Eulachon and Salmon as Beluga Prey and Indicators of the Health of the Cook Inlet Ecosystem: Summary of Existing Data, Identification of Information Gaps, and Recommendations for Future Research

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ABSTRACT

The National Fish and Wildlife Foundation (NFWF) initiated efforts to identify focal species to represent habitat types that are part of estuarine ecosystem in Cook Inlet along the northern Gulf of Alaska. Identified as keystone species of Cook Inlet were the endangered Cook Inlet beluga whale (CIBW; *Delphinapterus leucas*), eulachon (*Thaleicthys pacificus*), and five species of wild Pacific salmon: Chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), pink salmon (*O. gorbuscha*), and sockeye salmon (*O. nerka*). The CIBW is a highly conspicuous apex predator of Cook Inlet that declined rapidly in the mid-1990s due to overharvesting but has shown no improvement in population abundance despite curtailment of all harvests. The CIBW also now occupies a much smaller geographic range that is limited to Upper Cook Inlet. Eulachon and salmon were selected because high nutritional values and dense schooling behaviors make these fish drivers of much of the Cook Inlet food chain, and salmon are also an economic driver for the region. This report is intended to update information on general life histories and population trends of eulachon and salmon in Upper Cook Inlet, explore how these prey species may be interacting with CIBWs, and identify potential research to address data gaps in our understanding of these interactions, particularly aspects that may facilitate management decisions to aid CIBW population recovery.

Eulachon are an anadromous fish that returns to freshwater in dense schools to spawn in the spring; developing larvae migrate to the estuarine environment shortly after hatching. Upper Cook Inlet has a low effort, localized commercial fishery that harvests ~90,000 kg (200,000 lb) of eulachon each spring. In addition, personal use and subsistence fisheries occur in several locations of Upper Cook Inlet; harvests are not actively managed but are thought to be relatively low. There is little stock assessment information for eulachon, but eulachon stocks in Upper Cook Inlet appear to be healthy at this time. Eulachon have a relatively high lipid content and are likely a critical component of the spring CIBW diet after a winter of low food availability and prior to the salmon returns (Payne et al. 1999). However, data on CIBW diet composition is limited.

The five species of Pacific salmon return to Upper Cook Inlet streams during late May to October, although the abundance and timing of returns varies by species and stock. Based on the geographic distribution of CIBWs relative to the major salmon tributaries, CIBWs likely get the bulk of their summer nutritional intake through salmon, although specifics of CIBW foraging for prey are unknown. Most salmon runs appear to have been healthy in recent years, with the exception of Chinook salmon, which have been at low levels but seem to be improving. The extent to which CIBWs can effectively switch between prey types is unknown.

Understanding linkages among CIBWs, eulachon, and salmon is critical to developing effective management plans to facilitate recovery of the CIBWs. However, there is a lack of information on eulachon abundance. More importantly, there is little information on interactions among CIBWs and their prey, even at the level of spatial overlap over time. Some options we suggest to address of these issues are: development of a bioenergetics model; determination of spatial overlap among CIBWs and their prey; and collection of additional information on diet composition, perhaps through tissue samples.

Keywords: Cook Inlet, beluga whale, prey; Pacific salmon; eulachon; distribution, life history, distribution; fisheries

INTRODUCTION

The National Fish and Wildlife Foundation (NFWF) has undertaken an initiative to identify a portfolio of focal species that represent the habitat types that are part of Alaska's Cook Inlet Estuary Ecosystem, and to develop and implement a plan that will identify priority areas and actions for those species and their habitats while providing a conservation framework for the development of economic opportunities.

Keystone species of Cook Inlet include wild Pacific salmon (*Oncorhynchus* spp.), eulachon (*Thaleicthys pacificus*), and endangered Cook Inlet beluga whales (CIBWs;

Delphinapterus leucas). High nutritional values and dense schooling behaviors make salmon and eulachon drivers of much of the Cook Inlet food chain. As critical prey of CIBW, fluctuations in eulachon and salmon abundances, run timing, and availability may affect CIBW survival and recovery. To guide conservation efforts in Cook Inlet, it is imperative to understand linkages among these species and how these species interact and contribute to the health of the Cook Inlet Ecosystem.

Cook Inlet's long winters, silt-laden waters, extreme tides, and relatively remote location create a challenge for understanding human impacts to the ecosystem. Examining the relationship between a large, conspicuous predator in Cook Inlet, such as beluga whales, and conspicuous migrations of prey fish, such as eulachon and salmon, will allow us to better understand the dynamics of the Cook Inlet Ecosystem, and the effects of human activities on habitat, fish, and belugas.

As part of NFWF's Cook Inlet Ecosystem Initiative, we identify and describe data gaps and information needs for better understanding the interactions of eulachon, salmon, and beluga whales in a healthy Cook Inlet ecosystem. We reviewed the literature to develop a report that examines the physical environment of Cook Inlet, the ecology of eulachon and salmon, the role of eulachon and salmon as prey of beluga whales, and threats to these species and their habitat. We synthesized the research about these species, identified data gaps, and provided recommendations for future research and conservation actions. This report also includes proposed survey and analytical approaches to resolve data gaps.

Two of the report authors, Bechtol and McGuire, were asked by NFWF to conduct this work based on past participation as volunteers on the Cook Inlet Beluga Whale Recovery Team and our areas of expertise (Cook Inlet fisheries and Cook Inlet beluga whale ecology, respectively). In this report, we draw heavily on the sections of the draft Cook Inlet Beluga Whale Recovery Plan that we contributed to, as well as on discussions with, and input from, other team members. Team meeting notes, and a draft recovery plan, may be found at https://alaskafisheries.noaa.gov/pr/cib-recovery-plan. Third report author Burril is a professional fisheries biologist based in Anchorage with 20 years of previous experience commercial fishing in Cook Inlet.

OVERVIEW OF COOK INLET HABITAT

Cook Inlet is a semi-enclosed tidal estuary embayment in southcentral Alaska (Figure 1). With a northeast to southwest orientation, the inlet extends approximately 370 kilometers (km) (230 miles [mi]) from Knik and Turnagain arms on the north to Kamishak Bay and the Gulf of Alaska in the south (Figure 1). Cook Inlet covers 20,000 km^2 (12,427 mi^2) and has 1,350 km (839 mi) of coastline (Rugh et al. 2000). The Cook Inlet watershed encompasses 98,000 km^2 (60,894 mi^2) east of the Aleutian Range and south of the Alaska Range. The largest drainage basins are the Susitna River (50,800 km^2; 31,566 mi^2), the Matanuska River (5,670 km^2; 3523mi^2), and the Knik, Chakachatna, and Kenai rivers (each exceeding 2,500 km^2; 1,553 mi^2) (NMFS 2015). River discharges exhibit large seasonal variation with highest flows associated with spring snowmelt and fall storm events (Okkonen 2005). Glacial meltwater is the primary source for many of the major Cook Inlet river systems. These rivers introduce substantial sediment into the inlet, creating a highly turbid, low visibility environment, particularly in the north (Figure 2).

Cook Inlet bathymetry includes shoals, canyons and mudflats (Figure 3), with most waters shallower than 73 meters (m; 240 ft), but depths at the entrance to Cook Inlet ranging from 183 to 366 m (600 to 1,200 ft; Mulherin et al. 2001). The shape and depth of Cook Inlet is such that the tide resonates leading to a large tidal amplitude. Narrowing of the inlet towards the north causes the tidal amplitude and currents to increase towards the constriction around the Forelands near Boulder Point (Figure 3; Okkonen 2005). Difference between high and low tide levels may reach 12 m (39 ft). These large tidal exchanges, combined with broad tidal flats, can produce currents of 6.2 m/second (20.3 ft/second) and significantly reshape the shorelines (Moore et al. 2000). During low tides, large nearshore areas are exposed as mudflats in Knik Arm, Turnagain Arm, Chickaloon Bay, Redoubt Bay, Trading Bay, Kachemak Bay, and the Susitna River Delta (Figure 1). Bottom sediments in other Cook Inlet areas include cobble, pebble, sand, clay, and occasional patches of boulders or exposed coal seams, with sediments typically coarser in areas with stronger currents. Bathymetric changes in tidal flow create strong shear and convergence zones that are locally known as “tide rips.” There are three distinct convergence zones identified in the inlet, the east rip located 2-3 km (1.2-1.9 miles) off the eastern shore, and the west and mid-channel rips located east of Kalgin Island and associated with a 50–80 m (164–262 ft) deep north-south channel (Figure 3). These rips accumulate debris, ice, and can also serve to aggregate fish, such as salmon (Okkonen 2005; Shields and Dupuis 2015).

In winter, ice and snow covers much of the Upper Cook Inlet basin. Rivers historically began to freeze over in October and November with waters of Upper Cook Inlet covered by persistent ice in December. Under the ice cover, substantial amounts of freshwater continue to enter from tributaries of Knik and Turnagain arms, contributing to relatively high surface ice concentrations in the upper inlet. Small floes of open pack ice commonly extend south of the Forelands. Maximum ice extent is typically reached in late January. Current circulation and winter winds typically move the ice south down the west side of the inlet. Ice breakup in the inlet has typically ranged from March to May.

As a part of climate change, Cook Inlet has been shifting towards later freeze-ups and earlier ice breakups (ACIA 2004; IPCC 2013). The Alaska region is experiencing the greatest warming in the United States (Karl et al. 2009), and this warming is expected to increase. One implication of this warming is reduced snowpack and glacial recession, both of which will change the timing, quantity, and amount of freshwater available for Cook Inlet tributaries and contributing to the Upper Cook Inlet ecosystem. It is likely that under future climate change scenarios, some Cook Inlet tributaries will have insufficient water flow during critical periods of the year to support local spawning populations of fish. In addition, warming streams have the potential to cause heat stress to spawning salmon aggregations. Impacts to salmon and eulachon populations could have significant, deleterious effects on CIBW productivity (ACIA 2004).

OVERVIEW OF COOK INLET BELUGA WHALES

Although beluga whales are found throughout much of the Arctic and subarctic, including other parts of Alaska, the National Marine Fisheries Service (NMFS) considers the CIBW to be a distinct population segment due to its geographic and genetic isolation within Cook Inlet. A steep decline in the CIBW population occurred in the late 1990s, and the population was designated by NMFS as depleted in 2000 under the Marine Mammal Protection Act. The primary driver of the rapid CIBW population decline was unsustainable levels of subsistence hunting in the mid to late 1990s (Hobbs et al. 2008). In 1999 there was no harvest as a result of a voluntary moratorium by the hunters. During 2000–2003 and 2005–2006, NMFS and the hunters entered into co-management agreements for the CIBW subsistence harvest, limiting harvests to one or two whales per year. The CIBWs have not been subsistence harvested since 2005.

The CIBW population was listed as endangered under the Endangered Species Act in 2008 (NMFS 2008a). As a result of the ESA listing, NMFS was required to designate critical habitat (i.e., habitat deemed necessary for the survival and recovery of the CIBW population), develop a Recovery Plan, and consult on any development projects that have a federal nexus to ensure these projects do not further threaten CIBWs.

Despite the complete cessation of any harvest removal in the last decade, the CIBW population has shown no indication of recovering. During meetings and research in 2010–2013, the CIBW Recovery Team struggled to identify the primary stressors that are constraining beluga recovery. While a CIBW recovery plan is being finalized by NMFS, the draft recovery plan emphasizes data gaps and research needs for recovery, including the need for additional basic life-history data and details of habitat use and prey availability (NMFS 2015). Because food is an obvious driver of long-term survival for all species, reduction of available prey (i.e., seasonal availability, abundance, and quality) was one of the potential threats to CIBW recovery that was examined by the Recovery Team. Although prey resources wax and wane over time, the team was unable to identify a specific prey resource that had declined to an extent that would impede CIBW recovery. However, the recovery team did find some evidence that suggested reduction in prey may be affecting recovery of CIBW, via the mechanisms of decreased survival and/or overall range contraction, and a decline in localized prey abundance or prey quality cannot be ruled out.

Natural causes of death of CIBWs remain largely unidentified. Burek-Huntington et al. (2015) reviewed records for CIBWs that stranded during 1998–2009. Of the 144 dead stranded CIBWs reported during this time, only 34 carcasses were examined by veterinarians or biologists. Six individual CIBWs from the 34 examined were reported to be in poor body condition; i.e., they were so thin that poor nutrition was considered either the cause of, or a contributing factor to, death (Burek-Huntington et al. 2015). Potential causes of poor nutrition include the lack of appropriate prey, inability to obtain prey due to injury or infection, or disease that interfered with healthy metabolism.

An analysis of aerial survey data shows that the extent of the late spring/early summer distribution (June/July) of belugas in Cook Inlet has changed considerably since the late 1970s. Core summer distribution was estimated to have contracted from over 7,000km^2 (2,703 mi^2) in 1978–1979 to 2,800 km^2 (1,081 mi^2 in 1998–2008 (Rugh et al. 2010). Fewer sightings in this region in recent decades (Hansen and Hubbard 1999; Rugh et al. 2000, 2004, 2010; Speckman and Piatt 2000) indicate that ranging behavior has contracted to the mid and upper inlet, coincident with a decline in population size. The reason for this change of distribution is not known but several hypotheses have been proposed, including an effect of changing habitat, such as through diminished prey availability (Moore et al. 2000).

PREY OF COOK INLET BELUGA WHALES

The diet of beluga whales throughout their circumpolar range is dominated by fish and invertebrate prey. Published reports on beluga diets are available from Canada (Vladykov 1946, cited by Seaman et al. 1982; Doan and Douglas 1953; Sergeant 1973), Russia (Kleinenberg et al. 1964, cited by Seaman et al. 1982; Tomlin 1967, cited by Seaman et al. 1982), and Europe (Lono and Oynes 1961, cited by Seaman et al. 1982). There are few published data for Alaska on beluga whale diets (Seaman et al. 1982; Quakenbush et al. 2015), but several unpublished reports exist from Bristol Bay (Brooks 1954, 1955, 1956, 1957; Lensink 1961 and Klinkhart 1966, cited by Seaman et al. 1982). Diet data for CIBWs are currently limited to a relatively small number of stomach contents and stable isotope analyses (Quakenbush et al. 2015), as well as observations from Alaska Native subsistence harvests (Fall et al. 1984; Huntington 2000).

Contents were analyzed from 53 CIBW stomachs collected March to November during 1961–2012; 17 stomachs (32% of total number of stomachs) were empty (Table 1; Quakenbush et al. 2015). Of an additional four stomachs sampled during 2013–2015, only three contained prey; these stomachs have not been analyzed at the time of this summary (L. Quakenbush, ADF&G, pers. com). Months with the largest numbers of stomach samples during 2002–2012 were October (n=8) and August (n=7), although small sample sizes make seasonal comparisons difficult.

For the 36 non-empty stomachs sampled during 1961–2012, one was collected in 1962, 17 were collected during 1992–2001, and 18 during 2002–2012. Stomachs collected from 1992 to 2001 (April–October; n=24) were analyzed separately from stomachs collected during 2002–2012 (March–November; n=28). Because the focus in early studies was on salmon and eulachon, only a portion of the less-digested contents from each stomach was analyzed prior to 2002, whereas all stomach contents were analyzed beginning in 2002. However, additional prey items were likely present prior to 2002. Stomachs collected after 2001 were given more comprehensive analysis. Of the 18 non-empty stomachs collected during 2002-2012, 17 (94%) contained fish, 9 (50%) contained only fish, and 9 (50%) contained invertebrates (Quakenbush et al. 2015). Fish prey included at least 12 species representing seven family groups, with the most prevalent being salmon (67% frequency of occurrence [FO]), cod (39% FO), smelt (11% FO), and flounder (11% FO). The salmon identified from stomach contents included coho (28% FO), chum (21% FO), and Chinook (11% FO). Quakenbush et al. (2015) discussed some of the biases associated with the opportunistic collection of CIBW stomach samples. For example, a large component of the belugas sampled during 2002–2012 were stranded animals, which were likely stressed and may have regurgitated prey items. In addition, the reduction in the CIBW population has been accompanied by a compression of the beluga geographical distribution to middle and Upper Cook Inlet, possibly resulting in a reduction in the available prey types. The relatively small sample size for CIBW stomachs remains a concern as aspects such as feeding preferences by individual whales may be underrepresented in the available analyses. While salmon is obviously important as a prey item throughout the spring to fall season, some whales may be more proficient at foraging on salmon, while other whales supplement salmon with other prey items.

While eulachon are likely critical prey during the period of April to May, salmon appear to be the primary prey of CIBWs from June to September (Table 1). Despite the small sample sizes for beluga stomachs during summer, salmon were present in virtually all of the non-empty beluga stomachs during July–September, only declining in October, a month when salmon returns drastically drop. Beluga diet composition indicates a dramatic shift to consumption of cod species (gadids) in October. It is notable that salmon were still found in 40% of stomachs with fish and 25% of all non-empty beluga stomachs in October, a month when salmon returns essentially cease, suggesting a high degree of prey selectivity. While winter foraging is not well known, it is presumed that CIBWs prey more on benthic species or opportunistically on infrequently encountered pelagic species (NMFS 2008b).

Evaluation of prey selectivity depends on an understanding of the encounter rate and quality of prey that are available at a given time and the location of the predator (Pyke et al. 1977). During the ice-free months, CIBWs are often found from Tyonek to the Little Susitna River and in river mouths of Knik and Turnagain arms (Figure 1; NMFS 2015). This habitat can be affected by ecological events, including: Pacific decadal oscillation (potentially affecting rainfall, freshwater runoff, water temperature, and water column stability); climate change (potentially affecting glacial output and siltation, water temperature, and salinity in downstream estuarine environments); volcanic ash outfall (affecting siltation and water chemistry); and earthquakes, landslides, elevation changes, and tsunami waves. The impact that these events might have on the abundance, quality, or seasonality of Cook Inlet species composition varies with event frequency and intensity. For example, some events such as a tsunami may occur infrequently, if ever, but could have substantial impacts through aspects such as direct mortality to CIBW prey species, or habitat restructuring. Other events, such as Pacific decadal oscillation, may occur more frequently, but with changes effected over relatively long time periods.

Changes in ecological conditions have been correlated with shifts in prey selectivity of large marine mammals (Fleming et al. 2016). Ecological regime shifts which restructured species composition have been identified in the North Pacific (Hollowed and Wooster 1992; Anderson and Piatt 1999; Hare and Mantua 2000; Spies 2007) and likely affected species composition in Cook Inlet. For example, species dominance in the Gulf of Alaska ecosystem transitioned in the 1970s from crustaceans to groundfish, particularly gadid species (e.g., cods). Hare and Mantua (2000) identified an ecosystem change in the Gulf of Alaska during 1976-1977, with a less dramatic shift in 1989. Data from multiple decades of small-mesh trawl surveys conducted by the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G) further indicated an ecosystem reorganization occurred in the 1970s at Kachemak Bay in southern Cook Inlet and around Kodiak Island and in Shelikof Strait located in Gulf of Alaska waters southwest of Cook Inlet (Bechtol 1997; Anderson and Piatt 1999). A decline in forage species, such as pandalid shrimp and capelin, was accompanied by increases in cod, pollock, and flatfishes.

Because eulachon and salmon are known to be fundamental components of the diet of CIBWs during the ice-free months, the remainder of this report will focus on these two groups of fish and their role in a healthy Cook Inlet Ecosystem.

EULACHON AS AVAILABLE PREY FOR COOK INLET BELUGA WHALES

A large component of the citations listed here derive from citations in Willson et al. (2006) and Gustafson et al. (2010).

Eulachon (*Thaleicthys pacificus*), also called hooligan or candlefish, are an anadromous fish in the Osmeridae family, with adults growing to ~250 mm in fork length and to 40–60 g in weight. Eulachon are common in the marine environment, where they spend over 90 percent of their lives (Hay and McCarter 2000). Although detailed information on the marine distribution is limited, survey data suggest eulachon are most common from near-surface to 400 m depths in waters from Alaska to Monterey Bay, California (Mecklenberg et al. 2002). Eulachon may also occur in deep troughs such as are found west of Kodiak Island, Alaska. However, the distribution of eulachon in the Bering Sea suggests this species inhabited a southern refuge along the Pacific coast during the most recent glaciation, with a subsequent range expansion following the glacial recession (McPhail and Lindsey 1970). Recent analysis of eulachon genetics further supports the theory of a northerly postglacial dispersal from a southern refuge (McLean et al. 1999; Flannery et al. 2013).

In the marine environment, eulachon have a high oil-content (17–21% of wet weight; Payne et al. 1999) making them a valuable prey species for other fish, seabirds, and marine mammals. Several aspects of eulachon biology indicate that large aggregations of adult eulachon are necessary to support sustained reproductive output. Eulachon are a relatively short-lived, highly-fecund forage fish with a high natural mortality, and such species typically have large population sizes (Gustafson et al. 2010).

Eulachon spawn along the west coast of North America in freshwater coastal water bodies ranging from the Pribilof Islands and the eastern Bering Sea in Alaska to the Klamath River in California (Scott and Crossman 1973). In Alaska, eulachon repeatedly spawn in at least 35 rivers as far north as the Nushagak River (Mecklenberg et al. 2002; Moffitt et al. 2002).

Eulachon tend to be larger at age in both length and weight in more northern latitudes (NMFS 2008; Spangler et al. 2003). The cause of larger body sizes in Cook Inlet's Twentymile and Susitna rivers is unknown but may be the result of different environmental conditions in northern latitudes (Spangler et al. 2003). Eulachon males typically have greater length and longer and wider ventral fins than females of similar age (Spangler 2002). Males also develop pronounced tubercles on the body, head, fins, and, particularly, the lateral lines during spawning (McPhail and Lindsey 1970; Spangler et al. 2003).

Life History of Eulachon

Being anadromous, eulachon begin their life in freshwater, go to sea for the majority of their life, and then return to freshwater as adults to spawn. Eulachon have a relatively short time period between entry into freshwater, spawning, and downstream migration of post-spawn adults when compared to some other anadromous species. For example, radio tagging on the Twentymile River in Upper Cook Inlet's Turnagain Arm suggested average periods in freshwater of approximately 5 days for males and 3 days for females, although these periods likely vary with other factors such as river flow, distance to spawning grounds, and water temperature (Spangler et al. 2003). However, most eulachon spawning locations, particularly in Alaska, are located relatively close to the point of saltwater entry.

In general, more southern eulachon populations spawn earlier than northern populations, with spawning as early as December to January in the Columbia River Basin and as late as June in central Alaska watersheds (Gustafson et al. 2010). However, there are localized exceptions, such as reported spawning as early as January in tributaries to the Alaska's Copper River Delta and as late as May in Northern California (Gustafson et al. 2010). There is also evidence of multiple, temporally separate spawning waves, such as spawning in February and again in June for the Eyak River (Joyce et al. 2004). In river tributaries of Cook Inlet, eulachon run timing lasts from approximately April or May into June, although some variation may be evident across streams and years (Barrett et al. 1984; Spangler et al. 2003). Barrett et al. (1984) reported eulachon entered the Susitna River of Upper Cook Inlet in a spawning run in late May with a second run in early June, but a recent study on the Susitna did not identify distinct multiple runs (AEA 2014). Eulachon in the Twentymile River exhibited variation in run timing with age (Spangler et al. 2003). For example, in some years, age-2 males would arrive earlier in the spawning season, and age-4 and -5 males would arrive later. Neither age-3 males nor any female ages showed a distinct pattern in run timing.

Age determination of spawning eulachon has typically been based on visual identification of annuli on hard structures such as otoliths, although validation of these age structures has been difficult. Clarke et al. (2007) used variation in the barium to calcium ratio to assign annuli to eulachon otoliths, and showed that the majority of most spawning populations are represented by one or two age classes. Other studies have also affirmed the dominance of a single year class, with the specific year class shifting among years in response to strong cohort strength (Moffitt et al. 2002; Spangler 2002; Willson et al. 2006). Throughout their geographic distribution, eulachon appear to spawn at ages ranging from 1 to 6 years, although spawning at age 3 or 4 is typical of many populations (Willson et al. 2006). In the Twentymile River of Cook Inlet, most spawners were age 3, although the age distribution varies somewhat among years (Spangler 2002). Age at spawning tends to increase with latitude. Spangler et al. (2003) further found spawning males tend to be older than females.

Eulachon are generally thought to spawn only once in a lifetime (semelparity), an aspect supported by the isotopic study of Clarke et al. (2007). However, Scott and Crossman (1973) reported evidence of repeat spawning, and Spangler et al. 2003 noted that several studies, including their Twentymile River research in Cook Inlet, found high abundances of males, most spawned out, moving downstream late in the spawning season. Fish tend to lose their teeth in association with spawning, although females may retain their teeth (Mecklenberg et al. 2002; Spangler 2002).

Spawning may occur on a wide range of substrates (silt, sand, gravel, cobble, or detritus), with sand appearing to be the most common (Smith and Saalfeld 1955; Langer et al. 1977; Barrett et al. 1984; Vincent-Lang and Queral 1984; Lewis et al. 2002). Eulachon exhibit high average fecundity, ranging from around 7,000 to 70,000 eggs per female (Spangler et al. 2003; NMFS 2008b). Fecundity increases with eulachon body length, weight, or age (Willson et al. 2006). In the Twentymile River fecundity was strongly correlated with female weight (Spangler et al. 2003). Size of eulachon eggs has varied slightly among studies, ranging from approximately 0.75 to 1.02 mm (Parente and Snyder 1970; Hay and McCarter 2000; Hay et al. 2002; Howell et al. 2001; HDR 2008).

