatna mining district and formed the Mulchatna Development Company in Seattle (VanStone, 1967:83). Their activities were confined to the upper Mulchatna River in Dena'ina territory, and there was only a very temporary influence of miners on the local Alaska Native population. One Elder (New Stuyahok Interviewee in a non-recorded interview situation) told the story of his grandfather, who showed him gold and told him that if he found rocks with gold in them to throw them away, because they were bad. The grandson thought it was because it would cause social disruption by bringing strangers to the area who would disrupt the land and the culture of the people. The Elder said he had thrown a big chunk of gold away once, but he thinks he still knows where it is. The experience of the Yup'ik people with larger mining corporations has been minimal. Fish have been far more important both to subsistence and cash-based economies.

By the end of the nineteenth century, Bristol Bay had become an important commercial salmon fishing zone. The first salmon cannery, The Arctic Packing Company, began operation in 1884 at the village of Kanulik at the mouth of the Nushagak River (Troll, 2011:3). The fourth cannery, built at Clark's Point in 1888, is now the oldest surviving cannery in the region (Troll, 2011:4). The commercial fishermen in Bristol Bay used wooden sailboats for drift gillnet fishing for sockeye salmon and were mostly Italians, Scandinavians, and Finns, hired at Seattle and San Francisco (Troll, 2011:10), although some Yup'ik also fished commercially including Lena Andree, now an Elder from Dillingham who fished on one of the wooden sailboats with her father in the mid-1930s. When World War II began and kept many of the European fishermen from coming to Alaska to fish, the canneries "discovered that the Native Aleuts and Eskimos were marvelous boatmen and seemed to have been born to sail," according to Al Andree (cited in Troll, 2011:35).

The U.S. Bureau of Fisheries visited the Wood River lakes and Nushagak and Nuyakuk Rivers, and, in 1935, the U.S. Geological Survey conducted the first survey of the region and produced what would become, for decades, the standard reference for people not from the region. For the Yup'ik, the Elders continued to convey their traditional knowledge of their homeland, as they had for thousands of years (Van Stone, 1967). A crevasse of deepening proportions opened between two contrasting interpretations of the landscape, that of the outsiders, who saw the region as a land of resources to be exploited, and that of the indigenous peoples, who saw the region as the sacred landscape of home, and whose culture and way of life depended upon it.

C. History and Culture of the Dena'ina

1. Voices of the People

We harvest [subsistence foods] *three times for that one person: day of the burial, forty days later, and then one year later. It is really significant, just for that one person who passed away; we harvest from the land three times to honor and to pay our respects to ones who lost their family member. That has been going on for over 10,000 years*. M-33, 8-18-11

…from our ancestors, that is how we get all of our information to have fish. The way we put it; the way we store it for us to eat. That is where we learned it. It is passed on from generation to generation to have fresh fish. F-48, 8/20/11

I always think that we are very, very, very lucky people. I know where I came from. I know who I am. I know where I belong in this world. I know where my ancestors come from. I know the trips; the walking, the hiking, I know the history of where they were. Every time I come into this part of the country or fly over it, when I first see the Lake Clark area or coming from the south and see Sixmile Lake, I know I'm home! F-32, 8/18/11

*So the importance of this resource, specifically salmon, has a major impact on my people here. That's the reason why we live here. We have sockeye salmon until March, when everyplace else has no more. That's why my ancestors fought over this region… The reason why they've been here for so long is it's a healthy environment, and we have been kind of watching over it all these years. My ancestors fought over it, and they won every battle. We beat the Russians two times. It was musket against bow and arrow. So, you see, the importance of it has a really long history of why it is like it is now. We took care of it. Not only that, we have shared with everybody in the whole world.[*in reference to commercially caught salmon] M-33, 8/18/11

My Auntie [name] *would say, "Don't forget how to live off the land" and I'd think, "Oh, we could just go to the store and have microwave stuff." She said, "One day in this world something's going to happen where you guys are going to rely on living off the land, trapping off the land." Like we take things for granted now; we can go on an airplane and shoot a moose or trap beaver or trap squirrels up on the mountain. We have to. We can't just forget our ways; how to live off the land, because one day there's going to be something that happens in the world, where we are going to have to learn to survive out here.* F-32, 8/18/11

But what the spiritual aspect of what they believed was strong…they had energy. Energy from what they worshipped; everything living. M-33, 8/18/11

That is spring water [at Kijik]. *It does not freeze. That is why you can go over there and get a sockeye salmon in March; it might have a green head, and it's red, but it's still a sockeye salmon. You can go over there on New Year's Day and get a fresh sockeye salmon.* F-33, 8/18/1*1*

2. Pre-Contact Culture

Dena'ina origins are described in the section on Prehistory (II.C.2) and indicate the Dena'ina have been operating as a culture for whom salmon is the primary resource since A.D. 1000. Much can be inferred about the pre-contact Dena'ina culture because of Cornelius Osgood's (1976, originally published in 1937) comprehensive *Ethnography of the Tanaina* [sic]. Like the pre-contact Yup'ik culture, the Dena'ina pre-contact culture was sustainable and egalitarian in terms of equitable access to resources. The fundamental food source was salmon, but also included caribou, moose, bear, beaver, and other mammals and birds (Osgood, 1976:26) and about 150 edible plants (P. Kari, 1987:60-188). For the pre-contact Dena'ina salmon were caught in a number of ways, but primarily in weirs made of poles sunk into the bottom of a stream and strung with a lattice-like thatch, allowing water to pass through, but trapping migrating fish (Osgood, 1976:28). When they weren't fishing they simply opened a gate, and the fish swam through to spawn upstream. To solve the problem of storing this food resource for later use, the Dena'ina devised a simple but effective underground cold storage pit (Osgood, 1976:42). Two layers of birch bark, with moss in between, lined the pit, which was filled with dried fish, layered with grass, during fall freeze-up. The frozen fish were eaten throughout the winter and spring, until the next summer's salmon run. Like modern fish camps, traditional Dena'ina fishing was an extended family operation. Everyone worked for, and received the

benefits of, the clan-based family group.

Because of the stable salmon food resource and a means to preserve it, the Dena'ina lived in sedentary or semi-sedentary villages of substantial log houses, usually spread out along a ridge above a lake, a river side channel or a tributary to one of the major rivers (Osgood, 1976:55-62). The married men of a village were members of the same matrilineal clan and their wives and children were members of a different clan (Osgood, 1976:128-131). Within this family group, connected by blood and marriage, and allied for economic purposes, various individuals performed different assigned tasks. The Dena'ina called this group the *nakilaqa* (*ukilqa* in Osgood) (Osgood, 1976:134) or clan helpers. The clan helpers recognized a chief, called a *qeshqa;* in the Iliamna area the position was related to being a family head (Osgood, 1976:131-3; Fall 1987:6-8). The *qeshqa* had numerous characteristics, among them wisdom, experience, and generosity. He or she had three primary duties: first, to arbitrate and resolve disputes; second, to care for the elderly and orphaned; and third, to assure the survival of the clan helpers through the equitable distribution of food. Regarding the latter, the *qeshqa* controlled the foods gathered, processed, and stored by the clan helpers and had authority to redistribute the food (mainly salmon) back to people throughout the winter on an as-needed basis.

This system provided a safety net. Each *qeshqa* had a partner in a distant village, called a *slocin*. If one village ran low of food, the *qeshqa* could request aid from his partner, who would divert some of his village's food resources to the needy village. The second *qeshqa* would be willing to do this because, at some point, his village might be short of food, and the partner he helped would return the favor.

3. Post-contact History and Culture

In the study area Dena'ina territory includes the Kvichak drainage of Lake Clark, the Newhalen River and the west half of Lake Iliamna. Today, the Dena'ina villages in the Kvichak/Iliamna drainage are Nondalton, Iliamna, and Pedro Bay; Kokhanok is mixed Dena'ina Alutiiq, and Yup'ik. This brief history is germane to the project because it establishes: 1) the Dena'ina repelled Russian colonization maintaining population superiority in their homeland to this day: 2) they adopted Russian Orthodoxy which ritually incorporated traditional viewpoints of a symbolic relationship of people to the land, and, 3) they began to have economic ties to the Bristol Bay salmon canning industry. Through it all the people retained a strong subsistence lifestyle.

During the late eighteenth century, two Russian trading companies, the Shelikhov Company and the Lebedev Company, occupied Dena'ina territory, focusing primarily on the Cook Inlet region but extending into Iliamna Lake. The Lebedev established a post at Pedro Bay, on Iliamna Lake, in the 1790s (Ellana and Balluta, 1992:61). About 200 Russians occupied Cook Inlet and the Iliamna Lake area during the late eighteenth century; by the turn of the century, their presence had shrunk to a small handful through a complex series of events involving attacks and counter-attacks as outlined by Boraas and Leggett (in press, 2012). As a result of hostilities the Russian Lebedev Company left Alaska in the spring of 1798, and subsequent Russian presence in Dena'ina territory was minimal.

In 1838 a terrible smallpox epidemic decimated the Dena'ina (and most other Pacific coastal Alaska Natives). Where there are statistics, such as for the Kenai River drainage, about half the overall population died in two years (Fedorova 1973:164) and, although there are no specific statistics for the Lake Clark and Iliamna, it is likely the situation was tragically similar in

the study area. Traditional shamanic practices were ineffective against smallpox and, after 1840, many Dena'ina were baptized as Russian Orthodox, (Townsend 1981:634-6), accepting the church's explanation for the epidemic as "God's will" (Boraas and Leggett in press, 2012). In 1853 the Orthodox Church undertook an inoculation program, vaccinating baptized Dena'ina against smallpox, and an Orthodox Church was built at Kijik in 1884 (Ellana and Balluta, 1992:63). It is probable that by the early twentieth century, most Dena'ina in the Iliamna/Lake Clark area were baptized as Orthodox.

As summarized by Karen Gaul (2007:48) salmon canning in Bristol Bay emerged as a major industry in the late 1800s. Unregulated Bristol Bay canneries regularly blocked the mouth of the Kvichak and Nushagak Rivers to harvest salmon; consequently, there were years when there was little escapement into the rivers, creating extreme hardship for the upriver Dena'ina and Yup'ik subsistence communities. Starting in the early 1900s, men from the inland villages traveled to the coast to work seasonally in the commercial fishery, as many still do today. The fur trade was a second non-subsistence occupation, providing cash for food, guns and ammunition, traps, cloth, and other items, but commercial salmon fishing remained the primary source of money for most indigenous families and supplemented subsistence activities (Gaul 2007:48).

Well into the twentieth century Dena'ina practiced a ritual that involved sending the spirit of the animal to the "reincarnation place." Land animal bones were burned in the fire and water animal bones, like salmon, were returned to the water. These practices ritualized ecology and were said to bring the animal back to be hunted or fished again (Boraas and Peter 1996:188-190). Archaeological evidence indicates the Dena'ina were burning bones in their fire hearths (Boraas

and Peter 2008:220-222)

D. Traditional Yup'ik and Dena'ina Spirituality and Cosmology

Many modern practices of Yup'ik and Dena'ina have their basis in traditional spiritual and cosmological beliefs, though they are sometimes re-contextualized in Christianity. This section discusses the traditional spiritual and cosmologic beliefs and practices of both peoples

1. <u>The Yup'ik People</u>

Traditional Yup'ik values revolved around not only their extended families, but also their relationships with the wild animals and other components of the natural landscape. Within this belief system, the *Ellam yua*, or creative force, was a universal cosmic presence who coordinated existence and established a basic ordering framework; *tunghit* were powerful spiritual beings who controlled the recycling of different animals, fish, and bird forms (Langdon, 2002).

The Yup'ik have traditionally regarded animals as other peoples, or categories of kinsmen, with whom they have fluid relations that often cross species and interpersonal boundaries. There are numerous stories of half-animal, half-human beings who live in the villages or of people turning into seals, birds, fish, or other animals, and then turning back into humans, as well as stories of people who seem to be human, but turn out to be seals or other animals in a temporary human form. Several major traditional festivals and ceremonies, described below, honored this relationship. The spiritual values associated with each of these festivals emphasized sharing between humans and respect and care for animals. Traditional stories and advice speak of the animals giving themselves to the humans when the humans need them for food. The good practices of sharing, care, and respect (e.g., being careful with the animal's body and soul, and not wasting the food) ensured the animals' continued willingness to

give themselves to the hunters and fishermen in the future. Sharing of the products of subsistence with their human kin and other relations also strengthened the bonds of family and community. A version of The First Salmon celebration in the river communities is still celebrated today, when those who have caught the first king salmon in the spring share them with Elders and all those in need, as well as with friends and family, emphasizes these values.

The Yup'ik relations with the wild animals and fish of their landscape were primary, and in many ways still are. The Yup'ik related to the fish, the bear, the caribou, the moose, the ravens as relations, others equally inhabiting the landscape with them as interrelated peoples. During spring, summer, and fall the Yup'ik hunt and fish the animals as food, but when processing the animals as food they treat them with respect and care, and enable their return through rituals and ceremonies. In winter, a period of rest and renewal for the human population, in the past the Yup'ik attended to the renewal of life through the rebirth of the animals they had hunted, and fished, in, according to Fienup-Riordan five ceremonies, "three of which focused on the creative reformation of the relationship between the human community and the spirit world on which they relied." (Fienup-Riordan 1994:267). Today, many of the Russian Orthodox ceremonies continue to be based on this ancient calendar of propitiation of the world of the spirit, in all seasons. *Ellam yua* was a universal cosmic presence who coordinated existence and established a basic ordering framework; *tunghit* were powerful spiritual beings who controlled the recycling of different animals, fish, and bird forms (Langdon 2002). During the winter ceremonial season, the men beat the circular drum—traditionally made from stretching seal gut on a wooden frame—for songs and dances. The drum beats represented the heartbeat of *Ellam yua.* Thus, the celebrations were spiritual in the deepest sense. They were also material, involving the exchange and sharing

of wild subsistence foods from both animals who had given themselves willingly to the hunters and plants gathered from the landscape, considered to be spiritually alive.

During the Bladder Festival, at or around the Winter Solstice, the women brought out the bladders of seals, which they had been saving since their husbands brought the seals to them to prepare, because the Yup'ik believed that the souls or essence of animals are located or retreat to their bladders when they are killed. By saving the seal bladders and returning them to the sea, the Yup'ik enable the seals to be reborn, and present themselves again as food for the Yup'ik when needed. The women take the seal bladders to the *qasgiq,* or men's house, where the men inflate them and keep them for about ten days, while they go through a series of rituals to honor the seals and share food in the community, before returning the bladders under the ice, to the sea, enabling the seals to be reborn and to present themselves to the Yup'ik when needed again as food. The men would compose new songs for the Bladder Festival, including songs about salmon, and sing continuously in the *qasgiq*; people believed that light from the lamp and the songs drew the attention of animal spirits (Fienup-Riordan, 1994:284).

At *Qaariitaaq*, at the beginning of the Bladder Festival, the young boys were painted to represent the spirits of the dead, and went visiting, going around to the different houses to collect special food treats. Every house was brightly lit, and the hostesses wore their best clothes. The boys held out their hand-carved bowls, and the women handed out the special snacks. On the fifth night of these celebrations, the boys, and men, came to fully embody the spirits of the dead, and the fifth night was considered the arrival of the spirits. (Fienup-Riordan 1994:271). At *Aaniq*, held directly after *Qaariitaaq*, two men dressed in gut skin parkas, are referred to as mothers, the "*aanak,"* and they are taken around to collect newly made bowls filled with

akuutaq, traditionally a mixture of fat and berries. Small girls and boys referred to as their "dogs" would accompany them.

> *The way that people do things*
> *And the way of helping others*
> *And the way of creating friendship*
> *The Bladder Festival is like an opening for these things to occur*
> *And through those events*
> *The people being scattered*
> *Through that too they are gathered*
> *(Toksook Bay Eders, November 3, 1983 NI57 in* Fienup-Riordan, 1994: 267).

Today, starting during the Russian Christmas season the modern ritual of "Starring" follows this familiar pattern – groups go visiting from house to house, and receive special foods.

Other important ceremonies include the Great Feast for the Dead*, Elriq*, held every ten years, as well as the annual feast for the dead, and *Kelek*, a festival that included both serious and comic masked dances, when "animal spirits and shamanic spirit helpers made themselves visible in the human world in dramatic form" (Fienup Riordan, 1994:316). *Kelek* was performed to influence the animal spirits and elicit successful hunting and fishing through the return of the animals the following year.

Two other winter festivals underscored the redistribution of goods, including subsistence foods. The first, *Kevgiq*, the Messenger Feast, was a celebration and display of the bounty of the harvest, in which villages challenged each other to exchanges of wealth, with demands for specific items that were difficult to provide, such as certain game meat in a year when that game animal was scarce. *Kevgiq* served to reduce tensions between villages through sharing and friendly competition. It also provided food security by strengthening ties between villages and encouraging exchange relationships that could help people in times of food shortages. Sharing

was considered to be a behavior that would be rewarded by the return of the animals to those hunters and fishers the following year. *Petugtaq*, the Asking Festival, was a challenge to exchange gifts of value between cross-cousins and others, where the person whose gifts were the most valuable gained the highest prestige. Cross-cousins were in "joking cousin" relations with each other, and were able to call each other out on bad behavior, embarrassing each other without repercussions, since they were not permitted to get angry with each other (Fienup-Riordan, 1994:330). The behaviors were thus made public and frequently resolved through this tension-reducing mechanism. Both festivals involved teasing, dancing and singing as part of the ritual celebration of the exchanges. All of the traditional festivals required subsistence foods, not only for sustenance, but also for the meaningful symbolic and material exchanges.

During their ceremonies, the Yup'ik wore masks they had carved, often representing animals or those in transition between the animal world and the human world, the half–animal, half-human. These masks symbolized both the high regard of the Yup'ik for the animals and the importance of their roles Yup'ik culture. For the Yup'ik, the masks were *agayuliyararput*, or "our way of making prayer" (Fienup-Riordan, 1996:xviii).

Dances, including *ingulag*—the women's loon courtship dance—and other bird dances, filled the evenings and contributed to the festivities. Each dance told a story and many featured the animals with whom the Yup'ik partnered in their negotiation for existence in the challenging landscape. Dances were traditionally an essential part of the culture and celebrations and have returned in force as part of cultural revitalization along the Nushagak and elsewhere. Fienup-Riordan (1994:288) quotes Billy Lincoln:

> And at night, every night, they have what is called *nayangaq*. They dance. These young people who are sitting against the far wall go down in front of them and

> dance, sitting down pretending to be some animal, so thus, the *nayangaq***.** They imitate a certain animal. When the time came whatever animal he is pretending to be he imitates its noise. They imitate all kinds of animals – loon, hawk, raven, arctic fox. They make noise accordingly. They dance pretending to be some animal (July 10, 1985).

The dancers represented the many ways the stories and lives of the animals were woven into their own, in the richness of shared existence in the watersheds of southwest Alaska. Lincoln continues:

> These dance motions were more than the mere imitation of the motions of the animals. When the performers danced during *Kelek*, they actually performed the animals' dances. Just as married women danced the loon's mating dance during *Ingulaq*, so the performers during *Kelek* danced the dances of the animals whose presence they hoped to elicit in the year to come. . .

In 1913 Hawkes quoted a Unalakleet chief in an eloquent estimation of the value of these dances within Yup'ik culture: "To stop the Eskimo singing and dancing," he said, "was like cutting the tongue out of a bird" (Hawkes cited in Fienup-Riordan, 1994:320-321).

Fienup-Riordan (1994:355; see also Fienup-Riordan 2010) summarizes how the Yup'ik traditionally saw themselves in relation to the universe: "Yup'ik cosmology is a perpetual cycling between birth and rebirth, humans and animals, and the living and the dead. Their relationship between humans and animals reflects a cycle of reciprocity in which animals give their bodies in exchange for careful treatment and respect."

2. The Dena'ina People

The traditional Dena'ina spiritual world revolved around a quest for *k'ech eltani*, or "true belief," as a way to understand and interact with the natural world (Boraas and Peter, 1996:183-4). The Dena'ina believed that social and ecological harmony was affected by an individual's

attitudes, actions, and even thoughts toward other Dena'ina and to nature. To maintain harmony, the Dena'ina sought true belief, a kind of mind-set expressed through hunting practices, cooking rituals, communication with animals and plants (prayer), and other practices that demonstrated having a "good attitude" toward the forces of nature. Kalifornsky (1991:13) writes that, "Whatever is on earth is a person [has a spirit] they used to say. And they said they prayed to everything. That is the way they lived." Achieving *k'ech eltani* involved a spiritually torturous and mentally rigorous quest for understanding (Boraas and Peter, 1996:187).

Many of the Dena'ina traditional stories (*sukdu*) describe the dire consequences of having a bad attitude by not practicing the prescribed rituals such as burning the bones of consumed animals or distributing fish bones in the water as means to symbolically assure the animals would come back (Boraas and Peter, 2008:222-223). In these stories, a bad attitude would have the consequence of the animals, believed to be both sensate and willful, withdrawing and not offering themselves to be taken for food. The result would be starvation. A bad attitude could result in social turmoil or mental illness. There was immense pressure to behave and think respectfully toward the natural world including salmon.

In a forthcoming chapter on Dena'ina world view, Boraas (in press) writes the following about traditional attitudes toward animals:

> Attitudes toward bears typify attitudes toward animals. In "Three People in Search of Truth," (Kalifornsky 1991:164-167) three brothers hunt a brown bear, the most feared and respected animal. The first fails because he is poorly skilled; the second fails because he is impetuous, and the third succeeds because he is skilled, controlled and speaks the correct words to the bear, which then respects him and does not resist being killed. In Kenai a successful hunter used the phrase *Chadaka, k'usht'a nhu'izdeyeshdle*, which translates as "Great Old Man, I am not equal to you," to communicate humility toward the bear he was hunting (Kalifornsky 1991:167). In 1966 Mrs. Mike Delkettie, a Nondalton Dena'ina,

> reported that a similar saying was used in that area; moreover, the eyes of the bear were buried near the spot where it was killed as an offering showing proper respect (Rooth 1971:62). Francis Wilson, also from Nondalton, told Rooth (1971:50) that, after a bear was killed, they had to follow prescribed procedures, particularly in the treatment of the head, lest they never kill another bear, because "the bear still knows what is happening, so they have to be very careful with what they are doing." Hunting rituals and prayers were meant to thank an animal for allowing itself to be killed and sometimes it also involved giving an offering as a measure of the importance of proper attitude (Rooth 1971:50).

