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

Volume 3—Appendices E-J

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

Biological Characterization: An Overview of Bristol, Nushagak, and Kvichak Bays; Essential Fish Habitat, Processes, and Species Assemblages

December 2013

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PREFACE

The Bristol Bay watershed supports abundant populations of all five species of Pacific salmon found in North America (sockeye, Chinook, chum, coho, and pink), including nearly half of the world's commercial sockeye salmon harvest. This abundance results from and, in turn, contributes to the healthy condition of the watershed's habitat. In addition to these fisheries resources, the Bristol Bay region has been found to contain extensive deposits of low-grade porphyry copper, gold, and molybdenum in the Nushagak and Kvichak River watersheds. Exploration of these deposits suggests that the region has the potential to become one of the largest mining developments in the world.

The potential environmental impacts from large-scale mining activities in these salmon habitats raise concerns about the sustainability of these fisheries for Alaska Natives who maintain a salmon-based culture and a subsistence lifestyle. Nine federally recognized tribes in Bristol Bay along with other tribal organizations, groups, and individuals have petitioned the U.S. Environmental Protection Agency (EPA) to use its authority under the Clean Water Act to restrict or prohibit the disposal of dredged or fill material from mining activities in the Bristol Bay watershed. In response to these petitions and to better understand the potential impacts of large-scale mining, the EPA is conducting an assessment of the biological and mineral resources of the Bristol Bay watershed to inform future government decisions related to protecting and maintaining the physical, chemical, and biological integrity of the watershed. As part of this process, the EPA requested assistance from National Marine Fisheries Service (NMFS) as the agency responsible for the nation's living marine resources.

The EPA assessment focuses on salmon populations, their habitat, and the supporting ecosystem processes in the Nushagak and Kvichak watersheds. Under Section 305(b)(2) of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson Stevens Act), NMFS has designated the region's fresh and marine waters as Essential Fish Habitat (EFH) for anadromous salmon, groundfish, and other invertebrate species. EFH for salmon consists of the aquatic habitat necessary to support a long-term sustainable salmon fishery and salmon contributions to healthy ecosystems. Natural wild salmon populations are currently stable and abundant, and their habitat at the ecosystem scale, from headwater streams through marine processes, is functionally intact.

This report summarizes our current understanding of the region's oceanic and freshwater influence on the nearshore areas of Nushagak and Kvichak Bays; of the invertebrate, fish, and marine mammal assemblages found east of 162° West longitude; and of the range and distribution of Bristol Bay salmon. This report also highlights our understanding of the trophic contribution of Bristol Bay salmon both as smolt leaving the watersheds and as returning adults and our understanding of the importance of estuaries and nearshore habitat as nutrient rich nursery areas for numerous marine species.

ACKNOWLEDGEMENTS

This report was compiled and written by Douglas Limpinsel, NOAA Fisheries, Habitat Conservation Division, Alaska Region. Robert McConnaughey, NOAA Fisheries, Alaska Fisheries Science Center, and Jeanne Hanson and Jim Hale, NOAA Fisheries, Alaska Regional Office, provided technical and editorial reviews that improved the organization and readability of this report. The following people also contributed in various ways to this discussion:

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NOAA/NMFS - Alaska Fisheries Science Center and National Marine Mammal Lab: Robin Angliss, Kerim Aydin, Steve Barbeaux, Troy Buckley, Daniel Cooper, Keith Cox, Douglas Demaster, Edward Farley, Robert Foy, Sarah Gaichas, Jeffry Guyon, Paula Johnson, Sonja Kromann, Robert Lauth, Jamal Moss, Philip Mundy, James Murphy, Daniel Nichol, Olav Ormseth, Elizabeth Sinclair, Thomas Wilderbuer

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ABSTRACT

This report summarizes our current understanding of Bristol Bay as Essential Fish Habitat (EFH) for salmon at various life stages as well as for other species of marine invertebrates, fish, and marine mammals. As an ecosystem, the currently healthy habitat of the bay both supports and results from the interactions between natural processes and the presence and abundance of all five species of Pacific salmon. As a keystone species, Bristol Bay salmon facilitate energy and nutrient transport to and from the inner bay's terrestrial watersheds and the marine ecosystems of the eastern Bering Sea. Outbound migrations of billions of salmon smolts provide nutrition to numerous trophic levels and marine species, and salmon returning in their adult phase provide a valuable nutrient source to marine mammals and subsidize watersheds in the form of salmon-derived nutrients.

Table of Contents

BRISTOL BAY

Overview

Bristol Bay is a large, shallow sub-arctic bay (Buck et al. 1974, Straty 1977, Straty and Jaenicke 1980, NOAA 1997 and 1998, Wilkinson 2009). Its benthic topography is essentially flat, with an average gradient of 0.02 percent and a maximum depth of approximately 70 meters at the 162° West longitude line (Moore 1964, Buck et al. 1974). The substrate throughout the bay consists of silts and mud and vast aggregates of sand, gravel, cobble, and boulder (Sharma et al. 1972, NOAA 1987; see Smith and McConnaughey 1999 for a detailed description of benthic substrate).

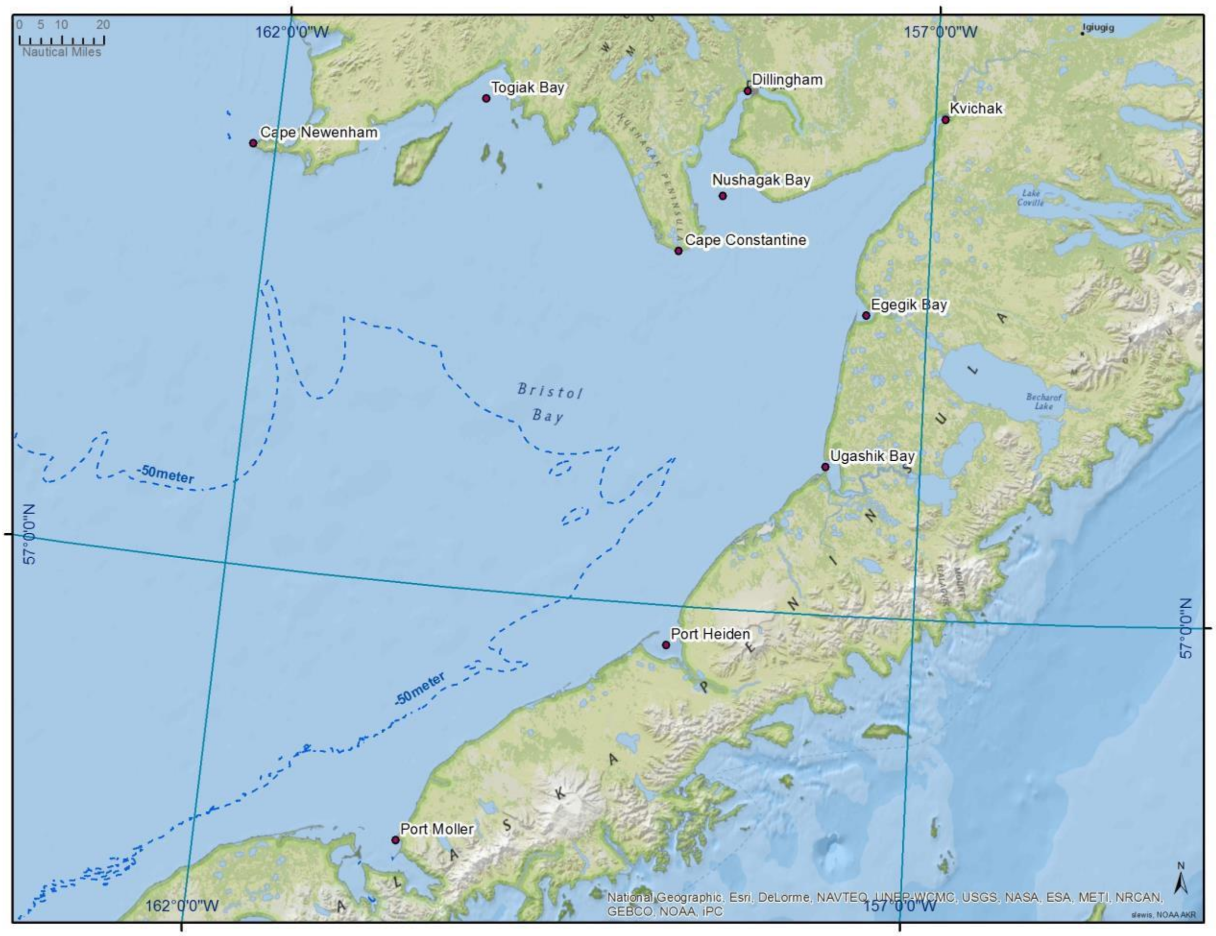

Fig1. Bristol Bay. Waters east of the 162° West longitude line are defined by the North Pacific Fishery Management Council as the Bristol Bay No-Trawl-Zone Protected Area.