Mature eggs have an outer sticky membrane that inverts after fertilization but remains attached to the egg allowing adherence to available substrates (Hart and McHugh 1944: Smith and Saalfeld 1955: Hay and McCarter 2000). Eggs may drift downstream before adhering to a substrate, or may be moved downstream after adhering to loose substrate (Lewis et al. 2002). Duration of incubation for eulachon eggs appears to increase with latitude (Spangler 2002; Spangler et al. 2003), and this duration may be related to water temperature. In a study on incubation time of eulachon eggs, eggs were taken from Cowlitz River spawning eulachon and fertilized in 250-ml beakers and placed in incubation trays with flowing Columbia River water. After 500 hours of incubation, larvae became active and all eggs hatched within 5 days (Parente and Snyder 1970). The incubation period appears to vary with latitude, ranging from approximately 21 days in British Columbia to 4 to 6 weeks in Southeast Alaska to 47 to 50 days in the Twentymile River in Southcentral Alaska (Berry and Jacob 1998; Flory 2008; Spangler 2002; Spangler et al. 2003). The survival of eggs to the larval stage varies with aspects such as: (1) water flow; (2) the substrate to which eggs adhere; and (3) exposure to salt water. Drifting eggs may have better survival than stationary eggs (Lewis et al. 2002), although survival declines rapidly if eggs drift into high salinity habitats.

Newly hatched larvae are ~4 mm long, transparent, slender, and weak swimmers. Larvae are typically washed downstream to the estuary within hours or days of hatching as the yolk sac is being absorbed. (Smith and Saalfeld 1955; Parente and Snyder 1970; Samis 1977; Howell 2001). Larval eulachon tend to occur closer to the bottom of the water column during their downstream migration (Robinson et al. 1968; Smith and Saalfeld 1955; Howell et al. 2001; Spangler et al. 2003), but tend to be found in the top 15 m of the water column in the estuarine environment (McCarter and Hay 1999; Hay and McCarter 2000). The larvae may reside in the estuary for weeks to months during which time they grow substantially (McCarter and Hay 1999; Hay and McCarter 2000). This extended estuarine residency likely facilitates homing by mature adults to the spawning river.

Limited data are available on eulachon larvae in Alaska estuaries. As part of an assessment for potential reconstruction of the Seward Highway from mileposts 75 to 90 along Turnagain Arm, the arm was surveyed for eulachon larvae during June 16 to July 25, 2006 (HDR 2006). Sampling gear included bongo rings, nets, and cod ends (McCarter and Hay 2003). Eulachon larvae were captured over the entirety of the 42-day study period, but 95% of the larvae abundance was captured during the 22-day period of June 21 to July 12.

Eulachon Stock Assessments

There is little discrete stock assessment information for eulachon populations spawning in the Upper Cook Inlet area (NMFS 2015). While not specific to Upper Cook Inlet, some data are available on general trends in observations of eulachon from other nearby areas in the Northern Gulf of Alaska. However, it must be stressed that these data from alternative areas are simply coarse indices of eulachon occurrence and are not to be considered formal assessments of eulachon abundance or distribution. Specifically, these data sources are not directed at eulachon but, rather, eulachon are a byproduct of the ongoing data collection. Much of the data derives from surveys in which catchability of eulachon is unknown, and likely inconsistent over time. In addition, species identification has been inconsistent over time; while species identification has likely improved in recent surveys, historical surveys may have simply identified eulachon as "smelt." Nonetheless, these data may provide some measure of general trends in eulachon abundance over time.

Marine Waters

Eulachon in the marine environment are not evaluated through a comprehensive stock assessment. However, multispecies bottom trawl and acoustic surveys conducted by the National Marine Fisheries Service (NMFS), and small-mesh trawl surveys conducted by NMFS and ADF&G, provide an index of relative abundance (Ormseth 2014). That is, these survey sampling protocols are not designed for eulachon and may provide an accurate estimate of population biomass within the survey context, but are better suited to simply provide information on general trends in population abundances. One additional source of biomass estimation is the mass-balanced ecosystem model (Aydin et al. 2007). This ecosystem model is based on food-web structure and attempts to balance biomass across species, species groups, and trophic levels using our understanding of productivity and predator-prey relationships. The ecosystem model, while typically providing larger biomass estimates of eulachon than is found in the surveys, is highly subject to predation assumptions as well as spatial and temporal variation in the source data supporting assumptions on predator-prey relationships (Ormseth 2014).

The NMFS bottom trawl survey in the Gulf of Alaska has been conducted either biennially or triennially from 1984 to 2015 (Figure 4; Ormseth 2014; http://www.afsc.noaa.gov/RACE/groundfish/survey_data/data.htm). Average catch rates (CPUE) of eulachon in the survey time series increased from 58 kg and 838 fish per hectare in 1984 to 286 kg and 9,575 fish per hectare in 1993, declined to 106 kg and 4,094 fish/hectare in 1999, increased rapidly to catch rates that were generally higher and ranged from a low of 346 kg and 11,344 fish per hectare in 2013 to a high of 814 kg and 22,818 fish per hectare in 2003 (Figure 5). Total eulachon biomass and abundance estimates in this survey, when scaled by available survey area, followed similar patterns (O. Ormseth, NMFS, pers. com.).

A NMFS (Alaska Fisheries Science Center [AFSC]) acoustic survey occurs in winter and targets walleye pollock (*Gadus chalcogramma*) in the Gulf of Alaska, notably in Shelikof Strait, but additional surveys have occurred occasionally in other areas and occasionally during the summer (Dorn et al. 2015). A midwater trawl is used to sample fish aggregations identified acoustically. Catch rates of eulachon in these midwater trawl samples varied dramatically over time, but exhibited peak catch rates in the late 1980s to early 1990s and again in the late 2000s (Figure 6; Ormseth 2014). While these peaks generally agreed with some of the peak catch rates observed in the bottom trawl surveys, the acoustic data differed in that there were fewer periods of high catch rates when compared to the bottom trawl survey time series. Part of this difference may be explained by the acoustic survey tending to be a much more localized survey, typically focused on the Shelikof Strait area. Another aspect is that the acoustic survey is typically an annual survey, whereas the bottom trawl survey has occurred every two to three years. Thus rapid and drastic changes in eulachon population levels might not be as easily detected by the bottom trawl survey. Finally, it must again be noted that: (1) these surveys are not directed at eulachon so survey efficiency for eulachon is limited; and (2) eulachon represent a relatively short-lived species (relatively r-selected; Pianka 1970) that tends to exhibit high and rapid fluctuations in population abundance in response to current ecological conditions.

Small-mesh trawl surveys have been conducted by NMFS and ADF&G in waters around Kodiak and by ADF&G in the Kachemak Bay area of Lower Cook Inlet (Jackson 2007; Gustafson and Bechtol 2005). The intent of these surveys has been to assess Pandalid shrimp populations targeted by commercial shrimp trawlers. Given the relatively small mesh size (32-mm stretch mesh) of the survey trawls, these surveys captured a wide variety of smaller species, including forage fish species, not retained in the larger mesh bottom trawls. The spatial distribution of survey effort was often inconsistent among survey years, but survey data may still serve as a general index of overall eulachon population abundance.

Eulachon catch rates in the Inner Marmot and Outer Marmot bays on the northern end of Kodiak island have been somewhat variable over the years 1976–2014, ranging from < 1 kg/km towed to 23.9 kg/km towed (Figure 7; A. Ellsworth, ADF&G, pers. com.). Years of low catch rates were evident in the mid-1980s to the early 2000s, and relatively high catch rates occurred in the 2000s. Note that survey frequency changed from annually in the mid-1970s to mid-1980s, to every two or three years until 2001 when an annual survey frequency was again implemented.

Small-mesh bottom trawl surveys of Kachemak Bay in Lower Cook Inlet were conducted by ADF&G from 1976 to 2006. Few eulachon were caught by the survey gear in the early portion of the time series, although a portion of this absence could have been attributed to sampling protocol in place at the time. However, eulachon catch rates increased in the late 1900s to a peak survey catch of 153 and 122 fish/nautical mile (nmi) in 2001 and 2004, respectively (Figure 8; J. Mumm, ADF&G, pers. com.). The variability among years of survey data, particularly when gaps exist in the survey coverage, can be substantial, and there is no indication as to whether there shifts are indicative of actual changes in the eulachon population or simply a shift in the spatial distribution relative to where the survey occurs. A large-mesh bottom trawl survey has also been conducted by ADF&G in Kachemak Bay from 1990 to 2013, and part of the multispecies catch has included eulachon. The large-mesh trawl gear includes no eulachon catch reported prior to 1998. Reported catches were quite variable thereafter, peaking at 71 fish/nmi in 2007, but with a mean survey catch of less than 5 fish/nmi reported in most years (Figure 8, J. Mumm, ADF&G, pers. com.).

Eulachon in Freshwater Tributaries

Although both small and large eulachon runs occur in a variety of Upper Cook Inlet tributaries, eulachon biomasses have not generally been estimated for these systems. Eulachon spawning migrations tend to occur in dense schools (Figure 9; J. Miller, ADF&G, pers. com.) A study was initiated in the spring of 2016 by ADF&G to assess returning adult eulachon and outmigrating larvae on the Susitna River, but data are not yet available (M. Willette, ADF&G, pers. com.). Historical studies have examined run timing and spawning location (Vincent-Lang and Queral 1984; Spangler 2002; Spangler et al. 2003), but abundance estimation studies have been limited. That is, there is little stock assessment information specific to eulachon abundance in Upper Cook Inlet, and certainly no long-term assessment data.

One recent study conducted as part of an environmental assessment for a potential hydroelectric project examined the run timing, distribution, and spawning of eulachon in the Susitna River of Upper Cook Inlet (AEA 2014). As part of the project, the study compared eulachon passage estimates based on fish tracking with a dual-frequency identification sonar (DIDSON), density-based estimated using the DIDSON data, and echo-integration using a split-beam transducer (A.-M. Mueller and D. Degan, Aquacoustics, Inc., pers. com.). The optimal acoustic platform depends on factors such as fish density, fish swimming speed, and presence of non-target species. Estimates of fish passage seemed reasonable, except for complications with assessing the likely peak of the spawning run when large aggregations of milling and spawning fish compromised the estimation process.

Ormseth (2014) explored the use of different time series of data for development of an indicator of forage fish abundances. For eulachon data, the comparison included the: (1) mean CPUE (kg/km towed) by sampling site in the trawl shrimp survey (i.e., small-mesh trawl nets) conducted in the western Gulf of Alaska during 1953–2010; (2) geometric mean of annual CPUE (kg/km towed) in the trawl shrimp survey conducted in the western Gulf of Alaska during 1953–2010; (3) biomass estimates from the Gulf of Alaska bottom trawl survey conducted by NMFS (see data in fishery description); and (4) incidental catches in sampling tows for the NMFS acoustic survey. The small-mesh trawl data and the acoustic survey sampling indicated two periods of relatively high eulachon CPUEs, although the periods differed between surveys. Eulachon CPUE in the small-mesh survey was highest in the mid-2000s, followed by the early 1980s and 1987 (Figure 7). However, substantial spatial variability was often evident with the mean CPUE often driven by large localized catches (Jackson 2007). Eulachon catches in survey trawls during the NMFS acoustic surveys indicated peak catch rates in 1989 and 1991, and in the late 2000s (Figure 6). Biomass estimates based on area-swept extrapolations from the NMFS bottom trawl surveys indicates eulachon biomass in the Gulf of Alaska peaked in 2003 followed by relatively large, but decreasing, biomass estimates from 2009 to 2013 (Figure 5). Despite the high interannual variability and the differences among surveys, there are some indications (including incidental catch…see below) of increased eulachon abundance in the Gulf of Alaska in the mid to late 2000s.

Eulachon Fisheries and Management

Both federal and State of Alaska fisheries regulations contain fisheries management plans that list eulachon as a forage fish. Federal regulations generally apply to marine waters 3–200 nautical miles (nm) offshore. Before 1998, forage fishes in federal waters of the Gulf of Alaska were classified under either the “Other Species” group, meaning nontarget species caught incidentally in commercial fisheries, or as “nonspecified,” with no conservation measures (Ormseth 2014). Amendment 39 to the *Gulf of Alaska Fishery Management Plan* in 1998 created a separate Forage Fish category, with conservation measures that included defining forage fish and a closure of directed fishing for forage fish. Beginning in 2011, species within the forage fish group were considered “ecosystem components.” The forage fish group under the federal plan contains over fifty species. Eulachon are listed under the Osmeridae taxonomic group, or smelts, with eulachon and capelin (*Mallotus villosus*) being the primary species. While directed fishing for forage fish in federal waters is prohibited, catches of forage fish species in aggregate (including eulachon) may be retained up to an amount not to exceed 2% by weight of the retained target species, and retained forage fish may only be converted into fishmeal. Incidental catch of eulachon by Gulf of Alaska commercial fisheries averaged 265 metric tons (range 18–

852 mt) during 2003–2015 (Table 2). Note that prior to 2005, species identification of many forage fish by fisheries observers were less reliable as many smelt species were simply recorded as "other osmerids" (Ormseth 2014).

State of Alaska fishing regulations for smelt generally apply to freshwater and to marine waters extending from shore to 3 nm offshore. For management purposes, eulachon are pooled into a "smelt" category that also includes longfin smelt (*Spirinchus thaleichthys)*; however, longfin smelt return in the fall and are not generally caught in the spring fisheries directed at eulachon (Shields and Dupuis 2015). Historically, the commercial smelt fishery in Upper Cook Inlet was relatively unregulated with an open season of October 1 to June 1, but the only documented harvests were 300 lb in 1978 and 4,000 lb in 1980 with gillnets, the presumed only legal gear at the time (Table 3; Shields 2005). Upon clarification that legal gear included dipnets, a gear preferable for marketing of eulachon as bait and marine mammal food due to reduced damage to the captured fish, harvests increased to 18,610 lb in 1998 and 100,000 lb in 1999 (the somewhat arbitrary harvest limit at the time). These harvests, coupled with implementation of forage fish protection measures in federal waters, raised concerns over the role of forage fish in aquatic ecosystems and the lack of regulatory measures to protect forage fish in state waters. Fishery discontinuation was also recommended by NMFS, in part due to the lack of data on eulachon runs into the Susitna River, and due to the lack of evaluation of fishery effects on beluga whales (NMFS 2008). It was noted that CIBWs may be heavily dependent on the oil-rich eulachon early in the spring (preceding salmon migrations), the runs are very short in duration, and that large eulachon runs may occur in only a few upper inlet streams. The Alaska Board of Fisheries subsequently adopted regulations under *5 AAC 39.212. Forage Fish Management Plan*, implemented in 1999. This plan contains regulatory language that was virtually identical to federal regulations, but allows exceptions as provided by other state regulations. In 2005 the board adopted *5 AAC 21.505 Cook Inlet Smelt Fishery Management Plan*. This commercial fishery is only allowed in salt water, from May 1 to June 30, in Cook Inlet from the Chuitna River to the Little Susitna River and in the Susitna River south of 61° 21.50'N lat. (Figure 1; Shields and Dupuis 2015). Legal fishing gear is limited to a hand-operated dip net with a maximum harvest of 100 tons. Participants must possess a miscellaneous finfish permit and a commissioner's permit. Since being reopened in 2006, annual commercial harvests have averaged 77 tons (range 45–107 tons; Table 3). Fishery management appears to have stabilized harvests during 2011–2015 (average harvest 100 tons), aided by consistent harvest effort (4–5 permits).

Cook Inlet has a long history of non-commercial eulachon harvests with hand-held dipnets or gillnets, depending on the specific area fished. Subsistence harvests of smelt are allowed under state regulation *5AAC 01.599 Subsistence Smelt Fishery* (Shields 2005). Subsistence fishing for smelt is opened from April 1 to May 31 and from September 1 to October 30 in saltwater, and from April 1 to June 15 in freshwater. There are no bag or possession limits, legal gear is gillnets or dipnets, and subsistence fishing is limited to subsistence areas designated in regulation *5AAC 99.015(a)(3)*. Currently, no subsistence records are kept for smelt or herring harvests in Upper Cook Inlet (J. Fall, ADF&G, pers. com.). However, household surveys conducted by the ADF&G in the Tyonek area estimated eulachon harvests of 780 lb, 1,811 lb, and 1,468 lb in 1983, 2006, and 2013, respectively (Fall et al. 1984; Stanek et al. 2007; Jones et al. 2015).

Personal use smelt fisheries in state waters are allowed under state regulation *5AAC 77.527* (Shields 2005). There are no bag or possession limits. Smelt may be taken with dipnets from April 1 to May 31 in saltwater and from April 1 to June 15 in freshwater. Drift gillnets may be used from April 1 to May 31 in both saltwater and freshwater. Participants in this fishery must possess a State of Alaska sport fishing license. The most significant areas for personal use smelt fisheries in Cook Inlet are the Twentymile River area (including shore areas of Turnagain arm) and the Kenai River (Figure 1; Shields 2005). Other important personal use harvest areas are the Big and Little Susitna Rivers, Deshka River, Placer River, Yentna River, and shoreline areas of Turnagain Arm and Cook Inlet north of the Ninilchik River (Figure 1). Harvests are assessed through an ADF&G Sport Fish Division statewide mail survey that is sent to randomly selected individuals possessing sport fishing licenses (http://www.adfg.alaska.gov/sf/sportfishingsurvey/). Survey participants are asked to provide information on the location, time and duration of fishing effort, number of people fishing, and catch and catch disposition (i.e., retained or released); data are expanded to unsurveyed fishing license holders. Note that for some harvest reporting, fishing area delineations are rather coarse. For example, the area designated as “Anchorage,” Area L, encompasses tributaries on the east side of Knik Arm to the north side of Turnagain Arm; the latter section including Twentymile River (Figures 1 and 10). Fishing effort for personal use harvests of smelt undoubtedly varies with socioeconomic variables (e.g., gasoline prices and cultural values), but effort also likely responds to annual changes in the population abundance of spawning eulachon. Thus, strong spawning returns observed in-season would be expected to generate increased fishing effort such that recreational harvests are somewhat correlated to the relative magnitude of the spawning populations, particularly in the Anchorage area where access is relatively close and personal use harvesters are largely highly mobile.

Personal use harvests of eulachon in the Cook Inlet area showed high interannual variability, both within and among harvest reporting areas (Table 4; Figure 11). Aggregate estimated eulachon harvests in the Cook Inlet area generally peaked in 1999, 2002, and 2012–2013, before declining drastically in 2014. Relatively low harvest years occurred in 2005–2008. From 1996 to 2014, the Anchorage area yielded an average harvest of 28,716 (range 8,885–57,079) eulachon/year, accounting for 56% of the long-term average among personal use harvest reporting areas (Table 4). The bulk of these harvests can be attributed to fishing in the Twentymile River areas, including nearby waters of Turnagain Arm. The next largest average yield (26% of total) of eulachon during 1996–2014 came from the Kenai Peninsula - freshwater (average 12,953; range 2,270–41,085). The primary producing tributary on the Kenai Peninsula is the Kenai River, although the Kasilof River also supports eulachon populations. The Kenai Peninsula freshwater area did yield the largest portion of eulachon personal use harvests in 2000, 2004, 2005, and 2014 (Figure 11). The remaining Upper Cook Inlet reporting areas, in ranked order of average long-term yield, were the Susitna River drainage (average 5,988; range 0–36,847; 12% of total), Cook Inlet saltwater (average 1,960; range 148–11,814; 4% of total), Knik Arm (average 642; range 0–6,131; 1% of total), and West Cook Inlet average 339; range 0–2,703; <1% of total). It should be noted that in terms of harvest reporting, some survey participants may have considered their eulachon fishing effort as part of a subsistence fishery rather than participation in the personal use fishery, thus failing to report their catch as personal use on the ADF&G statewide mail survey (Shields 2005). In addition, it is feasible that some individuals considered their efforts in the waters of Turnagain Arm as fishing Cook Inlet saltwater, rather than the Anchorage reporting area. Although eulachon harvests generally appeared greater in the late 1990s and mid-2000s, there was little correlation of annual harvests among reporting areas (Table 4).

A correlation comparison can indicate the strength in similarities among trends for different sets of data. For instance, we might expect that if abundances among different eulachon spawning populations respond similarly to shared marine environmental conditions, then those populations might exhibit somewhat similar population trends, i.e., a high correlation among population indices. Potential correlation values range from 1.0 (i.e., complete agreement such that an increase in one index is matched by a similar increase in another index) to -1.0 (one index goes up when another goes down). However, analyses of the time series of personal use harvests among areas with a Pearson correlation coefficient indicated maximum correlation of 0.38 between the time series of personal use harvest estimates for the Susitna River drainage and the Knik Arm (Table 4). Given the close geographic proximity of the different reporting areas and the shared environment of Upper Cook Inlet, this weak correlation in catch trends was unexpected and may indicate other socioeconomic factors driving harvests, such as people not fishing in an area or shifting areas due to certain conditions. Despite the uncertainty in the implication as a data index for eulachon population biomass, the mail survey is one of the few "long-term" data sources available.

Based on the few data available, the eulachon stocks of Cook Inlet do not appear to have declined to a low level. Ultimately, the population trends of Cook Inlet eulachon remain unknown as commercial and non-commercial harvests provide only coarse indices of abundance. This lack of stock assessment for eulachon stocks in Cook Inlet contrasts sharply with the salmon management, which applies standardized spawner escapement goals for index stocks and intensive management during the annual fisheries. Concurrent with ongoing fisheries and other sources of mortality, eulachon remains a high-lipid prey resource within Cook Inlet, available to CIBWs in a critical season when few other prey resources are available. Thus, there continues to be a need to better understand the ecosystem linkage between eulachon and CIBWs and how fluctuations in eulachon abundance and availability may contribute to Cook Inlet ecosystem health and CIBW survival and recovery.

SALMON AS AVAILABLE PREY FOR COOK INLET BELUGAS

There are five species of Pacific salmon common to Alaska: Chinook (*Oncorhynchus tshawytscha*), chum (*O. keta*), coho (*O. kisutch*), pink (*O. gorbuscha*) and sockeye (*O. nerka*) salmon. Pacific salmon are an anadromous species in which reproduction occurs when mature adult fish return from a marine environment, enter a freshwater system, and deposit eggs with simultaneous fertilization in the gravel of freshwater streams (Figure 12). The eggs hatch as alevin that are essentially fry with attached yolk sacks that provide the nutrition to support the small salmon in the gravel through the winter. The fish emerge from the gravel as fry in the spring and, depending on the species, either go directly to sea (pink and chum salmon), or spend an additional one or more years in freshwater water (typically Chinook, sockeye, and coho salmon) before entering the ocean as smolt. However there are exceptions, such as Chinook, sockeye, and coho salmon reared in aquaculture facilities with warm water that accelerates growth such that these fish become smolt and go to sea within a year of being fertilized as eggs. In addition, certain stocks or stock components of species that are generally associated with additional freshwater rearing may go to sea after emergence from the gravel. Regardless of the salmon species, the transition from freshwater to saltwater involves a major biological shift as fish transition from a freshwater to a saltwater existence, with the opposite shift as mature salmon return from the marine environment and enter the freshwater to spawn. This shift in osmoregulation requires changing from freshwater, where fish blood and cells have a higher salt concentration than the surrounding environment, to saltwater where the fish had a lower salt concentration than the surrounding environment. Upon returning to freshwater, the adult salmon no longer feed but rely on body reserves for the energy to swim to the spawning gravels of their birth. After spawning, the adult salmon die, with post-spawning carcasses contributing organic nutrients to the freshwater ecosystem. The role of anadromous salmon in transferring marine-derived nutrients to freshwater ecosystems is well-recognized (Schmidt et al 1998; Gende et al. 2002; Wipfli et al. 2004; Schindler et al. 2005).

Life History by Salmon Species

Chinook Salmon

Chinook salmon stocks occur from northern Hokkaido in Japan to the Anadyr River along the coast of Asia, north to Point Hope, Alaska, and south along the eastern Pacific to Ventura River, California (Healey 1991; Mecklenburg et al. 2002). Chinook salmon are often categorized into two life history forms. The "stream-type" spends one or more years in freshwater as juveniles before entering the ocean; this form is typical of northern Chinook salmon stocks like those common to Upper Cook Inlet. A second form, the "ocean-type," represents Chinook salmon that migrate to sea during their first year of life. Ocean-type Chinook salmon are typical of stocks occurring south of the Columbia River drainage at 56^{o} N. latitude (Healey 1991). Chinook salmon achieve the largest size of the Pacific salmon species, with specimens reaching sizes of 23 kg (50 lb), and the largest documented specimens exceeding 61 kg (135 lb; Mecklenburg et al. 2002).