The First Salmon Ceremony (Osgood, 1976:148; Kari and Fall 2003:184-190) expresses the intimate relationship of Dena'ina and salmon. The First Salmon Ceremony was based on a traditional story. As the Osgood's retelling goes, a *qeshqa's* (chief's) daughter was admonished not to go near the fish weir. The determined girl went anyway to find out what was in the trap, promising to return later. At the fish trap she saw a king salmon, began talking to him, and gradually transformed into a salmon and disappeared with him. The desperate *qeshqa* looked for his daughter to no avail. Years later, the *qeshqa* was collecting fish from the weir. He put them on the grass and took them to be cleaned, but forgot one little one. He returned to find a little boy sitting there. He walked around the boy three times and realized it was his grandson. The boy then told his grandfather the things that should be done to ensure the salmon return each year, and those things became the First Salmon Ceremony, a world renewal ceremony[3] which ritually recognized the salmon's return and the Dena'ina as salmon people whose spirit is merged with the fish.

In 1862 Hegumen Nikolai, the first missionary priest stationed in Dena'ina territory

[3] World renewal ceremonies are important identity-building ceremonies that recognize the beginning or end of a year's subsistence activity and social cohesion. In American culture Thanksgiving is a world renewal ceremony.

wrote in his travel journal, "In the middle of May the king salmon reached our area [writing from Kenai]. This is the best red fish we have here, and the Kenaitze celebrated the fish run with some sort of festivities, during which they treated each other with food" (Znamenski 2003: 91). Fr. Nikolai was clearly referring to the First Salmon Ceremony.

Water was particularly important in Dena'ina spirituality in the act of moving into a spiritually liminal state. One kneeled beside a river or lake and took three sips of water (Boraas in press). This was practiced well into historic times and also occurs in mythological stories (*sukdu*). For example in "The Woman Who Was Fasting" (Kalifornsky 1991:168-9) a young woman was ritually fasting and spoke these words "People will learn something from our beliefs" as she took three sips of water. She was then able to perform a spiritually power act upon which she said, "When we pray and we fast there is another dimension."

Some places took on special importance. The Giants Rock, *Dzełggezh*, was along an old Dena'ina trail that became the Pile Bay Road between Old Iliamna and Kamishak Bay on Cook Inlet, one of the major trails connecting eastern and western Dena'ina territory. The rock was the site of a mythological story and was a spiritual place (Johnson, 2004:49-54). The rock was dynamited in 1955 as part of road building activities by the Territory of Alaska; Dena'ina still regularly leave votive gifts at the site in homage to the place and the mythological event that happened there. Other sacred rocks and sacred locations exist in Dena'ina territory, but for most their locations are privileged cultural information (Boraas 2009:10-20).

Not only are there sacred sites but the Dena'ina believed the landscape retained a sense of events that happened there: events which could be good or bad. Spiritually powerful people and

animals could detect information about these events and, thus, to travel was to encounter morally good and morally bad events encoded into the landscape (Boraas 2009:8-10).

Figure 4. Nushagak River, January 18, 2012

E. The Yup'ik and Dena'ina Languages: Salmon and Streams

1. Voices of the People

Talk Native, no English….They talk Native [Yup'ik] better [than English]. [in reference to Elder interviews in Yup'ik] M-25, 5/18/11

That's why we quit using our Native tongue because we get our…ears pulled. I don't know how many times I sit in the corner because I use my Native tongue. We couldn't speak our own language in school because we get abused. F-46, 8/20/11

When we first went to school they took our dialect away from us and told us to speak English only. If we spoke our Native tongue we would get hit by the teacher which isn't right. Now they call it abuse. Anyways none of us speak our Native tongue [Dena'ina] because of that. My mom didn't speak English…. F-48, 8/20/11

2. Introduction

Language is intimately tied to cultural identity and Yup'ik and Dena'ina have evolved as languages of place for their respective areas over thousands of years. Landscape, subsistence, social relations, and spirituality are reflected in both languages. The variety of words a language has for a given topic generally reflects the importance of that topic to the people who speak it. Given their cultural importance, it is not surprising that both Dena'ina and Yup'ik have numerous, highly detailed terms involving salmon, other fish, and fishing. Streams are also intimately tied to Dena'ina and Yup'ik psyche and their languages reflect that fact.

3. The Central Yup'ik Language

The Yup'ik people of the Nushagak and Kvichak River watersheds are part of the Central Yup'ik group, of whom there is a population of about 25,000 in an area that also includes coastal communities and the lower and middle Kuskokwim River drainage (Krauss, 2007:408) (See Table 6). Ten thousand four hundred of this population, or 42%, speak Central Yup'ik of which the 7,000 mostly Yup'ik of the Nushagak and Kvichak River drainages are a part. Central Yup'ik

has one of the highest percentages of speakers among indigenous languages in the U.S and is an indicator of strong cultural heritage. Yup'ik is the first language for many residents in the study area and the language in which many feel most comfortable expressing complex or heartfelt ideas, which is why, for this project, we encouraged interviewees to respond in Yup'ik if they so choose. Eight of fifty-five interviewees spoke in Yup'ik. One Yup'ik interviewee (M-25; 5-18-11) spoke about helping set up a 2011 Elders Conference which occurred a few days before our interviews in New Stuyahok in which the entire discussion was in Yup'ik. He said, "I set up that meeting [Elders Conference], I try to do it for a long time…yes, talk Native [Yup'ik], no English. Get somebody else to translate…they talk Native better [than English]."

Table 6 Estimated Number of Central Yup'ik and Dena'ina Speakers. Data from Krauss (2007:408)

Language Family	Language	Population Estimate	Speakers	Percent Speakers
Eskimo-Aleut	Central Yup'ik	25,000	10,400	42%
Athabascan-Eyak-Tlingit	Dena'ina	1,000	50	5%

Table 7 presents Yup'ik terms for salmon, related fish, and fishing activities. In many cases there are multiple words and/or dialect differences. As indicated the sheer number of words are indicative of a long history with salmon and fishing activities. Moreover, the nuanced meaning of some words is indicative of a deep knowledge of salmon and related activities. For example the word *kiarneq*' means "unsalted strip or fillet of fish flesh without skin, cut from along the backbone and hung to dry"

Table 7. Yup'ik Words for Salmon and Other Fish Species and Related Fishing Terms. (x means literal translation same as English term.) From Jacobson (1984)

English Term	Yup'ik Word	Literal Translation
salmon (generic) *(Oncorhynchus spp.)*	*neqaraq*	any species of salmon
dog *salmon,* chum *salmon*	*aluyak* *iqalluk* *kangitneq* *mac'utaq* *teggmaarrluk*	**x** 'fish' 'old dog salmon after spawning' **x** boiled half-dried salmon
humpback *salmon,* pink *salmon*	*amaqaayak* *amaqsus* *cuqpeq* *terteq* *amaqatak* *sayalleraam amaqatii neqnirquq*	**x** **x** **x** **x** 'back of fish, hump on back' 'back of spawning red salmon is tasty'
silver *salmon,* coho *salmon*	*caayuryaq* *qakiiyaq* *qavlunaq* *uqurliq*	**x** **x** 'streak or wake made on surface by fish'
red *salmon,* sockeye *salmon*	*cayak* *sayak* *sayalleq* *sayagcurtuq* *imarnikaralegmun*	**x** **x** 'he is fishing for red salmon at a deep calm place'
spawning *salmon*	*masseq* *masruuq una neqa* *nalayaq* *nalayarrsuun*	'old salmon near spawning' 'this fish is a spawning salmon' **x** 'fish spear to catch

	talayaq *talmag (NUN)* *talmagtut*	spawning salmon' 'calico salmon' 'to spawn (of fish)' 'they are spawning'
king running under smelt	*aciirturtet*	'the first group of king salmon running under the smelt'
salmon egg	*cilluvak*	'salmon egg, especially aged salmon egg'
salmon strip	*culunallraq* *taryitaq*	'salted and dried salmon strip'
salted fish or meat	*culunaq* *culunanek ajurciuq* *sulunaq* *sulunanek ingqillruuq* *taryitaq, taryiraq* *taryirki sulunarkat*	'salted fish or meat that is eaten after it is cut up and soaked to remove excess salt' 'she is soaking some salted fish' see culunaq 'my wife cut up the salted fish' 'salted salmon strip' 'put salt on the pieces of fish to be preserved'
scale (fish)	*kapciq* *qelta* *akakiik qeltairru suu pirniaraqa*	**x** 'fish scale', 'take the scales off the whitefish so that I can make soup with it!'
rolled oats	*qeltengalnguut*	'things like fish scales'
smelt	*cemerliq* *cimigliq*	**x** **x**
stick(*n*) fish-spreading	*ayagta* *ayagtekartellruunga*	'prop, support, *especially* a small stick used to keep a cut fish open as it dries' 'I gathered material to use as spreaders for drying fish'
stickleback	*cukilek* *angun cukilegnek*	'one with quills' 'the man is dipnetting for

	qaluuq *ilaqcungaq* *quarruuk*	sticklebacks' **x** 'needlefish'
supper	*atakutaq*	'supper, evening meal'
tail, fish	*papsalqitaq* *papsalquq*	'dried fish tail' 'tail or caudal fin of fish'
preopercle	*ulluvalqin*	'gill cover of a fish, preopercle'
fish cheek	*ulluvalquq*	'cut from the fish'
trap, fish	*taluyaq*	'fish tray'
whitefish with pointed head	*cingikeggliq*	**x**
young whitefish	*esevsiar(aq)* *iituliar(aq)*	**x** 'whitefish fry'
frozen raw whitefish	*qassayaaq* *akakiigem meluanek qassallruunga*	'frozen whitefish aged before freezing and served frozen' 'I ate the whitefish eggs raw'
To fish (v)	*neqsur*	?
Fish	*iqalluk* *ilaqcuugaq* *neqa* *neqet amllertut maani* *qimugtet neqait nangyarpiartut* *neqtulnguunga* *neqa unguvangraan uklia* *neqngurtuq* *nereneqaiq, neqiaq*	'dog, chum salmon, fish' 'small fish found in lakes' 'food;fish' 'the fish are plentiful here' 'the dogs' food is almost gone' 'i'm tired of eating fish' 'even though the fish is still alive he is cutting it up' 'there was food everywhere',*lit. 'it became food'* 'food-stealing bird'
Boiled fish	*egaaq*	'any cooked fish or other food'

Bundled fish	*inartaq*	**x**
Canned fish	*paankaraq* *qakiiyak paankarak uksuqu nernalukek*	**x** 'he is canning two silver salmon so that he can eat them in winter'
Cut fish	*cegesseg-* *cegtuq* *cegaa, ceggaa* *ceg'aq, cegg'aq* *seg-* *ulligte-* *ulligtuq* *ulligtaaa* *ulligciuq* *ulligtaq* *ingqii-* *inguqin, inguqitaq* *neq'liur-* *neq'liurtuq*	'to cut fish for drying' 'she is cutting fish' 'she is cutting it' 'a fish cut for drying' (see ceg-) 'to cut fish for drying, in the traditional manner, making cuts so that air can reach all parts of the flesh; (NUN) to turn over' 'it is cut for drying' 'she cut it for drying' 'she is cutting it for drying' 'fish cut for drying' 'to make the horizontal cuts in fish flesh while preparing it for drying' 'board on which one prepares meat or fish' 'to work on fish (cleaning it, etc.)' 'he is working on fish'
Fish cut in half	*qup'ayagaq(NUN)*	'fish cut in half to hang and dry'
Dried fish	*neqaluk (NUN)* *neqerrluk* *palircima*	**x** **x** 'to be burnt by the sun (of dried fish)
Dried small fish	*nevkuq* *ulligtaruaq*	**x** 'split and dried small fish, such as whitefish, pike or trout'
Dried fish heads	*nasqurrluk*	'cut and dried fish-head'

	qamiqurrluk *irniani nerevkaraa tepnek*	(see above) 'she let her child eat some aged fish heads'
Dried frozen fish	*yay'ussaq*	'dried tomcod or whitefish that has been frozen all winter'
Air dried fish	*tamuaneq*	**x**
Fish dried in a basket	*tut'at (plural)*	'fish packed down and dried in a basket'
Fish partially dried and boiled	*egamaarrluk* *teggmaarrluk*	**x** 'boiled, half-dried salmon; dog salmon, chum salmon'
Frozen fish	*cetegtaq* *kumlaneq* *nutaqaq* *qercuqaq*	
Poke fish	*uqumaarrluk*	'fish slightly aged and stored in seal oil'
Fish partly smoked and stored in seal oil	*arumaarluk*	**x**
Fish in strips	*kiarneq* *palak'aaq (BB)*	'unsalted strip or fillet of fish flesh without skin, cut from along the backbone and hung to dry' 'strip of dried flesh'
Dried Fish tails	*parmesqatak* *papsalqitaq*	**x** **?**
Fish strung to dry	*piirrarrluk (Y, HBC)*	'small fish, such as tomcod strung up for drying'
Fish hung to dry	*kanartaq*	**x**
Raw fish	*qassaq, qassaulria* *qassar-* *qassartuq* *qassaraa*	'raw fish or meat' 'to eat raw fish or meat' 'he is eating raw fish' 'he is eating it raw'
Raw frozen fish	*quaq*	'fish to be eaten raw and frozen'
Cooked piece of fish	*ukliaq*	**x**

Fish bin	*qikutaq*	'bin used for temporary storage of fish before they are cut up for drying'
Fish trap	*taluyaq*	**x**
Fish rack	*initaq* *ker'aq* *qer'aq*	'part of a fish rack on which the fish is directly hung'
Fish wheel	*akalria*	**x**
Fish fence	*capon* *angutet capcirtut uqvianek manignarrnaluteng taluyakun* *kalgun*	'weir, fish fence; wall' 'the men set a weir of willows to catch loche with a fishtrap' 'weir, fish fence extending from the bottom of the river and leading fish to a place where one can catch them with a dipnet'
Fish spear	*aggsuun* *ag'ssuun*	**x** **x**
Fishing line	*ipiutaq (NSU)*	**x**
Fish camp	*kiagvik* *neqlilleq*	'summer fish camp' (see above)
Fish Village	*neqlercurvik*	'fish village, site on the lower Yukon'
Fisherman	*neqsurta* *neqsurtuq* *neqsurvik* *neqsurtuq tuniarkaminek* *aataka neqsurtenġuuq*	**x** 'he is fishing' 'fishing place' 'he is fishing commercially' 'my father is a fisherman'
Fish hook	*iqsak* *iqsag/manaqutaq*	**x** 'to fish with a hook and

		line, to jig for fish’
	iqsagtuq/manartuq	‘he is hooking for fish’
	iqsagaa/manaraa	‘he hooked it’
	manaq	‘fishing lure with hook’
	manar	‘to fish with a hook, lure, and line, usually (though not necessarily) through a hole in the ice in winter’
	manaryartuq	‘he went to fish with a hook and line’
	qerrlurcaq	‘fishhook which is baited and set below the ice, held in place with a stick across the hole, and left unattended to be checked periodically’
Fish net	*kuvyaq, kuvya, kuvsaq*	**x**
	kuvya	‘to fish by drift-netting or purse-seining’
	kuvyauq	‘he is drift-netting’
	kuvyaq cangliqellruuq nutaranek	‘the net caught lots of fresh fish’
	qemiraa kuvyaq qilagcuutmek aturluni	‘ he is stringing the net using a net shuttle’
	kuvyaq civtaa	‘he set the net’
	kuvyaq takuua	‘he checked the nets’
	kuvyarkaq	‘twine for making nets’
	qelcaq (Y)	‘net into which fish are driven by peopoole who walk in and thrash the water’
Set net	*petugaq*	**x**
Fine mesh net	*caqutaugaq(NUN)*	‘fine mesh net for dog salmon, worked by hand by men standing in the water, not left unattended’

Net shuttle	*imgutaq* *qilagcuun*	**x** **x**
Net setting line	*amun* *atlirneq* *nuvun* *qemiq* *qemirtuq* *qemiraa*	'line used to set and reset a net under the ice' 'lead line of fish net' 'threading device (such as the line used to set a net under the ice, or a needle threader)' 'lead line or float line of a net' 'he is stringing (a net)' 'he is stringing it'
Net sinker	*kic'aqutaq*	**x**
Fishing rod	*manaq* *piqrutaq*	'fishing lure with hook'
Roe	*cin'aq* *cilluvak* *imlauk* *meluk* *melug*	 'salmon egg, especially aged salmon egg' 'fish egg,roe' 'fish eggs, roe; fish eggs prepared by allowing them to age and become a sticky mass' 'to suck; to eat roe directly from the fish'
aged roe	*cuak*	**x**
herring roe	*imlauk (NUN)* *qaarsaq* *qiaryaq (NUN)*	'dried herring egg' **x** 'herring eggs, so called because they crackle when eaten'
fish rack	*ker'aq (NSU)* *qer'aq*	**x** **x**
trout	*anerrluaq (BB)* *anyuk (BB)*	'type of fish, salt-water trout' **x**

lake trout	*cikignaq*	**x**
steelhead trout	*irunaq*	**x**
rainbow trout	*talaariq*	**x**
dolly varden (char)	*iqallugpik*	**x**
herring	*iqalluarpak, iqallugpak*	**x**
Arctic cod	*iqalluaq*	'boreal smelt'
Pike	*uksumi-llu iqsagnaurtut cuukvagnek*	'and in the winter they would hook for pike'
Wolf Fish	*qugautnaq (NI, NUN)*	**x**
Smokehouse	*elagyaq* *puyurcivik* *talicivik* *neqnek aruvarqiyartua talicivigmi*	'partially underground cache; pit for cleaning fish; smokehouse' **x** 'shelter for smoking fish, smokehouse' 'go smoke the fish in the smokehouse'
Smoked Fish	*aruvarqi-* *aruvir-* *puyurqe* *puyurte-*	'to smoke fish' 'to be smoky; to smoke (fish)' 'to be smoked; to feed the fire when smoking fish' 'to smoke (fish)'
Subsistence	*angussaag-* *yuungnaqe-*	'to hunt, to try to catch game' **?**

4. <u>The Dena'ina Language</u>

There is a dramatic difference in language retention between the Yup'ik of the Nushagak and Kvichak River watersheds and the Dena'ina of the Iliamna Lake and Lake Clark area. In contrast to the Yup'ik, the Dena'ina population is much smaller, estimated by Krauss (2007:408) at 1,000 for the Iliamna/Lake Clark area and Cook Inlet Basin. Krauss estimates that within this population there are only 50 Dena'ina speakers remaining (see Table 6), most of whom live in

the vicinity of Nondalton or Lime Village (the latter outside the study area in the Kuskokwim River drainage). The youngest active Dena'ina speaker is 64 years old. Dena'ina is, thus, one of the world's most endangered indigenous languages (Boraas 2010:2). The reason for the disparity between Dena'ina and Yup'ik language usage is complex but the main reason for Dena'ina language extinction was the Alaska Territorial School's federally mandated policy of punishment for children speaking their indigenous language in school. This forced assimilation policy occurred to various degrees throughout Alaska but its application seems to have been particularly harsh in Dena'ina territory (Boraas 2010:2).

Given the importance of language to cultural identity, the Dena'ina have begun to revitalize their language and significant efforts are underway to avoid its extinction both in spoken and written form (cf. Boraas and Christian 2010). There is a history of Dena'ina Elders working with linguists dating back to Anna Brigitta Rooth's (1971) work in 1966 in Nondalton followed by dozens of bilingual publications by James Kari working in collaboration with Dena'ina speakers starting in the 1970s and the bilingual publication of Joan Tenenbaum (1984). More recently a number of speakers from Nondalton and Lime Village have participated in Dena'ina Language Institutes, sponsored by a consortium of institutions including the Alaska Native Language Center, Alaska Native Heritage Center, the Sovereign Nation of the Kenaitze, and Kenai Peninsula College. The one to three-week institutes have been held at various locations including Nondalton and include workshops on Dena'ina language learning and teaching. Recently, two speakers from the study area, Andrew Balluta of Nondalton/Newhalen and Walter Johnson of Pedro Bay, now of Homer, have collaborated with linguist James Kari on important bilingual publications: *Shtutda'ina Da'a Sheł Qudeł: My Forefathers are Still Walking*

with Me (Balluta 2008) and *Sukdu Neł Nuhtghelnek: I'll Tell You a Story: Stories I Recall from Growing Up on Iliamna Lake* (Johnson 2004). Finally, numerous speakers living and deceased (through archived recordings) contributed to *Dena'ina Ełnena [Dena'ina Territory]: A Celebration* edited by Karen Evanoff (2010).

The language is indicative of the importance of water and salmon and other fish to the Dena'ina. Streams are intimately tied to the Dena'ina psyche through language. The Dena'ina words for directions are not based on the cardinal directions, but on the concept of upstream or downstream. A Dena'ina description of direction results from combining one of five stems, indicating upstream, downstream, and related terms; one of six prefixes, indicating proximity; and a suffix indicating general direction or location (Kari, 2007:336). For example, the word "*yunit*" combines the stem "*ni*" (upstream) with the prefix "*yu*" (distant) and the suffix "*t*" (at a specific place) and means "at a specific place a long way up upstream." If one were using that phrase at Iliamna, *yunit* would mean the direction toward Nondalton, which is a specific place far upstream; in this case, the direction would be north, because from Iliamna the Newhalen River flows south.

Because of the importance of stream stems reflecting a fundamental cultural construct affecting a wide range of cultural activities (subsistence, diet, travel, directions, spirituality etc.) Kari (1996) has proposed migration theory for Dena'ina and other Athabascans (who employ a similar directional system) based on variants in the stream stem morpheme. Kari suggests a movement of people from northern British Columbia, to the Yukon River area to the Kuskokwim piedmont, to Dena'ina territory. Boraas (2007:35) believes this to be the best hypothesis of Dena'ina origins to date.

The spirituality of water is also embedded in the language. The Dena'ina have 36 terms for streams (Kari 2007:123-4), among those the primary word for 'water' is of special note. The Dena'ina word for "water" *viniłni* (in the Inland dialect, *miłni* in the Outer dialect) is unique among other Athabascan/Dene languages and Dena'ina linguist James Kari considers it to be esoterogenic meaning a special word reflecting special importance or sacredness (personal communication, Dr. James Kari, UAF Professor Emeritus, December 6, 2011). Dena'ina Elders Clare Swan and Alexandra Lindgren (2011) state "the Dena'ina word for water was held sacred" and by implication the water was sacred. The word *viniłni* and its sacred connotations is reflected today in the Orthodox Great Blessing of the Water ceremony described in section III.F.3 in which river water is annually baptized and made holy.

The Dena'ina named a general category of animal or plant by the name of its most important representative. For example, the name for animal is *ggagga*, for brown bear, and the name for tree is *ch'wala*, for white spruce. Not surprisingly, the name for fish is the name for salmon, *łiq'a*. Table 8 is a compilation of Dena'ina terms for salmon, freshwater fish, and fishing technology which, like the Yup'ik counterparts, shows an intimate connection with salmon, fish, and fishing.