The chemical properties of Bristol Bay waters are highly variable and constantly shift under the influence of dramatic currents, tide cycles, and severe weather events from the Bering Sea in the west and the influence of terrestrial freshwater discharges from Nushagak River, Kvichak River, and a number of other, smaller rivers in the east.

Earlier literature distinguishes the inner bay from the outer bay by physical properties such as salinity, temperature, and turbidity (Buck et al. 1974, Straty 1977, Straty and Jaenicke 1980). More recent investigations, however, distinguish different parts of the bay by depth, with an inner or coastal domain from the shoreline to 50 meters deep, a middle domain from 50 to 100 meters deep, and outer domain beyond the 100-meter contour (Kinder and Coachman 1978, Kinder and Schumacher 1981, Coachman 1986, Schumacher and Stabeno 1998, Stabeno et al. 2001**).**

Inner bay processes are continuously fed large volumes of fresh water from numerous watersheds, with salinity increasing toward the 162° West longitude line, while currents from the eastern Bering Sea move through the bay in a counter-clockwise gyre under the influence of tides ranging from 3 to 23 feet (Buck et al. 1974, Straty 1977, Straty and Jaenicke 1980).

Marine Influence

Bristol Bay is essentially an extension of the eastern Bering Sea. Flood tides from the North Pacific enter the eastern Bering Sea through several Aleutian Island passes contributing to the Aleutian North Shore Current (Schumacher et al. 1979, Reed and Stabeno 1994, Stabeno et al. 2002 and Stabeno et al. 2005). East of Unimak Pass, the marine current flows northeast as the Bering Coastal Current along the Alaska Peninsula and into Bristol Bay where it turns in a counter-clockwise gyre (Kachel 2011, pers. comm.). The majority of this current diverts north near the 50-meter contour and eventually flows west and then north around Cape Newenham toward Nunivak and Pribilof Islands (Coachman 1986). Part of the current, however, continues east and delivers marine nitrates, carbon, phosphates, and silica into the inner bay. These mix with fresh water discharges and dissolved organic material from several river systems at the eastern end of the bay (Buck et al. 1974, Stockwell et al. 2001, Kachel et al. 2002, Coyle and Pinchuk 2002, Stabeno and Hunt 2002, Ladd et al. 2005).

Fresh Water Influence

Estuarine characteristics of Nushagak and Kvichak Bays are the result of continual freshwater runoff from several watersheds (Straty 1977, Buck 1974, Straty and Jaenicke 1980). Four large rivers flow into Nushagak Bay: the Igushik, Snake, Wood-Tikchik and Nushagak; and three rivers flow into Kvichak Bay: the Naknak, Alagnak, and Kvichak. The discharge of these rivers contributes to the estuarine character of these bays (Buck et al. 1974). Of the rivers that drain into the inner domain, we measure the discharge of only two, the Nushagak and Kvichak Rivers, which together drain 22,172 square miles (14,190,134 acres) of watershed (USGS 2011). The Nushagak River has a mean annual discharge of 28,468 cubic feet per second (CFS) based on readings from the Nushagak River gauge (USGS No. 15302500, 23,645 cfs) and the Wood River gauge (USGS No. 15303000, 4,823 cfs). The Kvichak River has a mean annual discharge of 17,855 cfs based on readings from the USGS gauge (15300500) located at the outlet of Lake Iliamna. If these three gauges represent an accurate estimate, the total discharge is 46,323 cfs, or approximately 33,536,000 acre feet squared per year. This fresh water influence dominates Nushagak and Kvichak Bays between April and November creating the characteristic estuarine water chemistry. Other sources of fresh water also discharge into Bristol Bay and influence the water quality, but their flows are not monitored and cannot be currently included in estimates.

Out-welling freshwater contributions are significantly higher in spring and summer when winter snow and ice melt and rains are prevalent. As a result, summer ebb tide currents often considerably exceed the flood tides. Discharge from the watersheds keeps the waters of Nushagak and Kvichak Bays colder in early spring; however, by mid-summer these temperatures reverse with warmer terrestrial discharges (Buck et al. 1974). Furthermore, the counter-clockwise current pushes freshwater discharge from Kvichak Bay into Nushagak Bay which maintains a slightly lower salinity. Generally, lower sea surface salinity measurements are observed in Nushagak Bay than in Kvichak Bay (Radenbaugh 2011, pers. comm.).

Because of this seasonal terrestrial freshwater influence, Nushagak and Kvichak Bays exhibit the lowest salinity and greatest temperature fluctuation in Bristol Bay (Buck et al. 1974, Straty and Jaenicke 1980). Similar temperature and salinity gradients have been observed in the inner domain (temperature 11.4 °C, salinity 28.9%) and the middle domain (temperature 7.4 °C, salinity 32.7%) (NOAA 1987). Marine characteristics then dominate off shore. More recent analyses and descriptions of oceanographic currents and nutrients generally describe shallow, wind-driven, well-mixed, homogenous, nutrient-laden waters (Coyle and Pinchuk 2002, Kachel et al. 2002, Stabeno and Hunt 2002).

Bristol Bay - Fish and Invertebrate Assemblages

<u>Nushagak and Togiak Bays</u>

Recent mid-water surveys in Nushagak Bay have found the dominant species in numbers and biomass to include bay shrimp (*Crangon alaskensis*) and Gammarid amphipods and mysiids (*Gammarus* sp.) and confirm the presence of walleye pollock (*Theragra chalcogramma*, a marine pelagic species) and flatfish species (*Pleuronectiformes*) such as yellowfin sole (*Limanda aspera*) in this nearshore habitat (depths less than 30m), along with numerous other fish and invertebrate species (Radenbaugh 2010, pers. comm.). Additional surveys specific to Nushagak Bay shore line at low tide captured over 6,000 fish of 17 species. Two species accounted for 95% of the total catch: rainbow smelt and pond smelt (*Hypomesus olidus*) (Johnson 2012).

Recent surveys conducted in both Nushagak and Togiak Bays encountered over 40 fish and invertebrate species (Olmseth 2009). Most captured individuals were less than 20 cm in length. Of these species, shrimp (*Crangonidae*) and rainbow smelt (*Osmerus mordax*) were the most abundant species encountered, occurring in almost every trawl and beach seine, and were especially dominant in very shallow water with mud and silt bottoms. Forage fish species identified by these surveys were salmon smolt (*Salmonidae*), capelin (*Osmeridae*) and Pacific herring (*Clupeidae*), as well as poachers (*Agonidae*), sculpin (*Cottoidea*), flatfish (*Pleuronectidae* and *Bothidae*), and greenling (*Hexagraaidae*).

Nearshore

In addition to the surveys of Nushagak and Togiak Bays, surveys of other nearshore waters of Bristol Bay document forage fish species such as Pacific herring, eulachon (*Thaleichthys pacificus*), capelin, and rainbow smelt (Warner and Shafford 1981, Mecklenburg et al. 2002, Bernard 2010). In an evaluation of historical data, Gaichas and Aydin (2010) found that salmon smolts rank as one of the top ten nearshore forage fish. Pacific herring are also known to spawn in nearshore waters of Togiak Bay and along the northern shoreline of the Alaska Peninsula (Bernard 2010). Sand lance (*Ammodytes hexapterus*) have been found in particular abundance in these nearshore waters of the Alaska Peninsula (McGurk and Warburton 1992).

Surveys conducted to characterize the presence and distribution of forage fish species in Bristol Bay nearshore waters also identified several species of groundfish: Pacific cod (*Gadus macrocephalus*) and walleye pollock, as well as juvenile sockeye salmon (*Oncorhynchus nerka*) (Isakson et al. 1986, Houghton 1987). During one phase of these surveys, juvenile sockeye salmon were more abundant than any forage fish or juvenile ground fish species encountered. Present again, though in fewer numbers, were Pacific herring, capelin, pond and surf smelt, and eulachon. The presence, abundance, and biodiversity of these species in Bristol Bay nearshore habitat support our current understanding of these areas as nutrient rich fish nurseries.