For most northern stocks of Chinook salmon, a single migratory peak is typical and generally occurs in June. Within Upper Cook Inlet streams and rivers, Chinook salmon are usually the first to return in spring/summer. Returns have historically peaked in mid-June in the Susitna and Little Susitna rivers, in mid-July in the Kenai River, and in late June to early July in the Kasilof River (Figure 13; M. Willette, ADF&G, pers. com.). For management of Chinook salmon returning to the Kenai River, there is also the delineation of an early-run versus a late-run, separated at the calendar dates of June 30–July 1 (McKinley and Fleischman 2013). Fecundity in Chinook salmon has been estimated at fewer than 2,000 to over 17,000 eggs/female, although fecundities in the range of 4,000–8,000 eggs/female are more common (Healey and Heard 1984). Although there is a general increase in fecundity with female body size, this relationship can vary greatly among years and within and between stocks due to a tradeoff between egg size and egg numbers (Healey and Heard 1984; Healey 1991). Egg size appears to increase slightly with fish size, with larger eggs resulting in larger, more robust fry that have relatively greater survival (Quinn et al. 2004; Quinn 2005). There may also be a slight tradeoff between fecundity and energetic expenditures for growth and for freshwater spawning migration, particularly for long river systems (Healey 1991; Crossin et al. 2004; Jasper and Evenson 2006).

Upon emergence from the gravel, Chinook salmon fry in Upper Cook Inlet streams typically remain in freshwater for one additional year before entering the marine environment (stream-type; Healey 1991; Shields and Dupuis 2015); however, some stocks have a small portion of individuals that leave after emergence at age-0 (ocean-type). The average length of age-1 smolts ranges from approximately 65 to 95 mm, but can vary greatly by stocks and year (Roth et al. 1986; Healey 1991). Timing of seaward migration by Chinook salmon smolt also varies, but generally occurs from June to late July. During the smolt transition phase, Chinook salmon can be highly dependent on estuaries (Healey 1991). Beach seine catches of Chinook salmon smolt in nearshore waters near the Chuitna River in western Cook Inlet peaked in May, but smolts were caught in June to August and October (Nemeth et al. 2007). Similarly, a surface trawl survey in Upper Cook Inlet caught Chinook salmon smolt from early June to mid-July, although no Chinook smolt were caught in September (note - no tows were made from late July through August; Moulton 1997).

After reaching the estuaries, juvenile Chinook salmon disperse seaward, with stream-type juveniles tending to disperse sooner than ocean-type juveniles (Healey 1991). Stream-type juveniles also tend to occur farther offshore into the North Pacific Ocean, including across vast areas of the Gulf of Alaska and Bering Sea (Guthrie et al. 2014, 2016). Ocean-type fish tend to predominate in coastal waters (Healey 1983, 1991). In addition, there is a general northward migration trend in the marine environment for juveniles from most Chinook salmon populations (Healey 1991). Marine residency for Chinook salmon ranges from 1 to 6 years, although 2–4 years is most common (Mecklenburg et al. 2002; Begich 2010; Shields and Dupuis 2015). Lewis et al. (2015) examined changes in size and age of Chinook salmon from ten datasets across Alaska over recent decades and found: (1) the proportion of older and larger 4-ocean fish had declined in all stocks; and (2) the size-at-age had also declined for 3-ocean fish (9 of 10 stocks) and 4-ocean fish (5 of 10 stocks).

Non-spawning ("feeder") Chinook salmon that are primarily not of Cook Inlet origin also occur in Cook Inlet, particularly in the southern portion of the inlet (Szarzi and Begich 2004; Begich 2010; W. Bechtol, pers. obs.). There has been a general increase in the winter recreational harvest of these non-local stocks; tagging data suggests these stocks are largely from British Columbia, with additional contributions by Washington, Oregon, and other Alaskan stocks. The extent to which these stocks may provide a winter prey resource for CIBWs is largely unknown given the recreational harvest are largely south of the documented CIBW winter distribution.

Chum Salmon

Chum salmon have the broadest natural geographic distribution of all Pacific salmon species, ranging from southern Japan and Korea in the western Pacific Ocean, north to the Lena River along the arctic coast of Russia, east to the Mackenzie River on the arctic coast of Canada, and south along the eastern Pacific Ocean to central California (Salo 1991; Mecklenburg et al. 2002). Chum salmon in most regions are represented by spawning races; an early ("summer") run that returns sometime from May to August, depending on area, and a late ("fall") run that returns during July–September (Salo 1991). Fall runs tend to have lower return abundance, a larger body size, greater fecundity, and spawn in spring-fed habitats; summer chum rums tend to spawn in the main stems of tributaries (Buklis and Barton 1984; Salo 1991). Mature chum salmon are the second largest Pacific salmon with large specimens reaching sizes of 21 kb (45 lb; Mecklenburg et al. 2002).

Within Upper Cook Inlet tributaries, chum salmon have a spawning migration from June to September, with peak migrations from late July to early August (LGL/ADF&G 2015). Major spawning stocks of chum salmon in Upper Cook Inlet are found in tributaries along northern and western Cook Inlet, including the Susitna River drainage and Knik Arm, with minor returns in other areas (Figure 14; Shields and Dupuis 2015; M. Willette, ADF&G, pers. com.). Tributaries along the eastern shore of Upper Cook Inlet between Turnagain Arm and Anchor Point have no identified spawning populations of chum salmon (Figure 14; M. Willette, ADF&G, pers. com.).

Reported fecundity for chum salmon ranges from 1,500 to 4,000 eggs/female, although somewhat higher fecundities have been reported for chum salmon in Asia (Salo 1991; Beacham 1982; Gilk et al. 2005). Fecundity tends to increase with fish size, but may be lower on spawning tributaries of shorter length. Egg size increases with female size, and larger eggs result in larger alevin, with differences maintained through the fry stage giving a potential survival advantage to future life stages (Salo 1991).

Upon emergence from the gravel, chum salmon immediately migrate downstream to an estuarine environment, distinguishing them from the 1–2 year residence time in freshwater by most Pacific salmon except pink salmon. Downstream migration of chum salmon typically occurs during early darkness beginning in May to July, with downstream movement reduced or curtailed during daylight (Salo 1991). Fry tend to migrate earlier in larger rivers or when the spawning habitat is farther from the marine environment. Juvenile chum salmon in Upper Cook Inlet begin the seaward migration shortly after ice out (mid to late May), peak from late May to mid June, and are mostly complete by late July (Roth and Stratton 1985). Juvenile chum salmon leaving freshwater typically range from 30 to 60 mm fork length (measured from the tip of the snout to the fork of the tail; Roth and Stratton 1985; Roth et al. 1986; Salo 1991). Chum salmon smolt were caught in beach seine surveys along the Upper Cook Inlet nearshore areas from May to August, with peak catches in June; no chum salmon were caught in September or October (Nemeth et al. 2007). Similarly, a surface trawl survey found chum salmon smolt to be widespread in the estuarine environment of Upper Cook Inlet present in 82% of July tows and 76% of June tows; no chum salmon smolt were caught in September (Moulton 1997).

Chum salmon smolt have a high reliance on estuaries for feeding when transitioning into the marine environment (Salo 1991). This transition can depend on water temperatures and food resources through plankton blooms and insects drifting at the water surface. Moulton (1997) found over 52% of juvenile chum salmon stomachs examined in June contained insects, and over 50% of the consumed insects were adult aphids. Fish larvae were also an important diet component in June, but decreased in July when the insect contribution to the diet further increased.

As chum salmon move offshore, their diet becomes more size and taxa selective with a shift to neritic prey inhabiting the pelagic environment from the surface to about 200 m deep (Salo 1991). Common prey are calanoid copepods, amphipods, larvaceans, euphausiids, decapod larvae, and fish larvae. Chum salmon of North American origin are found offshore from the eastern Pacific Ocean west to ~175^{o} W. longitude. Juvenile chum salmon from Cook Inlet likely migrate west in coastal nearshore waters of the Gulf of Alaska, south into the North Pacific Ocean during fall and winter, then north and west in the subsequent spring and early summer (Salo 1991). Marine residency for chum salmon ranges from 2 to 6 years, although 3–5 years is most common (Thompson et al. 1985; Mecklenburg et al. 2002; Eaton 2014). For some chum salmon stocks, there is a strong even-odd year cycle in the strength of the return abundance (Smoker 1984; Salo 1991). This cycling may be related to strong biennial cycles of return abundance in pink salmon as a mechanism to reduce competition for spawning habitat or other resources.

Coho Salmon

Coho salmon are distributed from northern Japan and North Korea in the western Pacific Ocean, north to the Anadyr River in Kamchatka, and in the eastern Pacific Ocean from Point Hope, Alaska, south to Monterey Bay, California (Sandercock 1991; Mecklenburg et al. 2002). Spawning populations are most often associated with short coastal streams, but are also found in the Tanana River drainage over 700 miles (1,126 km) from the mouth of the Yukon River (Estensen et al. 2015). Coho salmon have also been introduced into many cold temperate areas of the world, including landlocked lakes, and are also commonly cultured on aquatic farms in some countries. Coho salmon were successfully introduced into the Great Lakes beginning in the 1960s (Sandercock 1991). The maximum reported size of coho salmon was 17.7 kg (39 lb; Mecklenburg et al. 2002), although fish over 9.0 kg (20 lb) are rare (Sandercock 1991).

While most coho salmon stocks have a single spawning migration, some stocks exhibit two peak spawning migrations evolved as an adaption to seasonal water flow conditions (Sandercock 1991). A more northerly latitude is usually associated with an earlier initiation of the coho spawning migration. In Alaska, coho salmon have a spawning migration extending from July through October (Figure 13; Chythlook and Evenson 2002; Szarzi and Begich 2004; Westerman and Willette 2013). Most stocks in Upper Cook Inlet have a single migration period, or with multiple modes that are only weakly developed, and the migration typically peaks in August (Figure 13). Spawning typically occurs from late August into at least late November. Fecundity for coho salmon increases with the size of the female, but there is also a general increase in fecundity with higher latitude. Mean fecundity for most coho salmon stocks in Alaska is likely in the range of 3,500–4,000 eggs/female, although fish returning to Karluk Lake on Kodiak Island have fecundities ranging from 1,720 to 6,900 eggs/female (Drucker 1972; McHenry 1981; Beacham 1982; Sandercock 1991).

Coho salmon fry emerge from the gravel at a relatively large size, ~30 mm in length, compared to fry of most other salmon species (Sandercock 1991). In addition, earlier emerging fry tend to be larger than later emergents which tends to convey a competitive advantage to early fish. While some fry may move upstream or downstream to rear in lakes, most remain in the stream habitat. The fry often establish territories in preferred locations, with the size of the territory increasing as the fish grows. As waters temperatures decline in the fall, feeding decreases and fish move into deeper pools with slower velocities or side creeks with structure such as logs and stable flow. In spring, the fry move back to preferred feeding habitats. Coho fry may spend up to four years in the freshwater environment, before migrating to sea, but one year after emergence from the gravel is more typical (Roth et al. 1986; Mecklenburg et al. 2002; Burril and Nemeth 2013). Downstream migration in Alaska usually occurs from May to July, but timing may be affected by fish size, water flow and temperature, and food availability (Drucker 1972; McHenry 1981; Sandercock 1991).

Upon entry into the estuarine environment, juvenile coho salmon remain relatively close to shore for a period of several weeks to several months before gradually moving farther offshore. Beach seine surveys in nearshore environments of Upper Cook Inlet documented coho salmon smolt presence from May to October with peak catches occurring in June and August (Nemeth et al. 2007). Similarly, in surface trawl surveys conducted more offshore in Upper Cook Inlet, coho salmon smolt were captured from early June through September, with peak catches in mid June and mid July (Moulton 1997). The largest surface trawl catches occurred near the Susitna River Delta in the northeast portion of Cook Inlet.

During their first year in the marine environment, juvenile coho salmon tend to migrate northward and westward in coastal waters with most fish remaining within 150 km (95 miles) of shore (Royce et al. 1968; Sandercock 1991). As fall approaches and becomes winter, some coho salmon gradually migrate southward along the coast, but other fish migrate in a counter-clockwise loop offshore in the Gulf of Alaska. “Jacks,” precocious males that mature in the same year of entering the marine environment, return in the fall to their natal streams. Jacks comprise a highly variable component of the spawning coho salmon population, anywhere from 1% to nearly 50%, but is likely less than 20% in most populations. However, over 90% of the fish from most coho salmon stocks in Alaska, including Cook Inlet, typically return to spawn after spending one winter at sea, with a small proportion returning after zero or two winters in the marine environment (Mecklenburg et al. 2002; Schmidt and Evans 2011; Elliot 2013; Ivey 2014).

Pink Salmon

Pink salmon are distributed in Asia from northern Japan and North Korea in the western Pacific Ocean, north through the Bering Strait and around to the Lena River along the Siberian Arctic. In North America, pink salmon occur from the Sacramento River in California, north through the Bering Strait, and east of Point Barrow into the Canadian Arctic (Heard 1991; Mecklenburg et al. 2002). Pink salmon are the most abundant of all Pacific salmon species, but are also the smallest Pacific salmon, averaging 1.0–2.5 kg (2.2–5.5 lb), and have the simplest life history. Pink salmon are unique in having a fixed two-year life cycle, which is to say that progeny from a particular year class return as mature adults exactly two years later. This creates a situation in which runs in alternate years are reproductively isolated and genetically distinct, often with pronounced differences in run strength referred to as an even-odd year pattern. For example, in the Fraser River of British Columbia only the odd-year stock exists and even year returns are negligible (Heard 1991). In contrast, even-year returns are pronounced and the odd-year runs are minimal in Bristol Bay, Alaska (Jones et al. 2016). But for most river systems off Alaska and British Columbia, even- and odd-year runs of pink salmon both occur, but returns to one run are consistently more abundant on a two-year cycle. Pink salmon returns in Upper Cook Inlet tend to be substantially stronger in even years (Shields and Dupuis 2015).

The timing of spawning migrations in pink salmon varies by stock and region. Inshore runs in western Alaska peak in late July, and in more northerly areas such as Norton Sound, peak spawning tends to occur earlier compared to more southern areas such as Bristol Bay (Heard 1991). Spawning migrations in central Alaska tend to occur from late July into early September. In southeast Alaska, spawning tends to be concentrated in late August through September. There is also evidence of run timing variation in southeast Alaska related to water temperatures such that mainland streams with cooler average temperatures have earlier runs and island streams with warmer temperatures have later runs. It has also been noted that in years when a particular return population is large, run timing may be slightly delayed (Heard 1991). In Upper Cook Inlet, pink salmon have a run timing ranging from mid July to mid August, and into early September for the Kenai River (Figure 13). Pink salmon are the least fecund of the Pacific salmon species. While fecundity generally increases with female size, there is substantial variation in mean fecundity-at-size among stocks, regions, and years (Heard 1991). Overall, average fecundity ranges from about 1,200 to 2,000 eggs/female.

The location within a river system where pink salmon spawn is often relatively close to the ocean such that the freshwater migration is of short distance. This is most pronounced in intertidal spawners, which may comprise up to 74% of the spawning population in some areas and years (Noerenberg 1963). After overwintering, pink salmon fry emerge from the spawning substrate and immediately migrate downstream toward the ocean, spending less time in the freshwater environment, and typically with little feeding, compared to other salmon species (Heard 1991).

Upon reaching the marine environment, juvenile pink salmon may immediately show a strong preference for saline water and often disperse offshore 50 km (30 miles) over a few days. However, other studies have found delayed dispersal from the estuarine to the marine environment. Beach seine surveys along nearshore habitats of Upper Cook Inlet caught small numbers of juvenile pink salmon from May to July (Nemeth et al. 2007). In contrast, Moulton (1997) found pink salmon smolt to be the most abundant salmon catch in surface trawl surveys of offshore habitats in Upper Cook Inlet during June to mid July, but pink salmon were absent in September tows. These differences suggest a rapid migration into the more offshore areas of Upper Cook Inlet, followed by movement toward the Gulf of Alaska.

Although extended offshore dispersal occurs, most pink fry form schools and follow shorelines near the water surface. As they grow, the juvenile pink salmon move slightly offshore and into deeper waters, migrating west along coastal areas of the Gulf of Alaska. During fall and winter, the pink salmon are presumed to migrate counter-clockwise through the Gulf of Alaska, first south and the east. In the next spring and summer, the salmon migrate to their natal streams (Takagi et al. 1981; Heard 1991). Overall, the pink salmon spend approximately 16 months at sea before returning to their natal streams.

Sockeye Salmon

Sockeye salmon are the third most abundant species of Pacific salmon. Primary spawning areas of sockeye salmon extend from Hokkaido, Japan, in the western Pacific Ocean north to Point Hope, Alaska, and south along the eastern Pacific Ocean to the Klamath River in California (Mecklenburg et al. 2002). Sockeye salmon have broad variety of life history strategies compared to other Pacific salmon species. While most salmon populations are anadromous, some stocks or components of sockeye salmon live and reproduce only in freshwater as kokanee (McCart 1970). Sockeye salmon may reach 7 kg (15 lb), but smaller as kokanee (Mecklenburg et al. 2002).

Sockeye salmon provide the largest salmon returns to Upper Cook Inlet (Figure 14; Westerman and Willette 2013; Shields and Dupuis 2015). In Upper Cook Inlet, run timing of sockeye salmon ranges from late May to late August with peak migrations occurring in mid July for most river systems, but with an additional early June peak for the Little Susitna (Figure 13).

The primary spawning habitat for sockeye salmon is river tributaries, but lake shorelines with upwelling groundwater also serve as spawning areas for some stocks (Burgner 1991). Most spawning locations are associated with one or more lakes that serve as rearing habitat for sockeye salmon fry. Spawning areas located in large rivers adjacent to lake rearing areas tend to support a higher proportion of older, larger sockeye salmon spawners (Rogers 1987). Finally, some unique sockeye salmon populations are adapted to river systems without a lake access (Wood et al. 1987; Burgner 1991; Yanusz et al. 2011). Sockeye salmon have the highest fecundity (relative to the fish size) and smallest egg size of all Pacific salmon. Fecundity across the entire spatial distribution of sockeye salmon ranges from 2,000 to 5,000 eggs/female, whereas kokanee fecundity ranges from 300 to 2,000 eggs/female (Burgner 1991).

Upon emergence from the gravel substrate, most sockeye salmon fry move downstream, or upstream, into a lake for freshwater rearing. For fish that do not rear in a lake system after emerging from the gravel, fry either rear in the river system or migrate directly to the sea, depending on the particular population (Burgner 1991). Based on the population characteristics, the rearing habitat available, and annual growth of individual fish, sockeye salmon fry rear in freshwater habitats from zero to three years (Koenings and Burkett 1987). Emigration as age-1 or age-2 smolt has been shown to relate to parent spawner abundance, with high spawner densities resulting in greater proportions of age-2 smolt (Rogers 1980). Most stocks in Upper Cook Inlet spend one or two years in freshwater before seaward migration, although an average of around 6% of the fry in the Yetna River spend zero years in freshwater (Westerman and Willette 2013). Seaward migration as smolt typically occurs within days of ice breakup on the rearing lakes (Burgner 1991). Migration of smolt from Upper Cook Inlet tributaries occurs from early May into early July with variation among years and within and between stocks (King et al. 1994).

Juvenile sockeye salmon may remain in the estuarine habitat or in nearshore coastal waters for several months after exiting the freshwater rearing system, but the fish begin migrating offshore in August to October (Burgner 1991). Beach seine studies along nearshore habitats of Upper Cook Inlet documented recently migrated juvenile sockeye salmon present from May to September with peak numbers occurring in June and July, but no juveniles found in October (Nemeth et al. 2007). Similarly, during surface trawl surveys of more offshore habitats in Upper Cook Inlet, Moulton (1997) documented the presence of juvenile sockeye salmon from June through mid July, with peak catches in mid June and no catches in September (note - no tows were conducted in August).

The juvenile sockeye salmon originating in the eastern Pacific Ocean likely spend the winter migrating southward and into a counter-clockwise loop of the Gulf of Alaska (French et al. 1976; Burgner 1991). In subsequent years at sea, the salmon migrate north and west during spring–summer, followed by southward migration in fall–winter in a continuation of the counter-clockwise loop. Upon approaching the age of maturity, those fish that are maturing separate from other sockeye salmon at sea and make an accelerated migration to their natal streams in spring to early summer. Across their geographic spawning distribution, sockeye salmon spend from one to four years in the ocean before returning to spawn (Burgner 1991; Mecklenburg et al. 2002). In tributaries of Upper Cook Inlet, sockeye salmon also spend one to four years before returning to spawn, but two or three years is more typical with the predominate age class depending on the freshwater tributary (Westerman and Willette 2013).

Upper Cook Inlet Salmon Stock Assessments

The highest priority of salmon management is to annually provide for an appropriate abundance of salmon to reach the spawning grounds (escapement) for replenishment of the stock. Escapement is affected by a variety of factors including harvests, predation, disease, and physical and biological changes in both the freshwater and the saltwater habitats. Salmon managers must balance or constrain human harvests and other anthropogenic impacts against the escapements needed to maintain productive salmon spawning populations (Hilborn and Walters 1992; Quinn and Deriso 1999). Escapement target numbers, referred to as “escapement goals,” are developed based on the type, quantity, and quality of historical spawner abundances for a given salmon stock (Yuen 1992; Fair et al. 2013; Clark et al. 2014; Conitz et al. 2015; Bue and Hasbrouck[1] *unpublished report*). The escapement goal is often expressed as either a minimum

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[1] Bue, B.G. and J.J. Hasbrouck. *Unpublished*. Escapement goal review of salmon stocks of Upper Cook Inlet. Report to the Board of Fisheries November 2001 (and February 2002). Alaska Department of Fish and Game, Anchorage.

threshold or a range for the abundance of spawning salmon returning to a given tributary. Escapement goals are developed by ADF&G and reviewed in consultation with stakeholders and the Alaska Board of Fisheries on a 3-year cycle (Fair et al. 2013). Currently for Upper Cook Inlet, there are two types of escapement goal ranges applied, although a third type (the optimal escapement goal) may be applied if specific conditions occur (Table 6; Shields and Dupuis 2015):

> State of Alaska regulation *5 AAC 39.222 (f)(3)* defines a "biological escapement goal" (BEG) as the escapement that provides the greatest potential for maximum sustained yield. A BEG is developed from the best available biological information, and typically is applied to stocks for which there is good information on harvests, age composition, and a spawner-recruit relationship. The BEG is expressed as a range based on factors such as salmon stock productivity and data uncertainty; the intent is to maintain evenly distributed escapements within the bounds of the BEG.
>
> State regulation *5 AAC 39.222 (f)(36)* defines a "sustainable escapement goal" (SEG) as a level of escapement, indicated by an index or an escapement estimate, that has provided for sustained yield over a 5 to 10 year period, but where a BEG cannot be estimated or managed for. The SEG is developed from the best available biological information; and is identified as either an "SEG range" or a "lower bound SEG."
>
> State regulation *5 AAC 39.222 (f)(25)* defines an “optimal escapement goal” (OEG) as a specific management objective for salmon escapement that considers biological and allocative factors and may differ from the SEG or BEG. The OEG will be established by the Alaska Board of Fisheries and will be expressed as a range, with the intent that escapement will be evenly distributed within the bounds of the OEG.

The Kenai, Kasilof, and Susitna rivers support the largest salmon runs in Cook Inlet (Figure 1; M. Willette, ADF&G, pers. com.). The dominant species in the Kenai and Kasilof rivers is sockeye salmon, with significant runs of Chinook, coho, and pink salmon also spawning in the Kenai River (Figure 14). Relatively small runs of Chinook salmon, and larger runs of coho salmon, return to the Chuitna, Beluga, Theodore, and Lewis rivers. The largest watershed feeding Cook Inlet is the Susitna River which supports significant runs of all five salmon species. Large returns of chum, pink, and coho salmon also return to the Little Susitna River. Finally, smaller runs of all five salmon species return to various smaller tributaries throughout Cook Inlet. Commercial fisheries in Upper Cook Inlet primarily target sockeye salmon with secondary catches of Chinook, chum, coho, and pink salmon, whereas non-commercial fisheries target focus on Chinook, sockeye, and coho salmon with secondary catches of pink and chum salmon Fair et al. 2013; Shields and Dupuis 2015).

The ADF&G maintains a database of salmon return surveys, with some records dating back to the 1930s for various Cook Inlet tributaries (Fair et al. 2013; http://www.adfg.alaska.gov/sf/FishCounts/). However, the tributaries surveyed and the survey methods have varied dramatically over time and tributary, largely because the focus of salmon stock assessments varies with management priorities and budget limitations (Table 6). In general, more productive systems tend to have a higher priority which results in the most comprehensive data for those systems. In addition, survey techniques have been revised for some tributaries as technology has improved and database counts may or may not have been revised accordingly so that counts over time are comparable (Fair et al. 2013; Shields and Dupuis 2015).

Escapement goals currently exist for 21 Chinook salmon stocks, 1 chum salmon stock, 9 sockeye salmon stocks, 3 coho salmon stocks, and no pink salmon stocks in Upper Cook Inlet (Table 6). Note that in some instances separate escapement goals have been established for runs of the same species but with different migration timing to the same river system (i.e., late run and early run sockeye salmon returning to the Russian River and early and late run Chinook salmon returning to the Kenai River). Determining and managing for the escapement goals of Upper Cook Inlet salmon stocks implies having adequate estimates or indices of both the historical spawning population on which the goals were established, and also of the current inseason assessment of a developing return. To manage fishing effort so as to harvest returns in excess of escapement also relies on an understanding of fishing patterns and harvesting capacity during the season, as well as inseason assessments of catch composition. For example, inseason analyses of the age and size of sockeye salmon in the commercial harvest with that from escapement allows for a preliminary apportionment of the commercial catch to the principal watersheds of Upper Cook Inlet (Tobias and Tarbox 1999; Shields and Dupuis 2015).