Table 8. Dena'ina Terms Involving Salmon, Freshwater Fish and Fishing Technology. (x means literal translation same as English term.) Data from Kari (2007) Dialect notations: I = Inland, U=Upper Inlet, O=Outer Inlet, L=Lime Village, Il=Iliamna, S=Seldovia, Lk-i=Kuskokwim Deg H'tan, Su=Susitna Station, E=Eklutna, Ty Tyonek, T=Talkeetna, Kn=Knik

English Term	Dena'ina Word	Literal Meaning
salmon (generic) *(Oncorhynchus spp.)*	*łiq'a (IU)* *łuq'a (OSl)*	x x
Male fish	*Hest'a, qest'a (IO)* *Tl'ech'I (U)*	
Female fish	*Q'in'i* *Q'inch'eya (IO)* *Q'inch'ey (U)*	'roe one'
Small fish	*Chagela gga (U)* *Shagela gguya (I)* *Shagela ggwa (O)*	
Fry, baby fish	*Lch'eli, dghelch'eli*	'shiny one'
Bottom fish	*Tahliq'a (IU)* *Tahluq'a (O)*	'underwater fish'
Spring fish run	*Łitl'eni (UI)*	x
Spring fish caught under ice	*Ten t'uhdi (U)*	x
king salmon, Chinook salmon *(O. tschawytscha)*	*łiq'aka'a (IU)* *łuq'aka'a (O)* *chavicha, tsavija (O)*	"big salmon' <Rus.
king; *salmon sizes*: smallest	*łiq'agga (U)* *ggas ten'a (L)*	'small salmon' 'king salmon's handle'
two-foot king salmon	*q'inagheltin (U)*	'?'
largest king salmon	*łiq'aka (U)* *vigit'in (L)*	'big salmon' x
middle-sized king salmon	*tl'istqeyi (U)*	x
humpback salmon, pink salmon *(O, gorbuscha)*	*qughuna (OUSl)*	'humped'
red salmon, sockeye salmon *(O. nerka)*	*łiq'a (I)* *t'q'uya (LNOSl)* *k'q'uya ON)* *q'uya (U)*	**x** 'ridged'
nickname	*veghutna qilin (I)*	'it exists for people'
old fall sockeye	*bendashtggeya (U)* *dghelbek'i (UO)*	'partially white' *a rare verb stem*
dog salmon, chum salmon *(O. keta)*, (I) early summer	*alima (OIl)* *seyi (U)*	< Esk.. **x**

chum salmon	*nulay (NL)*	'runs again'
August run dog salmon	*shighat'iy (Lk-i)*	"?"
silver salmon, coho salmon *(O. kisutch)*	*nusdlaghi (I)* *nudlaghi (O)* *nudlegha, nudleghi (U)*	'one that swims back'
steelhead trout *(Salmo gairdneri)*	*usdlaghi (O)* *telaghi (Il)* *tuni, tuni denłkughi (N)* *shagela (U)*	? 'one that swims past' 'one that runs' 'water one' 'fish'
running salmon	*tuzdlaghi (OI)* *tuydlaghi (U)*	'one swimming in water'
fish laying eggs	*taq'innelyaxi (I)* *taq'innelyashi (UO)*	x
spawned-out salmon	*nudujuzhi, dujuzhi (I)* *dujuyi (U)* *itak'i (O)*	x x x
dead salmon	*tiłani*	X
fall salmon, esp. sockeye	*hey łuq'a (O)* *hey łiq'a (IU)*	'winter salmon'
fingerling, baby salmon, alevin	*tuyiga (OI)* *łiq'agga (U)* *łiq'a gguya*	'water spirit' 'little salmon'
first fish run	*qtsa ghelehi*	x
last fish run	*q'ech'en ghelehi (I)* *unhtl'uh ghelehi (UO)* *unhtl'uyeh (I)*	x
old female salmon	*q'in ch'ezhi (I)* *q'in ch'eya (U)*	'infested roe'
red-colored salmon	*nuditq'azhi (I)* *nishtudghiłtani (U)*	'one that is red' 'that which floats in midstream'
spring (early) salmon run	*ts'iluq'a (O)* *łitl'eni (UI)*	'straight salmon' 'spring one'
summer salmon run, sockeye season	*chiluq'a (O)* *hchiliq'a (UI)* *shanlaghi (UI)*	x 'summer run'
fall-winter running salmon	*tuleha (OU)* *tulehi (I)*	'one running in water'
dead salmon that drift ashore	*niqatayilaxi (I)*	x
salmon captured in weir	*q'anughedełi*	'those swimming back'
Non-salmon fish	*Shagela (IO)* *Chagela (UIl)*	'fish'

	Chebay (U)	
Alaska blackfish	*Huzheghi, huzhehi (L,N)*	'gaping thing pointing up'
Freshwater sculpin	*Ch'qenłt'emich'a* *Ch'qenłt'emch'a (NL)* *Ch'qełdemich'a (Il)* *Ts'est'ugh'I, ts'est'uhdi (U)*	? 'the one beneath rocks'
Burbot, lingcod	*Ch'unya (I)* *Ch'anya (U)* *K'ezex (Lk-i)*	
Burbot's chin barbell	*Veyada k'ich'aynanik'et'i*	'one that hands out from chin'
Arctic char	*Vat (NL)*	
Eel, lamprey	*Suy łiq'a* *Łiq'a q'ints'a* *Łizil (O)* *Tl'eghesh (I)*	'sand fish' ? 'salmon roe female' 'dog windpipe'
Large lamprey	*Ts'iłten hutsesa (U)*	'arrow nock'
grayling	*Ch'dat'an (I)* *Ch'dat'ana (U)*	'one with a blanket'
Grayling's dorsal fin	*Vech'eda*	'It's blanket'
Freshwater herring, least cisco	*Ghelguts'I k'una (N)*	'pike's food'
Three-spined stickleback	*Dghezhi, dghezha (O)* *Dgheyay (U)* *Dghezhay (I)* *Vek'eha qilani (NL)* *Tuyiga (Il)*	'thorny one' 'one with quills' 'water spirit'
Spawning stickleback	*Bente qiyuya (U)*	'one going in lakes'
Northern pike	*Ghelguts'I (I)*	'swift swimmer'
Small pike	*Tl'egh tuzhizha*	'grass water beak'
sheefish	*Shish (L)* *Zdlaghi (L)*	 'one that runs'
sucker	*Duch'ehdi (IU)* *Dehch'udya €* *Łih (O)*	'open mouth one'
Brook trout, Landlocked Dolly Varden char	*Dghili juna (NL)* *Dghili chuna (Il)* *Dghelay tsebaya (T)*	'mountain dark one' 'mountain fish'
Lake trout	*Zhuk'udghuzha (I)* *Bat (Su)*	'spiny mouth'
Rainbow trout	*Tuni (I)*	'water one'

	Telaghi (U) *Shagela (Il)*	'one that swims, runs' 'fish'
Dolly Varden trout	*Qak'elay (I)* *Qak'elvaya (Il)* *Telch'eli (O)* *Chebay (U)* *Łiq'a k'qen (I)*	? ? 'shiny one' 'fish' 'salmon's husband'
Whitefish (any)	*Łih (UI)*	
Alaska whitefish	*Hulehga (I)* *Q'untuq' (Lk-i)*	'runs up' 'ridge on top'
Broad whitefish	*Telay (L)*	'swimmer'
Broad whitefish stomach	*K'jida (I)* *K'eghezh (Lk-i)*	'oval'
Round whitefish, pin-nose whitefish	*Hasten (IT)*	'pus handle'
Fish guts (all)	*K'inazdliy, vinazdliy*	'inner objects'
Fish bones	*K'iztin (IO)* *K'iytin (U)*	'inner long object'
Fish backbone	*K'eyena*	x
Fish belly	*K'eveda*	x
Dark fish blood along backbone	*K'tl'ech' (I)* *K'kuhchashga (I)* *K'kukelashch'a (L)* *K'chashga (U)* *K'kuhchash'a (O)*	x
Dark salmon meat near skin	*Beyes tut' tsen (UO)*	
Fins (any)	*K'ts'elghuk'a (I)* *K'ch'elna (OU)* *K'tay'a (U)*	x 'wings' 'paddle'
Pectoral fin	*K'ch'enla (U)* *K'ts'elghuk'a (I)*	'wing'
Dorsal fin	*K'iniq' ts'elghuk'a* *Ghuk'a (I)* *Biniq' ch'elna (U)* *K'inhdegga (O)*	'back fin' 'back swimmer' 'back wing' 'back collarbone'
Pelvic fin	*K't'egha (U)* *nilk'degga (O)* *k'eveda degga (I)* *nich' k'eltin'a (O)*	'paddle' 'paddles together' 'belly fin' 'one in the middle'
Anal fin and cartilage	*K'tselts'ena (U)* *K'tseldegga (IO)*	'anal bone' 'anal collarbone'

Adipose fin	*K'tagh'a (IO)* *K'tach'ełvasha (N)* *Tak'ełbasha,* *k'tach'ebasha (OU)*	'paddle' 'submerger'
Tail fin	*K'kalt'a degga (O)* *K'kalt'a ts'elghuk'a (I)*	x
Fresh air sack	*K'kuhlet'*	x
Fish collarbone, pectoral girdle	*K'degga*	x
Fish head gristle	*K'enchigija*	'head cartilage'
Fish meat	*K'enut'* *Duni (Il)*	x 'food'
Fish tail	*K'kalt'a*	x
Meat next to fish tail	*K'kalt'a veghun*	'body of fish tail'
gills	*K'q'eshch'a*	x
Gut with stringy end (pyloric caecum)	*K'delchezha (OIl)* *K'delcheya (U)* *K'jida*	'rattle'
Fish heart	*K'ggałggama (I)* *K'ggałggamam'a (IlOL)* *K'ghałggamama (U)* *K'qałdema (T)*	x
Hump on salmon's back	*K'eyenghezha (OI)*	x
Male sperm sac	*Hest'a vekuhlashga (I)*	x
Sperm, milt	*K'tl'ech'*	x
Nose cartilage	*K'ingija, k'engija (IOU)* *K'ingeja (Il)*	x
Oily strip of meat in front of dorsal fin of salmon	*K'ints'isq'a (U)* *K'yin tseq'a (I)* *K'intsiq'a (OI)*	'back strip'
Roe, fish eggs	*Q'in*	x
Roe sac	*K'q'in yes*	x
scales	*K'gguts'a (O)* *K'ggisga (IU)*	x
Fish slime	*K'eshtl'a (OIl)* *K'tl'eshch'a (IU)*	x
net-making tool, net stringer	*tahvił veł k'etl'iyi,* *tahvił qeyłtl'ixi* *tahvił dugula (I)*	'with it he weaves net'
net rack	*veq' k'etl'iyi* *veq' nuk'detggeni*	'on it he weaves something.' 'on it, it is dried'

net mesh measure	*ve» k'ettl'iyi*	'with it, it is woven'
fishing clothes	*va łiq'a ch'el'ihi*	x
awl for stabbing salmon	*ts'entseł (U)*	
bale of fish	*vava hał*	'dry fish pack'
cutting board	*veq' huts'k'det'esi*	x
dipnet, long-handled dipnet	*tach'enił'iyi (UO)* *nch'equyi (LN)*	x
short-handled dipnet	*tach'enił'i (I)*	x
salmon dipnet (longer handle)	*shanlaghi tach'nił'iy (I)*	'summer run dipnet'
trout dipnet	*taztin (I)*	x
dipnet frame	*taztin duves (I)*	x
fish bait (on hook)	*k'enełneha (O)* *k'inłneha (I)* *k'indneha (U)* *k'egh dghichedi* *beł ch'k'nułneq'i (O)*	x
rabbit or ptarmigan guts used for tomcod bait	*k'entleh, k'entleq' (U)*	x
natural rock hole fish bin	*tsaq'a (I)*	x
rock fish bin, fish cutting hole	*k'usq'a (NL)* *k'esq'a (OIl)* *k't'usq'a (U)*	 'cutting cavity'
fish box	*shagela yashiga*	x
fish club, seal club	*tsik'nigheli (IO)*	x
angled fish fence, dipnetting dock	*tanatl'ini*	'woven into water'
fish fermenting hole	*chuqilin q'a (O)* *chaqilin q'a (IU)*	x
gaff hook, branch hook, leister	*qishehi (IU)* *k'isheq'i (Il)* *sheh (L)* *shehi (O)*	'hooker'
fish hook	*ihshak, iqshak (OI)* *k'inaq'i, k'eninaq'i (U)*	Eskimo origin
Note: eleven separate types of named fish hooks		
fishing hole, fish trap location	*k'enq'a (OU)* *k'inq'a, -k'inq'a'a (I)*	x
fish trap location	*tach'k'eł'unt*	'where we set object'
fish jigging hole in ice	*tasaq'a* *tatsiq'a (Il)* *ges aq'a (L)*	'water head hole'

fishing line	*shehi tl'ila (O)* *k'inaq'i tl'ila (U)* *iqshak tl'ila (I)*	'hook line'
fishing pole	*iqshak ten (IO)* *shehi ten (O)* *k'inaq'i ten, k'inaq'i nikena, k'niten, k'neten (U)*	x
fishing reel	*shehi tl'ila telcheshi (UO)*	
fishnet	*tahvił*	'underwater snare'
net-like fish drag	*nich' nuk'tasdun (SlTy*	'in back is hole'
Russian-era fishnet	*sétga (O)* *satga (U)*	Russian origin
drift net	*te»edi (I)*	'one that floats'
gunny sack net	*chida yiztl'ini tahvi» (I)*	
seine net	*veł niqak'idzehi* *nébod (O)*	'with it one scrapes in circle' Russian origin
sinew net	*ts'ah tahvił*	x
twisted willow bark fiber net	*ch'eq' tahvił (IU)*	x
small hole, net mesh,	*k'eniq' (IO)* *k'eneq' (OU)*	x
net drying rack	*tahvił denluh*	x
lead line	*duyeh vetsik'teh'i* *duyeh vetsittehi (I)*	x
corks, floats	*tahvił ts'esa (IO)* *tahbił jija (U)*	x
cork line	*vetsik'teh'i*	x
fish pew, pike	*łiq'a eł dalyashi (OU)* *łiq'a veł telyayi (I)*	x
fish scaler, ulu knife	*vashla* *beł k'elggits'i (U)*	'little stone'
fish spreader stick	*k'enun'i* *nuk'ilqeyi*	x
hoop fish spreader	*dnalch'ehi (I)*	x
small fish spreader	*t'utseyŷi (O)*	x
hand-held fish snare with handle	*k'entsa quggił (I)*	x
spruce root fish snare	*qunqelashi quggił (OU)*	x
fish stringer	*k'e'esh tl'ił (OU)*	x
willow fish stringer	*q'eyk'eda (IU)*	'tough willow'
fishtrap, woven basket style trap	*taz'in (IO)* *tay'in (U)*	'object that is in water'

Note: Seventeen types of fishtraps for different species and conditions		
fishtrap funnel	*k'eshjaya (I)*	x
inner basket	*k'jaya (OU)*	'heart'
angled leads to trap	*taztin (I)*	'long object that is set'
long stick ribbing on fishtrap	*talyagi (IO)* *talyashi (U)*	x
spiral sticks on fishtrap	*k'etnalvesi (L)*	x
branch drag material put in weir	*k't'un dighali (U)* *k't'un dalghali (I)*	x
inner spruce bark reflectors pinned to bottom of weir	*tah'iggeyi (U)* *vejink'ehi (I)*	'under water turns white' 'stg. swims over it'
vertical stakes for weir	*dik'ali*	x
fish wheel	*niqak'uquł̨i (I)* *niqaghetesi (U)* *naqak'uł̨qu»i taz'in (O)*	'scoop that turns'
lead line	*duyeh vetsik'teh'i* *duyeh vetsittehi (I)*	x
net-making tool	*tahvił veł k'etl'iyi* *tahvił dugula (IL)*	x
net rack	*veq' k'etl'iyi* *veq' nuk'detggeni*	x

III. MODERN CULTURE

A. Interview Synopsis

Table 9 is a synopsis of respondents to the semi-structured interviews. The interview process is described in the Introduction and readers should refer to that section (II.A) and note the questions were not designed to elicit a simple yes/no-type response (nominal data) but rather to elicit a narrative of how the interviewee felt about or understood the topic in order to give a richer and more nuanced understanding of cultural patterns and values. The "Voices of the People" are a reflection of those deeper understandings. However, Table 9 has been derived from the interviews in order to give the reader a sense of the overall consensus or variation from consensus of the respondents. To accurately depict cultural practices, we read the interviews and characterized the response as Agree, or Disagree/Neutral for each interview question, generating nominal data. This data includes 47 interviews, the number transcribed at the time of the analysis (un-transcribed interviews were from Dillingham and Pedro Bay). Sometimes respondents in a group took up a topic at a later time during the interview in which case we included that response as it applied to a previous question. As discussed in the Introduction, not everyone responded to every question. In a small-group setting often one person would respond and others would nod or otherwise express agreement with the speaker. We only recorded the verbal response, not non-verbal indications of concurrence in formulating the data in Table 9. A second reason not every responded to every question concerned the well-being of Elders. If Elders were tiring in the course of the two-hour sessions, or if the session went long, we often skipped questions to shorten the interview time.

The responses represent consensus or near consensus: 694 responses were positive and 18 were negative or neutral. The data indicate Elders and culture bearers reflect indigenous cultural standards that have a very high degree of homogeneity as represented by this set of questions revolving around the importance of salmon and streams in their lives. Responses to interview questions are used in the Modern Culture sections (III) that follow with statements like: "interviewees universally felt…," "interviewees predominantly stated…," or "interviewees indicated…."

Table 9. Nominal Evaluation of Interview Responses to Semi-Structured Interview Questions. Based on 47 Interviews.

Question	Agree	Disagree or Neutral
1. Are salmon critically important in your lives? Note: often asked: "If the salmon were to disappear for whatever reason, how would it affect your lives?" *Agree means people perceive salmon to be critically important in their lives. Disagree means salmon are not perceived to be critically important.*	40	0
2. How many times in a week or a month do you eat salmon or other fish? Is it different during different seasons? *Agree means three or more times a week or "all the time." Disagree is less than three times a week or "seldom."*	35	0
3. Do people in your village need to eat salmon to be healthy? How does salmon maintain or improve physical or emotional health? *Agree means people perceive they need salmon and other wild foods to be healthy. Disagree means they do not perceive salmon to be necessary for health and wellbeing.*	37	0
4. Which foods are important to give to a child so that he or she will grow up to be smart or strong? *Agree means salmon and other wild foods are perceived to be necessary for children's health. Disagree means salmon and wild foods are not necessary and children can eat commercially purchased food and be healthy.*	30	2

5. Does it matter to you if the salmon you eat is wild salmon? Does it matter to you if the salmon comes from the streams and rivers in your area? *Agree means people perceive that the salmon they harvest and consume must be wild salmon from local streams. Disagree means it doesn't matter where the salmon comes from.*	40	1
6. Does it matter to you that the salmon are connected to the salmon your ancestors ate? *Agree means salmon genetically connected to fish their ancestor's ate is perceived to be important. Disagree means there it is not important that the salmon are genetically connected to ancestral harvests.*	27	0
7. If the fishing practices and care for the streams and rivers are good (what the ancestors call, 'without' impurity, Dena'ina *beggesh quistlagh*), does it result in salmon coming back? *Agree means proper practices are perceived to result in the salmon's return. Disagree means practices have no effect on the salmon's return.*	37	0
8. Have you observed changes in the numbers of salmon that come back each year? Is there a big difference some years? If there is, what do you think causes these differences? *Agree means people have observed changes in the number of returning salmon. Disagree means people have not observed changes in number of returning salmon.*	31	0
9. Are salmon important for the lives of other animals or birds that are important to the Yup'ik or Dena'ina ? What would happen to these animals or birds it they can't eat the salmon? *Agree means salmon are important to other animals. Disagree means salmon are unimportant to other animals.*	35	0
10. Who do you share food with? Relatives in Anchorage, Dillingham? Elders? Who decides how to share the salmon, and who to give salmon to? *Agree means wild food is shared with family and/or friends living outside of the area. Disagree means wild food is not shared outside the area.*	31	1
11. Do you share salmon with people who don't do subsistence and what type of things to you get in return? *Agree means salmon are shared with people who don't do subsistence. Disagree means salmon are not shared with people who don't do subsistence.*	14	0
12. What does it mean for families to go fishing together? Do young people learn a lot at fish camp? How do you teach the	41	0

young people to catch salmon? Do you teach young people to respect the salmon? *Agree means it is important for families to fish together. Disagree means it is not important for families to fish together.*		
13. How do you feel when you give salmon? How do you feel when you are given salmon? *Agree means people feel good when they give or receive salmon. Disagree means people have no particular emotion when they give or receive salmon.*	33	0
14. Do you feel an obligation to return the favor when someone gives you salmon? *Agree means people feel no obligation to return the favor of a salmon gift. Disagree means people feel an obligation to return the favor of a salmon gift.*	5	0
15. Are salmon and other wild foods eaten in community celebrations? Is this important? *Agree means it is important to include salmon and wild foods in community celebrations. Disagree means it is not important that salmon and wild foods are included in community celebrations.*	27	1
16. It has been said that most Yup'ik/Dena'ina believe that a wealthy person is one with a large family. Do you think that family is more important that material wealth? *Agree means the person believes family is more important than material wealth. Disagree means material wealth is more important than family.*	36	1
17. Do you do anything to make sure the salmon will return? *Agree means people do specific practices or rituals to assure the salmon return. Disagree means people do not do any specific practices or rituals to assure the salmon return.*	37	2
18. What would it mean to treat salmon badly? Why is this bad? *Agree means there are specific things that are identified as bad practices with disagree consequences. Disagree means there are no specific things identified as bad practices with disagree consequences.*	9	3
19. Did the old people tell of a time when there would be a disaster and the fish would disappear? *Agree means people heard elders tell prophetic stories of the disappearance of salmon. Disagree means people never heard Elders tell prophetic stories of the disappearance of salmon.*	15	2
20. Do you ever thank the salmon for offering itself to you? Do you ever pray when you catch salmon? Do you make an offering when you catch the first salmon?	37	0