Similar surveys of nearshore habitat conducted in neighboring Alaskan waters further illustrate the complexity and diversity of fish and invertebrate assemblages (Norcross et al. 1995, Abookire et al. 2000, Abookire and Piatt 2005, Arimitsu and Piatt 2008, Thedinga et al. 2008, Johnson et al. 2010). Anadromous species, as well as groundfish, forage fish, and invertebrate species, are all well represented in many of these nearshore areas in a variety of different habitat and substrate types and water conditions.

Offshore

Fisheries surveys of the offshore waters of Bristol Bay have been conducted since the 1930s. The AFSC has conducted annual surveys in the eastern Bering Sea offshore and outer Bristol Bay waters since 1982 using standardized gear and repeatable methods. These surveys identify numerous groundfish species inhabiting the eastern Bering Sea and Bristol Bay, generally deeper than the 15-20m contour (Lauth 2010)[1]. The more common species represented in the surveys are cod and pollock (*Gadidae*); fifteen species of flatfish (*Pleuronectiformes*); forage fish species such as herring, eulachon, capelin, smelts, sand lance, and sandfish; and dozens of other species well represented, such as skate (*Rajidae*), poachers (*Psychrolutidae*), greenling (*Hexagrammos*), rockfish (*Scorpaenidae*), sculpin (*Cottidae*), crab (*Cancer*), and salmon. In Table 1 we identify all species known to inhabit these waters.

The hundreds of fish species and invertebrate species that inhabit Bristol Bay waters contribute to trophic levels at various life stages; tides and currents transport and distribute larval marine fish and invertebrate species from offshore to nearshore nursery areas (Norcross et al. 1984, Lanksbury et al. 2007). The relationship between marine and nearshore processes and species presence in Bristol Bay has been well documented in the life histories of species such as walleye pollock, red king crab (*Paralithodes camtschaticus*), and yellowfin and rock sole. Larval forms of each species are transported and concentrated in nutrient-rich nearshore habitat. These four species illustrate relevant examples of recognized marine species with population segments that in a larval or juvenile phase rely on nearshore marine habitat (depths less than 30 m) for refuge and nutrition.

Walleye pollock are generally recognized as a pelagic species spawning in open marine waters (Bailey et al. 1999). As Coyle (2002) notes, pollock in their larval and juvenile forms are known to be transported into nearshore nursery zones: the current carries the eggs and larvae along the north shore of the Alaska Peninsula and into the nearshore nursery zones of Bristol Bay (Napp et al. 2000). A recent investigation of trophic interactions shows that juvenile pollock feed on euphasiid and mysiid populations nearshore, especially mysiids, which have been shown to be more abundant in the diets of pollock found in the northern nearshore zones than those found in deep water (Aydin 2010).

Bristol Bay is also home to the second-largest population of red king crab (Dew and McConnaughey 2005, Chilton et al. 2010). Although red king crab of both genders and several stages of maturity occur throughout central Bristol Bay, immature larvae and juveniles are often concentrated along nearshore areas. The Aleutian North Shore and Bering Coastal currents transport larval king crab from the eastern Bering Sea to inner Bristol Bay (Dew and McConnaughey 2005). Larval red king crab (smaller than 2 mm) settle in cobble and gravel substrates of Kvichak Bay[2] (Armstrong et al. 1981, McMurray 1984, Loher et al. 1998); juveniles are present along the nearshore zone in the Togiak district (Armstrong et al. 1993,

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[1] All species were found east of the 162° West longitude line and in waters deeper than 15m. Because the surveys represent a snap shot of species present at a particular time, they may not represent complete species diversity. Also, because standardized trawl gear mesh is size selective, juvenile and larval specimens of a species may not be well represented. It is important to note that salmon species at any life stage may not be well represented due to seasonality of surveys and species migration.

[2] Larval red king crab were present on substrates less than 70 to 80 feet (approximately 21 to 24 meters) at mean low water in Kvichak Bay.

Olmseth 2009). These juvenile phases inhabit nearshore rocks, shell hash, or a variety of biological cover in shallow depths (from 5 to 70 meters).

Yellowfin and rock sole are among several species of flatfish that inhabit the eastern Bering Sea and for which nearshore substrates (depths less than 30 meters) in Bristol Bay are optimal habitat (McConnaughey and Smith 2000, Lauth 2010; Table 1). Life histories of these species and other flatfish take advantage of the same currents that transport larvae into nearshore nursery areas (Nichol 1998, Wilderbuer et al. 2002, Norcross and Holladay 2005, Lanksbury et al. 2007, Cooper et al. 2011). Larval and juvenile yellowfin sole are abundant in shallow nearshore areas along the northern shore and Togiak Bay (Olmseth 2010, Nichol 1998, Wilderbuer et al. 2002).

These findings for Pollock, red king crab, and yellowfin and rocksole substantiate our understanding of nearshore and estuary zones as nutrient rich fish nurseries, providing juvenile fish species with greater forage opportunity in the form of abundant invertebrate populations.

Bristol Bay – Salmon

The ecological role of Bristol Bay salmon is complex. Salmon facilitate energy and nutrient exchange across multiple trophic levels from terrestrial headwaters through estuarine and marine ecosystems. Each species migrates through these waters at slightly different times depending on life history and watershed of origin. Because of their abundance, distribution, and overall economic importance, Bristol Bay sockeye salmon have been more extensively studied than other salmonids in the region. Generally, once in marine waters juvenile salmon spend their first summer in relatively shallow waters on the southeastern Bering Sea shelf, feeding, growing and eventually moving offshore into the Bering Sea basin and North Pacific Ocean (Meyers et al. 2007, Farley et al. 2011, Farley 2012, pers. comm.).

<u>Range and Distribution</u>

The Magnuson-Stevens Act defines EFH as “waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” For salmon, EFH consists of those fresh and marine waters needed to support healthy stocks in order to provide long-term sustainable salmon fisheries. Because of the broad range and distribution of salmon in Alaskan waters, all marine waters over the continental shelf in the Bering Sea extending north to the Chukchi Sea and over the continental shelf throughout the Gulf of Alaska and in the inside waters of the Alexander Archipelago are defined as EFH for all juvenile salmon (Echave et al. 2011). EFH for immature and mature Pacific salmon (*Oncorhynchus spp*) includes nearshore and oceanic waters, often extending well beyond the shelf break (Echave et al. 2011).

In their emigration phase, anadromous juvenile salmon occupy shallows of estuaries and nearshore zones, although timing, duration, and abundance vary throughout the year depending on species, stock, and life history stage (Groot and Margolis 1991, Quinn 2005). Nearshore and estuarine habitats act as transition zones supporting osmoregulatory changes (the physiological changes by which smolt adapt between fresh and salt water) (Hoar 1976 and 1988, Clarke and Hirano 1995, Dickhoff et al. 1997). Studies have shown that sub-yearling salmon in the Pacific Northwest move repeatedly between zones of low and high salinity, and although no studies have yet shown Bristol Bay salmon to behave similarly, the Pacific Northwest studies suggest that such behavior may be integral to the survival and growth of young salmon (Healey 1982, Levings 1994, Levings and Jamieson 2001, Simenstad et al. 1982, Simenstad 1983, Thom 1987).

The eastern Bering Sea shelf is an important nursery ground for juvenile and sub-adult Bristol Bay sockeye salmon (Farley et al. 2009). Early models of eastern Bering Sea and North Pacific salmon stocks describe migrations and broad distributions to the south and east in winter and spring and to the north and west in summer and fall (French et al. 1975, French et al. 1976, Rogers 1987, Burgner 1991, Shuntov et al. 1993). These studies were the first to suggest that population migrations crossed the Aleutian Island chain into the North Pacific (Myers et al. 1996, Myers 2011 pers. comm.). Recent investigations incorporating genetic (DNA) and scale pattern analysis validate these observations (Bugaev 2005, Farley et al. 2005, Habicht et al. 2005, Habicht et al. 2007, Myers et al. 2007). Investigations conducted in autumn 2008 and winter 2009 substantiate the migration of juvenile Bristol Bay sockeye salmon from the Eastern Bering Sea shelf to the North Pacific, south of the Aleutian Island chain (Habicht et al. 2010, Farley et al. 2011, Seeb et al. 2011):

> In their first oceanic summer and fall, juveniles are distributed on the eastern Bering Sea shelf, and by the following spring immature salmon are distributed across a broad region of the central and eastern North Pacific. In their second summer and fall, immature fish migrate to the west in a band along the south side of the Aleutian chain and northward through the Aleutian passes into the Bering Sea. In subsequent years, immature fish migrate between their summer/fall feeding grounds in the Aleutians and Bering Sea and their winter habitat in the North Pacific. In their last spring, maturing fish migrate across a broad, east-west front from their winter/spring feeding grounds in the North Pacific, northward through the Aleutian passes into the Bering Sea, and eastward to Bristol Bay. (Farley et al. 2011)

More than 55% of ocean age-1 sockeye salmon sampled during the 2009 winter survey in the North Pacific were from Bristol Bay stocks. These broad seasonal shifts in distribution likely reflect both genetic adaptations and behavioral responses to environmental cues (e.g., prey availability and water temperature) that are mediated by bioenergetic constraints (Farley et al. 2011). This extensive range and distribution suggest that Bristol Bay sockeye salmon contribute to the trophic dynamics in the Bering Sea as well as the North Pacific.