An offshore test fishery (OTF) is conducted each summer by ADF&G in the southern portion of Upper Cook Inlet off Anchor Point, Alaska (Figure 15; Dupuis et al. 2015; Shields and Dupuis 2015; M. Willette, ADF&G, pers. com.). Standardized OTF catch rates provide inseason information on run strength of some salmon species. Although the emphasis of the OTF is on inseason assessment of sockeye salmon, the cumulative catch-per-unit-effort in the OTF across years indicates the predominance of sockeye salmon among total returns among all salmon returning to Upper Cook Inlet (Figure 16). While a majority of these sockeye salmon are returning to the Kenai and Kasilof rivers, it is still evident that sockeye salmon are a major component of all Upper Cook Inlet salmon returns, and are present through much of the summer season (Figures 13 and 16). Estimated sockeye salmon returns to Upper Cook Inlet over the past 25 years showed relatively high values during the early 1990s, mid 2000s, and early 2010s, with relatively low returns during the late 1990s to early 2000s, and the late 2010s. Recent returns during 2012–2015 have been lower than the recent peak of 8.6 million sockeye in 2011, but similar to the 25-year average of 5.6 million sockeye (Figure 17).

One geographic region of particular interest is the area delineated by ADF&G regulations as the Northern District, an area where Cook Inlet beluga whales are concentrated within the Cook Inlet Management Area (Figure 18). Total annual commercial salmon harvests from Upper Cook Inlet, when averaged by decade, showed dramatic increases from the 1966–1975 period to the 1986–1995 period, then declined and stabilized during 1996–2015 (Figure 19; Shields and Dupuis 2015; P. Shields, ADF&G News Release, October 20, 2016). The contribution of sockeye salmon to the overall commercial harvest from Upper Cook Inlet is again evident.

Commercial harvests from the Northern District were high but variable in the late 1960s, relatively high in the 1980s, and subsequently declined and have remained relatively low levels since the 2000s (Figures 19 and 20; Shields and Dupuis 2015). Catch composition has varied over time, but sockeye salmon comprised the largest component of catch abundance in the Northern District commercial salmon harvests in 53% of the years during 1966–2015. Pink salmon provided the largest component of commercial catch abundances on mostly alternate years during 1966–1980, and coho salmon have provided the largest segment of commercial catch abundance throughout segments of time series, particularly in many years during 1988–2008. Reduced overall harvests in the most recent decades are partly related to declines in returns of some species such as coho, and partly related to constraints of commercial fisheries to depressed stocks, such as for Chinook salmon.

Reduced run strength of Chinook salmon stocks across Alaska, including Cook Inlet, has been a major concern in recent years (Catalano 2012; ADF&G Chinook Salmon Research Team 2013; Schindler et al. 2013; Hollowell et al. 2016; JTC 2016; Liller and Hamazaki 2016). While some areas appear to be showing some recovery, the impacts that the decline of a single salmon species, such as Chinook might have on Cook Inlet beluga whales is unknown. The CIBW would presumably be able to switch to alternative salmon prey, but the energetics involved in such prey-switching are not well known.

When evaluating historical salmon return to various Cook Inlet tributaries, the aspect of the ADF&G Fisheries Rehabilitation and Enhancement Division (FRED) must be considered. The FRED Division efforts were relatively broad in terms of increasing salmon production, particularly for sockeye, pink, and chum salmons across the state. Much of the increased salmon production during the 1980s could be partially attributed to improved marine productivity for salmon in the North Pacific Ocean, but might also be attributed to production from the FRED Division projects, particularly in the realm of increased sockeye salmon production through evaluation of rearing versus spawning limited productivity (Koenings and Burkett 1987; Koenings et al. 1989). The Private-Nonprofit hatchery program adopted in 1974 authorized permitting of regional aquaculture programs. To a large extent, much of the salmon production and enhancement work from state hatcheries has been transferred to regional aquaculture programs. We did not evaluate how changes in the salmon aquaculture may have affected the abundance and distribution of salmon as available prey for Cook Inlet beluga whales.

As an approach to evaluating indices of potential prey for Cook Inlet beluga whales, we examined return estimates for tributaries having returns estimates after the 1970s and extending into the 2010s, with a consistent time series, and something more than nominal returns.

ECOSYSTEM LINKAGES

Distribution, Movement, and Habitat Use of Cook Inlet Beluga Whales

Multiple sources indicate that CIBWs exhibit seasonal shifts in distribution and habitat use within Cook Inlet, and that such patterns appear to be related to seasonal changes in the physical environment (e.g., ice, currents, ice) and to shifts in food sources, specifically the timing of fish runs. Whales spend the ice-free months in the upper inlet, often at discrete high-use areas, then expand their distribution south and into more offshore waters of the mid Inlet in winter, although they are also still found in the waters of the upper Inlet (Hobbs et al. 2005). These seasonal patterns have been long observed and utilized by subsistence hunters (Huntington 2000; Carter and Neilsen 2011), and have more recently been documented by aerial surveys (Hansen and Hubbard 1999; Hobbs et al. 2015; Rugh et al. 2000, 2004, 2010; Shelden et al. 2013, 2015a, 2015b)), satellite telemetry (Ferraro et al. 2000, Goetz et al. 2012, Hobbs et al. 2005, Shelden et al. 2015a), and during shore- and boat-based observations (Speckman and Piatt 2000, Funk et al. 2005; McGuire and Stephens 2016 a, 2016b). Passive acoustic monitoring is also being used to assess seasonal distribution and foraging behavior throughout the much of Cook Inlet (Castellote et al. 2015; Lammers et al. 2013). Additional documentation of these patterns is provided from opportunistic sighting reports (Rugh et al. 2000; Vate-Bratstrom et al. 2010; NMFS *unpublished data*), NMFS stranding records (Vos and Shelden 2005; NMFS *unpublished data*), and a citizen science beluga sighting project (Svarny Carlson and Brunner 2012).

The CIBW feeds most conspicuously during the spring, summer, and fall months near the mouths of rivers when runs of anadromous fish are returning to spawn (Figure 13; Moore et al. 2000). Traditional ecological knowledge (TEK; Huntington 2000) reports that summer feeding is very important for CIBWs and that spring whales are much thinner than belugas observed in the fall after a summer of feeding. The large aggregations of CIBWs in specific areas of Upper Cook

Inlet during May to October are presumed to indicate a critical time period for beluga foraging, based on the need for all animals to assimilate resources for overwinter survival (Calkins 1983; Huntington 2000). It is during the ice-free months that calves are born and nursed, and the whales acquire the thick blubber layer they will need to survive through the winter months in the absence of anadromous fish runs end and when most potential prey move to deeper, offshore regions (Hobbs et al. 2005, Hobbs et al. 2008).

Dive behavior data from satellite tags deployed on 11 CIBWs indicted that dives were significantly shorter and shallower from June to November versus December to May (Goetz et al. 2012). Over 50% of the dive effort occurred in shallow, nearshore areas of Chickaloon Bay, Susitna Delta, Knik Arm, Turnagain Arm, and Trading Bay, suggesting feeding in these areas. These locations are also recognized as areas where anadromous prey concentrate when entering river mouths (Figure 14). The Susitna and Little Susitna rivers, Knik Arm’s Eagle Bay to the Eklutna River, Ivan Slough, the Theodore and Lewis rivers, and Chickaloon River and Chickaloon Bay were identified by NMFS (2008b) as primary “hotspots” for beluga feeding in summer and fall. Passive acoustic monitoring studies in Cook Inlet indicated that acoustic foraging behavior by beluga whales was more prevalent during summer than during winter, and was detected more often in the upper inlet than the lower inlet (Castellote et al. 2015). Tidal flow corridors are also important to the CIBW, as the tides that may occur up to twice-daily tides can facilitate or impede whale access to feeding areas (Funk et al. 2005; Hobbs et al. 2005; Markowitz et al. 2007). Access to these areas and to corridors between these areas is important for CIBW foraging success.

Concentrations of CIBWs within discrete areas of the upper inlet, and offshore of several important salmon streams, are assumed to represent a feeding strategy that takes advantage of the local bathymetry: the fish are funneled into the channels formed by the river mouths and the shallow waters act as a gauntlet for fish as they move past waiting belugas. Belugas may have greater success feeding in rivers where prey are concentrated than in areas such as bays where prey are dispersed (Hazard 1988). Thus, CIBWs seek areas where anadromous prey returning to spawn occur in relative high densities at the bottleneck of river mouths, but also areas that have specific habitat features. For example, Frost et al. (1983) observed that beluga whales in Bristol

Bay preferred certain streams for feeding based on the configuration of the stream channel, perhaps because feeding efficiencies improved in relatively shallow channels where fish were concentrated. The ability to echolocate prey is an additional asset for CIBWs feeding in the silty waters of Upper Cook Inlet. However, CIBWs do not always feed at the streams with the largest runs of fish, and it may be that bathymetry and fish density may be more important than absolute fish abundance for feeding success. This may also be due to preference for particular prey species, for example, a preference for a salmon species with a higher oil content than other species, although other aspects such as encounter rate and energetic costs to capture and process a given prey are also factors (Pyke et al. 1977; Payne et al. 1999; O'Neill et al. 2014).

Analyses by Goetz et al. (2012) concluded that CIBWs were found in areas of high fish availability and access to tidal flats and sandy substrates, and that belugas were negatively associated with anthropogenic disturbances. These habitat models predicted that beluga distribution would include coastal areas extending nearly the entire length of Cook Inlet (Goetz et al. 2007), and, in fact, historically belugas inhabited large parts of the Inlet, including its central and southern reaches (Rugh et al. 2000). However, since 1993 when NMFS began systematic documentation of the distribution, beluga sightings have been rare in areas south of the Forelands, and almost all sightings have been in the upper inlet, from the Susitna Delta to Knik Arm and Chickaloon Bay (Rugh et al. 2000, 2010). A significantly reduced CIBW population (Hobbs et al. 2008) in combination with beluga preference for estuarine waters with the largest concentration of prey species may explain the current reduced distribution of whales, but data on relative densities of fish by species and season are not yet available to test this hypothesis.

In April 2011, NMFS designated critical habitat for CIBWs (NMFS 2011). In designating the critical habitat, some aspects NMFS considered were physical and biological features essential to the conservation of the species that may require special management, including 1) space for individual and population growth, and for normal behavior; 2) food, water, air, light, minerals, or other nutritional or physiological requirements; 3) cover or shelter; 4) sites for breeding, reproduction, rearing of offspring, dispersal; and, generally, 5) habitats that are protected from disturbance or are representative of the historic geographical and ecological distributions of the species. The critical habitat is defined in terms of essential physical and biological features, which are the primary constituent elements (PCE) of the critical habitat. Based on the best scientific data available about the ecology of CIBWs, NMFS determined the following physical or biological features (PCEs) are essential to the conservation of this species:

1. Intertidal and subtidal waters of Cook Inlet with depths less than 30 feet (9.1 m; MLLW) and within 5 miles (8 km) of high and medium flow anadromous fish streams;
2. Primary prey species consisting of four species of Pacific salmon (Chinook, sockeye, chum, and coho), Pacific eulachon, Pacific cod, walleye pollock, saffron cod, and yellowfin sole;
3. Waters free of toxins or other agents of a type and amount harmful to CIBWs;
4. Unrestricted passage within or between the critical habitat areas; and
5. Waters with in-water noise below levels resulting in the abandonment of critical habitat areas by CIBWs.

In this designation, NMFS identified two specific marine areas in Cook Inlet, Alaska as containing one or more of the essential features (Figure 21). An area deemed important to the interests of national security was also excluded from the critical habitat designation**.** The NMFS Conservation Plan for CIBWs (NMFS 2008b) states the following about Type 1 Habitat (now called Critical Habitat Area 1): *This area is full of shallow tidal flats, river mouths or estuarine areas, and is important as foraging and calving habitats. Many rivers in Type 1 habitat have large eulachon and salmon runs. These shallow areas may also provide for other biological needs, such as escape from predators. This area has the highest concentrations of belugas from spring through fall as well as greatest potential for impact from anthropogenic threats. For these reasons, Type 1 habitat is considered the most valuable habitat type. Belugas are particularly vulnerable to impacts in Type 1 habitat due to their concentrated use and the biological importance of these areas. Because of their intensive use of this area (e.g., foraging, nursery, predator avoidance), activities that restrict or deter access to Type 1 habitat could reduce beluga calving success, impair their ability to secure prey, and increase their susceptibility to predation by killer whales. Projects that reduce anadromous fish runs could also negatively* *impact beluga foraging success during this time. Furthermore, the tendency for belugas to occur in high concentrations in Type 1 habitat predisposes them to harm from such events as oil spills.*

In 1996, the Sustainable Fisheries Act amended the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) to require the description and identification of Essential Fish Habitat (EFH) in fishery management plans, the identification of adverse impacts on essential fish habitat, and actions to conserve and enhance such habitats. The EFH includes those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. All of Cook Inlet has been classified by NMFS as EFH for all five Pacific salmon species that occur in Cook Inlet (Chinook, chum, coho, sockeye, and pink salmon), including the marine juvenile, marine immature, and maturing adults stages of each of these species.

As part of the CIBW listing as endangered under the ESA, human activities occurring in Cook Inlet that have a federal nexus (via funding or permitting) must evaluate any potential impact to critical habitat of CIBWs as well as to the EFH of salmon.

Effects of Human Activities on Eulachon, Salmon, and Belugas in Cook Inlet

The core geographic distribution of CIBWs is adjacent to the largest human population in the state. The 2015 national census estimated the Alaska population was 737,625 people, with 298,908 in the Municipality of Anchorage, 100,178 in the Matanuska-Susitna Borough, and 57,763 in Kenai Peninsula Borough; therefore, over 60% of the state's human population occurs adjacent to where CIBWs are found. The human population exhibited a 67% increase from 1980 to 2010 (http://www.labor.state.ak.us/research/census/home.htm). The whales are not uniformly distributed but tend to inhabit nearshore and other areas adjacent to high human use portions of Upper Cook Inlet. The inlet is the main route for transporting cargo into Alaska, and oil and gas exploration has occurred in Upper Cook Inlet since the 1960s (NMFS 2011). Other uses of the Cook Inlet Basin include hunting, recreating, timber harvesting, mining, dredging, renewable energy production, wastewater discharge, military activities, and residential and industrial development (Figure 22). Cook Inlet supports productive and well-established subsistence, commercial, sport, and personal use fisheries (Shields and Dupuis 2015).

A list of ten potential threats to CIBWs, their prey, and their habitat were identified and discussed in detail in the in the draft CIBW Recovery Plan (NMFS 2015). Those threats associated with human activities were: catastrophic events (including oil spills); cumulative and synergistic effects of multiple stressors; noise; disease agents; habitat loss or degradation; unauthorized take (e.g., entanglement in fishing gear), pollution, and reduction in prey. The impact of reduction of available prey on CIBWs is poorly understood and may have several aspects including changes in total availability, quality, and seasonality of prey.

Change in Prey Abundance, Quality, and Species Composition

Belugas seasonally exhibit strong seasonal site fidelity for specific areas in Upper Cook Inlet. These areas likely represent locations where preferred prey resources have been consistently available on an annual basis (NMFS 2008b). However, prey quality, particularly energy content, differs drastically among prey species (Payne et al. 1999; Abookire and Piatt 2005; Litzow et al. 2006). Beluga whales exhibit foraging preferences, particularly for high-lipid prey such as eulachon and salmon when available (NMFS 2008b; Quakenbush et al. 2015). Factors, whether anthropogenic or natural, affecting prey availability will generally have a greater impact on one prey species or species subcomponent (e.g., a specific size). Changes in the relative abundance of prey will affect the available prey composition (Pyke et al. 1977). The net positive or negative effect on belugas will depend on whether a disturbance, anthropogenic or natural, increases or reduces the abundance of preferred prey, and, if the belugas can shift to alternative prey to adequately compensate for loss of a preferred prey. Alternatively, if a disturbance reduces a non-preferred prey species, the relative or absolute abundance of preferred prey may increase over time, depending on the ecological linkages and response times. For example, northern pike, an invasive species illegally introduced into freshwaters of northern Cook Inlet, has likely reduced salmon, particularly Chinook, through predation on juvenile salmon (Oslund and Ivey 2011). Reduction of the abundance of northern pike would potentially allow greater productivity and increase subsequent returns of adult salmon to the benefit of the CIBW. Due to the uncertainties of such linkages, the threats described below are presented in a qualitative sense in that factors affecting beluga prey, and the response by CIBWs, are difficult to quantify.

Anthropogenic Threats to Prey Availability, Quality, and Species Composition

The spring and summer availability of commercially fished species that serve as potential beluga prey in Upper Cook Inlet can be somewhat inferred from the timing and location of fishery harvests and upriver spawning migrations ("escapements"). However, quantitative data on the spatial and temporal distribution of these beluga prey in the estuarine waters of Upper Cook Inlet are limited. For example, long-term salmon escapement estimates are available for the Kenai, Kasilof, and Crescent, three large mid-inlet rivers, and for the Yetna River, Susitna River tributary, with less frequent estimates available for some other Cook Inlet tributaries (Figure 1; Westerman and Willette 2013). Sockeye salmon returns to the Kenai and Kasilof rivers contribute the largest component of Upper Cook Inlet salmon harvests, the bulk of the commercial fishing activity occurs south of these rivers and, thus, "downstream" of the primary beluga summer habitat. Whales in northern Cook Inlet encounter fewer salmon than would be found in the central inlet, but likely benefit from a concentration of anadromous prey by shallow water and shoals, and the by the lingering of prey off the river mouths as they transition from saltwater to freshwater.

Fisheries management of anadromous fish populations in Alaska attempts to constrain harvests so as to provide for the theoretical level of escapement that maximizes surplus yield in subsequent salmon returns (Quinn and Deriso 1990). Harvest considerations must also include upstream consumptive uses, such as recreational and subsistence fisheries (Shields and Willette 2010), and allowances for natural mortality, including predation by beluga whales, bears, and other species. Stock productivity and the "optimal" level of surplus production are notoriously difficult to predict and estimate accurately due to high annual variation in factors such as freshwater and marine survival. Given this uncertainty, the potential for overfishing exists annually, and it is likely that escapement goals will not be met in all tributaries across all years. Thus, while fishery management, on average, should provide sufficient total numbers of prey for belugas, the timing of prey concentration or densities in the river mouths may not always be adequate for efficient feeding by CIBWs.

A contrasting management situation for beluga prey exists with eulachon that also return to spawn in freshwater. Although eulachon spawning stocks can be found in several central Cook Inlet rivers, human fishing effort for eulachon occurs primarily in Knik and Turnagain arms near the river mouths or upriver. Thus, most fishing impacts are “upstream” of CIBW foraging, such that population level effects of overfishing would be reflected by poor spawning escapement and reduced prey availability in subsequent years. Eulachon populations have not been routinely assessed or monitored, although a new study was implemented in 2016 to examine returns of eulachon spawning adults and downstream migration of eulachon larvae on the Susitna River (M. Willette, ADF&G, pers. com.). Historically, ADF&G has used the statewide mail survey to derive post-season estimates of recreational harvests (Table 4; Figure 11). These estimates are presumed to be somewhat related to eulachon population abundance. If a decline in annual harvests occurs and is suspected of indicating a substantive decline in eulachon abundance, ADF&G may implement more restrictive fishing measures in subsequent years. Current state regulations simply limit personal use/recreational harvests through time, area, and gear restrictions, but it uncertain what level of decline would be needed to trigger more restrictive harvest measures.

There was initially a sporadic commercial fishery for eulachon beginning in 1978 with harvests of 300–100,000 lb (136–45,360 kg) in 1978, 1980, 1998 and 1999 (Table 3; Shields 2005). Based on a concern that a reduction in the availability of eulachon could be detrimental to CIBWs, NMFS recommended to the Alaska Board of Fisheries that this fishery be discontinued effective beginning in 2000, in part due to the lack of data on the eulachon runs into the Susitna River, and due to the absence of any evaluation of the effect of this fishery on beluga whales in terms of disturbance/harassment or competition for these fish. Additionally, it was noted that CIBWs may be heavily dependent on the oil-rich eulachon early in the spring (preceding salmon migrations), the eulachon runs are very short in duration, and that large eulachon runs may occur in only a few upper inlet streams (NMFS 2008b). The commercial fishery for eulachon was closed in 2000, but reopened in 2005, under restrictions to hand-operated dip nets in saltwater between the Chuitna River and the Little Susitna River, with a total harvest of 100 tons or less (Table 3; Figure 1; Shields 2005; Shields and Dupuis 2015; P. Shields, ADF&G, pers. com.).

Beluga whale prey resources may be comprised of a mixture of spawning stocks that are also harvested in mixed-stock fisheries (Shields and Willette 2010; Westerman and Willette 2013; Shields and Dupuis 2015). The impacts of fisheries on CIBW foraging success are not well known, but include spatial and temporal components for any specific prey resource that is overfished. Prey composition is dynamic and varies both within and between years in both the run strength and run timing of contributing stocks. For an assessed stock, fishery managers attempt to determine the relationship between annual escapements and returns in subsequent years, and this relationship has an optimal range such that escapements outside of this range are presumed to generate fewer adult salmon returns in future years. Harvest managers attempt to regulate fishing effort such that spawning escapement goals are achieved for assessed salmon stocks. However, for mixed-stock fisheries such as those that exist in most of Upper Cook Inlet, it is not always possible to ensure that the lower bound of an escapement goal range is achieved for all stocks (not overfished) without exceeding the upper bound (underfished) on some stocks. Beluga whales, to some extent, compete for prey resources with fish harvesters. Both harvesters and CIBWs remove species at the upper trophic levels (i.e., prey organisms that are higher up in the food chain instead of lower trophic level items such as plankton) and are capable of structuring near-shore ecosystems. In general, such restructuring by fisheries may result from chronic and persistent overharvesting, such as annual overharvesting of one or more unique salmon stocks or stocks from a specific spatial and/or temporal component of the mixed-stock fishery (e.g., repeated overharvesting of Upper Cook Inlet, early season runs). Such a pattern could cause a shift in beluga foraging toward less-nutritious prey items or a geographic displacement from the optimal foraging habitat, ultimately with reduced survival and reproductive success. However, the time frame over which such shifts could occur is unknown, and baseline data needed to detect such shifts do not currently exist.

Other anthropogenic threats to CIBW prey and prey habitat are both seasonal and continuous. For example, mechanical disturbance of the seafloor (e.g., dredging) re-suspends silt, and buried chemicals, into the water column. In addition, increased acoustic impacts are associated with these disturbances. Such disturbances may result from activities such as: petroleum or gas drilling; laying of electrical, communication, or fluid lines; installation of support columns for docks, bridges, or other platforms; and boulder placement for breakwaters. These activities in Upper Cook Inlet largely occur outside of winter owing to the prevalence of ice floes in winter. Such disturbances may cause avoidance of an area by potential CIBW prey, potentially reduce the viability of prey species, or interfere with CIBW predation success.

Given the strong counterclockwise current patterns in Cook Inlet (Burbank 1977; Okkonen 2005), re-suspended silt and chemicals should have the greatest effects downstream and in close proximity to the source on the western side of Cook Inlet. Continuous anthropogenic activities are likely to produce localized habitat alterations. For example, a sewer outfall plume affects both the abiotic and biotic environments and is typically continuous and year-round. Various hormones, pharmaceuticals and other chemicals are also discharged from municipal water treatment facilities into Cook Inlet. Spills of hazardous chemicals may have a more immediate effect on the prey than on the CIBWs themselves. Some contaminants can bioaccumulate up the food chain, but may also impact the survival, quality and reproduction of the prey species.

Structures such as docks, platforms, and bridges alter the Cook Inlet habitat with a species-dependent effect on potential CIBW prey. Such structures alter local tidal flow, which may attract some species but repel others. In-water or intertidal development projects may affect the availability or quality of prey species through several mechanisms including: the loss of mudflat habitat through fill, death or injury from blasting or pile driving, water pollution, and avoidance or reduced use of an area as a result of displacement due to. Hydroelectric dams, altering the volume and seasonal pattern of river discharge, can affect eulachon and salmon productivity.

Information about specific development projects with the potential to affect whale distribution and habitat use of localized areas of Cook Inlet is available in studies conducted in conjunction with the following development activities (Figure 22): the Port of Anchorage Expansion Project; Ocean Renewable Power Company's Fire Island Tidal Project; Pac-Rim Coal's Chuitna Coal Project; AKDOT&PF's Seward Highway Project; the Knik Arm Bridge and Toll Authority; Joint Base Elmendorf Richardson; Susitna-Watana Hydro (AEA); Susitna Hydroelectric Project (APA); and various seismic programs for Apache Alaska, ConocoPhillips Alaska, and Furie/Escopeta Oil. Reports from some of these projects may be found at http://www.fakr.noaa.gov/protectedresources/whales/beluga/development.htm#pm.

Catastrophic events such as oil or chemical spills are infrequent, but may have significant effects on beluga prey, whether through changes to spawning or migration patterns, direct mortality, or potential long-term sub-lethal impacts (Moles et al. 1994; Marty et al. 1997; Murphy et al. 1999). The Draft Recovery Plan for the Cook Inlet Beluga Whale classified oil spills (NMFS 2015; listed under Catastrophic Events) as a threat to the recovery of CIBWs. However, the plan did not specially examine possible impacts to Cook Inlet from several known oil spills that warrant being mentioned here.