Agree means individuals give thanks through a prayer and give an offering when the first salmon is caught. Disagree means no prayer, offering or other recognition is given with the first salmon catch.		
21. Do you ever hear the Elders talk about the salmon having a spirit? *Agree means people perceive salmon to have a willful spirit. Disagree means people do not perceive salmon to have a willful spirit.*	19	3
22. Did you ever hear Elders talk about a stream having a spirit or being like it was alive? Do some people still think that way? *Agree means people perceive of a stream as having a spirit and being alive. Disagree means people do not perceive of a stream as having a spirit and being alive.*	7	0
23. Do rivers or streams have events – or stories - associated with them that are good or bad? Is it appropriate to tell any of them now? *Agree means there are stories associated with streams that have a moral implication. Disagree means there are no stories associated with streams that have a moral implication.*	8	0
24. How do people get money to buy boats and motors for subsistence fishing? *Agree means people commercially fish in Bristol Bay or engage in other part time employment. Disagree means people do not engage in Bristol Bay commercial fishery or other part-time employment.*	16	0
25. Do you feel a connection between the way you fish today and the ancestors' way of fishing? *Agree means people feel an emotional connection between subsistence fishing today and the subsistence fishing of their ancestors. Disagree means people feel no such connection.*	8	0
26. Why do you live in your village? *Agree means people desired to live in their village and felt an emotional attachment to their lifestyle. Disagree means people were ambivalent or disliked living in their village or felt they had no future there.*	39	2
27. Is there anything else you'd like to say? Is there any message you'd like to convey to Washington/EPA (Environmental Protection Agency)	N.A.	N.A.
Total	**694**	**18**

B. Subsistence

1. Voices of the People

It may be different, the way we gather it nowadays, but it's the same end product. It's the same. F-69, 9/18/11

If you get out in these outlying villages, about 80-90% of what they eat is what they gather from their front yards. I was in Igiugig this spring. A can of SPAM… Do you know how much a can of SPAM is in Igiugig? Eight dollars for a can of SPAM! …There are fewer jobs, so subsistence is one of the main cultures and the driving force of the economy within a community. M-60, 9/16/11

Our fish is more important for them. I tell my kids and grandkids with fish they are very rich; without fish you are hungry. This is the important thing all over in Alaska for us. It is very hard out here in the bush. We have to pay double for every food we get, double to get our heating fuel, double for gas, and without gas, we cannot travel. It is very hard in a rural area. In a big city it is easy; you just grab everything from the store, department store. Out here we don't have grocery stores; our grocery store is very expensive. They give us prices that, if you buy one item, you pay for four. So it is very hard for us, but we grow our kids, and you ask us if it is important for us to have fish. We have to have fish every day because the fish is most important. F-48, 8/20/11

For two families we put up in jars 32 cases [of salmon]*....that doesn't include frozen stuff*. M-60, 9/16/11

We get them [smelt] *until freeze-up here. Then, when the river freezes up, people go up and fish through the ice for them with hooks. They seine them up in the lake, too, but you have to catch them at the right time.* M-62, 9/16/11

When that first salmon is caught, it is in the news. KDLG [Dillingham radio station]. *Everybody knows about it*. M-61, 9/16/11

And he still, to this day, goes to fish camp. He gets all excited about fish camp. He's down there getting his net ready, and he still, at 89 years old, still go out and sets his own net, picks his own net, and work on his own fish, because he knows, and he always tells us how important it is to save our fish and salmon for the winter months. F-32, 8/18/11

We would starve if we don't have fish or salmon. In this area we have lived with fish all our lives, from generation to generation. The people that stayed before us and kids that are behind us will be living on fish. Salmon is very important; all kind of.... Without fish we are very poor; we have no food to eat. With fish we are very rich; our stomach is full. That's the way I look at it. F-48, 8/20/11

Salmon is one thing. They make you feel rich because you have something to eat all winter. Smoked salmon, sun-dried spawned-out fish; all of those make you feel good, because you grew up with it, it is in your body. Any subsistence food; what you eat, like him and I [gestures]; *we ate it for a long time.* M-53, 8/20/11

Salmon is very important to us. I don't think we could live without fish…. I'm seventy-six years old, and I have never been without fish, since I was small. I don't know how I would feel without it. I think I used fish more than meat when I was growing up, because my Grandma raised me, and that's all she could get, was fish, because it's easier to get. She used to help people put up fish for us to have her share in the wintertime. Then she would put up salt fish for us to have in the winter, so we use it year round. F-27, 8/17/11

Minority View Subsistence

We couldn't live like our parents lived, because it doesn't exist anymore. I mean, we could fish and catch fish and stuff like that. You know, nowadays, you can't live on fish like you used to. You can't even get meat like you used to; you can't even go out hunting for moose or caribou. Nothing is here anymore; everything is disappearing. I know, you know [name] *could verify too. There used to be so much caribou, we would see them all over the road, all over the lake, everything.* F-44, 8/19/11

Like she was saying right now, even with subsistence, we can't live on that. We have to have money to pay for our bills, telephone, our lights, our heat and trash, our toys, water, and sewer. You have to pay so much a month for that. I myself will support any kind of entity that comes and bills for jobs. I don't think subsistence; we love subsistence, but I don't think it is going to last forever….We need money to pay our bills. That is why a lot of people are moving to Anchorage. M-44, 8/19/11

We can't just go out there and get money from nowhere. You know, subsistence is gone in this village [Iliamna] and in Iliamna. Subsistence, we can't live on subsistence anymore. We have car payments to pay, we have Honda payments to pay, and we have our snowmobile payments to pay. How on subsistence; how are you going to pay all of those bills? Some pay $500 a month

for car payments. How are you going to pay $500 a month on subsistence? You can't do that anymore; you have to live to make money nowadays for those young kids. M-49, 8/20/11

2. Introduction

In southwest Alaska subsistence is a fundamental non-monetized economic activity of the region and forms the basis of cultural life. Though the economy involves both cash and subsistence sectors, most of the food comes from subsistence activity as indicated in the ADF&G Division of Subsistence data reproduced below. Moreover, cultural and personal identity largely revolves around subsistence. This concept is expressed in a 1988 film by Brink and Brink where Dena'ina leader Fred Bismark highlighted the importance of subsistence when he said, "If they take subsistence away from us, they're taking our life away from us." Two decades later that remains true; Fall et al.(2009:2) wrote of the Nushagak and Kvichak drainages, "At the beginning of the 21st century, subsistence activities and values remain a cornerstone of area residents' way of life, a link to the traditions of the past, and one of their bases for survival and prosperity." Bismark's statement and Fall's analysis as well as interview generated "Voices of the People" at the beginning of this section illustrate the idea that subsistence is "life" and the foundation of culture for the Nushagak and Kvichak watershed villages. Everyone who responded to Question 1, Table 9 felt the loss of salmon would impact them negatively and subsistence based on salmon and other wild foods is the cultural foundation for the region. Four of the 53 interviewees felt subsistence was no longer tenable.

Subsistence is not a return to practices of earlier centuries but employs modern technology. Nylon nets have replaced spruce-root or sinew nets; aluminum skiffs and four-stroke motors have replaced kayaks or canoes; metal pots have replaced birch-bark or willow baskets;

modern clothing has replaced sewn hides and skins; and freezers have replaced underground cold storage pits. Moreover, subsistence activities follow management practices formulated by the ADF&G, dictating bag limits and seasons. The results of these interviews and ADF&G research cited below confirm that the diet is still largely based on wild foods caught and processed by the people who live in the area; values, such as respecting the salmon and not taking more than you need, among others, are still honored; and the identity of the people is shaped by the subsistence process, just as it was in the past.

As described in the Pre-Contact and History sections (II A & B).), indigenous people in the study area have been harvesting wild resources for at least 12,000 years and have intensively caught salmon for at least 4,000 years. This immense time depth has shaped all aspects of the culture, including social structure, political structure, and religion. Because Dena'ina and Yup'ik are the dominant populations in the study area, and because healthy wild salmon stocks and many other components of their traditional way of life still persist such as language, sharing wild foods and sharing beliefs related to nature, the area has a cultural continuum with the past that is rare in North America. In few places do the same wild foods as their ancestors ate dominate the diet and shape the culture as they do today in the Nushagak and Kvichak watersheds

3. Subsistence in Alaska

The importance of salmon and other wild food resources in the study area is tied to federal and state subsistence legislation. No other state in the United States so broadly grants a subsistence priority to wild foods to indigenous peoples as does Alaska. Both federal and state subsistence legislation apply to Alaska but they differ, and have resulted in two sets of legislation

because of an inherent conflict between federal and state legislation over indigenous rights vs. inherent rights.

Federal subsistence legislation began with the 1971 Alaska Native Claims Settlement Act (ANCSA), which extinguished aboriginal hunting and fishing rights and, in return, charged the Secretary of Interior and State of Alaska to "take any action necessary to protect the subsistence needs of Natives" (La Vine 2010:30-34). The federal subsistence intent of the 1971 ANCSA legislation was clarified in Title VIII of the 1980 Alaska National Interest Lands Conservation Act, (ANILCA). ANILCA recognized the cultural aspect of indigenous subsistence stating: "the opportunity for subsistence uses by rural residents of Alaska...is essential to Native physical, economic, traditional, *and cultural* existence and to non-Native physical, economic, traditional, and social existence (emphasis added)" (La Vine 2010:32). The language describing the importance of subsistence to Alaska Native and non-Native rural communities is the same with the only difference that "cultural" importance is included in Alaska Native subsistence users' list of essential rights while that term is not included in the non-Native list of essential rights. That language became the basis for federally recognized indigenous subsistence rights. Federal ANCSA and ANILCA legislation set up a legal conflict between indigenous rights and state law. The "Inherent Rights" clause in Article 1, Section 1 of the Alaska Constitution specifies equal treatment under the law for all Alaskans and makes no provision for indigenous rights. Consequently, subsistence became an important political issue in the early 1970s and remains so today (cf. AFN Federal Priorities, 2011, pp. 1-9).

The State has developed subsistence legislation within the context of the "Inherent Rights" clause cited above. As depicted in the 1988 documentary *Tubughna: The Beach People*

by Brink and Brink, in 1973 Governor William Eagan made a promise to Alaska Native people. Speaking at a meeting in Anchorage, Governor Eagan said:

> Let me assure you that the state's commitment to preserving subsistence capability in our fish and game resources is of the first priority and will continue to be. Continuing attention to the Native for maintaining subsistence capability is an integral part of the state's overall fish and game management program. It always has been, is now, and will be so in the future. (Brink and Brink 1988)

That promise was partially realized as law in the 1978 *State of Alaska Subsistence Act*, which provided for a Division of Subsistence within the ADF&G and defined subsistence as "customary and traditional use." The act also specified a subsistence priority in wild resource allocation over commercial or sport caught resources. The act did not limit subsistence to rural (largely Alaska Native) residents and did not recognize indigenous rights; to do so would have been unconstitutional in state law. The act also directed establishment of a Division of Subsistence within the Alaska Department of Fish and Game to "quantify the amount, nutritional value, and extent of dependence on food acquired through subsistence hunting and fishing" (AS 16-05.094) and has resulted in three decades of the most detailed subsistence data collected anywhere in the world, some of which is used in this report.

As a result of over forty years of legislation and adjudication revolving around the "Inherent Rights" issue among stakeholders, a dual management system has emerged. As summarized by La Vine (2010:34) the state now manages fish and game for subsistence purposes on state and private land including regional and village corporation land, while the federal government, through the U.S. Fish and Wildlife Service or cooperative agencies, manages fish and game in federally designated subsistence areas as determined by criteria applied and regularly reviewed by the Federal Subsistence Board. On state lands all citizens are eligible to

harvest fish and game for subsistence purposes but are bound by the customary and traditional use criteria. On rural federal lands only rural residents are eligible to practice subsistence. On non-rural lands subsistence is prohibited. Alaska Natives of the communities of the Kvichak and Nushagak drainage fit both the "customary and traditional" and "rural' criteria and have engaged in subsistence fishing and hunting throughout this time period and will continue to do so as long as they remain rural. Significant non-Alaska Native population increases constituting a shift from rural to urban would potentially change subsistence access as has happened, for example, on the Kenai Peninsula where the Dena'ina do not have full subsistence rights because the area is largely determined to be urban.

4. Scope of Subsistence

Table 10 is an indication of the importance of subsistence activities and salmon to the people of the Nushagak and Kvichak River systems. Essentially everyone in every village and town (98% or more of the households) uses wild food subsistence resources, and most (88% to 100% of households) use salmon.

Table 10. Use and Reciprocity of Subsistence Resources. Data from Fall et al. 2009, Krieg et al. 2009, Fall et al. 2005

Community	Year	All Wild Resources; % Households that:			Salmon' % Households that:		
		Used	Gave	Received	Used	Gave	Received
Dillingham	1984	98	62.7	88.2	88.2	34.6	43.8
Ekwok	1987	100	86.2	82.8	89.7	48.3	51.7
Igiugig	2005	100	100	100	100	83.3	83.3
Iliamna	2004	100	53.8	76.9	100	30.8	38.5
Kokhanok	2005	100	82.9	94.3	97.1	62.9	60
Koliganek	2005	100	92.9	89.3	100	60.7	53.6
Levelock	2005	100	85.7	92.9	92.9	35.7	78.6
Newhalen	2004	100	80	96	100	64	32
New Stuyahok	2005	100	73.5	98	89.8	55.1	63.3
Nondalton	2004	100	92.1	97.4	92.1	55.3	63.2
Pedro Bay	2004	100	88.9	100	100	72.2	77.8
Port Alsworth	2004	100	72.7	90.9	100	45.5	54.5

(Recent data collected by Steve Braun and Associates funded by Pebble Limited Partnership for Environmental Impact Statement assessment includes more recent data not available as of this draft.)

The data of Table 10 also indicates reciprocal sharing of wild foods is a fundamental aspect of subsistence culture in the study area. In most villages almost 100% use wild food resources and more than 80% of households receive shared subsistence food resources of some kind. Sharing of salmon is lower than for all resources probably because, typically, extended family units work together at subsistence fish camps (Fall et al. 2010) and the fish they collectively harvest is not considered to be "shared" as much as "earned" among contributing extended family members. Further research could clarify the matter. Sharing is further discussed in Social Relations section (III. E.3). Table 11 presents subsistence resource data on a per capita basis.

Table 11. Per-Capita Harvest of Subsistence Resources. Data from Data from Fall et al. 2009, Krieg et al. 2009, Fall et al. 2005

Community	Year	Total Harvest Pounds	Estimated Per-Capita Harvest in Pounds						
			All Resources	Salmon	Non-salmon Fish	Land Mammals	Marine Mammals	Freshwater Seals	Beluga
Dillingham	1984	494,486	242	141.4	17.5	65.9	2.97	1.7	0
Ekwok	1987	85,260	797	456.2	68.6	249.2	0	0	0
Igiugig	2005	22,310	542	205.2	59.4	207.8	29.2	7.4	21.9
Iliamna	2004	34,160	469	370.1	34.1	32.7	6.5	6.5	0
Kokhanok	2005	107,645	680	512.8	36.3	95.9	1.7	1.7	0
Koliganek	2005	134,779	899	564.7	90.4	186.2	0	0	0
Levelock	2005	17,871	527	151.8	39.9	257.4	37.7	4.5	33.2
Newhalen	2004	86,607	692	502.2	31.8	104.5	4.4	4.4	0
New Stuyahok	2005	163,927	389	188.3	28.0	143.4	0	0	0
Nondalton	2004	58,686	358	219.4	33.9	81.8	0	0	0
Pedro Bay	2004	21,026	306	250.3	15.3	30	0	0	0
Port Alsworth	2004	14,489	133	89.0	12.0	24.7	0	0	0

(Recent data collected by Steve Braun and Associates funded by Pebble Limited Partnership for Environmental Impact Statement assessment includes more recent data not available as of this draft.)

Table 11 presents the range of some of the important subsistence resources used in the region and their relative importance to each village on a per-capita basis. This data does not include vegetation foods, birds/eggs, and marine invertebrates which are seasonally important, nor does it include salmon retained from commercial fishing. While all subsistence foods are important— particularly for the physical and emotional benefits derived from a varied diet— salmon is, by far, the most important subsistence food ranging up to 82% of the subsistence diet. Land mammals, including moose and caribou among other species, are the second most important form of subsistence food for most villages. Many villagers but particularly Iliamna,

Newhalen and Nondalton interviewees indicated that in recent years they are experiencing reduced subsistence returns of caribou. They feel the Mulchatna herd is declining or moving out, possibly due to overhunting from guided trips or seismic blasting and helicopter traffic from mining exploration.

Non-salmon fish (northern pike, Dolly Varden/char, various whitefish, trout, etc.) constitute a third important type of subsistence resource. Subsistence use of marine mammals includes beluga whales, which regularly move up the Kvichak River, and freshwater harbor seals, a unique freshwater population that lives year-round in Iliamna Lake. These are significant subsistence resources for the Kvichak River villages of Igiugig and Levelock.

The data indicates as much as 899 pounds of dressed meat is harvested per-capita (Koliganek) and an average of 503 pounds of meat per-capita is harvested per village. According to the U.S. Department of Agriculture's "Agriculture Factbook," in 2000 Americans consumed an average of 277 pounds of meat per year per-capita (USDA Factbook). The difference, of course, is the subsistence data presented here is pounds per-capita harvested, not pounds per-capita consumed. A substantial amount of subsistence-harvested food is shared which partially accounts for such high numbers of per-capita harvest. The numbers are high, however, because the people eat a lot of wild food and subsistence foods are the staple of the culture.

Table 12 Per-Capita Harvest of Salmon Resources. Data from Data from Fall et al. 2009, Krieg et al. 2009, Fall et al. 2005

Community	Year	Total Harvest, Pounds	Per-Capita Subsistence Harvest in Pounds				
			All Wild Resources	All Salmon	King (Chinook)	Red (Sockeye)	Non-Salmon
Dillingham	1984	494,486	242.2	141.4	52.8	38.5	17.5
Ekwok	1987	85,260	796.6	456.2	178.2	160.3	68.6
Igiugig	2005	22,310	542	205.2	5.4	168.0	59.4
Iliamna	2004	34,160	469.4	370.1	0	369.8	34.1
Kokhanok	2005	107,645	679.6	512.8	3.2	480.4	36.3
Koliganek	2005	134,779	898.5	564.7	193.9	192.5	90.4
Levelock	2005	17,871	526.7	151.8	43.1	85.9	39.9
Newhalen	2004	86,607	691.5	502.2	10.1	487.6	31.8
New Stuyahok	2005	163,927	389.2	188.3	112.6	36.3	28.0
Nondalton	2004	58,686	357.7	219.4	0.4	218.9	33.9
Pedro Bay	2004	21,026	305.5	250.3	0	250.2	15.3
Port Alsworth	2004	14,489	132.8	89.0	0.7	87.6	12.0

(Recent study by Steve Braun and Associates funded by Pebble Limited Partnership for Environmental Impact Statement assessment includes more recent data not available as of this draft.)

Table 12 breaks down the subsistence harvest of salmon by species. King or Chinook salmon spawn in the Nushagak River but not normally in the Kvichak River and consequently are not harvested in the Newhalen River system. Today, interviewees report most king salmon are fished in camps on the Nushagak River located at Lewis Point near the mouth of the river. Salmon are also taken near the villages (see Section II.B.3). Sockeye, or red, salmon constitute

the most important subsistence salmon species in the villages of the Kvichak and Newhalen River drainages and are also taken in significant numbers in the Nushagak River drainage.

5. The Seasonal Subsistence Round

As illustrated in Figure 5, the villages in the Nushagak and Kvichak River drainages have a seasonal subsistence round that involves harvesting wild resources at an optimal time throughout the year. Evanoff (2010:66) and Fall et al. (2010) have described the seasonal round for the Kvichak drainage Dena'ina and it is summarized as follows. In the spring, with the return of ducks, geese, and other waterfowl, small groups travel to hunting or egg gathering areas. In addition, villagers also gather early spring plants, such as fiddlehead ferns. In late May and early June, villagers begin harvesting salmon returning to spawn. Some families net salmon near their villages while others travel to fish camp. Subsistence salmon activities occur throughout the summer although many also engage in commercial fishing in Bristol Bay, depleting the fish camp personnel but providing cash to support subsistence activities. Late summer and fall subsistence activities involve berry and plant gathering. In late fall or early winter villagers engage in caribou and/or moose hunting depending on the ADF&G-determined hunting seasons for the specific area. Winter subsistence activities revolve around ice fishing for whitefish and other freshwater species, ptarmigan hunting, wood harvesting to supplement home heating and for steam baths, and trapping of furbearers.

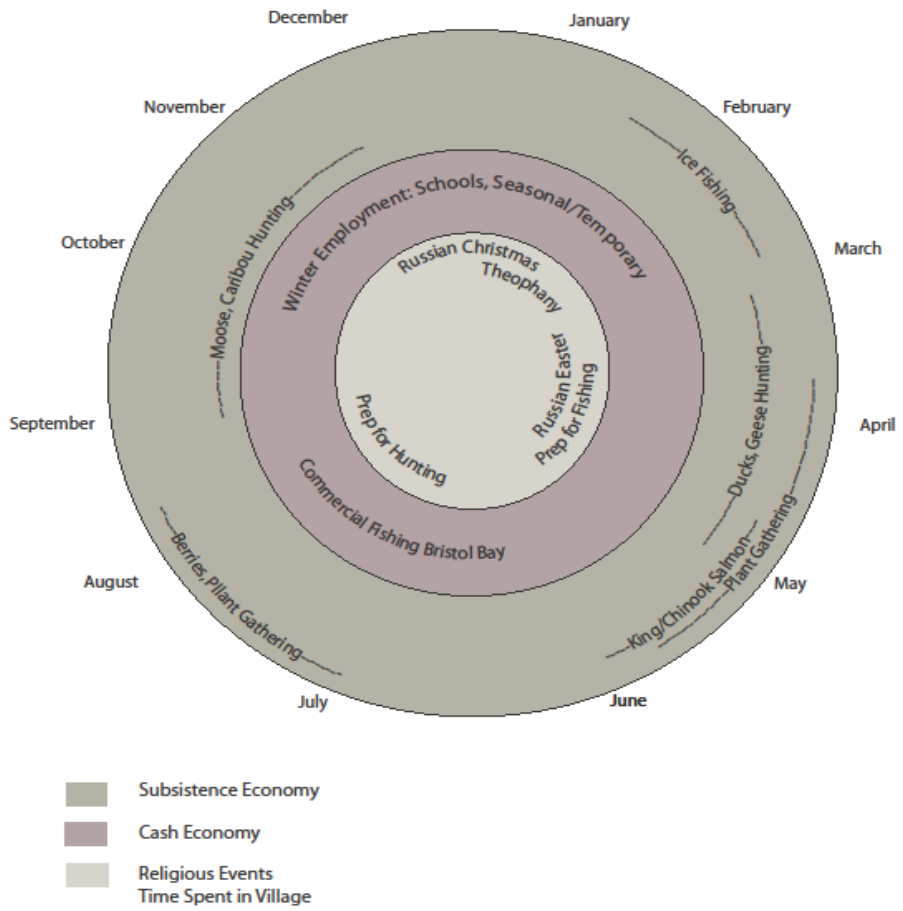

Figure 5. Significant Aspects of the Subsistence Seasonal Round. Modified from Evanoff (2010:66).