Salmon Contribution to Trophic Levels

A recent evaluation was conducted by the AFSC Ecosystem Modeling Team to assess the contribution of Nushagak and Kvichak River sockeye salmon to trophic dynamics of the eastern Bering Sea shelf and North Pacific ecosystems (Gaichas and Aydin 2010). Using estimates of outbound salmon smolt survival and adult returns, researchers calculate that these two rivers account for nearly 70% (56,000 of 81,100 tons) of adult salmon biomass in the eastern Bering Sea. In the open ocean, sockeye salmon represent 47% of total estimated salmon biomass present in the eastern subarctic gyre (Aydin et al. 2003). Bristol Bay sockeye salmon from the Nushagak and Kvichak Rivers compose 26% of total sockeye salmon biomass and 12% of total salmonid biomass in the entire eastern subarctic gyre. The Nushagak and Kvichak Rivers produce a significant portion of all salmon in offshore marine ecosystems and the majority of salmon on the eastern Bering Sea shelf, thus producing the majority of juveniles and returning adults in the salmon biomass (Gaichas and Aydin 2010). The AFSC's evaluation indicates sockeye salmon from these river systems rank among the top ten forage groups, comparable to Pacific herring or eulachon as a nutritional source for other marine species in the Bering Sea and North Pacific. One study supports this rational indicating that outbound salmon smolt export substantial levels of nitrogen and phosphorus seaward (Moore and Schindler 2004).

Returning adult salmon enrich watersheds in the form of salmon-derived nutrients (Gende et al. 2002, Schindler et al. 2003, Wilson et al. 2004), and these nutrients are flushed back into estuaries by out-welling[3] river waters. Salmon-derived nutrients are transported in the form of partial and whole salmon carcasses or particulates and dissolved nutrients (carbon, nitrogen and phosphorous) moving from watersheds back to the estuaries. Early studies identified the flow of salmon carcasses out of the coastal watersheds into marine estuaries as a result of high precipitation events (Brickell and Goering 1970, Richey et al. 1975). Salmon-derived nutrients stimulate primary production in estuaries where nitrogen and phosphorus are often limiting nutrients (Rice and Ferguson 1975). Estuarine algae use dissolved nutrients, in turn feeding copepods which feed juvenile salmon (Fujiwara and Highsmith 1997). One investigation identified several species of marine invertebrates feeding on salmon carcasses (Reimchen 1994). Stationary whole salmon carcasses were completely consumed in a week. Gende (2004) estimated that 43% of the tagged salmon carcasses washed into the study estuary within days. More recent investigations conducted in Alaskan waters suggest that 60% of the total nutrient or biomass transported into the watershed by salmon may be transported back to the estuary (Johnston et al. 2004, Mitchell and Lamberti 2005).

[3] Terrestrial freshwater runoff from large river systems and watersheds drains into marine estuaries. In referenced literature, this runoff is often referred to as "outflow" or "outwelling." Outwelling freshwater chemistry, temperature, and nutrient plumes influence marine estuary chemistry, productivity, and salinity gradients.

In Nushagak and Kvichak Bays, nutrients liberated from tens of millions of decomposing adult salmon likely have a significant influence on estuarine trophic interactions and biodiversity in the manner discussed above. Estuarine processes such as primary and secondary production and countless marine fish and invertebrate species benefit from this mass transport of nutrients. Numerous studies indicate that marine estuarine vegetation and larval and juvenile invertebrate and fish populations benefit from enrichment of nutrients flushed back into the marine estuaries. The influence of outwelling freshwater and nutrients from watersheds and terrestrial river systems on marine estuaries and processes can be substantial.

Bristol Bay - Marine Mammals

The eastern Bering Sea supports numerous species of marine mammals including whales (*Cetacea*) of the suborders Odontoceti (toothed whales and porpoise) and Mysticeti (baleen whales). Several species of seals (pinnipeds) are also represented (*Otariidae*, *Phocidae*, and *Odobenidae*) in these waters (Allen and Angliss 2011). Of marine mammals present in the eastern Bering Sea, twenty species occur in Bristol Bay waters in significant numbers and regularity (Table 2). Three species of baleen whale (fin, right and humpback whales) and one pinniped species (Western Distinct Population Segment Steller sea lion) found in Bristol Bay are listed as endangered under the Endangered Species Act. The seven species we discuss below are those Bristol Bay marine mammals known to feed on salmon.

In Bristol Bay, the presence of marine mammals and their prey species is highly variable depending on the season and location within the bay. For example, the presence and feeding habitats of sea lions or fur seals are difficult to identify because of variations in their seasonal range, in whether they are at sea or in rookeries, and in the migratory patterns of their prey. Less is known about pinniped prey selection in the open ocean because scat and stomach content studies are only conducted while specimens are on the rookery. Thus, the only prey species represented in dietary analysis are prey species near the rookeries.

Some marine mammal diet data show seasonal dependence on salmon. Several studies demonstrate that salmon are a prominent nutritional source for several marine mammal species (Pauly et al. 1998a). Many marine mammals, especially pinniped and ondontocete species, prey on adult and juvenile salmon in nearshore and estuary zones.

<u>Pinnipeds</u>

*Steller Sea lion*s

Steller Sea lion predation on salmon has been confirmed by data from scat and stomach content studies from which researchers have estimated the level of consumption and frequency of occurrence (NMFS 1992, Merrick 1995, Merrick et al. 1997, Sinclair and Zeppelin 2002, Trites and Donnelly 2003, Jemison 2011, pers. comm.). Depending on seasonal range and migratory patterns, salmon ranked high as a selected prey species in Steller sea lion diets (Sinclair and Zeppelin 2002). The endangered western stock of Steller sea lions relies on salmon during summer; salmon rank second in frequency of occurrence in summer diets in regions sampled between 1990 and 1998 (Sinclair and Zeppelin 2002). These regions include the Bering Sea shelf and waters surrounding the Aleutian Islands, where salmon were noted to increase in diets during winter due to out-migrating sub-adult Bristol Bay salmon (Sinclair and Zeppelin 2002).

Fur seals

Fur seals also feed on salmon throughout the Pacific range, from California to Alaska (Perez and Bigg 1986). One more recent investigation conducted to determine prey species of northern fur seals in the Pribilof Islands indicates salmon composed part of the diet of fur seals on St. George and St. Paul Islands (Sinclair et al. 2008). Pacific salmon had a mean annual frequency of occurrence of 14.4%, and 10% in any one year on St. George and St. Paul Islands respectively. Similar nutrition studies of eastern Bering Sea northern fur seals indicate salmon rank second among fish in frequency of occurrence for animals on both Pribilof Islands from late July through September, 1990-2000 (Gudmundson et al. 2006).

Harbor seals

Harbor seals also are found throughout Bristol Bay and the eastern Bering Sea and prey upon species of Pacific salmon (Jemison et al. 2000, Small et al. 2003, Allen and Angliss 2011, Jemison 2011, pers. comm.). The Bristol Bay population of harbor seals numbers approximately 18,000 seals and is increasing (Allen and Angliss 2013). Lake Iliamna supports a year-round population of harbor seals, which are currently included as part of the Bristol Bay stock. The number of seals residing in Lake Iliamna is relatively small; aerial surveys of hauled-out harbor seals count as many as 321 (which counts do not reflect absolute abundance) (Mathisen and Kline 1992, Small 2001, Burns et al. 2012; Migura 2013, pers. Comm.). Although this population has colonized Lake Iliamna from Bristol Bay via the Kvichak River, no scientific evidence shows that harbor seals migrate to and from Bristol Bay. However, some residents and Alaska Native subsistence hunters in the Iliamna Lake area say that harbor seals are seen within the entire expanse of the Kvichak River and migrate between the lake and Bristol Bay (Migura 2013, pers. Comm.). Harbor seals have also been identified in the Nushagak and Wood River systems. In the Wood River system, harbor seals are observed in Lake Aleknagik (B. Andrew 2011, pers. comm., D. Chythlook 2011, pers. comm., Tinker 2011, pers. comm.).