On July 2, 1987, the oil tanker *S.S. Glacier Bay* grounded south of the mouth of the Kenai River, spilling 3,000 barrels of crude oil (Ruesch 1988; Burden et al. 1990). To prevent the potential of fishing gear contamination or for harvested fish to enter the harvest production chain, numerous fishery restrictions were implemented. Contrary to expectations, surface oil remained in the area for over two weeks, but was no longer considered to be an issue after the volatile fractions had dissipated and the remaining crude lost buoyancy and sank (Ruesch 1988).

On March 24, 1989 the *Exxon Valdez* oil tanker ran aground in nearby Prince William Sound, and spilled 11 million gallons of crude oil. Distribution of crude oil from the spill extended into Upper Cook Inlet (Figure 23; http://www.evostc.state.ak.us/). To again prevent fishing gear contamination or the introduction of tainted fish into the harvest production chain, surveys were conducted to search for crude oil within Upper Cook Inlet (Ruesch 1990). The search found mousse patties of oil in much of the Central District, with particular concentrations near tide rips, the most important harvest areas for the gillnet fleet (Figures 3 and 18). As a result, the Upper Cook Inlet drift gillnet fishery was closed for the entire 1989 season, with the exception of a limited fishery for chum and coho salmon in Chinitna Bay in August (Ruesch 1990). Despite extensive searches, oil was less of a problem for the shore-based setnet fleet, resulting in only a single closure south of the Kasilof River from July 6 to 9. Even with the closures, the 1989 fishery yielded one of the highest sockeye harvests documented at that time. Residual oil was not reported as a problem during the 1990 Cook Inlet salmon fisheries. While the tide rips in the Central District of Upper Cook Inlet in 1989 may have concentrated sockeye salmon and other potential fish prey of Cook Inlet beluga whales, it is not clear that this is an area of critical importance for foraging whales at this time of year.

Natural Threats to Total Availability, Quality, and Species Composition of Prey

The CIBW may compete against other predators such as harbor seals and harbor porpoise for available prey resources, particularly in Upper Cook Inlet where the available prey resources may be more limited in abundance or diversity relative to other regions such as Bristol Bay where belugas occur (Seaman et al. 1982). Although there is likely some foraging specialization among predators and the available prey species, there is also likely to be a high degree of dietary overlap due to the limited prey diversity available in Upper Cook Inlet. Some predators, such as sea otters, have been shown to restructure the habitat based on foraging intensity associated with their presence (Kvitek et al. 1992). As such, a substantial and potential increase in competitors could reduce the foraging efficiency of beluga whales. Likewise, a reduction in the available prey would be expected to increase competition among CIBWs and other predators.

Harbor seals and harbor porpoises are found throughout Cook Inlet, but are more abundant in the lower inlet than in the upper inlet (Allen and Angliss 2012). Occasional surveys of harbor seal and harbor porpoise abundance and distribution in Cook Inlet have been conducted, but no long-term dedicated studies have occurred. A long-term acoustic monitoring study by the research team Cook Inlet Beluga Acoustics (CIBA) is focused on CIBWs but also monitors the frequency range of harbor porpoise vocalization (Small et al. 2011; Castellote et al.

2015). Preliminary results generally indicate a year-round inlet-wide presence of harbor porpoises. The exception was Knik Arm where detections have occurred only during the ice-free season of April to November, were infrequent in the lower part of the arm (Cairn Point and Six Mile), and were rare (twice in four years) in Eagle Bay of the northern arm. Porpoises and belugas were detected as co-occurring in most northern Cook Inlet study areas, including known CIBW foraging sites (e.g., the Beluga and Little Susitna rivers), indicating potential competition for prey. Recent population trends of these species in Cook Inlet are unknown (Allen and Angliss 2012). Local observations suggest that harbor seal abundance in the mid and upper portions of Cook Inlet has increased in recent years (B. Mahoney, NMFS, pers. com.; T. McGuire, LGL Alaska Research Associates, Anchorage, *unpublished data*), but no baseline data exits for comparison.

Sea otters and Steller sea lions are likely not effective competitors with CIBWs because of a limited geographic overlap. Sea otters are found in Lower Cook Inlet, with most of the population not extending north of 60° N. latitude (Gorbics and Bodkin 2001). Steller sea lions are more abundant in Lower Cook Inlet than in the upper inlet. Steller sea lion critical habitat has been designated at locations in the southern portion of Lower Cook Inlet. No known haulouts exist in Upper Cook Inlet and sea lions are rarely sighted north of Nikiski by Kenai (Figure 1).

Change in Seasonality of Prey

Selective pressure through fishing or other factors can alter reproductive migration timing or other characteristics of some prey species. For instance, fishing that targets larger, older fish may be responsible for the loss of larger, older Chinook salmon from many spawning populations (Ricker 1980; Lewis et al. 2015). Similarly, selective removal of salmon returning during the early portion of a run can slightly shift future run timing, but the extent of that shift is limited as survival decreases outside of an optimal migration timing window (Smoker et al. 1998). Alternatively, losses or drastic reductions of specific salmon runs may cause reduced densities or temporal gaps in availability of preferred prey, resulting a the reduction of the total days when beluga blubber fat storage can occur. The impacts of shifts in seasonality or temporal gaps in prey availability on reproductive success and survival of beluga whales is unknown. Annual blubber deposition and depletion in CIBWs is linked to the availability of high-lipid content prey in the summer. The seasonal availability of these prey resources is likely as important as the total prey biomass, particularly for growing juveniles and pregnant and/or lactating females.

While the potential exists for fishing pressure to dramatically change the abundance and composition of CIBW prey, Cook Inlet fisheries are considered to be managed relatively conservatively with in-season reductions or closures if targeted fish stocks appear to be weak. However, not all fish stocks are assessed, making unassessed stocks more susceptible to overharvest, and it is unknown whether management of fisheries for optimal returns provides sufficient densities in CIBW feeding areas for efficient foraging by belugas. Other sources of human-induced impacts (e.g., subtidal substrate disturbance) should include environmental assessments before, during, and after any activity, but such assessments have failed to identify baseline levels for many potential beluga prey items.

RECOMMENDATIONS FOR FUTURE RESEARCH

Following are recommendations for future research to provide information needed to better understand the interactions of eulachon, salmon, and beluga whales in a healthy Cook Inlet ecosystem.

Cook Inlet Eulachon

The eulachon surveys mentioned previously in this report and the available harvest information are all incomplete in terms of providing an indication of the status of eulachon, an important prey item for beluga whales, particularly in the spring. For the most part, the data from these various surveys is likely limited by a combination of:

- Survey timing inconsistency – Many of these surveys have temporal gaps in the time series of data. Such gaps compromise the tracking in population trends of a relatively short-lived species such as eulachon.

- Survey selectivity – None of the surveys discussed are directed at eulachon, but are directed at other species with the intent of collecting information on incidentally caught species. Additional studies are needed on gear selectivity if available data are to be developed into population indices.

- Lack of size, sex, and length data – Most of these surveys collect only limited information on eulachon meristics. Some information, such as age data, could potentially allow tracking of cohorts across missed survey years.

- No spawning population information – Similar to salmon, eulachon return to freshwater to reproduce, with harvesting efforts focused on the concentrations of returning spawning

> adult eulachon. However, there had been only limited effort to assess these returning populations.

One unevaluated, but potential, source for eulachon assessment data in Upper Cook Inlet is the hydroacoustic program used by ADF&G for inseason assessment of salmon returning to the Kenai River (Burwen et al. 1995; Miller et al. 2015). Eulachon tend to migrate upriver to spawn before or during the early portion of upstream migration of spawning salmon. From 1994 to 2009, ADF&G used a split-beam sonar for this salmon assessment. Acoustic echoes were recorded on paper and, later, electronic echograms. The sonar sampling equipment was put in place in advance of the bulk of the salmon returns, usually by about May 15. Depending on the particular year, this may or may not be early enough to identify the majority, or a portion, of the upstream eulachon passage on the Kenai River. The general sampling strategy was to operate the sonar counters for 20 minutes out of each hour (Burwen et al. 1995). The dense schools of eulachon appear as “clouds” of echoes (Figure 9; J. Miller, ADF&G, per. com.). These historical data, particularly those data on paper chart print-outs, do not readily discriminate between eulachon and other species based simply on the echo return (B. Key, ADF&G, pers. com.). However, it may be possible to draw inferences about general return strength of eulachon based on patterns in the echo returns.

Experiments with a DIDSON for salmon enumeration on the Kenai River began in 2002, and were focused on one side of the river during 2007 to 2009 (Miller et al. 2013). The DIDSON system has the advantages of fish detection, direction tracking, and improved species discrimination. Beginning in 2010, both banks of the Kenai River were sampled with the DIDSON. Data were recorded digitally for later review. Given the species discrimination, eulachon are fairly identifiable under the DIDSON system and recordings in field notebooks have often identified eulachon passage. However, eulachon passage has not been enumerated to date. While the paper and electronic data are available, it would take a substantial effort to review all of the acoustic recordings for a given year to determine eulachon passage (B. Key and D. Burwen, ADF&G, pers. com.). Field notebook recordings would facilitate this process, but are likely incomplete. In addition, protocols would need to be developed to address the high densities of eulachon passing at a given time. It may be more practical to initially develop a protocol that subsamples the available data for the observed duration of the eulachon passage. At the very least, such a protocol would allow development of a coarse annual index of eulachon passage over past years.

One additional developing assessment technique involves the potential of using environmental DNA (eDNA) to assess fish species, including abundance of those species. The technique is based on the fact that all animals that live in water leave DNA behind via their feces, urine or skin cells. Collection of water samples, then use of a polymerase chain reaction to amplify DNA of the target species allows detection of that species. The relative amount of DNA in the water may serve as an index of biomass. The use of eDNA to assess eulachon is being explored on the Chilkat River in Southeast Alaska (B. Ryan, Southeast Alaska Watershed Coalition, pers. com.; T. Levi, Oregon State Univ., pers. com.).

Cook Inlet Salmon

Efforts to assess salmon returns to Upper Cook Inlet tributaries are typically directed at stocks having the highest commercial or recreational value. For example, sockeye salmon produce the largest commercial harvests in Upper Cook Inlet and most major sockeye production systems are monitored and have established escapement goals (Table 6; Fair et al. 2013; Westerman and Willette 2013). Similarly, Chinook salmon are important to recreational, and to a lesser extent commercial, fisheries, and are monitored at various locations, notably the Kenai and Deshka rivers (Table 6; Miller et al. 2015). However, while multiple species may be concurrently observed by many assessment projects, the utility of the data may be limited for non-priority species because of: (1) species behavioral difference such as avoidance of survey gear; or (2) the project duration does not encompass the full run timing of the non-priority species, especially for stocks that return in the “shoulder seasons” of spring or fall. Understanding of salmon availability and distribution during the shoulder seasons is of particular importance from the aspect of potential prey for CIBWs. In particular, is the migration of Chinook salmon in May and June, a time when little or no commercial exploitation occurs, but the period when foraging may be critical to CIBWs emerging from winter and having low fat reserves. There is a general weak understanding of the availability of salmon in the areas where CIBW females with calves occur in the spring. There is also a poor understanding of prey availability during the winter months. Understanding winter prey abundance and composition may be even more important given the decline in spatial distribution of CIBWs as the population declined. While extension of assessment programs to additional tributaries or for greater coverage of the migration of all salmon may facilitate improved management, such extensions are unlikely given the near-term outlook for agency budgets within the state of Alaska, which is currently faced with a budget deficit due to falling oil prices. In reality, it is more likely that some existing assessment programs will be cut or shortened in order to accommodate reduced budgets.

Integration of Salmon and Eulachon Information into Beluga Recovery Efforts

An evaluation is needed on how the abundance and quality of prey changes annually and seasonally within the specific habitat occupied by CIBWs. Based on salmon run timing and commercial and recreational catch rates, there are significant differences in prey composition both north to south, and east to west, especially nearshore versus offshore. Particularly important is understanding prey availability during critical life history stages, such as when calves are born, and also at times when foraging options are less certain (winter months). One option is the development of a seasonal bioenergetics model to compare daily intake against our understanding of available prey. Such a model might reveal if any prey availability is potentially limiting to production. Another option is a comparison of CIBW abundance against various datasets of potential prey. Although correlation does not necessarily imply causation, such an exercise would identify potential areas for further research. A preliminary effort at a correlation analysis is provided in Appendix A of this document.

- Conduct analyses to understand if a prey reduction is occurring and if so, the effect of such reductions on beluga recovery. Using historical trends in prey population indices, correlations among annual deviations in population indices of CIBWs and their potential prey should be examined through a retrospective analysis. An example of this approach is provided in Appendix A. Because abundance estimates are lacking for many potential prey within Upper Cook Inlet, any such analysis may be highly qualitative due to data limitations, particularly for non-commercial fish species.

- Because the quality of potential CIBW prey differs substantially among prey species, and the nutritional characteristics of a given prey species vary seasonally, research is needed to understand the quantity, quality, and distribution of prey available in CIBW habitat and the extent to which these characteristics vary spatially and seasonally. Although some information is available on the upstream spawning escapements of some species in select Cook Inlet tributaries, this does not provide a clear understanding of the prey available in the marine/estuarine areas, particularly in Upper Cook Inlet where belugas occur. There is also a severe lack of information on prey available from late fall to early spring, and on the quality of CIBW prey resources (e.g., energy content, contaminants, stable isotopes, fatty acids). Standardized surveys are needed to determine the spatial and seasonal distribution of beluga prey in Upper Cook Inlet.

- Data on levels and types of fatty acids and stable isotopes among predator and prey organisms can be used to better understand seasonal trophic linkages (i.e., the relationship between potential predators and potential prey species at different times of the year). This information is an important component of the data needed to understand beluga foraging patterns. Data should be collected through tissue samples of prey species for comparison to stable isotopes in beluga blubber fatty acids and skin.

- Compare the distribution, abundance, seasonal movements, and behavior of beluga groups to the documented or inferred the distribution of their prey to provide insights into how belugas respond to changes in prey distribution and abundance as well as their own feeding requirements. For example, both traditional knowledge and our own experiences indicate that CIBWs are focused on feeding in late May and mid-July to mid-August, staying in or moving to areas of high prey density. Mid-June, and again in September, CIBW groups are more easily disturbed, suggesting prey are less important at that time. Data from belugas with attached satellite transmitters show some individuals regularly moved among feeding areas while others remained in the same location for long periods of time, suggesting individuals change their behavior relative to energetic needs. Understanding these changes in behavior, and the relationships between beluga distribution and their anadromous prey, will allow us to use CIBW as an index of the strength of the fish resources upon which they feed (see results in Appendix A) and may provide a way to monitor the health of the Cook Inlet Ecosystem.

- Review available data which may provide information about CIBW calving rates derived from different studies and assess if the calving rate (population-wide) or calving interval (individual whales) is correlated with prey abundance in different years. Information currently available on the calving rate collected during aerial surveys is limited to the years 2006–2010 (Hobbs et al. 2012). Additional data has been collected via vessel- and land-based photo-identification surveys 2005–2016 (T. McGuire, pers. obs.). This information should be incorporated in models used to estimate the extinction risk for CIBWs.

- Examine the reproductive histories and body condition of individual female CIBWs in the 2005–2016 CIBW Photo-Id Project catalog as indicators of health and feeding success, and relate annual trends in reproductive success and body condition to annual salmon and eulachon run-strength. This information should be incorporated in models used to estimate the extinction risk for CIBWs.

- Develop a CIBW bioenergetics model that expresses energetic needs in terms of the amount of salmon and eulachon consumed seasonally and annually. Then estimate the prey biomass available to CIBWs by converting fish run timing information by species to daily biomass estimates by looking at number of fish per day (by species), then multiplying by the average weight of each fish species. Do this for all prey species and at the mouths of all river systems in Cook Inlet for which data are available. A similar analysis may be applied using commercial catch data as a proxy for fish passage in the Northern District. An understanding of CIBW bioenergetics would allow ADF&G to consider beluga dietary needs when managing for harvests of anadromous species.

- Factors such as tidal mixing, temperature, salinity, sedimentation, and contaminants affect the characteristics of the aquatic environment. Prey species with high mobility may seek better aquatic habitats in areas not being exploited by CIBWs. While prey that spend extended periods of time in suboptimal environments are unlikely to attain optimal body condition and will not provide optimal CIBW forage, the relationships among environmental factors and prey distribution and quality remain poorly understood and need further research. This research could include collaborative studies to understand the status of Upper Cook Inlet salmon stocks, particularly the declines of Chinook salmon. Spatial distribution of many fish species is often associated with aquatic fronts defined by environmental boundaries. Anthropogenic factors can introduce new aquatic fronts, such as boundaries created by chemical releases or downstream plumes resulting from sediment disturbances, sewage outfalls or other point sources of pollution requiring mixing zones. Given our lack of understanding about how different aquatic fronts determine CIBW prey distribution, additional research is needed to determine how anthropogenic alterations to the aquatic fronts may affect the timing and distribution of prey.

- The impact of fishing pressure on spatial and temporal prey availability within CIBW habitat is poorly understood, especially for non-salmonid species such as eulachon and Pacific herring that are targeted by fisheries, but for which stock assessments are lacking. While fishing can reduce prey availability in CIBW habitat within the fishing season, the impact on future recruitment is less well known. Also, the impacts of anthropogenic noise on potential prey in CIBW habitat is poorly understood, rarely considered, and in need of further study. If anthropogenic activities, such as fishing or noise, result in a loss of feeding opportunities or reduction in prey, there will likely be an adverse effect on CIBWs. Consequently, these effects will be most important to beluga recovery in areas preferred for feeding and during times of the year when energetic demands are greatest (e.g., pregnancy and lactation). Mitigation techniques have already been proposed to reduce impacts upon fish from some sources, such as pile driving. Further research is needed to improve mitigation techniques, especially for noise sources where no mitigation is yet proposed.

Consideration of measures to adequately provide for CIBW prey consumption may be even more important for prey resources for which there are no ongoing stock assessments. For example, many of the salmon stocks returning to Cook Inlet tributaries are not actively assessed, but may be assumed to fluctuate similar to an index salmon stock returning to a nearby tributary. However, in the case of eulachon, there is no assessment program, and any decline in eulachon stock productivity or at-sea mortality rate might not be detected until after several years of fishery harvest declines.

Applications of Results from Recommended Research

Despite the strong interest in the recovery of the CIBWs, information associated with past CIBW research projects and relevant literature and environmental data have not always be easily retrieved by interested stakeholders. Results from past, present, and future Cook Inlet prey studies should be incorporated into the publically available CIBW geospatial database initiated by NMFS and funded in part by NFWF (http://portal.aoos.org/cibw). This database portal is evolving to contain some information from past CIBW research projects, along with corresponding environmental data, in a format readily accessible to all stakeholders.

The NMFS decision to list CIBWs as endangered was based on a population viability analysis (PVA) to determine the probability of extinction. A similar PVA was previously used to justify restrictions of CIBW harvests under the Marine Mammal Protection Act. A PVA incorporates a mathematical population dynamics model, informed by our understanding of ecological mechanisms operating on this population, into a statistical framework, including parameter uncertainty, which relates the population status and the risk of errors in assumptions to the probability of extinction. A PVA may be used to help identify specific factors directly contributing to extinction risk, to quantify the effects of these factors on extinction probability, and to relate these factors to specific indicators as well as test the impact of proposed or anticipated changes in the ecosystem management on the probability of extinction or recovery. The Science Panel for the CIBW Recovery Team recommended that the PVA be updated to help establish Recovery Criteria for CIBWs (http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/recovery/ci.htm). We reaffirm the need to update the PVA for CIBWs to incorporate information about eulachon and salmon stocks in Cook Inlet, as well as information about other prey not examined in this report.

CONCLUSION

Our efforts to identify linkages among CIBWs and their prey have met with similar results as previous studies. There is little data available on eulachon spawning returns. While some studies have been conducted, there is certainly no time series of data on which to draw conclusions of population trends over time. There are also few data on the role eulachon play in CIBW diet, notably in the spring when eulachon are spatially concentrated in their spawning migrations to Upper Cook Inlet tributaries. Spring is undoubtedly a critical time for CIBWs as they emerge from a winter with few prey resources and must build up energetic reserves for the next winter. More importantly, adult female CIBWs may be lactating or pregnant during this critical period. But interactions among CIBWs and their potential prey are not well understood in any season.

Salmon are assumed to be a major prey once the salmon runs develop, but prey selectivity is not known. Salmon availability as prey differs among species, and even among stocks, and the extent to which CIBWs selectively forage is unknown. It is also unknown to what extent CIBWs selectively forage among the available salmon resources, but the summer salmon run is likely the period when CIBWs build their energy reserves for the coming winter.

Understanding linkages among CIBWs, eulachon, and salmon is critical to development of effective management plans for recovery of CIBWs while maintaining harvests for commercial, personal use/recreational, and subsistence fisheries. However, a lack of data on eulachon abundance impedes our understanding. More importantly, there is little information on interactions, or even spatial, overlap, among CIBW and their prey. Some options include: development of a bioenergetics model; determination of spatial overlap among CIBWs and their prey; and collection of additional information on diet composition, perhaps through tissue samples.

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Table 1. Prey items in stomachs sampled from Cook Inlet beluga whales, 2002–2013.

	Number of stomachs by month										
	March	April	May	June	July	August	September	October	November	Total number	Frequency of occurrence[a/]
Stomachs sampled	1	0	0	3	4	7	3	8	1	27	
Stomachs with prey	1	0	0	2	4	5	1	5	0	18	67%
Stomachs with fish	1	0	0	2	3	5	1	5	0	17	94%
Salmon	0	0	0	2	3	4	1	2	0	12	67%
Gadid	1	0	0	0	0	1	1	4	0	7	39%
Smelt	1	0	0	0	1	0	0	0	0	2	11%
Flounder	0	0	0	0	1	0	1	0	0	2	11%
Other identified fish	0	0	0	0	1	0	1	0	0	2	11%
Unidentified fish	1	0	0	0	0	1	0	0	0	2	11%
Stomachs with invertebrates	1	0	0	0	3	1	0	4	0	9	50%
Shrimp	0	0	0	0	1	1	0	4	0	6	33%
Amphipod	0	0	0	0	1	0	0	1	0	2	11%
Polychaete	1	0	0	0	0	0	0	1	0	2	11%
Other identified invertebrates	1	0	0	0	2	1	0	0	0	4	22%
Unidentified invertebrates	0	0	0	0	0	0	0	1	0	1	6%

[a/] Frequency of occurrence – percent of non-empty stomachs containing a prey type
Source – Quakenbush et al. (2015); L. Quakenbush, ADF&G, pers. com.

Table 2. Incidental catch (metric tons) of forage fish in Gulf of Alaska groundfish fisheries, 2003–2015.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Eulachon	18.1	169.6	852.1	397.7	229.1	760.9	223.5	213.8	285.0	188.0	26.5	249.5	97.2
Other osmerids	353.1	66.2	185.7	183.5	51.8	406.1	174.0	6.8	69.0	82.0	11.2	77.8	17.7
Capelin	6.2	68.0	2.8	0.1		0.0	0.0	0.0	6.2	0.0	0.0	5.2	4.2
Surf smelt	0.0	0.4	0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	
Gunnels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	5.4	0.0	
Pricklebacks	0.5	0.1	2.2	0.9	0.3	0.1	2.8	0.8	0.5	0.1	0.8	0.5	
Pacific sand lance	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	
Lanternfishes	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total	377.5	304.3	1,041.1	581.3	280.9	1,167.1	397.4	220.6	360.2	270.0	37.8	332.5	119.1
% osmerid[a]	99.9	100.0	99.8	99.8	99.9	100.0	99.3	99.7	99.9	99.4	87.1	99.8	
% eulahon in osmerid	4.8	55.7	81.8	68.4	82.5	65.2	56.2	97.1	79.2	68.8	70.0	75.4	

[a] Osmerid in the summary at the bottom of the table includes eulachon, other osmerids, capelin, and surf smelt.

Source: Ormseth (2014); O. Ormseth, NMFS, pers. com.

Table 3. Commercial harvest of smelt (eulachon) and the number of permits issued in Upper Cook Inlet, 1978–2015.

Year	Pounds	Short Tons	Number of Permits
1978	300	0.2	NA
1980	4,000	2.0	NA
1998	18,610	9.3	2
1999	100,000	50.0	NA
2006	90,783	45.4	8
2007	125,044	62.5	11
2008	127,365	63.7	6
2009	78,258	39.1	6
2010	126,135	63.1	3
2011	201,570	100.8	5
2012	195,910	98.0	4
2013	190,830	95.4	4
2014	198,814	99.4	4
2015	213,934	107.0	4

Source – P. Shields, ADF&G, pers. com.

Table 4. Personal use harvests (number of fish) of eulachon summarized by Upper Cook Inlet reporting area designated by the ADF&G Sport Fish Statewide Mail Survey, 1996–2014.