6. <u>The Interplay of Subsistence and Wage Income</u>

Interviewees indicate that, for those fully engaged in it, subsistence is a full-time job, but it is necessary to supplement subsistence with cash from part-time wage labor or commercial fishing, to defray the costs of subsistence activities. With gasoline costs presently in the $6 per gallon range (summer 2011), trips to fish camps and other subsistence areas are expensive.

Guns, ammunition, fishing gear, and modern winter clothing, among other expenses, also add to the subsistence investment. While conducting village interviews, researchers observed that besides having a skiff and motor powerful enough to navigate rivers like the Nushagak, Mulchatna, Newhalen, and Kvichak, most families must also rely on one or more all-terrain vehicles (ATVs) and snowmachines for subsistence, all of which require considerable initial investment and maintenance costs. Rather than being recreational vehicles, these means of transport have become necessary for the longer travel distances required for modern subsistence. During the nineteenth century, dog teams, canoes, kayaks, and foot power via snowshoes or hiking were the primary means of transportation, and people, by necessity, lived in small villages located close to subsistence resources. In contrast, the twentieth-century establishment of trading posts/stores, schools, churches, and health services led to residents consolidating in fewer, larger villages. For example, today, there are only three interior villages on the Nushagak River whereas, in the mid- to late nineteenth century, there were eight (VanStone, 1967:114-115). The result of the consolidation is that village residents must now travel farther to obtain subsistence resources, requiring mechanized transportation to do so, and there is overlap among the range of village subsistence activities.

Interviewees indicate that to deal with these costs, many families report holding commercial fishing permits and fish the sockeye run in Bristol Bay during late June and into mid-July or engage in other forms of part time employment. Besides providing needed cash, these forms of employment, with their short duration and/or seasonal nature, are ideally suited to provide another ingredient critical to a subsistence lifestyle, time to engage in subsistence activities. Thomas Lonner indicates that in Bristol Bay villages cash is obtained from wage

employment such as working in the commercial fishery (also corporate dividends from membership in Alaska Native Corporations and social welfare payments) and states "wage employment is intended to underwrite subsistence equipment; the time, energy, and opportunity cost in wage employment may be seen as an investment in subsistence" (Lonner cited in Lowe 2007:40). Table 13 is the number of 2010 Bristol Bay Fishing permit holders and crew member licenses for the study area villages reflecting the major source of cash to support subsistence activity.

Table 13. Commercial Fishing Permit and Crew Member Licenses

	Commercial Permit Holders, 2010	Commercial Crew Member Licenses, 2010	Subsistence Permits, 2007
Dillingham	227	272	n.d
Ekwok	3	5	n.d
Igiugig	4	4	6
Iliamna	15	26	54*
Kokhanok	9	19	29
Koliganek	18	25	n.d
Levelock	6	10	1
Newhalen	11	1	n.d
New Stuyahok	24	43	n.d
Nondalton	6	6	29
Pedro Bay	3	0	19
Port Alsworth	2	4	30

2010 Data from ADF&G Commercial Fisheries Entry Commission. http://www.adfg.alaska.gov/index.cfm?adfg=fishingcommercial.main

2007 Data from Fall et al. , 2009, page 19

- * Combined data for Iliamna and Newhalen

Figure 6. Subsistence Skiffs, Nushagak River, New Stuyahok. May, 2011

7. Subsistence as an Economic Sector

Labor statistics do not identify subsistence as an employment category because it is not based on wage-labor or a salary and, hence, people engaged in subsistence are considered "unemployed." However, those who choose the subsistence lifestyle work long hours, utilizing considerable skill to provide food for themselves and their families and in interviews described subsistence as a full-time occupation.

The official unemployment rate in the study area ranges from zero (Igiugig, Iliamna, Pedro Bay and Port Alsworth) to 31.1% (Koliganek). The weighted average is 10.9%; compares to 8.0% for Alaska and 9.6% for the U.S. (http://www.census.gov/compendia/statab/2012/tables/12x0629.pdf). The unemployment rate includes only people actively seeking wage-based employment and does not include villagers for whom subsistence is their non-wage employment. The percentage of working-age population "not in labor force" (http://www.bls.gov/cps/cps_htgm.htm#nilf) may better reflect

how many people might seek employment should subsistence salmon/other resources no longer be available.

Based on 2010 U.S. Census Data, 4.0% (Port Alsworth) to 44.5% (Nondalton) of the residents in the study area communities have wage incomes below the poverty level. The weighted average for all communities (excluding Pedro Bay) is 17.1%. These rates compare to a 9.1% rate for Alaska and a 15.1% for the U.S. (DeNavas-Walt et al. 2011:14). These numbers are high but do not reflect the role of wages in a subsistence economy: wage income which for many is not considered the primary source of sustenance but functions to support non-wage subsistence activities. Neither do the statistics consider the non-monetized value of subsistence foods to the economies of the villages.

Subsistence is dictated by the seasons, is time-consuming and must be understood differently from recreational fishing or hunting. It is not critical if a recreational fisher or hunter misses a season due to work obligations or other demands, but, for many Bristol Bay village residents, subsistence is one's work obligation and employment in the cash economy impinges on the time that is necessary to obtain and process food for a family for a year.

Thornton (1998) writing in the on-line edition of *Cultural Survival Quarterly,* considered Alaska subsistence to be the leading employment sector of rural Alaska because of the number of people engaged in subsistence and the economic benefits derived from harvesting one's own food Several attempts have been made to measure subsistence economically by monetizing wild food resources. Fall et al. (2009:3) measured the economic importance of subsistence by calculating the cost of replacing wild foods obtained from hunting, fishing, and gathering with similar foods obtained in a market. Their published data indicates the average annual per-capita

harvest of wild foods in the villages of the Nushagak and Kvichak River drainages is 304 pounds of salmon, 123 pounds of land mammals (mostly moose and caribou), 39 pounds of other fish, 23 pounds of plants and fungi (mostly berries), 9 pounds of marine mammals (freshwater seals and beluga whales), 8 pounds of birds and eggs, and one pound of marine invertebrates (mostly clams). To supplement their subsistence harvest, households in the Nushagak and Kvichak River drainages spend 15 to 26% of their annual cash income on store-bought food (Fall et al., 2009:3). In the ten villages for which there is recent data (i.e., excluding Dillingham and Ekwok), the annual per-capita cost of purchasing food ranged from $1,467 to $2,622. At 2004 prices (when the initial analysis was done), the annual replacement cost for the average subsistence harvest described above would be an additional $7,000 per capita, which would increase the demands on the annual cash income an average of nearly 80% ranging from 23% for Port Alsworth to 157% for Koliganek. As high as they are, the estimate may be an under-representation of the estimated worth of subsistence resources. With rising food prices, the replacement value would be significantly higher today. King salmon fillets, for example were $17/pound on December 30, 2010 at 10th and M Seafoods, Anchorage, Alaska. The replacement value of 193 pounds of king salmon alone for Koliganek, for example, would be $3281 per-capita.

While monetizing subsistence gives a measure of its importance to the economy, these values do not reflect the fact that the people of the region unanimously reject replacing their traditional subsistence foods with farmed fish or other imported products, should deterioration of wild salmon runs occur (Interviews). This is based on the belief that such products are of

inferior quality and that doing so would result in cultural degradation. See Section III.C.6 for a discussion of the importance of wild salmon from one's home river.

Figure 7. Salmon Drying. Koliganek. September 17, 2011

8. Subsistence and "Wealth"

In Alaska many non-Native people perceive subsistence as an activity for impoverished, unemployed rural people who live in employment-poor communities and cannot afford to buy food so they have to hunt and fish for it. Thornton (1998) asserts that this perception relates to the "minimum food and shelter necessary to support life" dictionary definition of subsistence and has given rise to the "subsistence-as-welfare" concept and associated negative implications. The Yup'ik and Dena'ina perceive subsistence quite differently. Interviewees spoke of the cultural value of subsistence as a chosen lifestyle. As indicated in the 2011 interviews, subsistence is a

lifestyle chosen by both old and young. Subsistence is a job, in which the wages are healthy wild foods and the benefits include not only vigorous outdoor activity shared with friends and family, but also a large measure of self-determination supported by a community of like-minded people. Subsistence is coterminous with culture, and the entire range of social and spiritual activities that "culture" implies. Consistently, the Yup'ik and Dena'ina communities of the Nushagak and Kvichak River drainages define a "wealthy person" as one with food in the freezer and the freedom to pursue a subsistence way of life in the manner of their ancestors (see Social Relations).Their ability to continue their reliance on subsistence and their concept of wealth has contributed to the maintenance of vital and viable cultures for the last 4000 years.

C. Physical and Mental Well-being: the Role of Subsistence

1. Voices of the People

We crave it [salmon] *when we don't have it. We just need it.* F-30, 8/17/11

You know, it's got that one oil in it that is a cancer-fighting oil, and it's really good. F-38, 8/18/11

I think it [salmon] *is healthier than probably beef or pork or something like that.* M-68, 9/18/11

Yes, to be healthy, like I say, if we don't eat fish we won't have anything to eat. That is our health. F-48, 8/20/11

When you are eating fish…you get a drink of water to flush yourself out. If you don't eat fish, you will starve. You got to flush yourself out with water every day; that is what your health is about. God put us on this earth to eat fish every day. That's what it is. Without fish, like I said, we are hungry; with fish we are full. F-48, 8/20/11

We have…to live healthy to be free from diseases if we eat healthy food. Not breathe air that's no good or drink water that is no good; it will affect your whole body. So, on the subsistence, I say let's protect Mother Earth; I demand it. If we don't protect Mother Earth, we are gone. M-51, 8/20/11

We don't buy meat very much. Salmon is our most important dish. F-27, 8/17/11

Salmon is a really an important part of our diet. I think it has things that meat [domestic beef for example] does not have. You are always hearing things about fish oils and how healthy [they are]*, but we already have that, so we must be healthy.* F-34, 8/18/11

We can't live without salmon. We'll be missing something. F-27, 8/17/11

Well, we grew up with it. We need it. If we don't have it, we miss it. I can't see anybody that lives around here without it. F-30, 8/17/11c.

I've seen kids teethe on smoked salmon strips. They're hard. They get all fishy and smelly, but man, they just chew. It's better than the rubber toy. F-38, 8/18/11

…[salmon] *is one of our healthiest foods we can give to our child…. It is really healthy.* F-69, 9/18/11

To me, I think eating salmon has sustained our ways of life. I think by eating a lot of salmon, we are a healthy, healthy Dena'ina. I always tell children there at potlaches or wherever; I say that, "If you eat this piece of fish you're going to be a smart Dena'ina woman, you might be able to be a lawyer or a doctor." It's surprising that, just by telling them that, they…eat it, and they will say, "Oh, taste good." F-32, 8/18/11

When my kids grew up, I mostly gave them fish and moose meat. F-44, 8/19/11

I definitely limit my child; you know, the fast foods, we eat it once a week, sometimes more… [They eat] *moose meat, the fish…berries, and wild plants as well… We want to give to our children the fish and we want to keep the water clean for them. It was a gift to us from our ancestors, which will then be given to our children*. F-69, 9/18/11

The school system here does get volunteers who donate fish to the schools. Prior to that they used to order cod fish and other fish from out of the area. The kids didn't like it. Not from here. They finally started the donation program, and the fishermen stepped up to the plate and said, "Yes, definitely." The crew members didn't balk. There were no qualms whatsoever about donating fish to the schools. M-61-9/16/11

It is the best hot lunch program we have; the kids just love it when they have salmon day. M-60, 9/16/11

Yes, and that it is healthy [wild salmon]*…and something they* [Yup'ik] *wouldn't have without …. But if we ever lose it, then we won't have anything at all.* M-68, 9/18/11

I think it would matter [that the salmon be wild]*; that would be our concern. We like to take our wild natural renewable resource salmon rather than farmed salmon because you never know what they've* [farmed salmon] *been eating.* M-26, 5/19/11

Wild salmon is more important for us, or wild fish. I don't believe in farmed fish, because wild fish is better for all our health. It has all natural oil, and we don't paint it with artificial paint

like the farmed fish you get. You can sell your farmed fish all you want, but wild salmon is more important to us. F-48, 8/20/11

…people from Kenai or Anchorage, they can go to Kenai and get their salmon, but they always say there's nothing like the lake salmon. There's nothing like salmon that comes from Sixmile Lake. We hear that all over…. I always try other people's fish, but there's nothing like salmon from our own stream, salmon from the lake that comes up. Well, I guess we're spoiled having our own. F-32, 8/18/11

There is nothing better than wild salmon…I have talked to many people all over the state, and the best salmon comes from this area, Bristol Bay. M-29, 8/17/11

One year we got a farmed salmon…. What a difference! It came in with the usual run, and it was salmon that was raised in the University of Washington [salmon farm]. *They have a big place out there in Seattle. We went in there, and they had a lot of fish. The meat was soft, and the skin was not firm and scaly. I remember, my daughter was cleaning salmon that year, and she said, "Where'd this fish come from? It looks like a salmon, but it's terrible." It was soft. It wasn't like a wild salmon.* F-38, 8/18/11

Matter of fact…I had [salmon] for breakfast this morning before I come over. They stay inside all day. M-53-8/20/11

In the summertime it is every day [we eat fish], as long as the fish are running. We eat fish every way we could: boiled, baked, fried. Every way we could, we eat fish. In the wintertime, what we preserve in the summertime is what we eat in the wintertime, like the dried fish, the canned fish. The fresh canned is something we eat a lot, because you can do so many different things with it. F-35, 8/18/2011

2. Introduction

As described in Section II.A.3., archaeological evidence indicates that salmon were an important component of the diet of the probable genetic ancestors of the Yup'ik and Dena'ina, who left evidence of their presence in this region up to 4,000 years ago. These genetic ancestors of the present day Yup'ik had an important component of salmon in their diet as long as 4000 years ago, according to the archaeological record (see Section II.B.3). The Dena'ina track back

to the Paleo-Arctic tradition, as old as 10,000 years ago, although evidence for intensive salmon utilization in Dena'ina territory does not occur until A.D. 1000.

Based on studies of other Yup'ik populations in the nearby Kuskokwim River villages, there is a strong possibility that, within their long history, the Yup'ik may have become genetically adapted to eating salmon. Several recent studies have shown that physical adaptation and evolution based on dietary factors (e.g., lactose intolerance) can occur in 3,000 years or less (Tishkoff, et al., 2007; Bersaglieri et al., 2004: Hollox et al., 2001). Other studies are demonstrating genetic changes at the population level in humans in a similarly short time frame based on adaptation to environmental stressors such as living at high altitudes in Tibet (Peng et al., 2010 :1075-1081; Xin et al., 2010: 75; Simonsen et al., 2010: 72-74).

The National Science Foundation recently funded a University of Alaska study to assess the differences between Yup'ik and other populations in drug metabolism, as well as in vulnerability to metabolic syndrome (development of risk factors for coronary disease, stroke, and diabetes). This study will consider the relevance of dietary differences and resulting long-term physical adaptation, including genetic adaptation. In a separate study, researchers from the Center for Alaska Native Health Research (CANHR) are assessing how a subsistence diet affects the vulnerability of Yup'ik people to disease (O'Brien et al., 2011). In a 2009 study whose results strongly support the validity of red blood cell deltaN as a biomarker of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA); the researchers state, "the omega-3 (n-3) fatty acids derived from fish, eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3) are associated with a reduced risk of cardiovascular disease and other chronic diseases (O'Brien et al, 2009:913).

While the amounts of salmon and other fish consumed varies from village to village, and from one season to the next, the demonstrated importance of these foods in the diet is consistent with the traditional knowledge shared by Yup'ik Elders and culture bearers, as presented above. As discussed below, the salmon-dependent diet of the Yup'ik and Dena'ina benefits their physical and mental well-being in multiple ways, as well as encouraging high levels of fitness based on practices involved in subsistence activities.

3. Nutrition

The dietary habits of Yup'ik and Dena'ina living in the villages of the Bristol Bay region shows regular dependence on several species of wild salmon which they sometimes consume several times a day as the interviews attest. Yup'ik and Dena'ina primarily prepare and eat two species of Pacific wild salmon, Coho (red) and Chinook (king) in different ways, including fresh, salted, pickled, canned, dried, and smoked. Salmon and other traditional wild foods comprise a large part of the villagers' daily diet throughout their lives, beginning as soon as they are old enough to eat solid food (Interviews, 2011).

In addition to salmon, villagers also regularly consume other wild fish species, such as humpback whitefish, Arctic char/Dolly Varden, Arctic grayling, rainbow trout, and northern pike, the wild ungulates caribou and moose, and, to a smaller extent other mammals, birds, and bird eggs. Wild plants, including blueberries, crowberries, salmonberries, ferns, and other species, add fiber, vitamins, and minerals (Interviews).The Yup'ik and Dena'ina continue to harvest certain plants with medicinal values (cf. P. Kari 1995). It is important to recognize that in addition to providing a wide range of valuable nutrients and protein sources, the subsistence diet provides a year round workable harvest schedule with adequate time for preparation and storage.

While subsistence technologies have changed and are now supported in part by the cash economy that commercial fishing provides, enabling purchases of snow machines, rifles and other equipment, the basic subsistence seasonal schedule has been approximately the same for hundreds and probably thousands of years. The implications for population sustainability within the environment, and co-evolution of the human population with environmental food availability mean that hypotheses about the risks of significant changes to the salmon population are important, and change in dependence on local wild salmon could have far-reaching impacts on Yup'ik and Dena'ina physical and psychological health, including at the genetic level.

Villagers in the study area also eat store-bought foods, but do not prefer them (Interviews 2011). Like other northern subsistence cultures, the Yup'ik and Dena'ina consider their traditional foods to be healthful and satisfying, in addition to providing strength, warmth, and energy in ways that store-bought food does not (Hopkins, 2007:42-50). Hopkins' study on health and aging also provides an insight into women's views of the importance of the subsistence diet. Eating subsistence foods was an overwhelming theme among all participants.. They generally viewed market or *kass'aq* (white person) food as unhealthful (Hopkins, 2007:46). Hopkins quotes one of the participants, describing the importance of the subsistence diet for Elders: "In years back, before I was born, I know there were elders that were very healthy and strong because they have their food, their native food, not mixed up with the *kass'aq* food. Although they have a hard life, they were healthy, strong, because of their native food. Seal oil, dried fish" (Hopkins 2007:46-50).

4. <u>Fitness</u>

Yup'ik and Dena'ina dependence on subsistence foods has the additional health benefit of providing opportunities and incentive for physical fitness, since engaging in subsistence harvesting improves fitness and fitness, in turn, enhances the efficiency of subsistence harvesting. Subsistence hunting, fishing, and gathering demands stamina to endure long periods of physical activity and strength to handle meat, large quantities of fish and heavy fishing gear . Hopkins (2007:45-46) quotes from the response of one study participant, over sixty years of age: "I think today most of the women are healthy for activity, physical activities. When they go berry picking, they're working using their bodies everything. When we are cutting fish, we are using everything, our muscles, lifting things."

The fitness needed for and resulting from subsistence is part of other aspects of village life, as well. Throughout the winter the Yup'ik villagers, from youth to middle-aged, play basketball and other sports regularly competing in vigorous games. Researchers watched in New Stuyahok as a team of middle-aged men defeated a youth team in an intense, hour-and-a-half game, then went to church services for an hour and returned to play another game of equal length. In several Yup'ik villages, including New Stuyahok, the physical activity of traditional dancing, is making a comeback. As described in Section III.E., this cultural activity is based on dance as story-telling, which both values and elaborates on traditional cultural practices, such as fishing.

While in New Stuyahok, researchers observed that Elders, including the oldest present, at around age 86, frequently walked to locations within the village. According to Hopkins, walking was the primary physical exercise identified in that study's interviews. "The participants referred to walking as an important component of health, both physical health and mental well-being.

Walking is believed to keep the body strong, promote energy, and is a basic physical activity in gathering subsistence foods" (Hopkins 2007:46).

The apparent overall fitness of the village population in New Stuyahok gave researchers present at the Elders' Conference the impression of frequent exercise, and led to the hypothesis that the practices of subsistence food gathering, in addition to the food itself, create higher levels of fitness, and act to prevent and reduce health risks from more sedentary lifestyles. For Alaska Natives, as for other Native Americans, the high risk of diabetes and subsequent health consequences is serious enough to make the hypothesis an important one to test.

5. Disease Prevention

Beyond the Yup'iks' own personal conceptions and cultural knowledge about the importance of wild foods in their diets, many studies also confirm the remarkable health benefits of omega-3 fatty acids and the other nutrients found in high percentages in subsistence foods such as wild salmon, and the combination of salmon, wild greens, blueberries and other berries for preventive health among the Yup'ik. These studies particularly underscore the importance of salmon-rich diets for the prevention of maladies, including cardiovascular diseases and type 2 diabetes. O'Brian et al. (2009:913; see also O'Brian et al 2011; O'Harra 2011), for example, concluded that "the omega-3… fatty acids derived from fish…are associated with a reduced risk of cardiovascular disease and other chronic diseases."

In a cohort study of Yup'ik from the Yukon-Kuskokwim area (Boyer et al., 2007:2535-2540), the Center for Alaska Native Health Research (CANHR) found that metabolic syndrome is uncommon in that population relative to others, occurring at a prevalence of 14.7% in the

study population, compared to 23.9% in the general U.S. adult population. The study population also had significantly higher high-density lipoprotein (HDL) cholesterol levels and lower triglyceride levels than the general U.S. adult population.

In another related study of the same population, the Fred Hutchinson Cancer Research Center, in collaboration with the CANHR, found that Yup'ik Eskimos consume 20 times more omega-3 fatty acids from fish than the average American and display a much lower risk of obesity-related disease despite having similar rates of being overweight and obesity (Makhoul et al., 2011; Fred Hutchinson Cancer Research Center, 2011). Lead author, Zeina Makhoul, said:

> Because Yup'ik Eskimos have a traditional diet that includes large amounts of fatty fish and have a prevalence of overweight or obesity that is similar to that of the general U.S. population, this offered a unique opportunity to study whether omega-3 fats change the association between obesity and chronic disease risk…. It appeared that high intakes of omega-3-rich seafood protected Yup'ik Eskimos from some of the harmful effects of obesity…. While genetic, lifestyle, and dietary factors may account for this difference, it is reasonable to ask, based on our findings, whether the lower prevalence of diabetes in this population might be attributed, at least in part, to their high consumption of omega 3-rich fish (Makhoul quoted in Woodward 2011).