Spotted seals

Spotted seals have also been sighted in Bristol Bay. Other spotted seals tagged in Alaskan and Russian sectors of the Bering Sea show clear seasonal preference for nearshore habitat and associated fisheries, which suggests that spotted seals sighted in Bristol Bay may have a persistent presence there. These populations feed mostly on salmon, saffron cod (*Eleginus gracilus*), and herring (Burkanov 1989, Lowery et al. 2000).

Whales: Toothed Whales

Beluga whales

Beluga whales are abundant in Bristol Bay waters primarily from spring through fall near the mouths of the Kvichak, Nushagak, Wood, and Igushik rivers. Early studies document the importance and contribution of sockeye salmon for beluga nutrition (Brooks 1955). Lensink (1961) notes that belugas fare poorly in Bristol Bay when migratory (anadromous) fish are not available. In addition to following the general movements of its prey, belugas appear to feed specifically where their prey species are most concentrated. The frequency of occurrence of salmon species in beluga stomachs is correlated with the abundance of each species during their respective migrations (Brooks 1955). Studies conducted by Brooks in the 1950s further indicate that beluga whales feed on both juvenile and adult salmon, as well as on several other forage fish and invertebrate species (Klinkhart 1966).

From 1993 to 2005, the beluga population increased in abundance by 4.8% per year, and while thresholds of prey abundance needed for belugas to thrive are not fully understood, the larger size of red salmon runs before and during the period covered by aerial surveys may partially explain the increased beluga numbers (Lowry et al. 2008). Belugas are well known to travel up these regional rivers in pursuit of salmon. They have been seen feeding on salmon in the Kvichak River past Levelock to the Igiugig Flats (Cythlook and Coiley 1994, G. Andrew 2011, pers. comm.). Traditional knowledge also indicates that beluga whales have also been seen in Lake Illiamna (M. Migura 2013, pers. comm.). In summer, belugas are routinely observed in the Nushagak River (P. Andrew 2011, pers. comm.). In the Wood River system, belugas have been observed in Lake Aleknagik (Fried et al. 1979, B. Andrew 2011, pers. comm, Tinker 2011, pers. comm).

Killer whales

Killer whales also inhabit Bristol Bay waters. They have been seen in nearshore waters and frequent the lower river reaches chasing and preying upon salmon and beluga whales (Frost and Lowry 1981, Frost et al. 1992, Allen and Angliss 2011, Quakenbush 2011, pers. comm.). In a recent observation (July 17, 2002), killer whales displayed cooperative feeding behaviors near the Nushagak spit. A pod formed a circle with their tails facing toward the center, flukes slapping on the surface of the water. A male killer whale emerged through the center of the circle with a mouth full of salmon (Tinker 2011, pers. comm.). In the Nushagak River, killer whales have been observed chasing both belugas and coho (*Oncorhynchus kisutch*) salmon (D. Cythlook 2011, pers. comm.). In late fall, in the absence of beluga whales, killer whales pursue late-run and fall coho up the Nushagak River (P. Andrew 2011, pers. comm.).

Although they are opportunistic feeders, fish-eating killer whales outside of Bristol Bay show an affinity for salmon. In Prince William Sound, the results of a 14-year study of the diet and feeding habits of killer whales identify two non-associating groups of killer whale, termed resident and transient (Bigg et al. 1987). The resident groups (fish-eaters) appear to prey principally on salmon, preferring coho (*O. kisutch*) over other more abundant salmon species (Saulitis et al. 2000). Another distinct population of Alaskan fish-eating killer whales off the coast of British Columbia moves seasonally to target salmon populations (Nichol and Shackleton 1996). Field observations of predation and stomach content analysis of stranded killer whales collected over a 20-year period document 22 species of fish and one species of squid that dominated the diet of fish-eating resident-type killer whales (Ford et al. 1998). Despite the diversity of fish species taken in these studies, fish-eating resident killer whales showed a clear preference for salmon: 96% of fish taken were salmonids. Of the six salmonid species identified, by far the most common was Chinook (*Oncorhynchus tshawytscha*) representing 65% of the total sample. The second most common was pink at 17% (*Oncorhynchus gorbuscha*), followed by chum (6%) (*Oncorhynchus keta*), coho (6%), sockeye (4%), and steelhead (2%) (*Oncorhynchus mykiss*) (Ford et al. 1998). Although a separate population, Bristol Bay killer whales may have similar feeding behaviors.

Sperm whales

Sperm whales are also known to prey upon salmon and have been sighted, however infrequently, in Bristol Bay. Sperm whales feed primarily on mesopelagic squid in the North Pacific, but have also been documented consuming salmon as well as several other species of fish (Tomilin 1967, Kawakami 1980).

<u>Whales: Baleen Whales: Humpback Whales</u>

Investigations of baleen whale food habits in the North Pacific and Bering Sea have documented species such as humpbacks targeting small schooling fish populations. Salmon were among numerous species of fish identified (Nemoto 1959, Tomilin 1967, Kawamura, 1980). More recently, humpback whales have been observed off Cape Constantine in Bristol Bay in the spring of year, presumably feeding on schooling herring and possibly outmigrating salmon smolts (D. Cythlook 2011, pers. comm.). In southeast Alaska, humpback whales have been observed preying upon both wild and hatchery outbound salmon smolts as well as adult pink salmon (Straley et al. 2010, Straley 2011, pers. comm.). Humpback whales have been shown to exhibit site fidelity to feeding areas, and return year after year to the same feeding locations (Baker et al. 1987, Clapham et al. 1997). There is very little interchange between feeding areas (Baker et al. 1986, Calambokidis et al. 2001, Waite et al. 1999, Urban et al. 2000. The humpback whales observed off Cape Constantine may reasonably be assumed to exhibit a similar site fidelity for purposes of feeding.

Discussion

The primary purpose of this report is to identify the range, distribution, and trophic contribution of salmon originating from the Nushagak and Kvichak watersheds and bays. In a broader context, this report also presents information on known species assemblages and environmental influences on the estuarine and marine habitat. This report also attempts to acknowledge other habitat attributes that influence nearshore and estuary conditions and are important to salmon smolt physiology and to the trophic dynamics that support the abundance and resilience of current salmon populations.

Habitat Condition

The abundance, resilience, and stability of regional salmon populations are at once a product of and contribute to the currently healthy habitat, which includes the water quality. Natural ecosystem and hydro-geomorphic processes in the region remain functionally intact from headwater tributaries through marine waters. Salmon are abundant at various life history stages, which abundance influences and contributes to the productivity of other fisheries at multiple trophic levels. At their current abundance, salmon influence habitat condition in these watersheds by providing a rich source of nutrition to a broad range of invertebrates, fish, and marine mammals, as well as to countless terrestrial flora and fauna. Salmon enrich watersheds and influence water chemistry.

Water

Fish habitat includes not only structure such as hard substrate, reefs or rock, and vegetation such as eel grass or kelp, but also—and it seems odd to have to say so—the water itself. The success and abundance of a species are largely determined by the quality of the water, its temperature, its salinity, and its chemical composition, which includes the availability of nutrients necessary for life. If nutrient sources, forage opportunities, and prey are diminished, the habitat itself is changed, and all the dynamics of the food web are thus altered.

Nushagak and Kvichak Bays resemble other Alaskan estuaries as subarctic and allochthonous (turbid) in nature. As discussed above, these waters are dominated by seasonal freshwater runoff from snow melt and rains. Turbidity in the bays minimizes photosynthesis, primary production, and associated algal blooms; however, nutrient is carried in outwelling discharge of detritus, dissolved organic material, and salmon-derived nutrients. These materials provide the essential nutrients and energy for lower trophic levels supporting assemblages of minute bacteria, fungi and algae, through larval stages of plankton, invertebrates, juvenile fish and salmon smolt. The abundance and availability of nutrient sources at the lower trophic levels are essential to the survival of salmon smolt in their early estuarine and marine phase. Successful smolt survival is reflected years later in the strength of returning adult runs and escapement.

Estuaries

Although no studies to date have been conducted specifically identifying the importance of estuarine habitat to salmon smolt in Nushagak and Kvichak Bays, a number of other studies conducted in Alaska and the Northwest document several attributes of estuaries important to juvenile salmon smolt (Murphy et al. 1984, Heifetz et al. 1989, Johnson et al. 1992, Thedinga et al. 1993 and 1998, Koski and Lorenz 1999, Halupka et al. 2003, Koski 2009). Cited studies identify estuaries as an often preferred habitat choice for coho salmon, providing increased food and growth, expanding their nursery area, and increasing overall production from the watershed.