Year	Knik Arm (K)	Anchorage (L)	Susitna River (M)	West Cook Inlet (N)	Kenai Peninsula (freshwater) (PF)	Cook Inlet (saltwater) (PS)	Total
1996	0	21,212	1,455	363	7,366	11,814	42,210
1997	0	39,071	6,150	2,703	11,847	500	60,271
1998	0	33,637	5,795	1,832	10,727	1,053	53,044
1999	2,708	44,597	36,847	0	5,294	148	89,594
2000	6,131	13,488	5,492	204	29,295	1,811	56,421
2001	1,574	35,909	10,056	0	23,023	432	70,994
2002	0	57,079	3,298	0	20,036	373	80,786
2003	1,578	35,841	5,465	455	12,145	436	55,920
2004	11	9,987	12,562	0	41,085	2,246	65,891
2005	0	8,885	3,068	0	9,206	1,102	22,261
2006	71	9,927	0	0	3,121	2,076	15,195
2007	124	16,527	620	0	3,221	1,889	22,381
2008	0	20,047	1,832	0	2,270	277	24,426
2009	0	28,953	3,520	880	4,796	1,136	39,285
2010	0	34,724	4,643	0	6,536	399	46,302
2011	0	34,067	6,763	0	5,932	2,576	49,338
2012	0	52,676	3,296	0	12,037	2,472	70,481
2013	0	39,028	1,704	0	26,179	2,052	68,963
2014	0	9,942	1,213	0	11,998	4,440	27,593
Average	641.9	28,715.6	5,988.4	338.8	12,953.4	1,959.6	50,597.7
Minimum	0	8.885	0	0	2,270	148	15.195
Maximum	6,131	57,079	36,847	2,703	41,085	11,814	89,594
% of total	1.3%	56.8%	11.8%	0.7%	25.6%	3.9%	100.0%

Source – http://www.adfg.alaska.gov/sf/sportfishingsurvey/; Kim Sundet, ADF&G, pers. com.

Table 5. Pearson correlation coefficients among the time series of personal use harvests of eulachon from Upper Cook Inlet reporting areas designated by the ADF&G Sport Fish Statewide Mail Survey, 1996–2014.

Arear	Knik Arm (K)	Anchorage (L)	Susitna River (M)	West Cook Inlet (N)	Kenai Peninsula (freshwater) (PF)	Cook Inlet (saltwater) (PS)
(K)	1.00					
(L)	-0.08	1.00				
(M)	0.38	0.28	1.00			
(N)	-0.11	0.18	-0.04	1.00		
(PF)	0.32	-0.03	0.08	-0.10	1.00	
(PS)	-0.15	-0.29	-0.26	-0.10	-0.05	1.00

Table 6. Current escapement goals for Chinook, chum, coho, sockeye, and pink salmon stocks of Upper Cook Inlet, 2013.

	Current Escapement Goal			
System	Range	Type[a]	Adopted	Data[b]
Chinook Salmon				
Alexander Creek	2,100–6,000	SEG	2002	SAS
Campbell Creek	380	SEG	2011	SFS
Chuitna River	1,200–2,900	SEG	2002	SAS
Chulitna River	1,800–5,100	SEG	2002	SAS
Clear (Chunilna) Creek	950–3,400	SEG	2002	SAS
Crooked Creek	650–1,700	SEG	2002	Weir
Deshka River	13,000–28,000	SEG	2011	Weir
Goose Creek	250–650	SEG	2002	SAS
Kenai River - Early Run	3,800–8,500	SEG	2013	Sonar
Kenai River - Late Run	15,000–30,000	SEG	2013	Sonar
Lake Creek	2,500–7,100	SEG	2002	SAS
Lewis River	250–800	SEG	2002	SAS
Little Susitna River	900–1,800	SEG	2002	SAS
Little Willow Creek	450–1,800	SEG	2002	SAS
Montana Creek	1,100–3,100	SEG	2002	SAS
Peters Creek	1,000–2,600	SEG	2002	SAS
Prairie Creek	3,100–9,200	SEG	2002	SAS
Sheep Creek	600–1,200	SEG	2002	SAS
Talachulitna River	2,200–5,000	SEG	2002	SAS
Theodore River	500–1,700	SEG	2002	SAS
Willow Creek	1,600–2,800	SEG	2002	SAS
Russian River - Early Run	700,000–1,200,000			

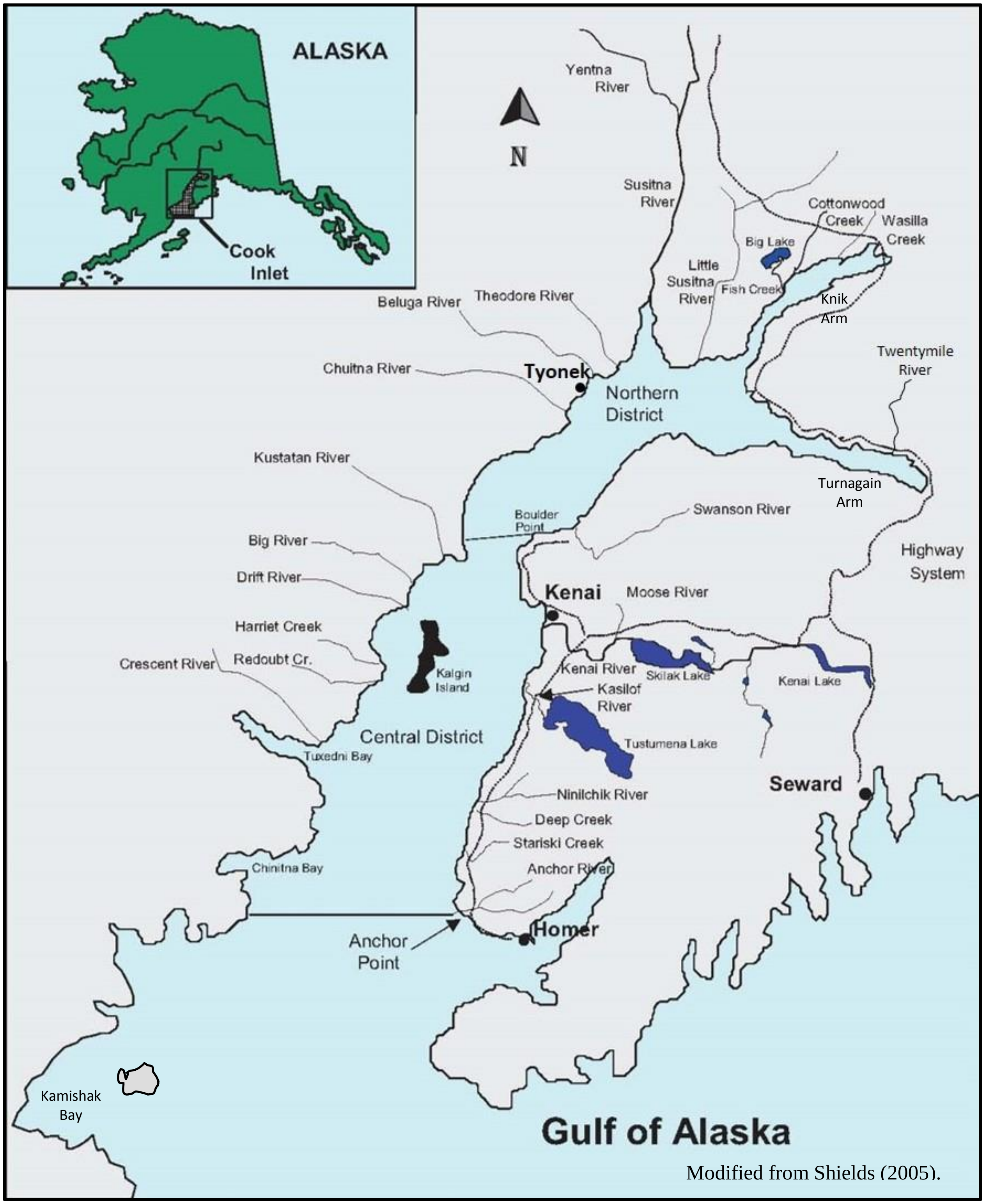
Table 6. – Page 2 of 2.

	Current Escapement Goal			
System	Range	Type[a/]	Adopted	Data[b/]
Chum Salmon				
Clearwater Creek	3,800–8,400	SEG	2002	PAS
Coho Salmon				
Fish Creek (Knik)	1,200–4,400	SEG	2011	Weir
Jim Creek	450–1,400	SEG	2002	SFS
Little Susitna River	10,100–17,700	SEG	2002	Weir
Sockeye Salmon				
Chelatna Lake	20,000–65,000	SEG	2009	Weir
Fish Creek (Knik)	20,000–70,000	SEG	2002	Weir
Judd Lake	25,000–55,000	SEG	2009	Weir
Kasilof River	160,000–340,000	BEG	2011	Sonar
Kenai River	700,000–1,200,000	SEG	2011	Sonar
Larson Lake	15,000–50,000	SEG	2009	Weir
Packers Creek	15,000–30,000	SEG	2008	Weir
Russian River - Early Run	22,000–42,000	BEG	2011	Weir
Russian River - Late Run	30,000–110,000	SEG	2005	Weir
Pink Salmon				
No stocks with escapement goal				

[a/] BEG = biological escapement goal, SEG = sustainable escapement goal.

[b/] Indicates the current method, although the applied method may have changed over time. PAS = peak aerial survey, SAS = single aerial survey, and SFS = single foot survey,

Source: Fair et al. (2013)

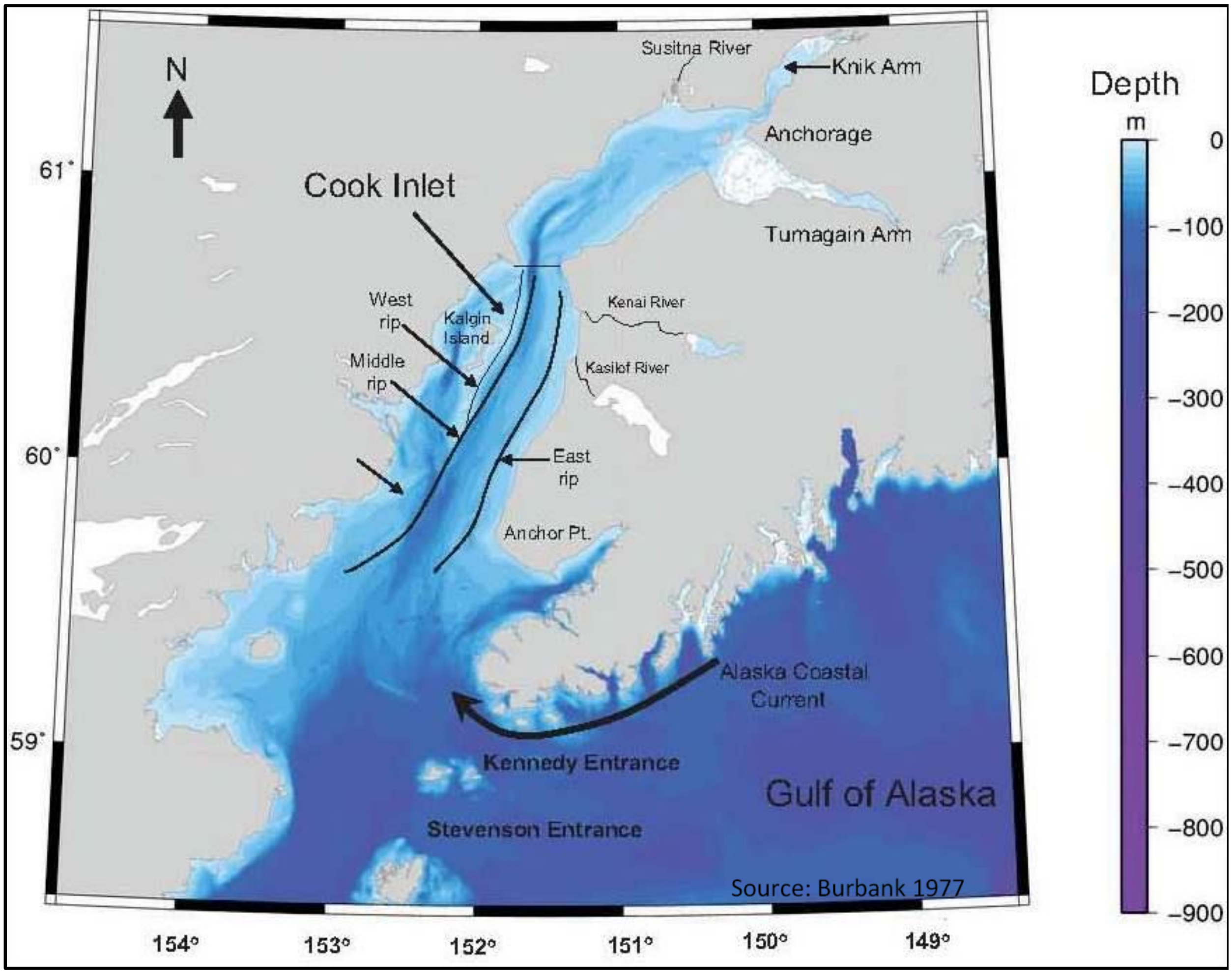


Modified from Shields (2005).

Figure 1. Primary tributaries and points of interest in Cook Inlet, Alaska.

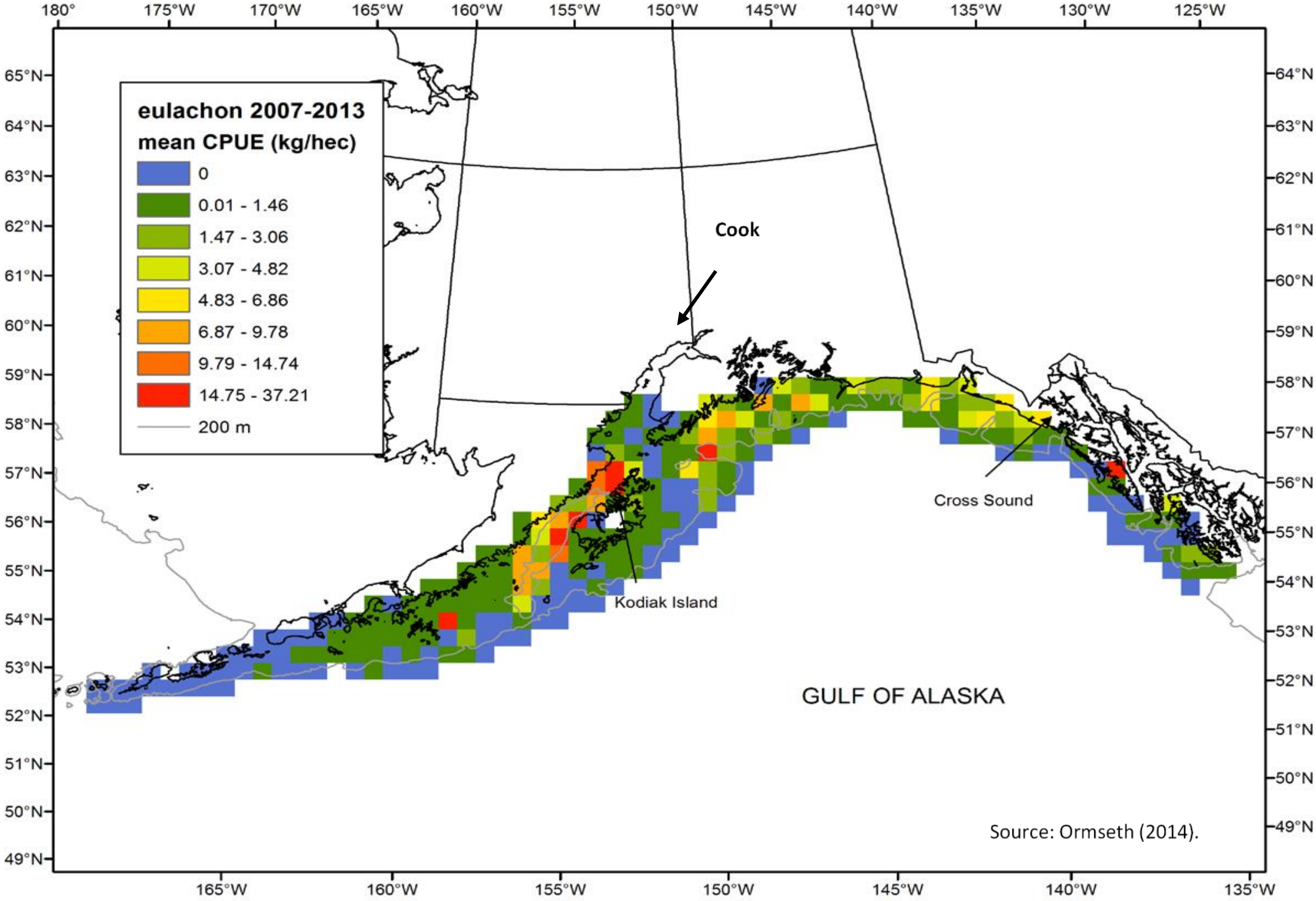
Source: Okkonen 2005

Figure 2. Glacial input into Cook Inlet as shown by a MODIS true color image, acquired September 2, 2002.



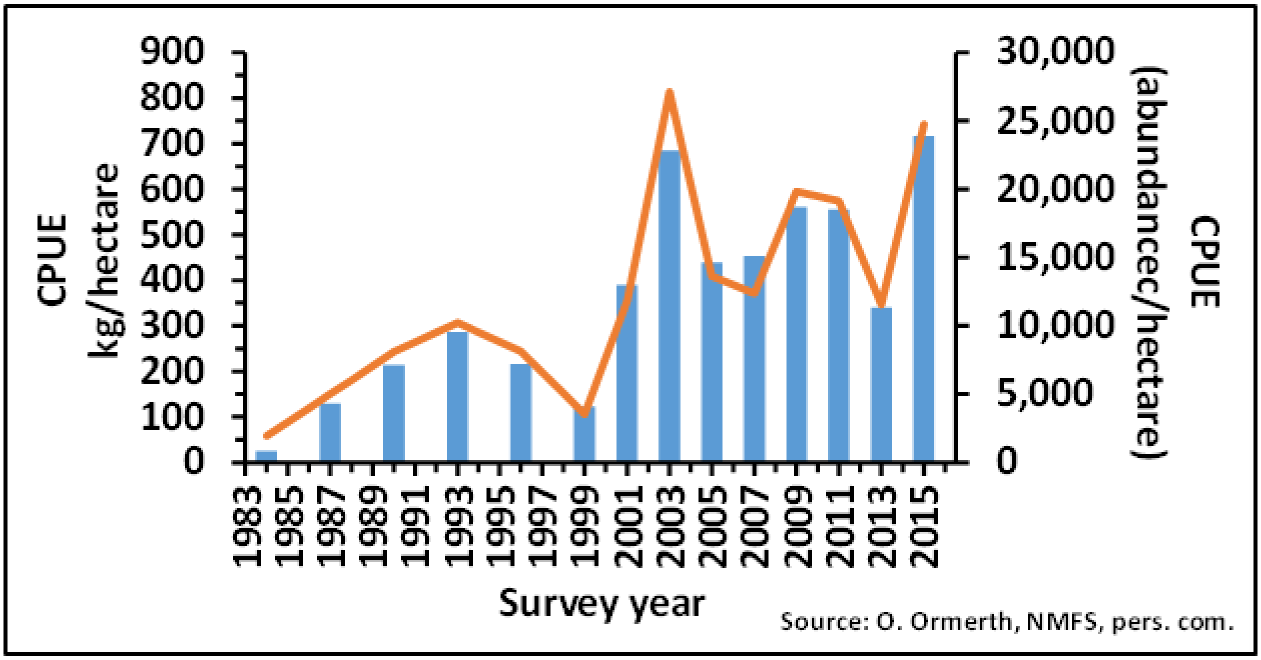
Source: Burbank 1977

Figure 3. General bathymetry of Cook Inlet and the locations of the major tide rips.



Source: Ormseth (2014).

Figure 4. Example of general survey distribution and general catch rates (kg/hectare) in NMFS surveys along the north Gulf of Alaska, 2007-2013.



Source: O. Ormerth, NMFS, pers. com.

Figure 5. Eulachon catch rates, in terms of biomass (kg/hectare) and abundance (number of fish/hectare), in the NMFS bottom trawl surveys of the northern Gulf of Alaska, 1984-2015.

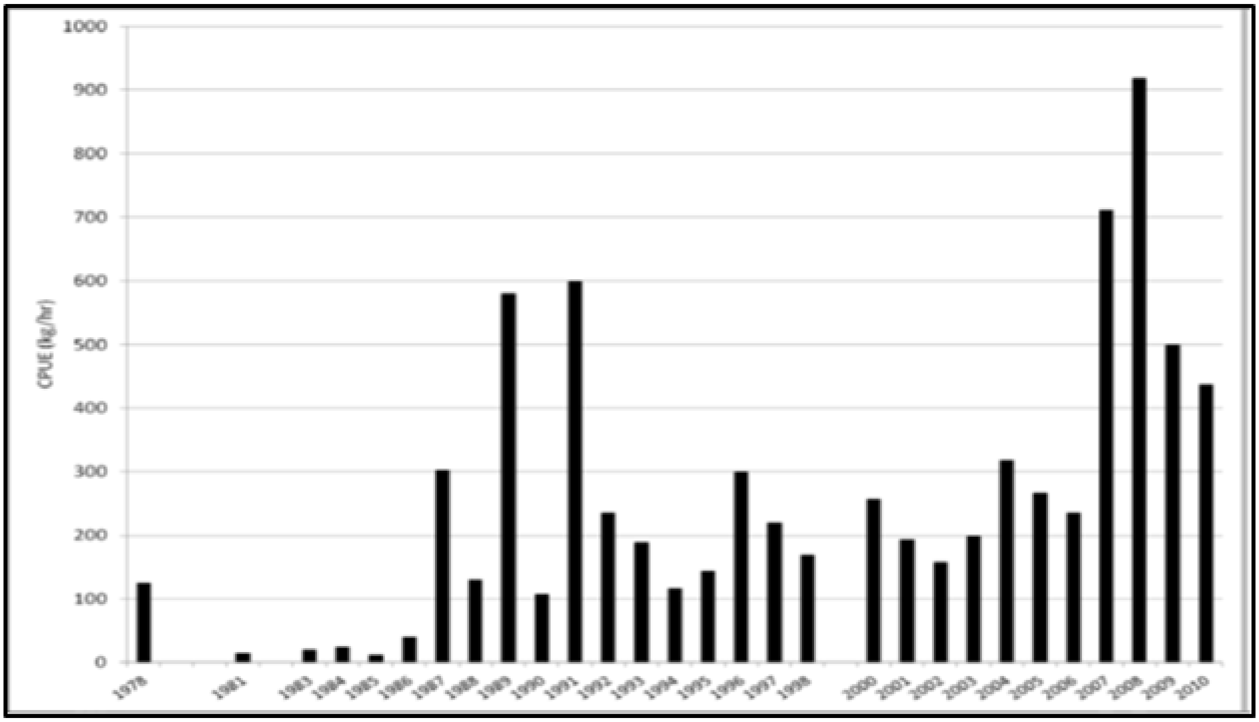
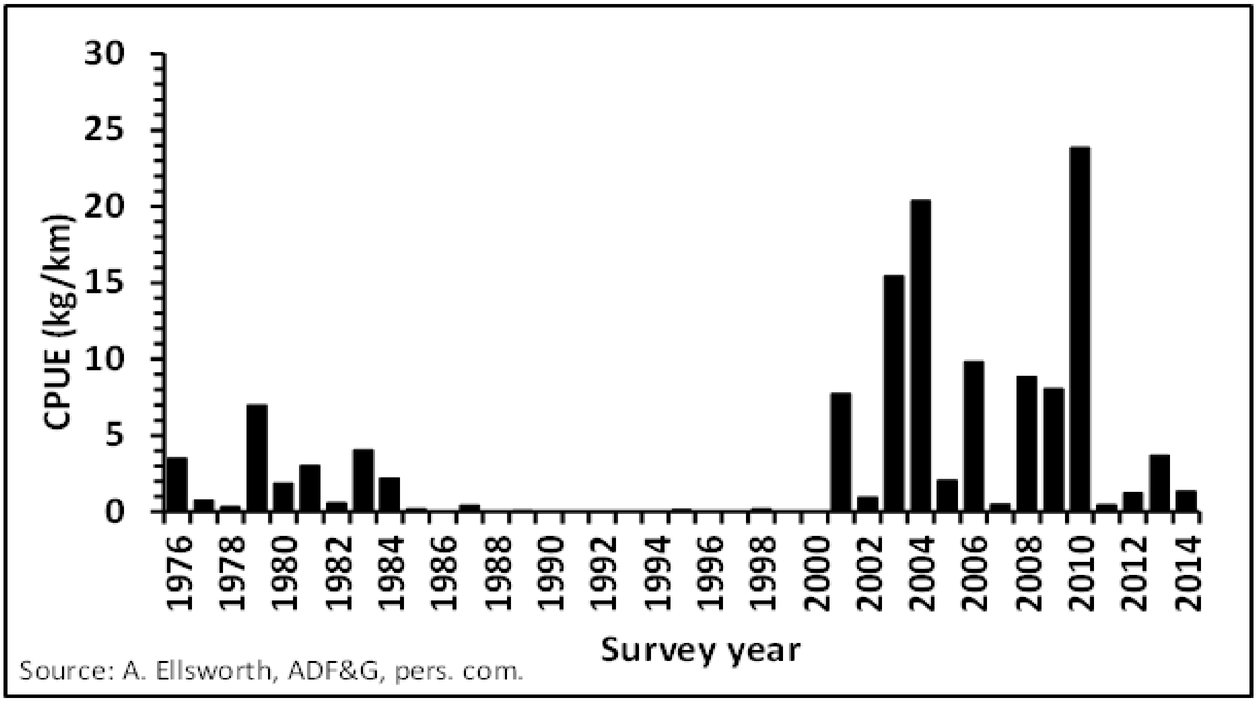
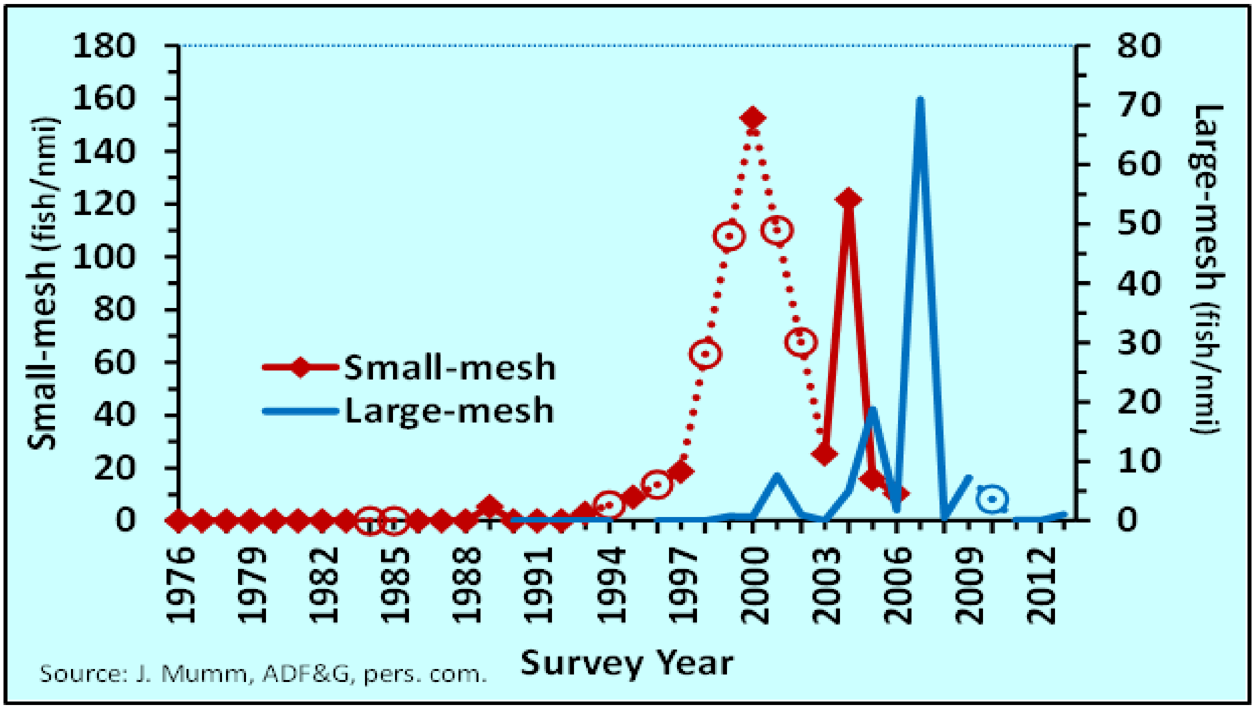


Figure 6. Eulachon catch rates (kg/hr) in sampling tows conducted during NMFS (AFSC) acoustic trawl surveys in the Gulf of Alaska, 1978-2010.