Compounds derived from their subsistence diet, including omega-3 fats from wild salmon consumption, may also benefit mental health in Yup'ik populations. Lesperance et al. (2010), for instance, report that omega-3 fats can help prevent depression. Another study showed greater improvement in symptoms for patients with chronic depression who consumed omega-3 fats with their medication compared to those receiving only a placebo with their medication. After four weeks significantly reduced symptoms of depression occurred in six of ten patients

receiving E-EPA while reduced symptioms only occurred in one of ten receiving a placebo (Nemets et al. 2006).

Other subsistence foods, such as wild greens have nutritional elements associated with better mental health, including folic acid and Vitamins A and C. Other factors associated with a subsistence lifestyle, including time spent outdoors and the physical fitness resulting from subsistence activities, may also benefit mental health. It is interesting to note that several Elder interviewees (Interviews 2011) said that, 20 years ago, no one in their villages knew anything about Alzheimer's disease; it was not an illness they had seen before, but it is appearing now.

6. Local Wild Fish

The Yup'ik population of Bristol Bay Region has an interdependent relationship both ecologically and nutritionally, and possibly evolutionarily, with the local wild salmon populations. It is clear that the benefits, and particularly the long term fit between the human and fish populations, depends upon maintaining the local wild salmon for subsistence fishing. While it would be easy to assume that any salmon would provide a similar quantity and quality of omega-3 fats, a Norwegian study showed that farmed salmon, fed a typical farmed salmon diet, did not have the omega-3 fats in beneficial quantities, in contrast to the wild salmon which did (Sincan, 2011).

It is important to underline that if a human population has adapted to particular environmental dietary elements with a genetic modification in their population, that modification is based on a relationship to the genetics of specific regional species, and subspecies. The fit between environment and population may not be transferable to other places.

Thus the elements of the subsistence diet, in particular wild salmon, provide several substantial health and fitness benefits to the Yup'ik of the Bristol Bay region. According to recent studies at CANHR led by Andrea Bersamin, "Diets emphasizing traditional Alaskan Native foods were associated with a fatty acid profile promoting greater cardiovascular health than diets emphasizing Western foods" (Bersamin et al., 2007: 266; see also Bersamin et al. 2008). The loss of the local wild salmon as a large component of the Yup'ik diet would result in risks to the physical and psychological health of the population, including greater risks of cardiovascular disease, type II diabetes, and depression.

D. Traditional Ecological Knowledge

1. Voices of the People

But, I think, when they're spawning, that's where they hit the spring waters, where it doesn't freeze. It's always open, even in the dead of the winter. It's always open; you got to be careful there. Especially up in Lake Clark, around Kijik. It's, man, 30 below zero, and it's still open water. M-29, 8/17/11

Our societies are not different than other societies we have special people that know fishing inside and out, we have people in our society that know weather inside out, that know plants inside out, and that know animals inside out. M-61, 9/16/11

…they drop last year's fish in the middle of the river and we do the same thing here. We put king salmon remains on a string tied to a rock and go out with a boat to the middle of the river and let it sink. That makes king salmon go on both sides [near the banks where they can be netted with set nets.] M-26, 5/19/11

When the fish first come up here we don't put our nets out here before a bunch of them go by for the people who live at the end of the river up in Nondalton and all those guys. They start calling up then maybe middle of July [to tell us they have fish, and then] we start putting our nets out. We just kind of watch the salmon go by for the people who live upstream from us. M-54, 8/20/11

They [the fish] are like us, when we want to know something we ask. The fish are the same way. As we were talking about earlier he mentioned that the fish have souls. Every living creature has a soul. All the animals have souls. They are sensitive, very sensitive. If you put something bad in the water the fish will sense it. They will probably not go up the river, they will go somewhere else. If they spawn here and they notice something different they will move to another spot. The fish are very sensitive. M-20, 5/18/11

What they used to say, was the first time, when they first moved down to fish camps, then this wild celery, I don't know if you know what that is, but we eat those. They go up on the mountainside and pick lots of that, and then they peel it, they peel the peelings off and we eat the inside part. So we have big parties with that. We just really enjoyed the fresh salads that we just had. it was already tall enough to eat. So when we get done with that, then the Elders would tell us, take all the leaves and the skin and everything off of this plant, take it out in the river and throw it in, and they would do that. Then we started asking why we were doing this. This fresh salad plant and the skin will meet with the salmon, and let the salmon know that they are already good to eat, and they need to hurry up and come up because we are hungry. F-28, 8/17/2011

In the winter not only salmon, we do a lot of ice fishing, and my uncle you met this morning [a man in his 90s]*, he has a trout net he puts out.* F-35, 8/18/2011

2. Introduction

Anthropologists and other scientists have used different terms to describe the knowledge of indigenous peoples, including "cultural knowledge," "indigenous knowledge," "traditional knowledge," and "local knowledge" (Berkes 1999:8). Fikret Berkes and others working in this area of ethnoscience use the term, "traditional ecological knowledge" or TEK. Berkes defines TEK as "a cumulative body of knowledge, practice and belief evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes 1999:8). TEK, as Berkes describes it, includes spirituality and social relations, as well as a wide range of cultural beliefs and behaviors related to surviving in a particular landscape, because of the holistic nature of culture itself.

Early studies of TEK depended on comparisons between taxonomies and species lists drawn up by Western scientists and those created by indigenous peoples (Knott, 1998). More recently, however, it has become clear to anthropologists, geographers, biologists, and others working with indigenous peoples that their knowledge is far more ecological in scope and requires more than species lists to document. Therefore, a number of scientists working with indigenous peoples have come up with a diverse range of tools to collect and document indigenous knowledge. These research tools include, but are not limited to:

- Maps of local hunting, fishing, and gathering areas
- Maps of sacred sites and other special use areas
- Traditional Place Names mapping

- Species lists
- Collection of stories, songs, and dances of interactions between animals, humans and other species, humans and the natural environment, or allegorical animal stories
- Studies of subsistence technologies
- Animal life histories and their interactions with other plant and animal species including humans, told as information by locals
- Plant life histories and their interactions with other plant and animal species, including humans, told as information
- Stories of human mistakes made, and lessons learned, about interactions with nature and the environment, including storms, earthquakes, floods, ice, glaciers, changes in nature
- Advice in the form of rules, proscriptions against certain behaviors, prescriptions for other behaviors, and guidelines for management of animal and plant harvests
- Uses for animal and plant species, including recipes for foods and medicines
- Observations shared, often about the complex interactions and ecological relationships in the landscape where the people live, hunt, fish, and gather.
- Local descriptions of long term trends for species numbers and migration patterns, weather patterns, climate, and other natural events
- Linguistic, biological, and archaeological evidence.
- And finally, at a broader level, the values, beliefs, social systems and spiritual practices that have developed over thousands of years through the cumulative application of TEK.

It requires months and years of patient work with indigenous groups to elicit and document in-depth TEK. Researchers must spend adequate time in the field to understand the

landscape and local ecosystems as well as the local cultures. More important, local people need time to develop trust in the researchers' methods and personal qualities before they will be willing to share such important confidential knowledge as hunting sites or productive fishing locations. Fortunately, while the months afforded to this project were not sufficient to develop new in-depth TEK studies with local populations in the villages, there are several existing studies, both in the Nushagak and Kvichak River watersheds, and in the Lake Clark and Iliamna Lake area, that cover TEK in detail. Among the Nushagak studies is one by the Nushagak-Mulchatna Watershed Council (NMWC) (2007) and among the Kvichak studies are those by Stickman et al. (2003) and Fall et al. (2010). These long-term studies have focused on the Yup'ik and Dena'ina TEK in the Bristol Bay region and have provided sufficient information for our Bristol Bay TEK characterization, which we summarize in Sections a through c below.

To supplement those long-term studies, we focused interview sessions on the broader levels of TEK, including the values, beliefs, social systems, and spiritual practices of the Yup'ik and Dena'ina that have developed over thousands of years through their cumulative application of TEK. During those sessions we learned much from the Elders and culture bearers about TEK and the cultures as a whole. We also heard some specific examples of ecological insights, prescriptions and proscriptions, and management guidelines for several species.

a. <u>Nushagak-Mulchatna Watershed Conservation Plan</u>

Over a two-year period [dates unspecified], the NMWC conducted interviews with Elders, residents, and others who use the watershed to create a database of the TEK of the Nushagak and Mulchatna drainages (NMWC 2007:3). The NMWC used the data to create an overall plan for protecting the waters and natural resources of the watershed. The interviews

helped with the development of maps to identify areas critical to protection of subsistence resources and habitat. The plan identified 12 fish, 6 mammal, and 12 bird species important for subsistence and mapped 125 traditional use areas and 153 traditional area names. The flora and fauna considered most integral to traditional subsistence use were all five species of Pacific salmon, whitefish, winter freshwater fish, moose, caribou, waterfowl, and edible and medicinal plants (NMWC, 2007:19).

The study also identified probable threats to the watershed in the next fifty years, and, based on the TEK information collected, developed four strategic actions:

1. Reserve adequate water flow for the Nushagak River and tributaries under existing laws for in-stream flow reservation.
2. Maintain the vegetative complex that supports moose, fish and other species within and adjacent to the floodplain.
3. Maintain water quality standards that protect wild salmon and other fish.
4. Prevent habitat damage that could result from mining. (Nushagak-Mulchatna Watershed Council, 2007:3)

What is at stake includes habitat, and wildlife including terrestrial mammals, birds, fish, and the subsistence way of life, along with the unique cultures it supports. The report states:

> "The Nushagak River system is the fifth largest river in Alaska by volume of water discharged. The drainage supports at least 13 anadromous species, 16 resident species, and four species of fish restricted to estuaries. The Nushagak River and its tributaries host five species of Pacific salmon and provide significant habitat for Bristol Bay sockeye salmon – the largest runs in the world. The Nushagak river hosts the largest sport fishery for Chinook salmon in the United States, with the third-largest Chinook run in the country. In addition there are significant numbers of rainbow trout, grayling, Arctic char, Dolly Varden, northern pike, lake trout, and non-game species (NMWC, 2007:8).

The flora and fauna considered most integral to traditional subsistence use includes the following. Fish: 1. Sockeye, Chinook, and Coho salmon; 2. Pink and Chum Salmon; 3.

Whitefish; 4. Winter Freshwater Fish. Mammals: 5. Moose; 6. Caribou. Other: 7. Waterfowl; and 8. Edible and Medicinal plants. The Elders and other knowledgeable individuals also identified critical habitat for the species of concern and their harvest locations. The conservation plan used this information to delineate the watershed into conservation target areas, in terms of habitat types important for traditional use species (NMWC, 2007:20). Salmon are the keystone species in the region, and provide enormous amounts of marine derived nutrients to the ecosystems described above.

In the present study interviewees identified potential threats to the area including recreation, recreational subdivisions, commercial lodge development, community development, mining, roads, high seas salmon fishing, oil and gas development, and habitat shifting and alteration. Interviewees in Pedro Bay during the fall of 2011, for example, confirmed the high earthquake activity and expressed concerns about new road construction and its potential impacts on their streams and community, based on their long-term ecological knowledge.

b. K'ezghlegh: Nondalton Traditional Ecological Knowledge of Freshwater Fish

K'ezghlegh: Nondalton Traditional Ecological Knowledge of Freshwater Fish is based on interviews with 18 Nondalton residents in 2001 and focused on their current and past subsistence use of sockeye salmon and other fish in the Lake Clark/Newhalen River drainage (Stickman et al. 2003: 8). Interview questions related to fishing practices, geographic locations, and Dena'ina place names. The questions were presented in semi-directed interviews, with USGS quadrangle maps of the Lake Clark Newhalen River area used to plot

information. Answers revealed that the summer months, from mid-June through August, are traditionally devoted to harvesting sockeye salmon that are returning to Sixmile Lake and Lake Clark. Fish camps used to be set up around the outlet of Kijik Lake, but now are primarily at the outlet of Sixmile Lake but also along the shores of the Newhalen River, Sixmile Lake and Lake Clark (Stickman et al., 2003:11).

The interviewees listed nearly a dozen places as the most important locations for sockeye fishing and eighteen as primary locations for harvesting spawned-out sockeye or "redfish." Residents described in detail how and where they get salmon, listed 36 separate places where sockeye spawn, and gave descriptions of several areas where they have noticed reduced spawning activity, particularly Kijik Lake, which used to be well known as a very productive area. This area in particular has reduced spawning activity due to beaver dams that seem to be blocking the entry of the salmon into the Kijik River, and preventing fish from moving upstream to spawning grounds in and around Kijik Lake. The study also asked about harvest methods and detailed the use of seines, spears, and fish traps. Seining is no longer allowed under State of Alaska fishing regulations and fish traps were banned in 1959. People do use commercially manufactured gill nets.

It was important to the residents that they were respectful of the fish and cared for them. "Everyone interviewed reported that they generally stop fishing once they have caught the number of fish they need" (Stickman et al., 2003:23). Residents also disapproved of people leaving their nets out too long unattended. Andrew Balluta, one of the residents interviewed, said, "They used to say if you don't use what you are catching in your net, don't leave your net out there" (Stickman et al., 2003:24). The study also elicited descriptions of putting up fish.

The remaining sections of this report document residents' comments about change: observed change in salmon over time, observed environment changes, human-induced change; and finally the importance of salmon to the population as documented in the observance of the fish camps and the First Salmon Ceremony. A separate section documents the use of other freshwater fish, including rainbow trout, Dolly Varden, whitefish, grayling, northern pike, burbot, candlefish, sucker, and lake trout, and their relative abundance. Residents also noted significant changes in the number of fish returning in the five to ten years prior to the 2003 report. "Each person interviewed reported fewer fish than in the past, and all indicated that they first noticed the change in abundance between five and ten years ago." (Stickman, 2003:26). While Stickman et al. describe numerous possible reasons for the reductions in numbers, as well as changes in timing of the runs, the report also noted that flows in the Newhalen River in 2001 exceeded the level observed to prevent or delay sockeye migration into the lower river (Stickman et al., 2003:27-28 citing C. Woody).

c. Tanaina Plantlore: Dena'ina K'et'una

Two important TEK studies were conducted largely by Priscilla Russell Kari. The first is a study of Dena'ina (also known as Tanaina) plant lore describes the seasonal cycle in the Dena'ina use of plants, as well as detailing the gathering, processing, and preserving of the most important plants (P. Kari, 1995). She also covers Dena'ina beliefs concerning plants and the Dena'ina plant classification system. Her study, based on long-term work in several Dena'ina communities, with a wide range of Dena'ina women, documents more than 150 plants that the Dena'ina depend on for foods, medicines, and other uses (P. Kari, 1995). The second was done with George West (Russell and West 2003) and details Dena'ina use of birds.

E. Social Relations

1. Voices of the People

I feel good, proud [to share]. *And when our friends give us back, way proud*. M-60, 9/16/11

We share with the Elders first, then with family. Usually how I do it, if someone goes with me we go 50-50 and he can decide who to share his fish with, and we do the same. It's not decided by one person, usually me and my wife decide. M-26, 5/19/11

It makes me feel good when I give salmon to somebody. F-47, 8/20/11

It makes you feel good inside because you are sharing. M-53, 8/20/11

It's a good feeling, because we know other people want it. It's a good thing to give away, it's healthy. F-30, 8/17/11

Oh, it makes you really feel good [to give salmon]*, because I know we enjoy it, and people that can't get it that were almost raised on it…. That's just the way the whole village is; they share.* F-38, 8/18/11

In our culture here you share with everybody. When I got my first moose, I had to give it to people; when my grandson got his first moose, you give it to people. You share it. That is one thing good about the community of Bristol Bay; we still hold on to our cultural values really strong. Sharing is a very important component to our culture. If somebody is handicapped and unable to provide for themselves, you find some Young Turk or young family to go help them out. You don't expect pay. M-60, 9/16/11

You know, I was having a hard time, and her husband [gestures] *brought me a whole truckload of food, and I damn near cried…. Now, when somebody needs help, we do the same thing. If someone needs help, I try to help as much as I can; we always share. When we give something, it feels good, and when we are having hard times and get something, it feels good*. M-43,8/19/11

[Reference to a woman's] *mom was blind, and she couldn't do certain things, so my mom always made sure she shared with her. That is one of the things she told me about sharing. She thought it was good to share with people who couldn't do things for themselves. But, she was always*

doing nice things for us, too. She [the blind woman] *made us string to hang fish and things like that. She was really a nice person, her mom.* F-44, 8/19/11

Yeah, we always share. Holidays, we share, and if somebody passes away, after burial we have a potlatch; we share. We share with people; that is the way we are brought up. F-41, 8/19/11

We share with people here and in Anchorage…. I like to go fishing, so if we run out of freezer space, I will ask people [who can't fish in the village, e.g. Elders] *if they want fish, then I'll go out and catch some fish if they want*. M-70, 9/18/11

Me, I share it with my younger sisters who never do subsistence. Like, some can't work anymore. They [gesture] *share it with their parents. Me, I share it with my younger sisters or my son, my kin*. F-23, 5/18/11

Me and my daughter always share after we fish for all summer, but she always tries to give me lots more, but I say, "No, you've got more kids." Sometimes we give [fish to] our daughter-in-law. F-22, 5/18/11

I think, with us, during potlatch times, during hard times or Russian Christmas, or, if we gather together, everybody brings out their dry fish or their jarred fish or their salt fish. Nobody goes hungry; there's always sharing. We would be greedy if we kept it all to ourselves, but there's always a sense of sharing with the community or sharing with relatives. F-32, 8/18/11

The people up there [Kvichak River villages in the 1990s] *were not meeting their subsistence needs [*allegedly due to ADF&G management decisions*]. They weren't screaming about the cost of gas or the price of lights. They were screaming that they didn't have fish. There were people from over here that were shipping fish over there for people to meet their subsistence needs.* M-60, 9/16/11

You are a very rich person if you share. If you don't share, you are nobody…. I have to go share food with my grandkids, great grandkids; it doesn't matter. I don't care if someone comes in and eats with us; I like to share. That's the way we were brought up. Anybody that is in the house, come and eat with us; you are welcome. F-46, 8/20/11

You know, when I was working down in Seattle, my mom used to send me pieces of dried fish all the time. You know, that mail was slow back then. When I would get it, man, it was just like candy. No, but one time she sent me mixed berries. You make it with lard; we call it "agutak." She sent me those, and by the time it got there, it wasn't good. Salmon doesn't spoil when it is dried. M-53, 8/20/11

We catch moose and caribou and give it away; it ensures good luck back. Even beaver, you give the whole beaver away after you skin it. After you skin the beaver, you give it away; give the whole beaver away. That animal that you give away…give[s] *you back in return good luck.* M-54, 8/20/11

[My wife] *and I have been doing it for thirty some years, doing the fish camp, and putting up fish for the winter. When the kids were small, we were down there for them too, and hopefully, they will have a family, too, and carry on the tradition.* M-33, 8/18/11

Some of the salmon we put up at my fish camp even goes all the way down [to] *the states. My friend* [name] *comes in here, and she puts up fish, and she cans salmon….* [My daughter] *and her friend…they also can fish and dry fish….* [My grandson] *was here all summer*. F-27, 8/17/11

The parents, their sisters, their aunties, their grandparents, their great grandparents. Everybody is there [at fish camp]*, you know, telling them* [the children] *how to do this….Everybody does it at their own camps, fish camps…. Everybody is living in different fish camps, so all these families that are together, that's how they taught the younger kids.* F-28, 8/17/11

He [five-year-old grandson] *went fishing with us once; now, he went and seined with us. That's …how we learn, that's how we teach our kids [fish camp]. I mean, it's togetherness.* F-30, 8/17/11

One of the things we were taught and we are teaching our kids and grandkids are that you do not waste. Boy if they let the fish get rotten boy they would be disappointed in us really bad. So we teach and pass that on, don't waste nothing. M-29, 8/17/11

We usually get our subsistence foods, salmon, and a wealthy person, years ago, was when he had a lot of dry fish for his dogs, salt fish, smoke fish. The women had their wooden kegs full of berries for their Eskimo ice cream. Maybe the father was fishing commercially and made enough to buy a few groceries form the store, enough [rifle] *shells. That was a wealthy person. I think today a lot of people still think the same way.* M-62, 9/16/11

Yeah, I think growing up in a small village wealth was defined by what you provided for your family. If you were a highline fisher, you were very wealthy, both physically, as well as mentally. If you were a good hunter, that in itself was very wealthy. Or a good trapper, good provider. M-61, 9/16/11

Salmon is one thing. They make you feel rich, because you have something to eat all winter. Smoked salmon, sun-dried spawned-out fish, all of those make you feel good, because you grew up with it; it is in your body. M-53, 8/20/11

As long as we have a lot of fish and meat and stuff, they are wealthy. We don't believe in… having lots of money. The wealth to us is having more fish put away for the winter, and meat; that's our wealth. F-27, 8/17/11

In this Western society of living in the city, everybody is for themselves. Everybody is worried about "Joe Blow" next door, who has a bigger TV or a bigger car; they are worrying about money, money, money! It just brings on the sickness of worrying. Here, we run a healthy life, because we have everything we need here; everything we could possibly want is right here. F-32, 8/18/11

They don't learn that at school [proper attitudes toward salmon]. [Laughter]. Elders teach them, Elders are teachers and pass it down to younger generations. They learn it and pass it down to their children. Right down to grandchildren, great grandchildren. M-53, 8/20/11

2. Introduction

Though each has a different cultural social organization going back to pre-contact times, today there are many similarities between the Dena'ina and Yup'ik of the Nushagak and Kvichak River watersheds. Among them are the importance of sharing subsistence foods, fish camp as a social and educational as well as economic institution, gender and age equity, and the concept of wealth.

3. Sharing and Generalized Reciprocity

The Yup'ik and Dena'ina cultures center on belonging to community and on sharing food as a means of creating and maintaining the living bonds of relationship. The focus on sharing functions as the elemental ordering factor in sustaining the culture and the long-term health of the communities. The practice of sharing is elemental in both indigenous and other cultures both

from a material and a social standpoint (Counihan, 1999:13). Interviewees indicated that the sharing, preparation, and consumption of food together has created opportunities for efficient and sometimes ritualized teamwork, as well as social bonding and building of networks. The Yup'ik and Dena'ina of the Nushagak and Kvichak River watershed villages, as traditional cultures, continue these practices through harvesting, preserving, and preparing food together and sharing food through traditional practices and ritual celebrations. They continue to experience the social, spiritual, and nutritional benefits from sharing food, especially salmon, the staple food, up to the present.