The high productivity of some estuarine habitats in Alaska and the Northwest allows an array of life history patterns (Healey 1983). One such pattern involves rearing in both rivers and estuaries, allowing salmon to migrate and rear in estuaries for a summer and in some cases return and over-winter in rivers (Reimers 1971, Murphy et al. 1984, 1997, Harding 1993, Koski and Lorenz 1999, Miller and Sadro 2003, M. Wiedmer 2013, pers. comm.). Being able to move between estuary and river increases feeding opportunities, allows smolt to achieve critical size (as discussed below), and supports osmoregulatory change in their early marine phase. The dominant freshwater influence of Nushagak and Kvichak Bays supports osmoregulatory adjustment prior to entry into the highly saline marine phase. It should also be recognized that smolt outmigration coincides with increased freshwater influence in these estuaries. Similar studies and literature of northwest salmon substantiate the importance of estuarine habitat to salmon smolt survival (Rich 1920, Healey 1982, Levy 1992, Thorpe 1994, Groot and Margolis 1998, Bottom 2005, Quinn 2005, Koski 2009).

Studies focused on flatfish species in other regions further identify the importance of estuarine habitat as fish nurseries. Disproportionate numbers of juvenile flatfish from estuarine habitat compose adult populations found in nearshore marine waters (Brown 2006). In this instance, although estuarine habitat composes only about 6% of the available juvenile habitat, the estuary appears to be the source of approximately half of the adult fish collected in the region. These results validate previous findings further explaining the linkage between estuarine and nearshore habitats for other species (Yamashita et al. 2000, Forrester and Swearer 2002, Gillanders et al. 2003). As noted in this review, these nearshore waters are “fish nurseries” supporting numerous species in their larval and juvenile life history stages.

Salmon Food Habits

Studies of the feeding habits of North Pacific salmon in general (that is, not specific to Bristol Bay salmon) show that the species’ feeding habits vary by species, life stage, region, and seasonal prey availability. Prey species repeatedly identified were euphausiids, hyperiids, amphipods, copepods, pteropods, and chaetognaths. Egg, larval, and juvenile stages of numerous forage fish, groundfish, and invertebrate species were also identified. Landingham and Sturdevant (1997) report that the prey spectrum for juvenile salmon species was composed of 30 taxa. The six taxa groups of most importance were calanoid copepods, hyperiid amphipods, euphausiids, decapods, larval tunicates and fishes. Other studies identify similar prey assemblages: euphausiids, hyperiids, amphipods, copepods, pteropods, chaetognaths, and polychaetes (Auburn and Ignell 2000, Orsi et al. 2000, Powers et al. 2006, Weikamp and Sturdevant 2008). Food habit studies conducted in Cook Inlet and Knik Arm further illustrate the importance of nearshore invertebrate prey assemblages for salmon smolt (Houghton 1987, Moulton 1997, summarized in USFWS 2009). Brodeur and Pearcy (1990) describe prey of all five North Pacific salmon and ocean-phase trout in all regions where they occur.

These studies analyzed stomach-content data and reveal that juvenile salmon ingest substantial quantities of food while in nearshore and estuary habitat. Salmon smolts tended to be well nourished and in some cases demonstrated prolonged estuarine residence time feeding extensively on plentiful larval invertebrate and juvenile fish species. Although these studies are not specific to Bristol Bay, the salmon prey species identified in these studies are also abundant in the Nushagak and Kvichak Bays.

Salmon Critical Size

The importance of abundant prey opportunities during the transition from fresh to marine waters, especially in the early marine phase, has been illustrated in “critical size” discussions. Earlier studies suggest that more slowly growing salmon smolt experience greater size-selective predation (Parker 1968, Willette et al. 1999). Smolt that fail to achieve a critical threshold size by late spring and early summer commonly fail to survive their first winter (Mahnken et al. 1982). Stunted smolt suffer protein-energy deficiency and are more likely to become prey for other marine species. Salmon smolt need to reach a critical size and strength to survive their first year in the open ocean (Beamish 2001 and 2004). Studies of Bristol Bay salmon in their marine phase in the eastern Bering Sea again suggest that reduced growth during their first year at sea may lead to substantial mortality (Moss et al. 2005, Farley et al. 2007). Greater nutrition and prey availability lead to larger juvenile salmon which gain a survival advantage over smaller individuals (Farley et al. 2007, Farley et al. 2011).

Trophic Contribution

Salmon-derived nutrients subsidize watersheds with organic nutrients such as carbon, nitrogen, and phosphorus, first in the form of whole carcasses and large solids and later as dissolved particulates (Willson et al. 1998, Cederholm et al. 1999, Gende et al. 2002, Naiman et al. 2002). Salmon carcasses, which are considerably enriched in carbon and nitrogen, contribute to primary production in freshwater streams, lakes, and estuaries (Stockner 1987, Cederholm et al. 1989 and 2000, Kline et al. 1990 and 1993, Bilby et al. 1996, Wipfli et al. 1998). As discussed above, marine estuaries and nearshore zones benefit from seasonal pulses of these nutrients. Terrestrial and aquatic species, from invertebrates and insects to mammals, as well as aquatic and riparian vegetation, also receive benefit from these seasonal pulses (Reimchen 1994, Wilson and Halupka 1995, Bilby et al. 1996 and 1998, Ben-David et al. 1997 and 1998, Wipfli et al. 1998, Cederholm et al. 1999, Gende and Wilson 2001, Helfield and Naiman 2001, Chaloner et al 2002, Chaloner and Wipfli 2002, Darimont and Reimchen 2002, O'Keefe and Edwards 2002, Reimchen et al. 2002 and 2003, Darimont et al. 2003, Mathewson et al 2003, Johnston et al. 2004, Lessard and Merritt 2006, Moore et al. 2007, Christie 2008, Christie and Reimchen 2008, Janetski 2009).

Coastal watersheds drain to the ocean-influencing estuaries and nearshore coastal zones (Kennish 1992, Caddy 1995 and 2000, Milliman 2010, Dade 2012). Watershed and riparian processes influence downstream estuaries through the transport of terrestrial and freshwater nutrients (Murphy 1984, Jauquet et al. 2003, Jonsson and Jonsson, 2003, Cak 2008, Von Biela 2013). Nutrient metabolism in estuaries can be strongly influenced by freshwater river inputs of organic and inorganic material (Hopkinson 1995, Kennish 2002). Some studies have demonstrated the importance of terrestrial-generated carbon to juvenile and adult bottom-dwelling marine fish species in periods of even moderate river discharge (Darnaube 2005). Recently, these nutrient sources have been identified as contributing to coastal estuaries and trophic interaction in Arctic zones as well (Dunton 2006 and 2012, Von Biela 2013).

Salmon-derived nutrients influence and contribute to estuary production of seasonal larval and juvenile plankton, invertebrate and fish species. One early study to suggest the influence of these nutrients on estuary water chemistry was conducted in Port Walther, Alaska (Brickell and Goering 1970). This study found that after spawning and dying in Sashin Creek, salmon carcasses were flushed into the estuary and elevated levels of organic nitrogen. Richey (1975) observed similar flushing of salmon carcasses into estuaries. Reimchen (1994) observed entire salmon carcasses rapidly consumed by several species of estuarine invertebrates. Gende (2004) reports that 43% of tagged carcasses in one watershed washed into the estuary within days. Fujiwara (1997) presents evidence suggesting that dissolved nutrients fuel estuarine productivity and associated bacteria and algae, which in turn increase the numbers of harpacticoid copepods that serve as primary prey for outbound juvenile salmon. Estimates of recent nutrient transport indicate that substantial amounts of salmon-derived nutrients (46%-60%) move directly back to the estuary (Mitchell and Lamberti 2005). A similar study suggests that bivalves also benefit from these nutrients (Chow 2007).

The results of this research indicate an influence of salmon-derived nutrients on trophic productivity in marine estuaries. These studies also suggest a positive feedback mechanism in salmon production, given that decomposing adult salmon subsidize lower trophic levels and provide prey species to their outbound offspring (Fujiwara and Highsmith 1997, Gende et al. 2004). As Aydin (2010) explains, “Mysiids, as an inshore zooplankton (appearing in diets primarily in shallow waters of Bristol Bay) have a nitrogen isotope ($\delta 15N$) level higher than deepwater forage fish.” This strong nitrogen signal was observed in euphausiid and walleye pollock inhabiting northern Bristol Bay nearshore waters. This unusually high nitrogen signal may result from the seasonal increase of freshwater discharge and dissolved organic matter (a seasonal terrestrial nutrient pulse from salmon) carried on currents along the northern shore of Bristol Bay. In addition, smolt emigration theoretically exports more nutrients out of the watersheds than previously recognized, and salmon in sub-adult and adult phases in the eastern Bering Sea and North Pacific also contribute to marine mammal diets.