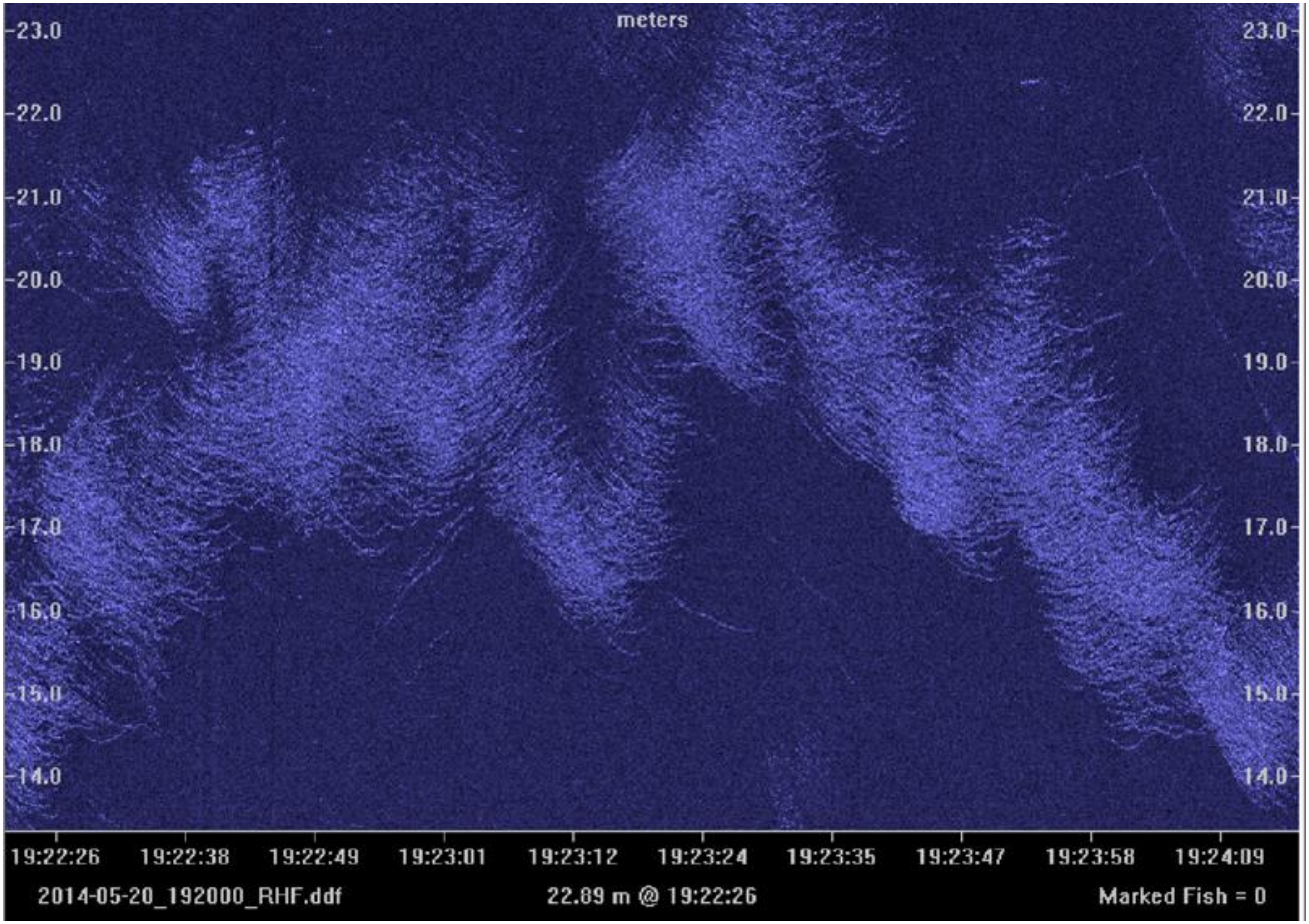
Source: A. Ellsworth, ADF&G, pers. com.

Figure 7. Eulachon CPUE in a small-mesh bottom trawl survey conducted by ADF&G in Marmot Bay north of Kodiak Island in the Gulf of Alaska, 1976–2014.



Source: J. Mumm, ADF&G, pers. com.

Figure 8. Eulachon catch rates (fish/nautical mile) in ADF&G small-mesh (1976-2006) and large-mesh (1990-2013) bottom trawls surveys in Kachemak Bay, Lower Cook Inlet. Circles and dashed lines shows where values for missing years were interpolated for graphing purposes.



Source: J. Miller, ADF&G, pers. com

Figure 9. Screen image of eulachon passage as displayed on DIDSON acoustic system, Kenai River.

Figure 10. Cook Inlet reporting areas used for the Alaska Department of Fish and Game statewide survey of recreational and personal use harvests (http://www.adfg.alaska.gov).

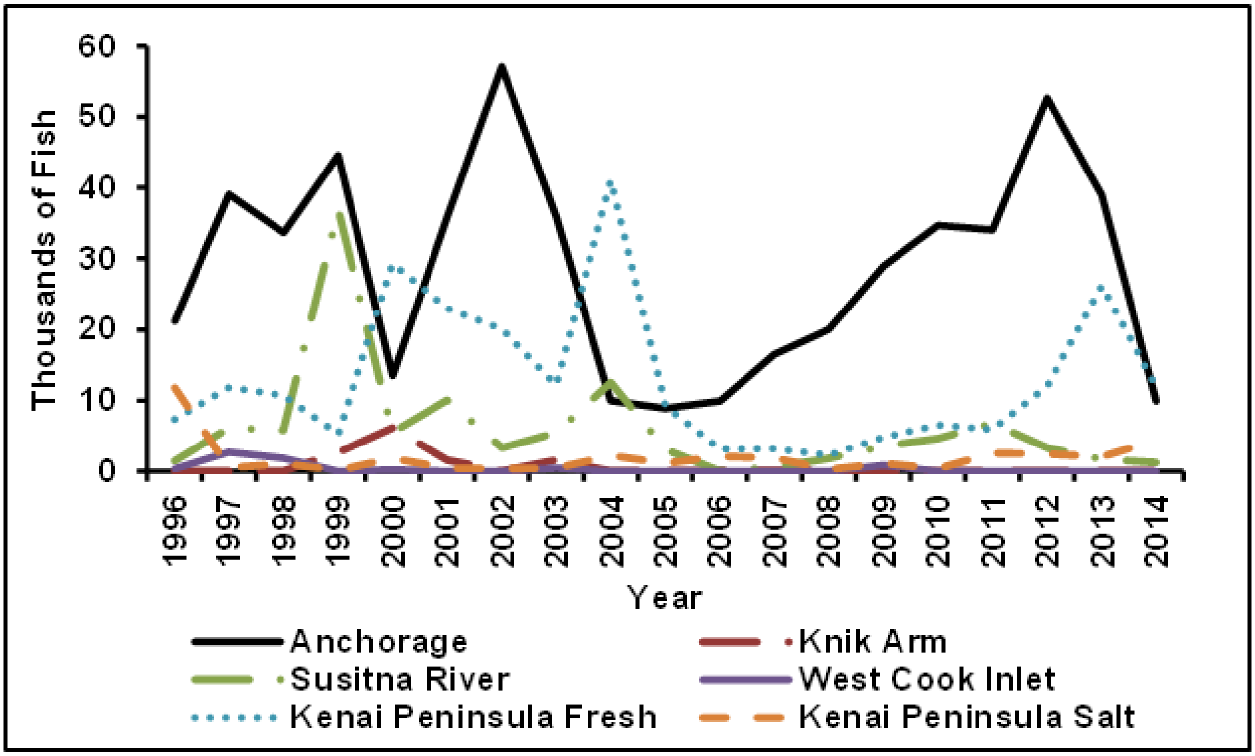
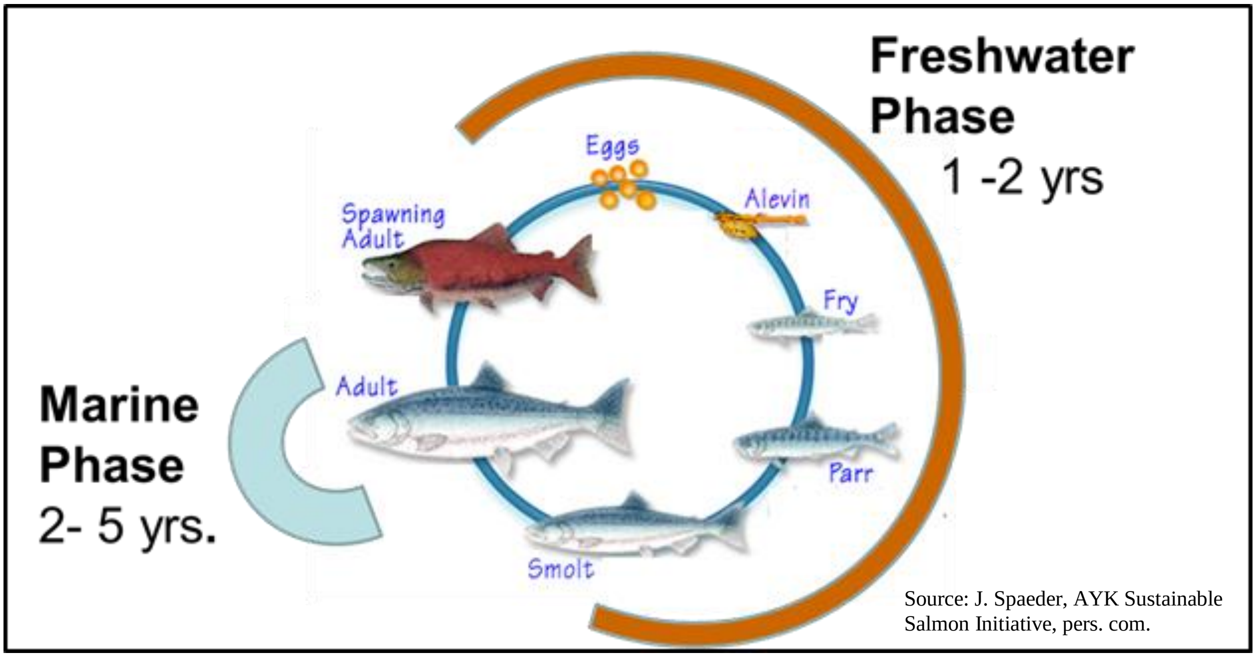


Figure 11. Eulachon smelt) catches in the personal use fishery by area from Upper Cook Inlet, 1996–2014.



Source: J. Spaeder, AYK Sustainable Salmon Initiative, pers. com.

Figure 12. Generalized depiction of salmon life history stages.

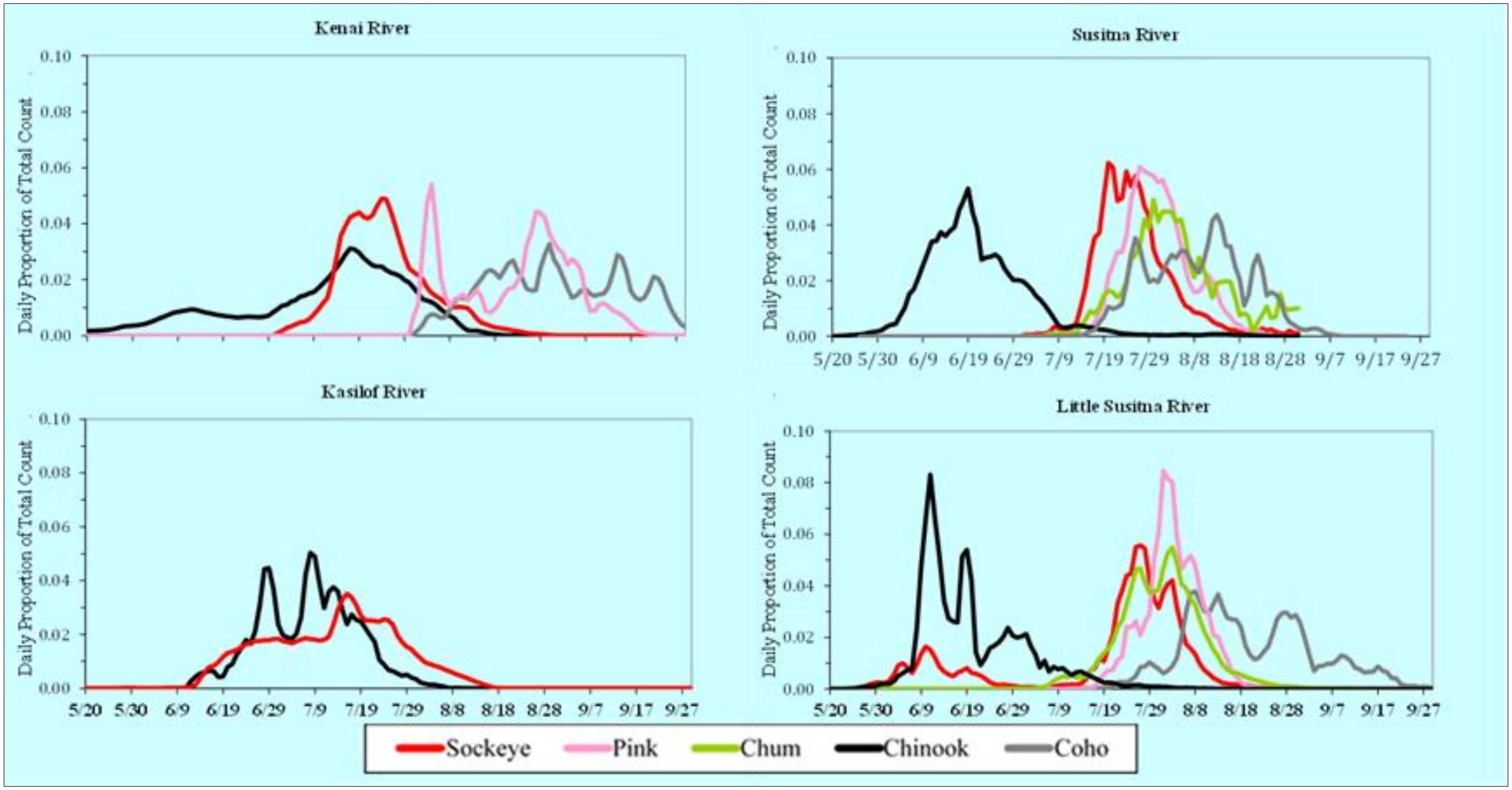


Figure 13. Historical timing of salmon runs to the Kenai, Kasilof, Susitna, and Little Susitna rivers in upper Cook Inlet.
Source: http://www.adfg.alaska.gov/sf/FishCounts/; M. Willette, ADF&G, pers. com.

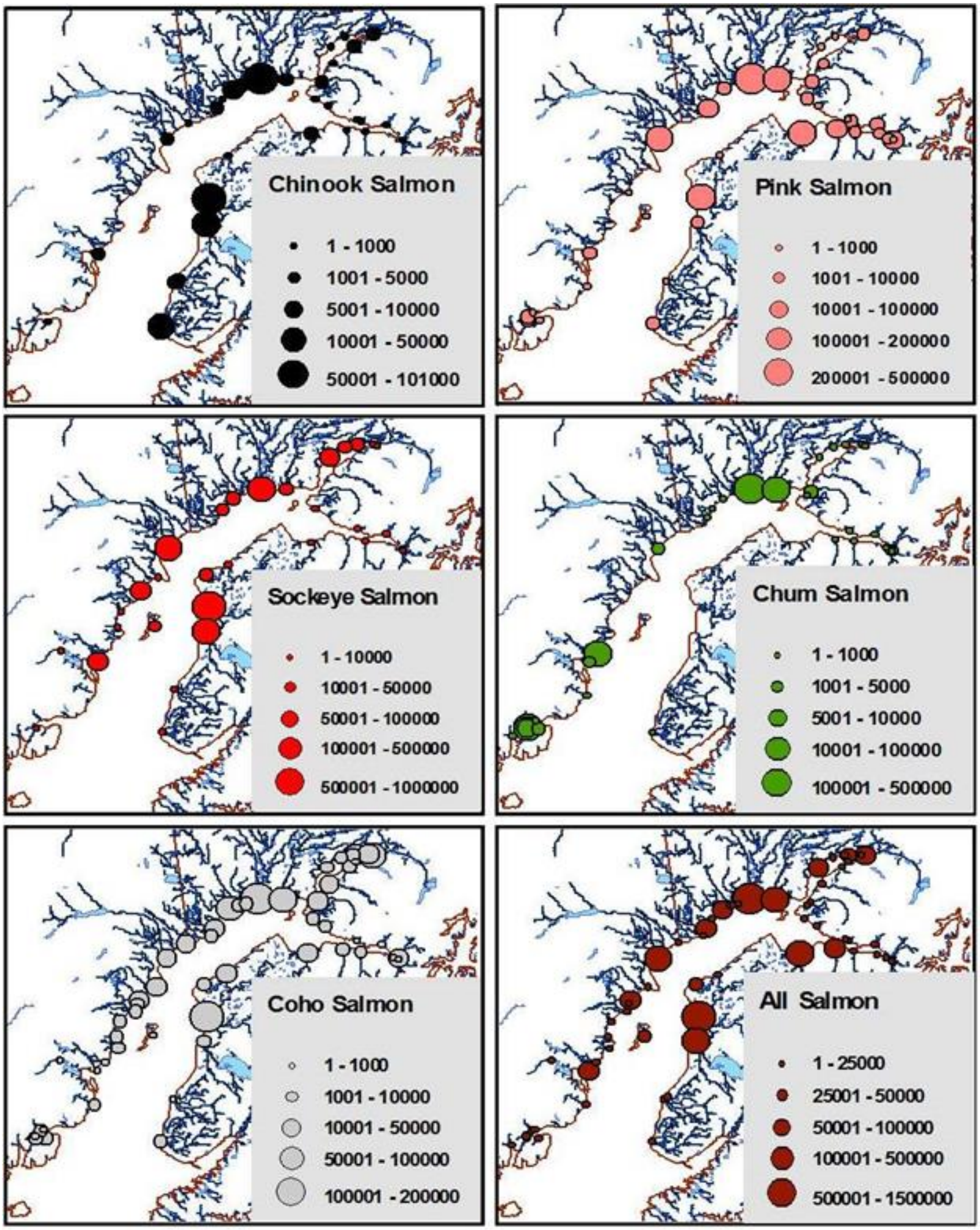
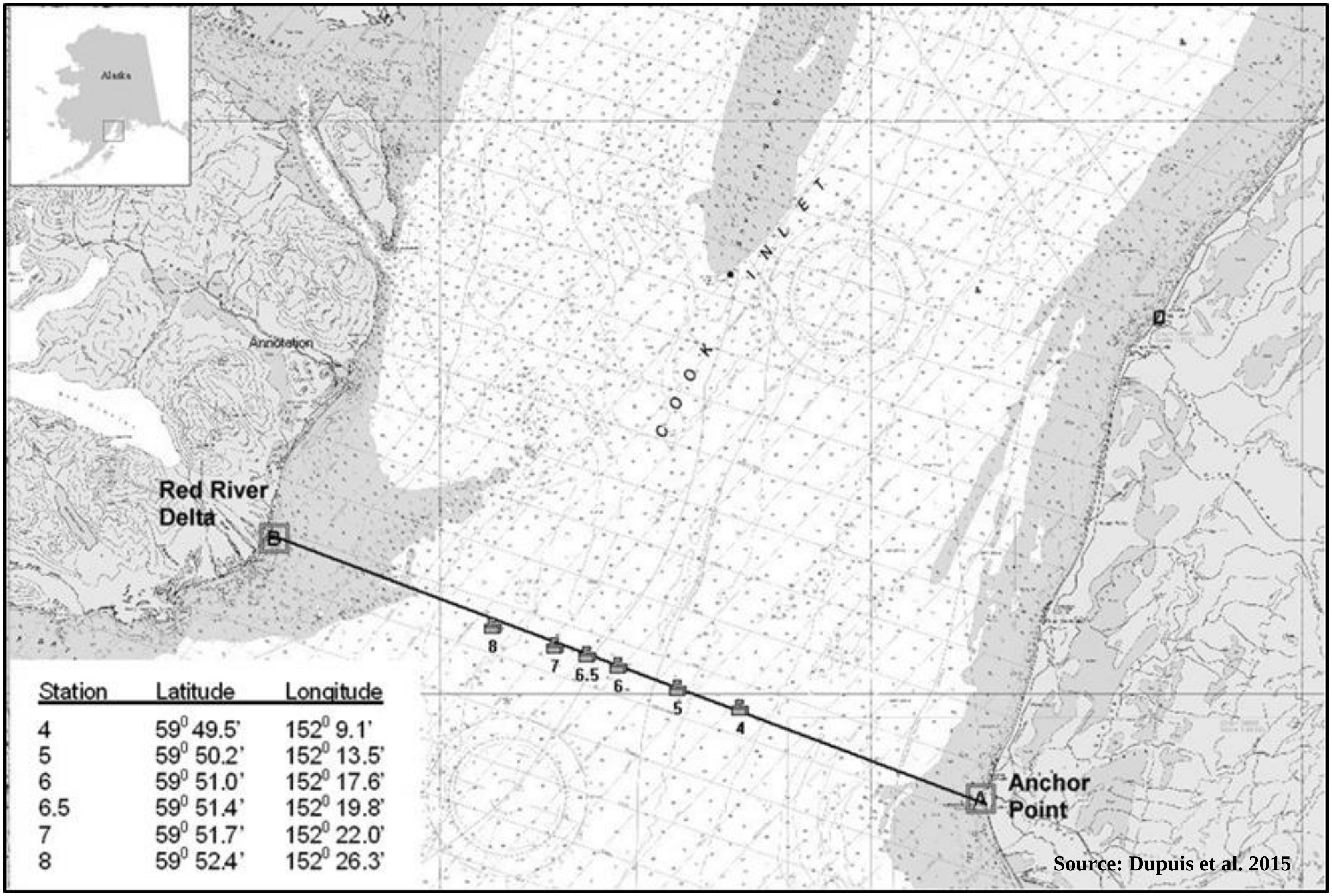


Figure 14. Mean historical annual salmon returns to tributaries of Upper Cook Inlet.