Sharing remains a fundamental institution within Yup'ik and Dena'ina cultures today, according to interviewees, and the importance of sharing food, especially salmon, cannot be overemphasized. Among the Yup'ik, for example, *elaqyaq* means "those of the same stomach" and refers both to sharing food and being biologically related. Oscar Kawagley noted a similar linguistic reference: "The Yupiaq [Yup'ik] term for relatives is associated with the word for viscera, with connotations of deeply interconnected feelings" (Kawagley, 2006:11). As Langdon indicates, the time people spent together in subsistence activities is extensive: "The Yupiit [Yup'ik] enjoyed the bounty of some of the world's richest salmon fisheries. Large quantities of fish were harvested and processed through relentless hours of work in order to sustain families and their dogs throughout the long winters" (Langdon, 2002:41).

Yup'ik and Dena'ina sharing is "generalized reciprocity," because the time and place of a return gift is not specified. In general, interviewees indicated that people do not expect a return gift when they share salmon or other subsistence foods with someone else, particularly an Elder, but a return gift of food always seems to appear, whether that month, that year or sometime in

the future. The altruism is part of social solidarity. Villagers do not consider sharing to be an obligation, but a way of life, as the Voices of the People at the beginning of this section indicate. Interviewees universally indicated that giving or receiving salmon or other subsistence foods makes them feel good. The altruism of sharing food expresses social solidarity between the participants. Almost universally, Dena'ina and Yup'ik seem to have small jars of salmon available for visitors to take with them.

Villagers particularly recognize some Elders who cannot participate in the rigors of subsistence harvesting as people with whom to share salmon and other subsistence foods. The informal first salmon sharing, for instance, always includes Elders (see Section III.F.5). Sharing salmon and other subsistence foods with family living in Anchorage or even farther away is an important bond to home, family, and place. Interviewees consistently talked about how much they appreciated a gift of canned or jarred salmon from home when they were away from the village. They also talked about how important it is for them to send a part of the place to family and friends living away from Bristol Bay.

The Dena'ina believe that tangible items can take on aspects of the owner. This personification is called *beggesha* if the aspects are positive and *beggesh* if negative (Boraas and Peter 2008: 215-9). Artifacts or places can have *beggesha* or *beggesh* depending on events associated with them. A place, something someone made, such as a birch bark basket, or salmon someone prepared take on *beggesha.* The term does not easily translate into English, so today people talk about giving "love" when giving a gift of something they made or prepared. Conversely, one receives "love" when receiving a similar gift. This perspective is one of the reasons that Alaska Native foods, especially salmon, are served at all gatherings such as potlucks

and potlatches. Preparing and giving food is a tangible act of love. Recipients appreciate non-Native foods, but they are not from the place, were not made by the giver and, consequently, are not an expression of love when gifted.

4. Fish Camp

Both the Dena'ina and Yup'ik have a long tradition of going to fish camp to harvest salmon. As interviewees indicate, the villages of the Nushagak and Kvichak River drainages harvest salmon either at or very near town, and fish camp may be only a short boat ride or four-wheeler trip to a traditional fishing locality where they may or may not camp out (cf. Fall et al. 2010). Many villagers, however, still travel to a traditional place, set up camp, and live for several weeks catching and putting up salmon. Villagers from Kokhanok, for example, travel to fish camp on Gibraltar Lake, while residents of New Stuyahok, Ekwok, and Koliganek stay at various camps on the Nushagak River, downstream of the villages primarily at Lewis Point, and villagers from Nondalton go to camps on Sixmile Lake and Lake Clark. Generally, the interviewees indicate the fish camp consists of an extended family, with three or more generations, but close friends may also participate (Fall et al. 2010).

Families typically view fish camp as a good time when they can renew bonds of togetherness by engaging in the physical work of catching and processing salmon. Family members who don't live in the villages often schedule vacation time to return home to fish camp, not just for the salmon, but for family. The importance of sharing in vigorous, meaningful work cannot be overestimated. It creates cross-generational bonds between children, their parents,

aunts, uncles, and/or grandparents that, today, are rare in Western culture because there are so few instances in which meaningful, multi-generational work occurs (Interviews, 2011).

Fish camp is a time when children and teens learn not only the practice of how to properly catch, clean, and process fish, but the values that are an integral part of harvesting salmon and interacting with nature. As such, it is a primary educational institution (Fall et al. 2010). Young people learn from their parental generation and, particularly, from their grandparents, their Elders, about the Yup'ik or Dena'ina way. The primary value passed on at fish camp is respect for nature and, particularly, respect for salmon. As discussed in Section III.F.4., showing this respect involves using everything and disposing of what little is left over in a respectful manner. Fish are not disparaged, bragged about or made fun of. Catching salmon with a good attitude is the first step in imbuing it with the *beggesha* or love discussed in the previous section.

5. <u>Steam Baths</u>

In many villages, informal gender-specific groups meet several times a week for steam baths in small wooden buildings heated with wood-fired barrel stoves and share stories, the advice and wisdom of the Elders, and cultural connections. In some ways, these steam baths, or *maqi* as the Yup'ik call them, have taken the place of the men's traditional house, *qasgiq*, and the women's house, *ena,* where the transmission of cultural values and knowledge traditionally occurred, as well as much entertaining talk. Among Dena'ina the traditional word for steambath is *neli* which traditionally was a spiritually powerful place as well as a place for healing

(Kalifornsky 1991:48-50; 218). Today the Dena'ina *neli* has many of the social aspects of the Yup'ik *maqi*.

Figure 8. Firewood sled (foreground) and Steambath (background). New Stuyahok, January, 2012.

6. <u>Gender and Age Equity</u>

Gender equity among subsistence families is balanced and has many of the characteristics of a traditional family farm or family-run business. Both men's roles and women's roles are equally valued, and it is common that men can do most "women's" activities (cook, clean fish, etc.), while women can do most "men's" activities (shoot a moose, run a boat, etc.) (Interviews 2011).

Traditionally, Elders are important members of village society, seen both as sources of values and storehouses of traditional knowledge, and they are valued in child-rearing, village decision-making, and life guidance. A common saying in the villages is: "When an Elder dies, we lose an encyclopedia."

7. Wealth

When asked their perception of wealth, only 3 of 53 interviewees, all from the same village, indicated that they measure at least part of their wealth in terms of money, material items, and potentially high-paying jobs (see Section III.B.8.). The remaining interviewees who commented responded that wealth is measured in terms of one, or more, of three themes: food in the freezer, family, and/or freedom.

To the majority of interviewees, stored subsistence food means a family is wealthy or rich as noted in Section III, B. Various entities attempt to monetize this value, but to the people, subsistence is priceless. It means you won't starve; it means you will have among the healthiest diets in the world; it means you will be able to actively engage in the sharing networks described above; and it means shared, activity that enhances family and/or village togetherness. A full freezer (or freezers, as is often the case), a well-stocked pantry and a full wood bin are the primary symbols of wealth in the Nushagak and Kvichak River villages. Most villagers, of course, recognize that money is a necessity, but money is not the singular measure of wealth. Money is necessary for the tools for subsistence, gas and oil for boat and house, and occasional travel, and locals generally acquire it through part-time jobs or commercial fishing that still allows time for subsistence activities. By Western materialist standards most of the villages are poor; by their own standards Nushagak and Kvichak River villagers are rich, and it is the people who live a non-subsistence lifestyle who are poor (summarized from interviews, 2011).

Interviewees indicate that wealth also derives from having a large, extended family, particularly one that is closely knit by subsistence activities. Having an extended family means

having people you can count on if need be, and it means having people to whom you can give your love and assistance. This tradition of alliance through marriage has its origin in pre-contact Yup'ik and Dena'ina culture (see Sections II.B.3 and II.C.2).

Few interviewees spoke with fondness of living in Anchorage or other urban places they have lived or visited. Though hunting and fishing require abiding with ADF&G regulations, most villagers see those activities as involving a degree of freedom that does not often occur in non-subsistence work settings. As described in many interviews, with subsistence as your job, you don't have to punch a clock, you only follow nature's clock; you don't have a boss, you are your own boss, and you either suffer the consequences if you do not perform well or reap the benefits if you do. During our May visit to one village on the Nushagak River, two young men in their early twenties left on a 17-day subsistence trip upriver into the Mulchatna area, one of the most remote places in North America at any time of year, but virtually deserted in spring, when snow was still present. They were on their own, and apparently all who were connected to the endeavor embraced that freedom. As they left, for example, the mother of one of the boys simply said, "Be careful," just as a parent living on Alaska's road system might say to a son embarking on a trip to Anchorage. This view comes from villagers having knowledge of and ranging over a vast territory, almost all of which is in a natural state. Consistently, people are thankful to live in a place where they can live off the land in the manner of their ancestors, and don't want to live anywhere else (Interviews, 2011).

8. Suicide in the Study Area

Tragically, suicide is one of the primary indicators of individual loss of identity and breakdown of society (anomie). Alaska has one of the highest suicide rates in the nation and that,

sadly, is due in part to very high rates in rural Alaska. However, as indicated by data from the Alaska Bureau of Vital Statistics (see Table 8), those high rates are not spread equally throughout rural Alaska. In the Northwest Arctic census area the age adjusted suicide rates per 100,000 are four times the Alaska rate (22.7 in 2009) and six times the national rate (11.5 in 2011) (see Table 14). Similarly suicide rates for the Bethel area north of the study area indicate a similarly grim picture.

Table 14. Suicide Rates in the Study Area compared to Alaska and Other Selected Areas. Data from "Alaska Bureau of Vital Statistics, Detailed causes of Death in Alaska. http://www.hss.state.ak.us/dph/bvs/death_statistics/Detailed_Causes_Census/frame.htm

	Alaska	Dillingham Census Area		Lake and Peninsula Census Area		Bethel Census Area		Northwest Arctic Census Area	
2010 Population	698,473	4,933		1,488		17,236		7,208	
	*per 100,000	*per 100,000	Actual Number	*per 100,000	Actual Number	*per 100,000	Actual Number	* per 100,000	Actual Number
2007-2009	22.7	42.4	6	--	0	61.6	30	67.5	15
2006-2008	22.6	--	2	--	0	50.1	25	93.0	21
2005-2007	20.9	--	2	--	0	38.3	19	81.9	18
2004-2006	21.0	--	2	--	0	48.1	24	79.4	18
2003-2005	21.0	--	4	--	0	56.9	29	66.1	15
2002-2004	21.5	--	4	--	1	50.8	26	74.8	17
2001-2003	19.4	--	3	--	1	32.7	17	78.4	17
2000-2002	19.6	--	1	--	3	27.6	13	74.5	16
1999-2001	18.3	--	2	--	2	23.8	11	62.2	13

* Rate is Age-Adjusted per 100,000 calculated at the 95% confidence interval
-- Rate per 100,000 not calculated because the incidence is too low to be within the 95% confidence interval

The suicide rates for the study area including the Dillingham census area which includes the Nushagak drainage villages of Dillingham, Ekwok, Koliganek, and New Stuyahok as well as five other villages outside the study area are comparatively much lower. In only one two year period was the Age-Adjusted rate per 100,000 even calculable at the 95% confidence level because the number of suicides was so low (see Table 14). Suicides were even lower for the Lake and Peninsula Census area which includes the study area villages of Igiugig, Iliamna,

Kokhanok, Levelock, Newhalen, Nondalton, and Pedro Bay in the Kvichak drainage and 10 other villages outside the study area. While any suicide is a horrible loss for family and community, especially in small rural villages, statistics indicate suicide is not of epidemic proportions in the study area it is in other parts of Alaska.

While suicide is complex, one of the chief reasons is a debilitating feeling of hopelessness. The 2011 Alaska Federation of Natives panel on suicide identified specific factors including historical trauma, substance abuse, sexual abuse and family violence (DeMarban 2011). It is also not easy to determine why suicide rates are much lower in some parts of rural Alaska such as the Nushagak and Kvichak drainage. One reason is that Orthodoxy is generally strong in these villages and Orthodoxy considers suicide to be a sin and a violation of the fifth commandment "Thou shall not kill" (Morelli n.d.). Resident priests with close ties to the village no doubt provide effective remediation, in some cases, to those in despair who might be contemplating suicide. The cultural strength of a subsistence lifestyle cannot be discounted as a second effective antidote to suicide. Eating a healthy, natural diet, engaged in vigorous outdoor activity with family and friends and the village support of those friends and family, and having a measure of independence and therefore feelings of control of one's destiny, and living in a cultural continuum that goes back thousands of years on the landscape of one's ancestors no doubt truncates the despair that can lead to suicide before it ever gets to a critical state.

F. Spirituality and Beliefs Concerning Water and Salmon

1. Voices of the People

Respect and Thanks

Yes, they do [streams have a spirit]*, like everything else, all living things. Before Russian Orthodox came here, that is what we worshipped. We worshipped all the living things, even the air, the sky, the moon, the sun, snow, rain. It is in every aspect of our lives, how we are made up, what we believe in, why are we still here?* M-33, 8/18/11

They say everything on Earth has a spirit, like we have a spirit. So everything has spirits, the streams, the waters, the lakes, the mountains, trees, birds; everything has a spirit. To me, I think, that's why we have to pray, and you have to keep the streams clean, not pollute it. F-27, 8/17/11

I think that, if you treat animals disrespectful, that they are not going to show up again. F-32, 8/18/11

That is why we are so clean around here…they [outsiders] don't know if we camped around here or not, because we clean up our garbage, and we hardly leave any evidence that we were there. M-36, 8-18-2011

Yes, like all other things you are granted [by God]*, you give thanks for* [salmon]. F-69, 9/18/11b.

First Salmon Ceremony

The first salmon, it's still tradition to share with everybody. You do say a prayer. F-47, 8/20/11

When we catch the first king salmon, about this month [May], *maybe next week, we share that king salmon, cut in little pieces, to give to them to cook, especially to the Elders, because they always want fresh fish.* F-22, 5/18/11

First catch is shared with all of the Elders. Elders first, always the priority, Elder, because they cut it in pieces, you know, if you catch a king, you share, instead of eating the whole fish by yourself. The first catch. M-20, 5/18/11

Tradition--first salmon, the very first salmon you catch you boil everything, everything. You don't waste anything then you eat it too. I mean, even the liver, if it's a male the sperm sac, everything. M-29, 8/17/11

Every year, when I first catch a king salmon, I usually pray to God and thank Him for it. A lot of people do the same thing, because he is the one giving us these wild foods. M-63, 9-18-11

Figure 9. Russian Orthodox Church, Koliganek. September 15, 2011.

Great Blessing of the Water

There are a lot of folks along the Nushagak, down to Dillingham, and along the chain that are Orthodox because of the Russian influence. They actually have three ceremonies in the church that deal with the salmon. The first one is the Blessing of the Water in the winter time. You have probably seen the newspaper articles about the priest that goes out there and blesses the water. It can be minus 40 or minus 50 [degrees Fahrenheit], and you seem them running that cross in the water, and they never freeze. That in itself is a miracle, I think. The other thing that happens is that, just prior to fishing, the church has a special service of the blessing of all the resources. The third thing is the blessing of the fishing boats. The individual fishermen, when they get done with all their nets and all their gear, they can ask the priest to come and bless their boats. M-81, 9/16/11

They do it every year at Theophany…. It's very important to us; it's a blessing of the water, blessing the river so the fish come in. It's an Orthodox religion ceremony.M-20, 5/18/11

The Holy water is so pure. We believe it is healing, has healing powers. When you are sick or have a cold, have just a little tiny bit. F-69, 9/18/11

And over on the Iliamna side, they will do the same thing that Father will do over here with the water, make holy water. People will come down there too with either buckets or jugs and fill them up. M-65, 9/18/11

I used to live in Portage where there is no clinic. That is the only thing I could give my kids [holy water, when they were sick]. *You know pray upon them and let them make the sign of the cross and let them have a taste of the holy water. F-72, 9/19/11*

That holy water is strong. To be honest with you people, I would not be talking with you right now [if not for holy water]. A long, long time ago, before I become a lady, we were upriver with my mom and dad. My mom was sick too, my grandparents and dad, too, and uncle [name]. In night time, I guess I almost go [die] you know. But my dad, he prayed for me. If you're really true, praying really hard, I guess he'll answer you. My dad tell me I have no more breathing, no more pulse. And when I come to, my dad was holding me like this, up you know, feeling my heartbeat. As soon as I opened my eyes my dad said 'you get up'. I said yeah, I told him I was going to sleep, how come you woke me up? I was going to go to Big Church [heaven], and my dad said 'you can't go to Big Church' When he tell me that, I told him holy water—I call Native way, malishok, holy water, malishok [Yup'ik]--'give me holy water to drink'. He did, my dad, he did. A little bit you know. I opened my mouth, I swallowed, the water was going down into my stomach… I closed my eyes, pretty soon I come through. My dad was up, my momma was sleeping, she was sick too upriver [Yup'ik placename]. I go but I came back. Almost going to that Big Church. My dad he tell me not to go into the church, come back, that's why I become a lady. It's true, I tell you guys the truth, better not forget that. Holy water is strong, that is what made me come back. F-66, 9/18/11

2. Introduction

Most of the residents of the interior villages of the Bristol Bay drainage are Russian Orthodox Christians, and the Orthodox Church, along with the public school and the tribal structure, is among the dominant institutions in the small villages. Many of the villages have a resident priest or priests; for others, clergy visit periodically on a scheduled basis. In some villages Protestant churches have formed: Port Alsworth, and Dillingham have Protestant church buildings, the latter in addition to an Orthodox church.

Beliefs concerning streams and salmon, in those villages where Orthodoxy is the dominant religion, involve a syncretism merging traditional beliefs with Russian Orthodox practice. Dena'ina writer Peter Kalifornsky (1991:249) described syncretism when writing about his great-great-grandfather's nineteenth century message to the Dena'ina people after his conversion to Orthodoxy: "Keep on respecting the old beliefs, but there is God to be believed in; that is first of all things on earth." Russian Orthodoxy itself has a syncretic tradition of melding Middle Eastern-derived Christianity with spirituality influenced by the northern environment. Billington (1970:18-19, and 403) points out that, though Orthodoxy moved north from Greece and Asia Minor into Russia in the ninth century A.D., its long history in the northern forest has shaped the belief system to interpret and interact with aspects of the subarctic taiga. Billington writes, "God came to man not just through the icons and holy men of the Church but also through the spirit-hosts of mountains, rivers, and above all, the forests" (Billington 1970: 403). Consequently, many Russian Orthodox rituals involve interaction with nature. The mystical aspects of Orthodoxy fit well with traditional Dena'ina and Yup'ik beliefs, many of which related to interacting with the

landscape on which their survival depended (Boraas, in press). For the Dena'ina and Yup'ik living in the Nushagak and Kvichak River drainages, beliefs regarding pure water and the return of the salmon, discussed below, ritually and spiritually express the meaning of life as people of the salmon.

3. Great Blessing of the Water

The "Great Blessing of Waters" takes place during the Feast of Theophany, a major event in the Orthodox Church calendar and is celebrated on January 6th of the Julian calendar, the calendar of Orthodoxy (January 19th in the Gregorian calendar). While all church rituals are important, Theophany can be considered to be the third most important church ritual after Christmas and Easter to the Orthodox of the Nushagak and Kvichak watersheds (personal communication, Fr. Alexi Askoak, St. Sergis Russian Orthodox Church, New Stuyahok, January 19th, 2012). A theophany is an event in which God reveals himself to humans and the Great Blessing of the Water marks the baptism of Jesus by John the Baptist. After Jesus' baptism God appears saying, "this is my son whom I love, with him I am well pleased," (Matthew 3: 17, New International Bible). As explained by Fr. Alexi Askoak (personal communication, January 19, 2012), in the Orthodox view, baptism both redeems sin and brings the Holy Spirit to the recipient. Orthodoxy believes in the triune God, consequently Jesus is God and without sin. So Orthodoxy transfers the ceremony to one of God's most important creations, water, and one of the creations most important to the people of the Nushagak and Kvichak since salmon and related wild foods are dependent on clean water. An evening church service is held on the eve of Theophany in preparation for the blessing the next day. The two-day ritual is a liminal event with believers moving into a deeply spiritual mental state. At the service I (Alan Boraas) attended, 211 villagers of New Stuyahok were present filling the small

church in New Stuyahok. The next morning a communion service was held and, as the sun rose, the people led by the priests went out onto the frozen Nushagak River where an Orthodox cross had been cut into the ice and a small hole had been made to withdraw holy water (Figure 10). There a baptism service was held purifying and sanctifying the water of the Nushagak River. At the moment in the service when the priest dips the cross through the hole in the ice into the water for the third time, God is believed to sanctify the water making it holy. According to Father Michael Oleksa the Great Blessing of the Water is done to "reaffirm the Church's belief that the natural world is sacred and needs to be treated with care and reverence" (Orthodox Church in America, n.d.). The Orthodox Saint John Maximovitch (n.d.) wrote:

> …when we bless waters of lakes, rivers and streams, we ask God to send His blessings upon the waters of His creation so that even though humanity has spoiled the world through sin and abused the environment over many generations, God has not forsaken the world. He sends His spirit to cleanse and sanctify His creation.

"Sin" in the form of human-caused pollution and other contaminants are ritually removed from the water and it is now considered pure and holy (personal communication, Fr. Alexi Askoak, January 19, 2012). In New Stuyahok, and other villages where the ceremony is performed, the now blessed water is removed in containers for personal spiritual use and a large container is taken back to the church for use as holy water.

Figure 10. Great Blessing of the Water, Fr. Alexi Askoak, St. Sergis Church, New Stuyahok. January 19, 2012.

Holy water from the sanctified rivers is believed to have curative powers for both physical and mental illness and is drunk or put on the affected part (Fr. Alexi Askoak, personal communication, January 19, 2012). Several interviewees shared very personal incidents of the power of holy water to cure. Fr. Alexi told the story of one bitterly cold Theophany when he frosted his face during the ceremony. When they returned to the church one of the parishioners rubbed holy water on his face and he subsequently did not blister or suffer any ill effects other than one little spot the water had missed which left a mark for several years. Fr. Alexi believes God healed him through the holy water. A young interviewee in Koliganek movingly told of a time when her children were gravely ill and there was no doctor, health worker, or suitable medicine available. She said, "all I had was holy water." She had the children drink the holy water and in a few days they recovered. She attributes their recovery to the power of the blessed water. An elderly woman movingly told the

story of being brought back from near death when she was a child by holy water. Both stories are recounted in the "Voices of the People" at the beginning of this section.

From a secular standpoint, the question is not whether or not holy water has healing efficacy, but how the Great Blessing of the Water ceremony and holy water reflect values of the people. People elevate to the sacred those things that are most meaningful or critical in their lives. As described in section II. E. 4 the Dena'ina word for water, *vinłni*, has sacred overtones and water, itself, is sacred. Since the word predates Christianity in south-central Alaska, we can assume sacred water has long been a part of the salmon cultures of the Nushagak and Kvichak watersheds because clean water and salmon are fundamental to life itself. The Great Blessing of the Water ceremony is an obvious extension of that very old concept, rendering in Christianity that water is sacred to life.