Summary

Pacific salmon are a keystone species providing nutrients that influence the habitat condition of terrestrial, estuarine and marine ecosystems (Willson and Halupka 1995; Cedarholm et al.1999; Helfield and Naiman 2001; Piccolo et al. 2009). Due to their life history, anadromy, range, and distribution, Bristol Bay salmon represent a link between fresh water and marine systems. Discharges of seasonal freshwater transport dissolved organic matter to the estuary. The freshwater discharge facilitates osmoregulatory adaption in salmon smolts, providing a buffer to highly saline marine conditions. The estuary provides rich foraging opportunities and a rearing environment that allow smolt to achieve the size essential for survival in the early marine phase. At the beginning of their life cycle, emigrating smolt from rivers contribute to estuarine and marine productivity as a forage fish species. At the end of their life cycle, adult salmon provide the nutrients that influence productivity from watersheds through the estuary. These nutrient sources provide a feedback mechanism to their outbound offspring fueling lower trophic levels, from minute bacteria and fungi to a multitude of plankton, invertebrate, fish, and marine mammal species.

Bristol Bay provides EFH for salmon at various life stages as well as other marine species. The Nushagak and Kvichak estuaries provide nutrient-rich transition zones where salmon smolt can achieve critical size while acclimating to the marine environment. At an ecosystem level, from the head water tributaries through the marine environment, the healthy habitat of the bay both supports and results from the interactions between natural processes and the presence and abundance of Bristol Bay salmon.

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Tables

Table 1: Fish and Invertebrate Species List

Species listed have been identified in the NOAA-AFSC Bering Sea Trawl Surveys between 1982-2010 (Lauth 2010).

FISH SPECIES	
Common Name	***Scientific Name***
	Salmonidae
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Steelhead	*Oncorhynchus mykiss*
	Gadidae
Pacific cod	*Gadus macrocephalus*
Walleye pollock	*Theragra chalcogramma*
Arctic cod	*Boreogadus saida*
Saffron cod	*Eleginus gracilis*
	Anoplopomatidae
Sablefish	*Anoplopoma fimbria*
	Osmeridae
Eulachon	*Thaleichthys pacificus*
Capelin	*Mallotus villosus*
Rainbow smelt	*Osmerus mordax*
Smelt unident	*Osmeridae*
	Clupeidae
Pacific herring	*Clupea pallasi*
	Ammodytidae
Pacific sand lance	*Ammodytes hexapterus*
	Trichodontidae
Pacific sandfish	*Trichodon trichodon*
	Pleuronectidae
Pacific halibut	*Hippoglossus stenolepis*

Yellowfin sole	*Limanda aspera*
Northern rock sole	*Lepidopsetta polyxystra*
Rock sole unident.	*Lepidopsetta sp.*
Flathead sole	*Hippoglossoides elassodon*
Dover sole	*Microstomus pacificus*
Rex sole	*Glyptocephalus zachirus*
Butter sole	*Isopsetta isolepis*
Sand sole	*Psettichthys melanostictus*
Starry flounder	*Platichthys stellatus*
Alaska plaice	*Pleuronectes quadrituberculatus*
Arrowtooth flounder	*Atheresthes stomias*
Kamchatka flounder	*Atheresthes evermanni*
Longhead dab	*Limanda proboscidea*
Sanddab unident.	*Citharichthys sp.*
	Scorpaenidae
Northern rockfish	*Sebastes polyspinis*
	Rajidae
Big skate	*Raja binoculata*
Bering skate	*Bathyraja interrupta*
Starry skate	*Raja stellulata*
Alaska skate	*Bathyraja parmifera*
Aleutian skate	*Bathyraja aleutica*
	Hexagrammos
Whitespotted greenling	*Hexagrammos stelleri*
Rock greenling	*Hexagrammos lagocephalus*
Kelp greenling	*Hexagrammos decagrammus*
Smooth lumpsucker	*Aptocyclus ventricosus*
Greenling unident.	*Hexagrammidae*
	Psychrolutidae
Sawback poacher	*Leptagonus frenatus*
Gray starsnout	*Bathyagonus alascanus*
Sturgeon poacher	*Podothecus accipenserinus*
Aleutian alligatorfish	*Aspidophoroides bartoni*
Arctic alligatorfish	*Ulcina olrikii*
Warty poacher	*Chesnonia verrucosa*
Bering poacher	*Occella dodecaedron*

	Anarhichadidae
Wolf-eel	*Anarrhichthys ocellatus*
Bering wolffish	*Anarhichas orientalis*
	Gymnocanthus sp.
Threaded sculpin	*Gymnocanthus pistilliger*
Arctic staghorn sculpin	*Gymnocanthus tricuspis*
Armorhead sculpin	*Gymnocanthus galeatus*
Northern sculpin	*Icelinus borealis*
Sculpin unident.	*Cottidae*
	Artediellus sp.
Hookhorn sculpin	*Artediellus pacificus*
Irish lord	*Hemilepidotus sp.*
Red Irish lord	*Hemilepidotus hemilepidotus*
Yellow Irish lord	*Hemilepidotus jordani*
	Triglops sp. Ribbed
sculpin	*Triglops pingeli*
Brightbelly sculpin	*Microcottus sellaris*
Warty sculpin	*Myoxocephalus verrucosus*
Great sculpin	*Myoxocephalus polyacanthocephalus*
Plain sculpin	*Myoxocephalus jaok*
	Myoxocephalus sp.
Pacific staghorn sculpin	*Leptocottus armatus*
Antlered sculpin	*Enophrys diceraus*
Spinyhead sculpin	*Dasycottus setiger*
Crested sculpin	*Blepsias bilobus*
Eyeshade sculpin	*Nautichthys pribilovius*
Sailfin sculpin	*Nautichthys oculofasciatus*
Bigmouth sculpin	*Hemitripterus bolini*
Thorny sculpin	*Icelus spiniger*
Spatulate sculpin	*Icelus spatula*
	Liparis sp.
Variegated snailfish	*Liparis gibbus*
Snailfish unident.	*Liparidinae*

	Stichaeidae
Daubed shanny	*Lumpenus maculatus*
Snake prickleback	*Lumpenus sagitta*
Decorated warbonnet	*Chirolophis decoratus*
Bearded warbonnet	*Chirolophis snyderi*
Polar eelpout	*Lycodes turneri*
	Cryptacanthodidae
Giant wrymouth	*Cryptacanthodes giganteus*

INVERTEBRATE SPECIES

Common Name	***Scientific Name***
Octopus	
	Octopodidae sp.
Common Octopus	*Octopoda*
Eastern Pacific bobtail	*Rossia pacifica*
Crab	
	Cancer sp.
Oregon rock crab	*Cancer oregonensis*
Graceful decorator crab	*Oregonia gracilis*
Tanner crab	*Chionoecetes bairdi*
Circumboreal toad crab	*Hyas coarctatus*
Pacific lyre crab	*Hyas lyratus*
Snow crab	*Chionoecetes opilio*
Hybrid tanner crab	*Chionoecetes hybrid*
Helmet crab	*Telmessus cheiragonus*
Hermit crab unident.	*Paguridae*
	Pagurus sp.
Sponge hermit	*Pagurus brandti*
Aleutian hermit	*Pagurus aleuticus*
Splendid hermit	*Labidochirus splendescens*
Knobbyhand hermit	*Pagurus confragosus*
Fuzzy hermit crab	*Pagurus trigonocheirus*
Bering hermit	*Pagurus beringanus*
Alaskan hermit	*Pagurus ochotensis*
Longfinger hermit	*Pagurus rathbuni*
Widehand hermit crab	*Elassochirus tenuimanus*
Hairy hermit crab	*Pagurus capillatus*

Purple hermit	*Elassochirus cavimanus*
Wrinkled crab	*Dermaturus mandtii*
	Hapalogaster sp.
Fuzzy crab	*Hapalogaster grebnitzkii*
Red king crab	*Paralithodes camtschaticus*
Horsehair crab	*Erimacrus isenbeckii*

Shrimp

	Pandalus sp.
Ocean shrimp	*Pandalus jordani*
Alaskan pink shrimp	*Pandalus eous*
Humpy shrimp	*Pandalus goniurus*
Shrimp unident.	*Hippolytidae*
	Lebbeus sp.
Spiny lebbeid	*Lebbeus groenlandicus*
	Crangon sp.
Abyssal crangon	*Crangon abyssorum*
Twospine crangon	*Crangon communis*
Ridged crangon	*Crangon dalli*
Sevenspine bay shrimp	*Crangon septemspinosa*
Crangonid shrimp unident.	*Crangonidae*
	Argis sp.
Arctic argid	*Argis dentata*
	Sclerocrangon sp.
Sculptured shrimp	*Sclerocrangon boreas*
Kuro argid	*Argis lar*

Clams, Mussels, Scallop, Cockles

	Mytilidae sp.
Northern horse mussel	*Modiolus modiolus*
	Mytilus sp. Blue
mussel	*Mytilus edulis*
Weathervane scallop	*Patinopecten caurinus*
Arctic hiatella	*Hiatella arctica*
Arctic roughmya	*Panomya norvegica*
	Yoldia sp.
Crisscrossed yoldia	*Yoldia seminuda*
Northern yoldia	*Yoldia hyperborea*
Discordant mussel	*Musculus discors*
Boreal astarte	*Astarte borealis*

Many-rib cyclocardia	*Cyclocardia crebricostata*
	Mactromeris sp.
Arctic surfclam	*Mactromeris polynyma*
	Tellina sp.
Alaska great-tellin	*Tellina lutea*
	Macoma sp.
Bent-nose macoma	*Macoma nasuta*
	Siliqua sp.
Pacific razor	*Siliqua patula*
Alaska razor	*Siliqua alta*
	Mya sp.
Softshell clam	*Mya arenaria*
Alaska falsejingle (soft oyster)	*Pododesmus macrochisma*
Soft shell unident.	*Anomiidae*
	Ciliatum sp.
Hairy cockle	*Clinocardium ciliatum*
California cockle	*Clinocardium californiense*
	Serripes sp.
Greenland cockle	*Serripes groenlandicus*
Broad cockle	*Serripes laperousii*
	Cyclocardia sp.
	Clinocardium sp.

Coral, Soft coral

	Gersemia sp.
Sea raspberry	*Gersemia rubiformis*
	Gorgonacea sp.
Sea pen (sea whip)	*Pennatulacea*

Snail, snails, welk

	Natica clausa sp.
Aleutian moonsnail	*Cryptonatica aleutica*
Rusty moonsnail	*Cryptonatica russa*
Pale moonsnail	*Euspira pallida*
Great slippersnail	*Crepidula grandis*
Moonsnail eggs unident	*Naticidae eggs*
	Volutopsius sp.
Warped whelk	*Pyrulofusus deformis*
	Beringius sp.
	Beringius kennicottii

	Beringius beringii
	Neptunea sp.
Pribilof whelk	*Neptunea pribiloffensis*
	Neptunea borealis
Lyre whelk	*Neptunea lyrata*
Fat whelk	*Neptunea ventricosa*
	Neptunea heros
Helmet whelk	*Clinopegma magnum*
	Plicifusus kroyeri
	Neptunea sp.
Oregon triton	*Fusitriton oregonensis*
	Tritonia sp.
Rosy tritonia	*Tritonia diomedea*
	Buccinum sp. Angular
whelk	*Buccinum angulosum*
Sinuous whelk	*Buccinum plectrum*
Ladder whelk	*Buccinum scalariforme*
Polar whelk	*Buccinum polare*
Smooth lamellaria	*Velutina velutina*
	Hyas sp.
Snail eggs	*Gastropod eggs*
Snail eggs unident.	*Neptunea sp. eggs*

Barnacles

	Balanus sp.
Giant barnacle	*Balanus evermanni*
Beaked barnacle	*Balanus rostratus*
Barnacle unident.	*Thoracica*

Anemone

	Halipteris sp.
Sea anemone unident.	*Actiniaria*
	Metridium sp.
Clonal plumose anemone	*Metridium senile*
Gigantic anemone	*Metridium farcimen (=Metridium giganteum)*
	Stomphia sp.
	Urticina sp.
Mottled anemone	*Urticina crassicornis*
Chevron-tentacled anemone	*Cribrinopsis fernaldi*

Tentacle-shedding anemone	*Liponema brevicornis*
Stony coral unident.	*Scleractinia*

Star fish, sea star

	Evasterias sp.
Mottled sea star	*Evasterias troschelii*
Giant sea star	*Evasterias echinosoma*
	Leptasterias groenlandica
Blackspined sea star	*Lethasterias nanimensis*
	Henricia sp.
Blood sea star	*Henricia leviuscula*
Tumid sea star	*Henricia tumida*
	Leptasterias polaris
	Leptasterias katharinae
	Leptasterias arctica
	Leptasterias sp.
	Crossaster sp.
Grooved sea star	*Crossaster borealis*
Rose sea star	*Crossaster papposus*
	Asterias sp.
Purple-orange sea star	*Asterias amurensis*
Brittlestarfish unident.	*Ophiuroidea*
Basketstar	*Gorgonocephalus eucnemis*
Notched brittlestar	*Ophiura sarsi*

Sea urchin

	Echinacea sp.
Green sea urchin	*Strongylocentrotus droebachiensis*
	Strongylocentrotus sp.
	Strongylocentrotus polyacanthus
Sand dollar	*Echinarachnius parma*

Sponges

	Stelletta sp.
Stone sponge	*Suberites ficus*
Clay pipe sponge	*Aphrocallistes vastus*
Barrel sponge	*Halichondria panicea*
	Suberites sp.
Sponge	*Porifera*

Jelly fish

	Amphilaphis sp.
Jelly Fish	*Chrysaora melanaster*
Lion's mane	*Cyanea capillata*
Chrysaora jellyfish	*Chrysaora sp.*
Jellyfish unident.	*Scyphozoa*
Comb jelly unident.	*Ctenophora*

Miscellaneous Invertabrate Species

Worm

	Polychaeta
Giant scale worm	*Eunoe nodosa*
Depressed scale worm	*Eunoe depressa*
Striped sea leech	*Notostomobdella cyclostoma*
Echiuroid worm unident.	*Echiura*
Cat worm unident.	*Nephtyidae*
Scale worm unident.	*Polynoidae*
Peanut worm unident.	*Sipuncula*
Tube worm unident.	

Hydroids

	Abietinaria sp.

Bryozoans

Feathery bryozoan	*Eucratea loricata*
Leafy bryozoan	*Flustra serrulata*
	Alcyonidium pedunculatum
Ribbed bryozoan	*Rhamphostomella costata*
Bryozoan unident.	*Bryozoa*

Sea Cucumbers

	Cucumaria sp.
Sea football	*Cucumaria fallax*
Sea cucumber	*Holothuroidea*
	Cucumaria frondosa
Foraminiferan unident.	***Psolus sp.***
	Foraminifera

Ascidians

Orange sea glob	***Aplidium sp.***
Sea pork	*Aplidium californicum*
	Molgula sp.
Sea grape	*Molgula grifithsii*
Sea clod	*Molgula retortiformis*

Table 2: Marine Mammals Species List

Marine mammal species listed have been identified from several sources (Allen 2011, ADFG 2010, BBESI 2001, BB-CRSA 2009).

MARINE MAMMALS	
Common Name	***Scientific Name***
Toothed Whales	***Cetaceans - Ondontocetes***
Beluga whale	*Delphinapterus leucas*
Killer whale	*Orcinus orca*
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
Harbor porpoise	*Phocoena phocoena*
Dall’s porpoise	*Phocoenoides dalli*
Baird’s beaked whale	*Berardius bairdii*
Baleen Whales	***Cetaceans – Balenotropha***
Gray whale	*Eschrichtius robustus*
Humpback whale	*Megaptera novaeangliae*
Fin whale	*Balaenoptera physalus*
Minke whale	*Balaenoptera acutorostrata*
Bowhead whale	*Balaena mysticetus*
Sealion	***Pinnipeds - Otariidae***
Steller sea lion (Eastern)	*Eumetopias jubatus*
Northern fur seal (Eastern)	*Callorhinus ursinus*
Seals	***Pinnipeds - Phocidae***
Harbor seal	*Phoca vitulina*
Spotted seal	*Phoca largha*
Bearded seal	*Erignathus barbatus*
Ringed seal	*Pusa hispida*
Ribbon seal	*Histriophoca fasciata*
	Pinnipeds – Odobenidae
Walrus	*Odobenus rosmarus*
	Mustelidae - Lutrinae
Northern Sea Otter	*Enhydra lutris kenyoni*