The antiquity of the Great Blessing of the Water in Alaska is apparently as old as Orthodoxy. Hegumen Nikolai was an Orthodox missionary priest briefly stationed in the Nushagak area in 1846 and then transferred to be the first permanent priest in Kenai where he served from 1846 to 1867 (Znamenski 2003:15-18). In his travel journals Hegumen Nikolai describes conducting the Great Blessing of the Water in Kenai in 1862 and 1863 on January 6th, Julian calendar. (Znamenski 2003: 94, 108) (Travel journals, official church documents missionary priests were required to submit to the diocese yearly, have not been translated for earlier years for missionary priests operating in the Dena'ina or Yup'ik areas of the Nushagak and Kvichak watersheds.)

4. <u>Respect and Thanks</u>

Water and salmon play additional roles in modern Orthodoxy in the study area as derived, in part, from traditional subarctic spiritual practices. Describing traditional Dena'ina beliefs,

Kalifornsky (who was also a devout Orthodox Christian) writes (1991:362-363) that, after putting out his net, "*≡uq'a shegh dighelagh*" or "a fish swam to me," indicating that the spirit of the salmon had a will and would allow itself to be taken for food if the net-tender had the correct attitude. Today, all interviewees that commented on it still believe that salmon have a spirit or soul and that soul is a creation of God. Further, all interviewees who responded report offering a prayer of thanks when they catch salmon, particularly the first salmon as noted in the "Voices of the People" at the beginning of this section. That prayer may be a humble "in one's mind" statement or it may be spoken thanking God for the salmon.

Interviewees also still believe in treating all animals, including salmon, with respect. Several modern practices reflect this belief, for example, using the entirety of a fish for food, except the entrails, which villagers return to the water along with the bones that remain after consumption. Another example, interviewees report, is never allowing fish or meat to spoil. Interviewees repeatedly stressed the importance of giving salmon and all subsistence animals respect. This attitude echoes the pre-contact beliefs that animals had a will and, if not treated properly, would not allow themselves to be taken for food, leading to dire consequences for the people (Boraas and Peter 1996:190-192).

5. <u>First Salmon Ceremony</u>

The First Salmon Ceremony is a world renewal ceremony which, like other world renewal ceremonies, recognizes the cyclical onset of the most important yearly event in the culture. As mentioned in Section II.C.2, the First Salmon Ceremony was described by ethnographer Cornelius Osgood (1976:148-9) and was practiced in pre-contact times and is

based on a mythical story that merges people and salmon. Because of the importance of salmon in the lives of the Bristol Bay villagers, interviewees report they continue to mark the return of salmon in the spring by a special observance. The actual practice varies, but involves a prayer of thanks to God for the return of the salmon and sharing the first salmon caught in the spring with Elders and others in the community. Typically, according to interviews, each receives a small piece, and there is a general feeling of happiness that the salmon have returned and the cycle of the seasons has begun again and nature will provide the people with sustenance. In some places the First Salmon Ceremony takes place at fish camp, where extended families and others present share the first salmon they catch with one another, including the Elders. In at least one village, New Stuyahok, the ceremony includes sharing the first salmon with "the underground," by placing a small piece of it under the forest mat at the cemetery, symbolically sharing salmon with the deceased ancestors buried there.

Figure 11. Kvichak River and Lake Iliamna at Igiugig. May 16, 2011.

G. Messages From the People

At the conclusion of the interviews we asked interviewees if there was anything else they wanted to say, anything we had not covered, and/or any message they wanted the Environmental Protections Agency to hear. The following reflect those comments:

1. Voices of the People

I, myself, get very emotional when the topic of the Pebble Mine comes up. I don't even want to think about it. In the future I don't want to think about total ruin of our way of life. It really saddens me. F-69, 9/18/11

For quite a few years there when we were building up the king salmon run we didn't even fish in June. It was just to build up those runs. It is kind of ironic that the kings we built up are on the Koktuli River where that mine is going to go. It is almost a whole decade that we sacrificed to build up that run. We built it up and now it might go away. M-61, 9/16/11

You don't see Bristol Bay having troubles because our ecosystem is whole and not damaged. We are very appreciative of what we have. In relationship to the mine the place I work up here is the Bristol Bay Economic Development Corporation and… one of the companies we bought is Ocean Beauty Seafoods which is one of the largest salmon producers in Alaska. We put up 161million pounds of commercially caught goods in a year. So I talk to the people and if there is a mine that goes in like pebble and we have copper coming out and affecting our fish, are you interested in buying our fish? These are customers we sell 300-400 thousand pound lots to. No, we are not interested….We don't want ourselves and our kids to eat contaminated foods. M-60, 9/16/11

It is clear, good water to drink. This is what we protect our good water to drink. F-48, 8/20/11

We can't even fathom somebody hurting the salmon. When the pebble mine folks first came in they said they were going to pump the tailings right into the middle of the lake. We said you are going to kill the lake. They said you guys got no say so….We said no you'll kill the lake. We couldn't fathom it. We said you kill the lake and we will go to war. M-60, 9/16/11

Since the Pebble Mine started their exploration, I speak for everyone around here that we have not had the big caribou herds that come through here anymore. F-69, 9/18/11

That is our greatest fear about the mine. The size of the hole and the tailing pond they are going to build. You know you see our KDLG water tower up here and the size of the walls are going to be greater than that and if we get a spill we are done. What we say is that we can't afford the risk. The mine might be safe but there might be an earthquake and pollution happens. We can't afford the risk. M-60, 9/16/11

In Easter they went up to Koliganek the next village up. He said people up there caught white fish and pikes. He said the water is good upriver, it's not like down here. I think it's the water that is coming down from up Mulchatna. He thinks it's from them working on that pebble up there [pebble mine]. F-23, 5/18/11

There's open water all over. They got drilling rigs that are sitting on open water. You can't walk up there with knee boots you got to have hip boots there is so much water this year. The ground is saturated. M-60, 9/16/11

[Translator of 80+ year old Yup'ik-only speaking Elder] *He is only worried about the Pebble, right now. If the Pebble starts, the water is going to get effected before anything else. That's what he is worried about.*

M-21, 5/18/11*We feel that EPA is very important around here to give us a fair shot at examining this*.... [reference to specific individuals deleted] *You know they [state officials] are all for this economic development. You know economic development up in that mine they are going to bring in outsiders they are going to destroy the culture up there like you wouldn't believe. Most of the outsiders will, most of the jobs will go to outsiders and we will be left with the pollution.* M-60, 9/16/11

They [Salmon] would not go there [where water is contaminated] They are also very sensitive to temperature. They have a really keen sensory acuity, not only them, but all the critters, all the birds. ...They are so sensitive in every aspect of that word. ...It's relying on the renewable resources for our people have been going on for a long time. The respect for it, it is still there for those of us who do respect it. We have been sharing it with everybody. Nobody was jumping up and down, hollering about one group or another, until the Pebble people came. We took all these resources just for granted. We did not know anything about open pit mine or mining. I realize as human beings we need mines. I have to buy bullets now and then. I have to buy a prop for my outboard motor. I have to go buy bearings for my Honda. This is not a place to have that. They cannot have that here. There is no balance there. They talk about coexistence, that is not…that's coming from the other side. That stuff can't coexist with salmon. Are you going to compare coal to copper? Copper is a thousand times more devastating that coal. [M-33, 8/18/11

*The drill wells are making all the noise. We were over there, my wife and I were over there last spring, and when we went over there to check out the Pebble, there [*we*] saw three other helicopters right in the same area, and that's lots of traffic. We have not had caribou meat around here ever since. Haven't had caribou meat caught here in probably the last six years.* M-68, 9/18/11

Bristol Bay is renowned for what it has to offer. Like I was saying earlier, this region had a very good working agenda before the Pebble people came. M-33, 8/18/11

[Name] went with her and she is about 88 years old [mother and daughter on an Outside mine visit]. They went out to look at mines and [name] cried at every mine she looked at, she couldn't believe that man would be that disrespectful of the earth. She said literally cried… like her brother, mom or dad died. She represents us all, we can't see destroying the earth like that. We're not greenies you know we are far from green but we can you know. Without EPA we are sunk. …We know it is just a matter of time. All of us have had a few cocktails and drove, one of these times we are going to have a few cocktails and get in a car wreck. It is just a matter of time. Just like that mine. We really feel helpless with the state government. It is like we are dispensable out here and it is better for the big boys to come in. that is what the mine people are telling us. Right guys? When they first started coming? You got no say, so we are coming. M-60, 9/16/11

And what is going to happen when this mine closes up? Our great-great-great grandchildren are going to end up paying for it. If they are fortunate enough to still be living in Bristol Bay if the salmon, the streams are not contaminated and sustained. I hate to think of the future if this mine goes through. The long haul it is going to be devastating. M-62, 9/16/11

We are very rich. With this new mine coming up, I would never trade my fish for money or a new house, or whatever. I'd like to have all that, but I would not trade what we have every year for how many centuries. F-35, 8/18/2011

IV. CONCLUSIONS

As described in Sections II and III, the Yup'ik and Dena'ina cultures of the Nushagak and Kvichak River watersheds practice a subsistence lifestyle that developed over several thousand years of living in the area and depends primarily on salmon. At the same time the people have incorporated modern technology, political participation and educational standards into a successful transition into the modern world. As illustrated by the Elder and culture-bearer interviews, this lifestyle has built strong, connected networks of extended families and a culture based on sharing, traditional knowledge, and respect for the environment.

Most of the villages have schools (except Pedro Bay where children are home schooled), city government or tribal council, a health clinic, post office, small store, church, airstrip, and electricity and running water in most homes. Homes have radio and satellite TV and many are being connected to high-speed fiber-optic internet. Basketball games in the school gym and bingo at the council building, and sometimes Yup'ik and Dena'ina dancing, and communal sweatbaths are popular in the evenings. Four-stroke outboards on large skiffs, four wheelers, and snow-machines are everywhere. These changes are recent, however; up until about sixty years ago, traditional dog sleds and kayaks provided the transportation, and caring for dog teams took much time and effort. The availability of material goods from beyond the villages was limited, modern housing was nonexistent and formal education was mainly offered through boarding schools. The villages of the study area grew dramatically between 1980 and 2000, probably due to post-ANCSA changes in land-ownership (Fienup-Riordan 1994:39) and the population is now holding steady although there is local village variability.

These changes have resulted in some loss of traditional cultural practices; for instance, people no longer openly practice the Bladder Festival, *Kelek* or *Petugtaq*, although essential elements of these can be found in more informal practices, and in some cases transformed through corollary rituals in the churches (see Section III.F). Other changes have been more severe and have both made the communities more vulnerable to changes in their environment and placed them at higher risk for further cultural and individual losses. Examples of such changes include loss of control over traditional use areas, loss of community members to Western diseases and outmigration of young people, for either employment or education, the latter of which included, in the past, the involuntary placement of children in distant boarding schools, removed from the traditional culture (Interviews, 2011).

Some interviewees expressed a fear of the future that a traditional prophecy of "bad times" told by Elders might be coming true due to economic development resulting in cultural loss characterized as "anomie," the loss of meaningfulness, sense of belonging, and direction in life. The cultural and social impacts associated with Westernization have been described as anomie. Merton (1938: 682) gave a classic definition of anomie where he writes, "At the extreme, predictability virtually disappears and what may be properly termed cultural chaos or anomie intervenes." Anomie, the loss of meaningfulness, sense of belonging, and direction in life has occurred among all Alaskan Native cultures to one degree or another. Anomie increases cultural and individual risk for social ills such as depression and suicide, alcoholism and drug abuse, domestic violence, and aggressive behaviors. Healing practices can include those used for trauma and post-traumatic stress disorders, including traditional practices that reconnect the individual to society and the natural environment through meditative rituals. Traditional

drumming, singing, and dancing have been shown to be effective in treating trauma and post-traumatic stress. Culture camps and other methods of cultural revitalization (see Section III.E.4, 5) can be both preventative and healing for children and adults of indigenous cultures. It is critical to assess future risks and vulnerability, and take appropriate measures to reduce both.

Despite colonial disruptions to indigenous peoples in Alaska, the underlying cultures have so far endured among the Yup'ik and Dena'ina people of the study area because of a strong subsistence base. Wholesale changes to the ecosystem that supports their subsistence resources, however, whether they come from large-scale development, including mine development, climate change, high-seas overfishing, and/or declines in the ecological integrity of the North Pacific Ocean such as acidification, carry with them the risk of substantially altering the subsistence lifestyle and the fabric of Yup'ik and Dena'ina cultures. Among the specific potential risks associated with diminishment in either the quantity or quality of subsistence, and especially salmon, resources are:

- Degradation of nutrition and physical health due to diminishment of subsistence foods and lifestyle.
- Loss of political power due to becoming a minority in one's own homeland, if there is an influx of outsiders to the region due to extractive resource development.
- Deterioration in mental and emotional health due to the loss of traditional culture and meaning for life.
- Loss of language and traditional ways to express relationships to the land, one another, and spiritual concepts.
- Loss of meaningful work by extended families operating together as a cohesive unit.
- Reduction of gender equity resulting from loss of important economic activities and social networking opportunities, due to the potential diminishment of subsistence foods harvest and preparation, and replacement of this work with jobs that are typically more accessible to men (e.g. mining) or to fewer women (such as those who do not have small children).

- Loss of the means to establish and maintain strong social networks though sharing of subsistence foods.
- Impact on belief systems that revere clean water and a clean environment.
- Increased discord within and among villages between the majority and the minority over development issues within the villages has the potential to create long term rifts within the villages and between them.

In summary, salmon and clean water are foundational to the Yup'ik and Dena'ina cultures in the Nushagak and Kvichak watersheds. The people in this region not only rely on salmon for a large proportion of their highly nutritional food resources; salmon is also integral to the language, spirituality, and social relationships of the culture. Because of this interconnection, the cultural viability, as well as the health and welfare of the local population, are extremely vulnerable to a loss either quality or quantity of salmon resources

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V. APPENDIX 1. METHODOLOGY and TRIBAL LETTER OF INTRODUCTION

April 11, 2011,
Revised April 25, 2011,
Revised May 24, 2011

Purpose:

The purpose of this qualitative study is to describe the subsistence, nutritional, social, linguistic, and spiritual importance of salmon to the Yup'ik and Dena'ina of the Nushagak and Kvichak River drainages of Bristol Bay. This information will be integrated into a larger study, called the Bristol Bay Assessment, coordinated by the Environmental Protection Agency to be used to determine to proceed with a Section 404c review of the Clean Water Act. This action was requested by nine tribes/villages of the Bristol Bay region. If approved, 404c designation would prohibit any discharge into, fill, or similar modification of a stream or river in the region or other actions that would impact the subsistence fishery.

Design:

The product of this study consists of two parts.

A. Summary of existing research: One part of this assessment consists of a literature and gray literature search and summary of the culture history, linguistic, subsistence and other aspects of cultural lives of the traditional and cultural lives of the Nushagak and Kvichak drainage people as it relates to streams and fishery subsistence, particularly salmon

B. Elder and Culture Bearer Interviews: Second, this study will incorporate Elder and culture bearer interviews to ascertain the importance of salmon and other stream-related resources and places in the ideal culture of the people. Ideal culture is a standard to aspire to and thus is a measure of values and ideology that form the core of the people's contemporary identity. We are not undertaking a statistical sample of attitudes reflecting everyone in the culture, but listening to culture bearers who have the status of expert witnesses and act as spokespeople for their respective cultures.

The remainder of this methodology will describe the Elder and culture bearer interviews.

Selected Villages

Both time and money prohibit interviews in all villages in the region. Since this is not a statistical study, nor a hearing, we believe that a self-selected group of Elders and culture bearers

can best represent the perspective of the region. We intend to interview Elders and culture bearers from six villages.

Semi-Structured Questions:

The interview format will be semi-structured, meaning the same questions will be asked of each of the Elder/culture bearers. The questions are intentionally open-ended and intended to elicit narrative responses. If an Elder/culture bearers wishes to provide additional information or talk about subjects beyond the scope of the question, that, of course, will be recorded.

Interview Questions

Draft Interview questions will be formulated in the following categories:

- Subsistence
- Nutrition
- Language and Stories
- Place names and Special/Spiritual places
- Social Factors
- Spirituality related to streams and fishery

The draft interview questions will be distributed for review by

- Village councils or similar authority
- E.P.A. personnel
- Selected anthropologists

and reformulated and condensed as needed.

Self-Selection

Village councils, traditional councils, or similar entity will be asked to select Elders/culture bearers to be interviewed. We anticipate this will involve about three men and three women in each village.

Release

Interviewees will be asked to sign a consent form allowing the interviewers to use the recorded and transcribed interviews in a written document. In addition the village councils will be asked to sign a release form for the village to permit photographs and video both of individuals or the village to be taken and potentially used in the final product. Restrictions will be respectively adhered to.

Recording and Transcription

Interviews will be recorded either individually or in small groups. A digital recording and transcription will be made. Elders may wish to speak in Yup'ik in which case we ask a translator

provide a summary at the time of the interview. Elders and culture bearers will be paid according to current standards for village/Elder interviews. The interviews will be approximately two-hours and conducted at a comfortable place.

The interviews will be transcribed into MS Word documents and both the recording and transcription be archived either at the National Park Service Alaska or suitable repository. Copies of recordings and transcriptions will be sent to tribal councils.

Coding

Word document interviews will be coded. Key words will be set up for use in identifying the subject of the paragraph of the transcribed recording. For example, through sophisticated searches everyone who responded to or used the term "sharing salmon" will be electronically listed and some or all of these responses either quoted or paraphrased in the final document.

Confidentiality

According to Institutional Review Board standards, names of interviewees will not be revealed in the final document. Each interviewee will be asked to sing a consent form that includes the voluntary nature of the interview, confidentiality, and that there is no known or perceived risk in granting the interview.

Peer Review

Both drafts and a final document will undergo peer review. For the purpose of this study anthropologists, EPA reviewers, other scholars, and Village Elders or Culture Bearers are peers.

Community Review

The final draft will be sent to communities who have participated in this study for their review.

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March 1, 2011

To Whom It May Concern:

The purpose of this letter is to formally introduce our friend and honorary Kenaitze Tribal member, Dr. Alan Boraas. Dr. Boraas has worked with and on behalf of our Tribe for over 30 years. We have found him to be ethical, fair, and responsive to our requests for confidentiality. He respects our Dena'ina culture, traditions, and values, and lives them.

Dr. Boraas asked for this letter of introduction in observance of tribal protocol and because he values and respects our rights to sovereignty and self determination. We have no doubt that you will find him to be a man of integrity who shares our love for our waters and lands.

Please feel free to contact me if you have any questions or concerns.

Sincerely,

Jaylene Peterson Nyren
Executive Director
Kenaitze Indian Tribe

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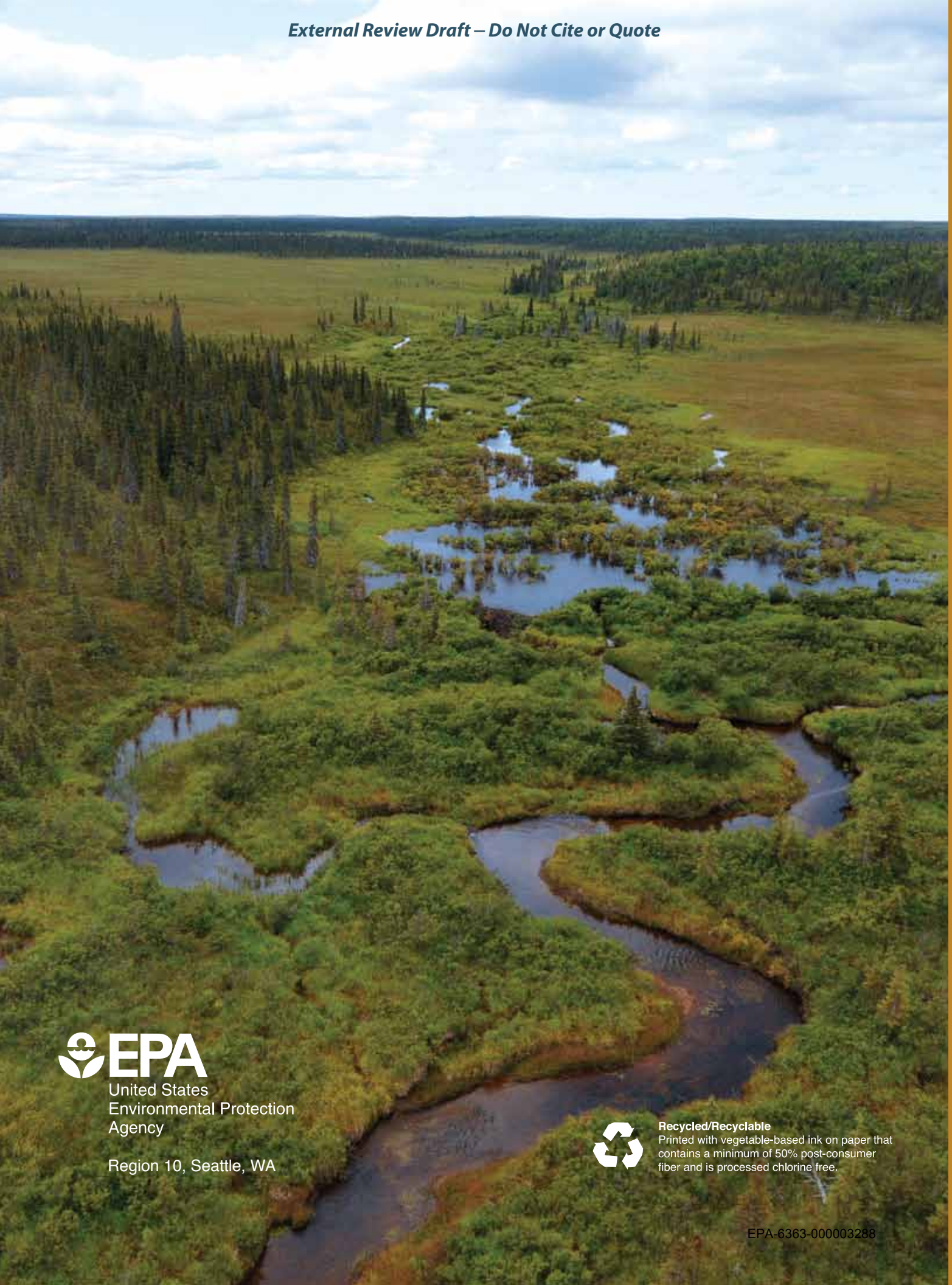

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