Source: M. Willette, ADF&G, pers. com.



Station	Latitude	Longitude
4	59^{0} 49.5’	152^{0} 9.1’
5	59^{0} 50.2’	152^{0} 13.5’
6	59^{0} 51.0’	152^{0} 17.6’
6.5	59^{0} 51.4’	152^{0} 19.8’
7	59^{0} 51.7’	152^{0} 22.0’
8	59^{0} 52.4’	152^{0} 26.3’

Source: Dupuis et al. 2015

Figure 15. Location of the offshore test fishery transect and fishing stations off Anchor Point in Cook Inlet, Alaska.

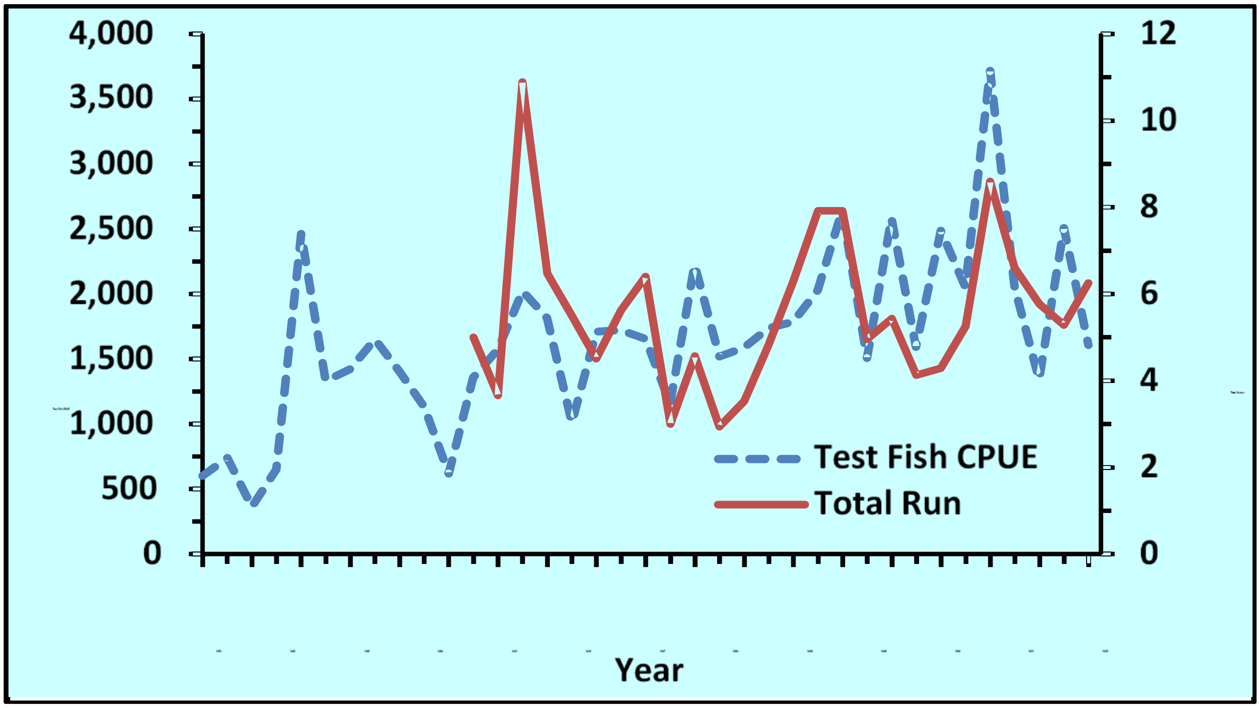


Figure 16. Cumulative annual catch-per-unit-effort (CPUE) of sockeye, coho, pink, and chum salmon in the southern offshore test fishery for Upper Cook Inlet, 1992–2015.

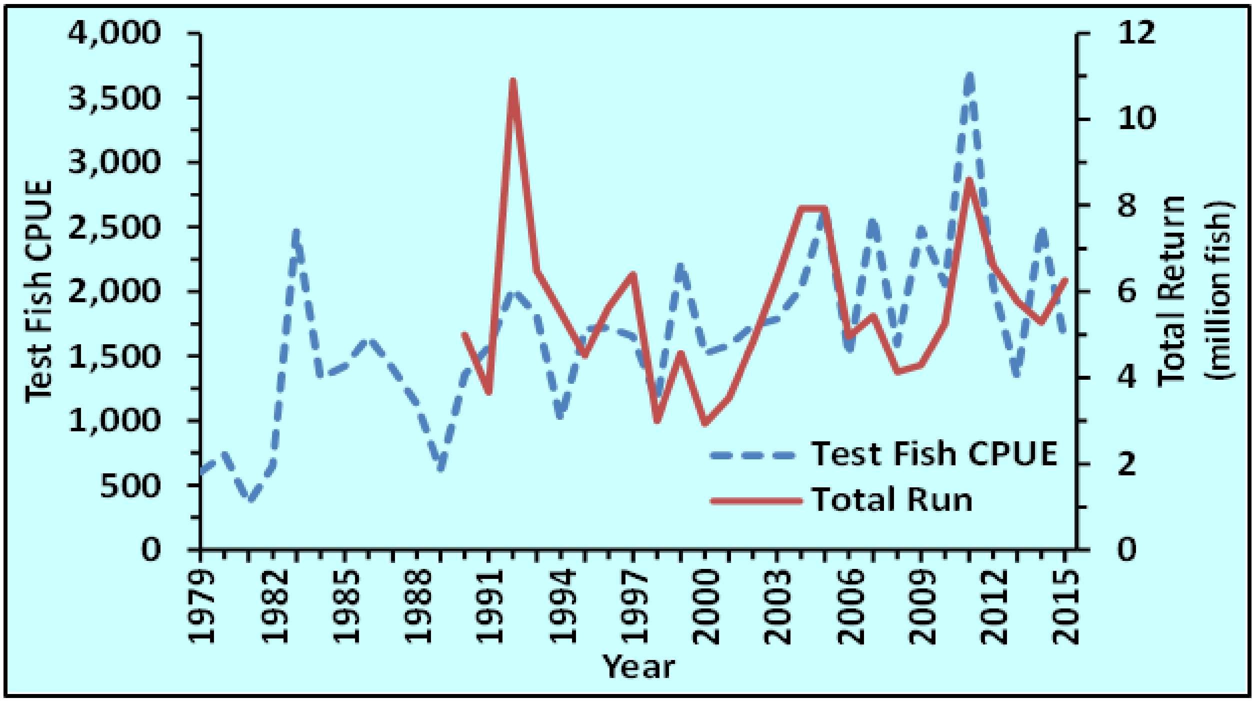
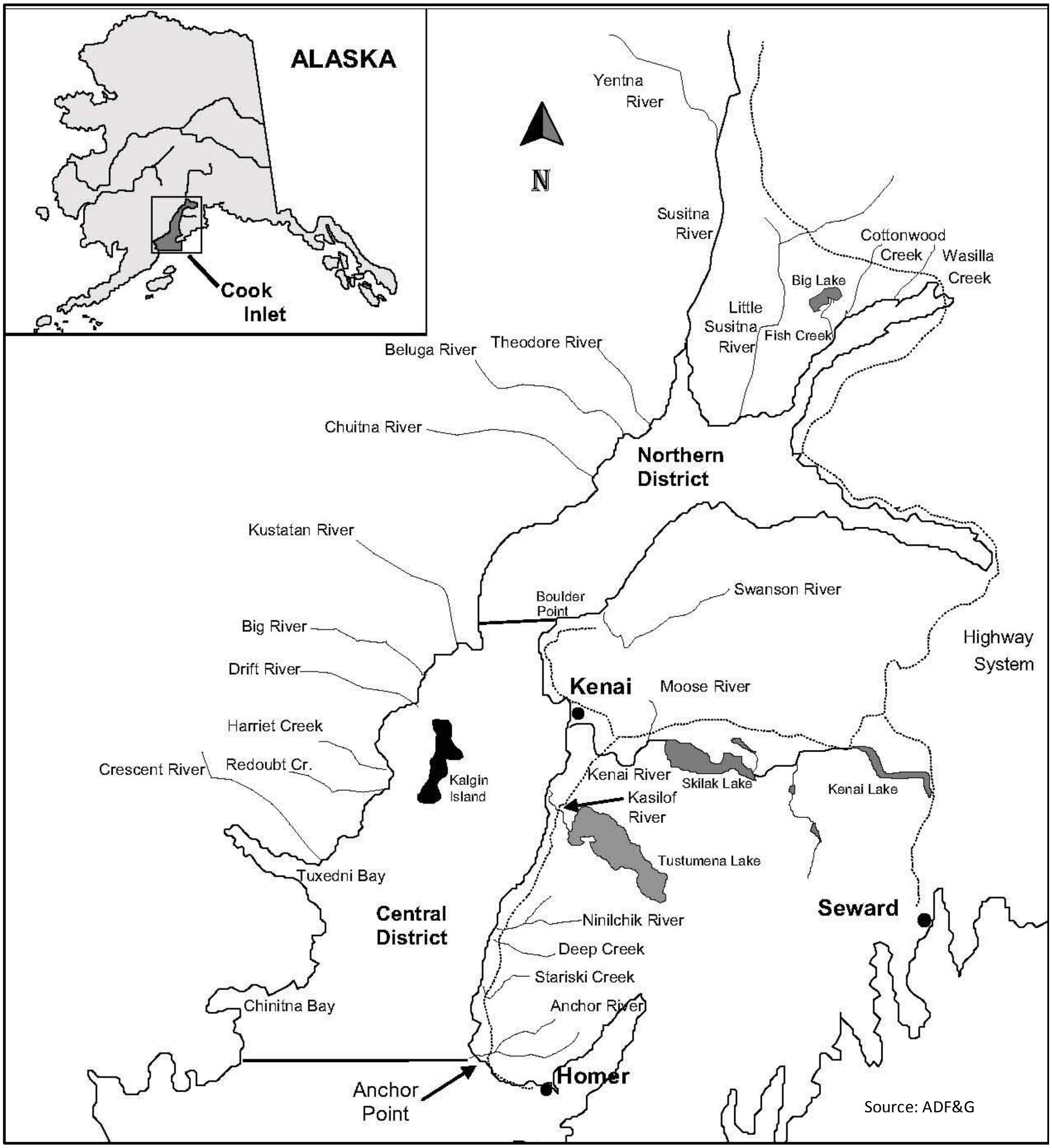


Figure 17. Sockeye salmon catch-per-unit-effort (CPUE) in the Upper Cook Inlet Anchor Point offshore test fishery (1979–2015) and estimated total return of sockeye salmon to Upper Cook Inlet (1992–2015).



Source: ADF&G

Figure 18. Commercial fishing district boundaries in Upper Cook Inlet.

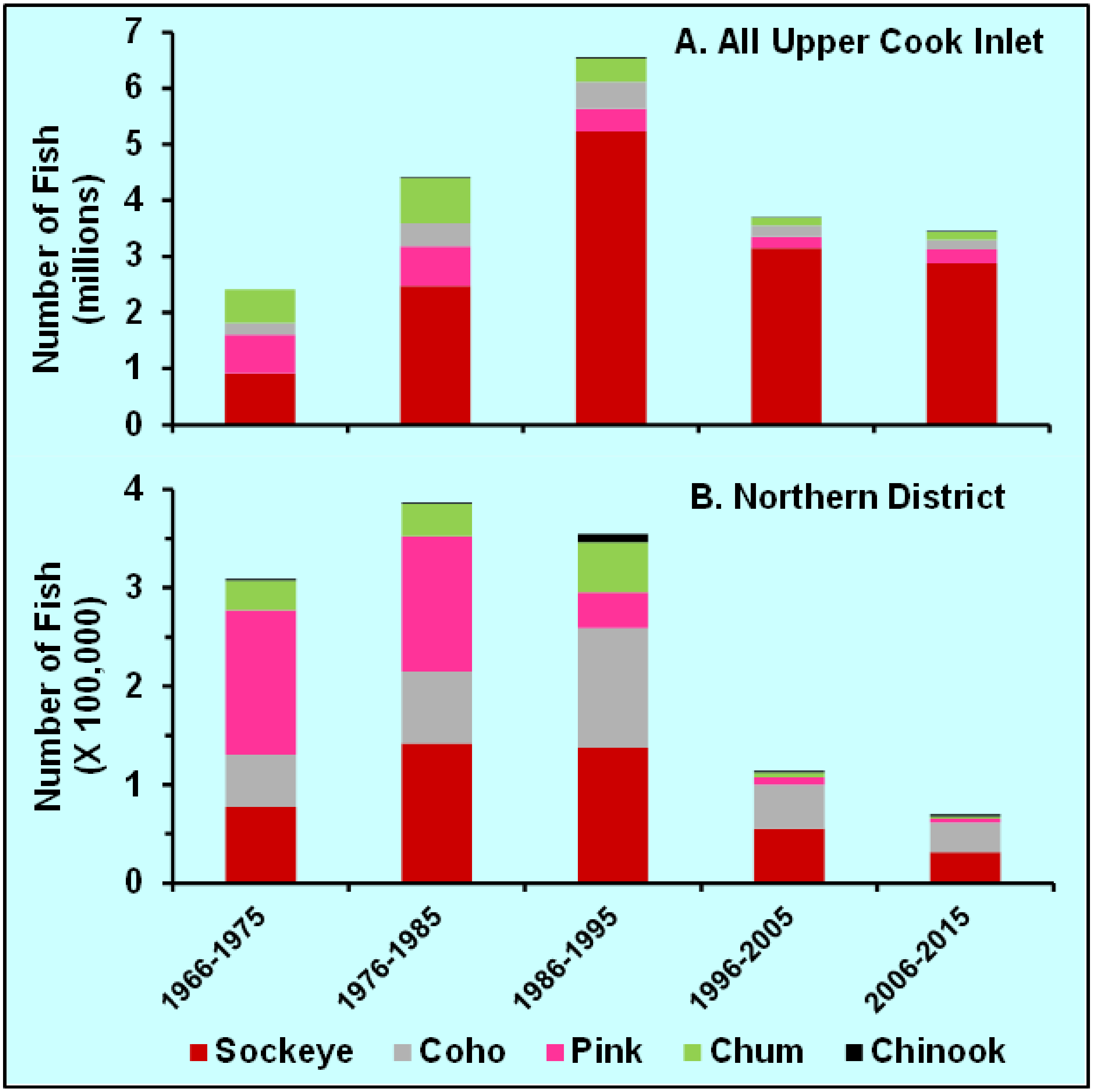


Figure 19. Average annual commercial salmon harvest by species from (A) all of Upper Cook Inlet and (B) the Northern District by decade during 1966–2015.

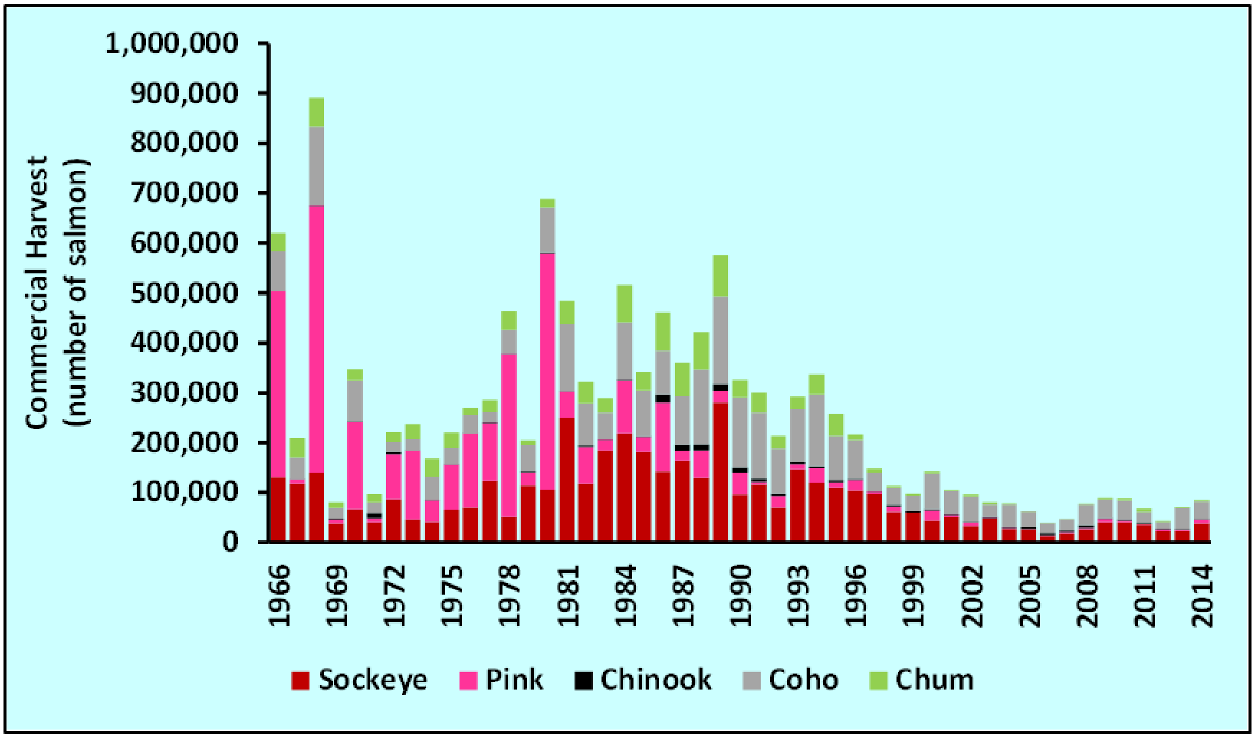


Figure 20. Commercial salmon harvest by species from the Northern District of the Upper Cook Inlet Management Area, 1966–2014.

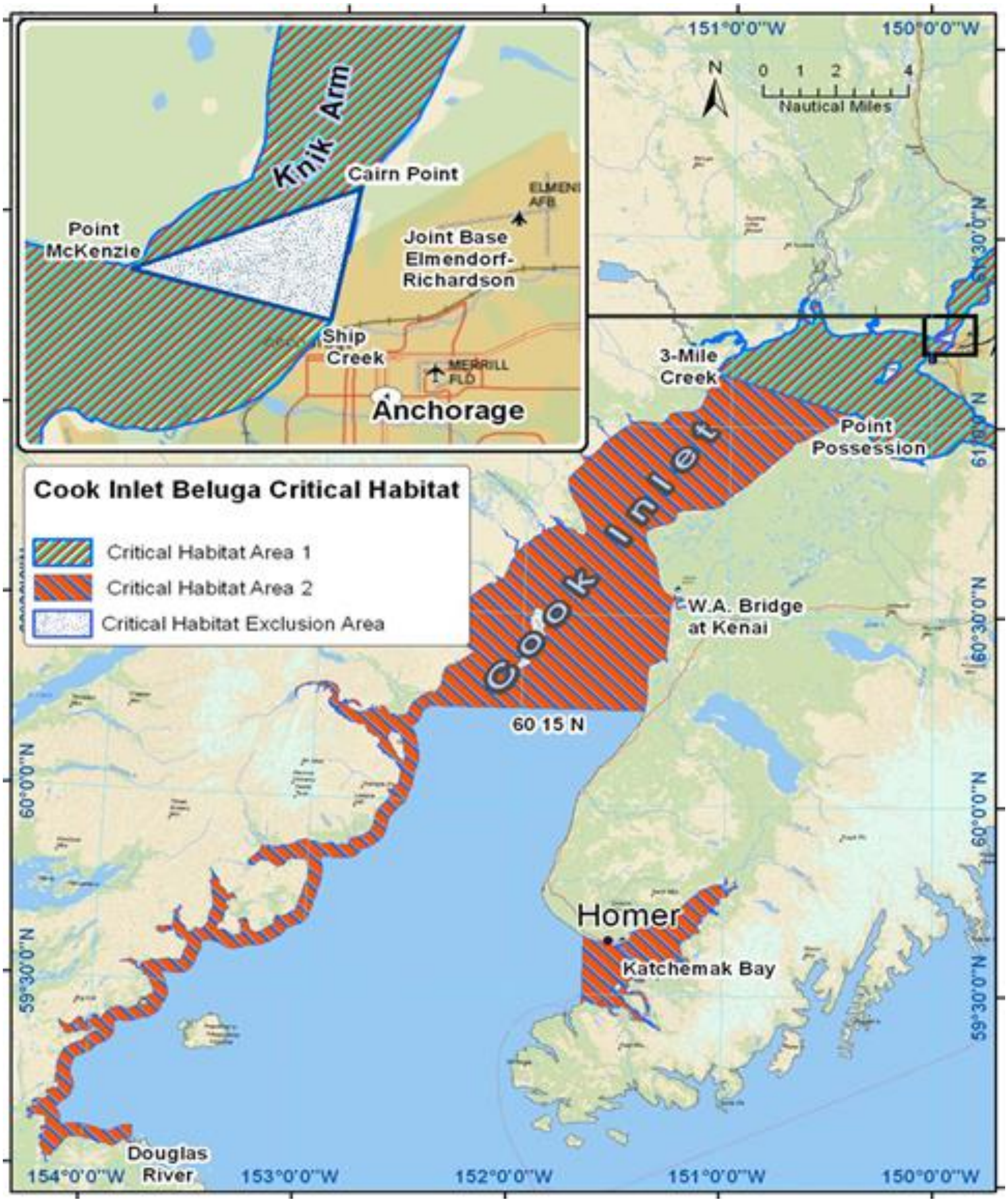


Figure 21. Cook Inlet beluga whale critical habitat designations and exclusions (NMFS 2011).

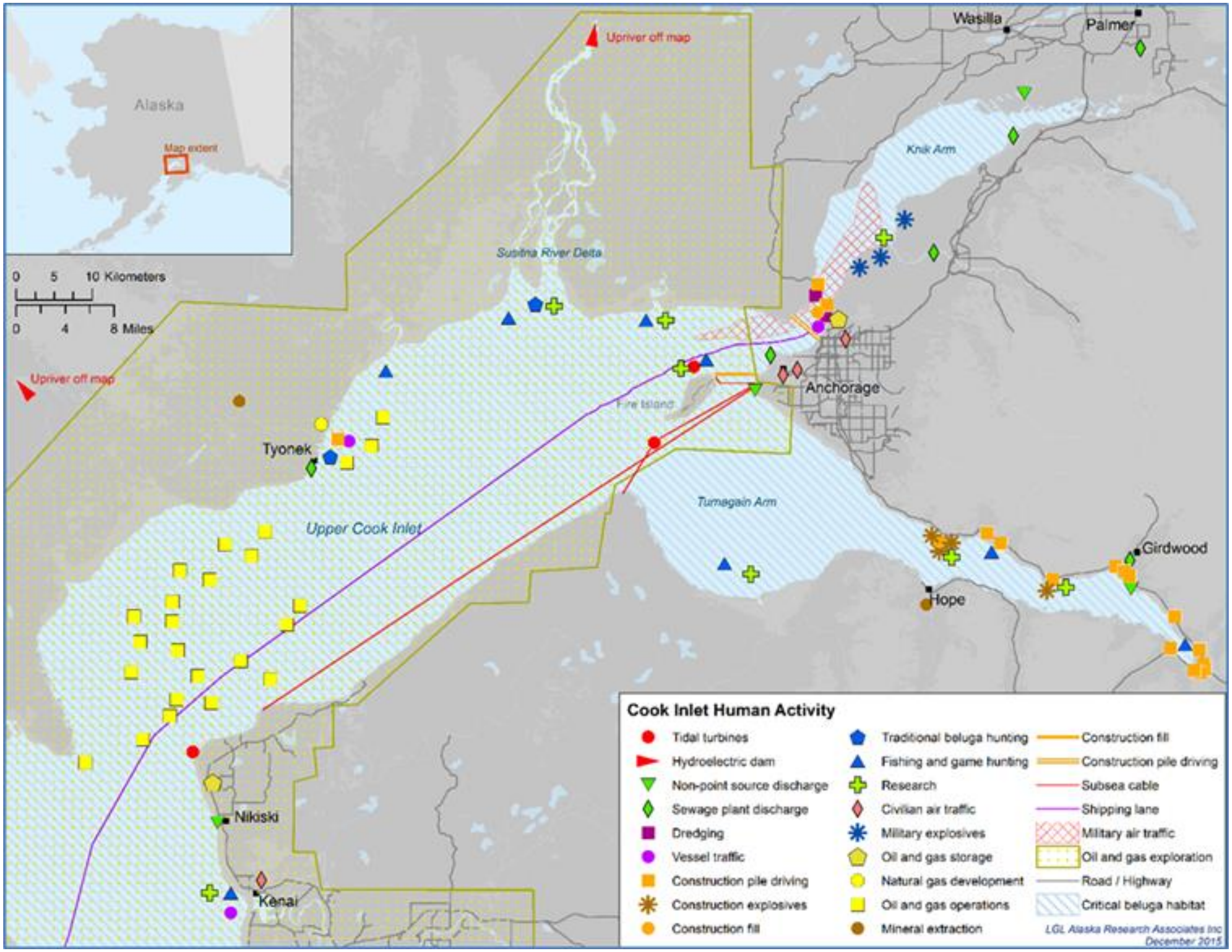
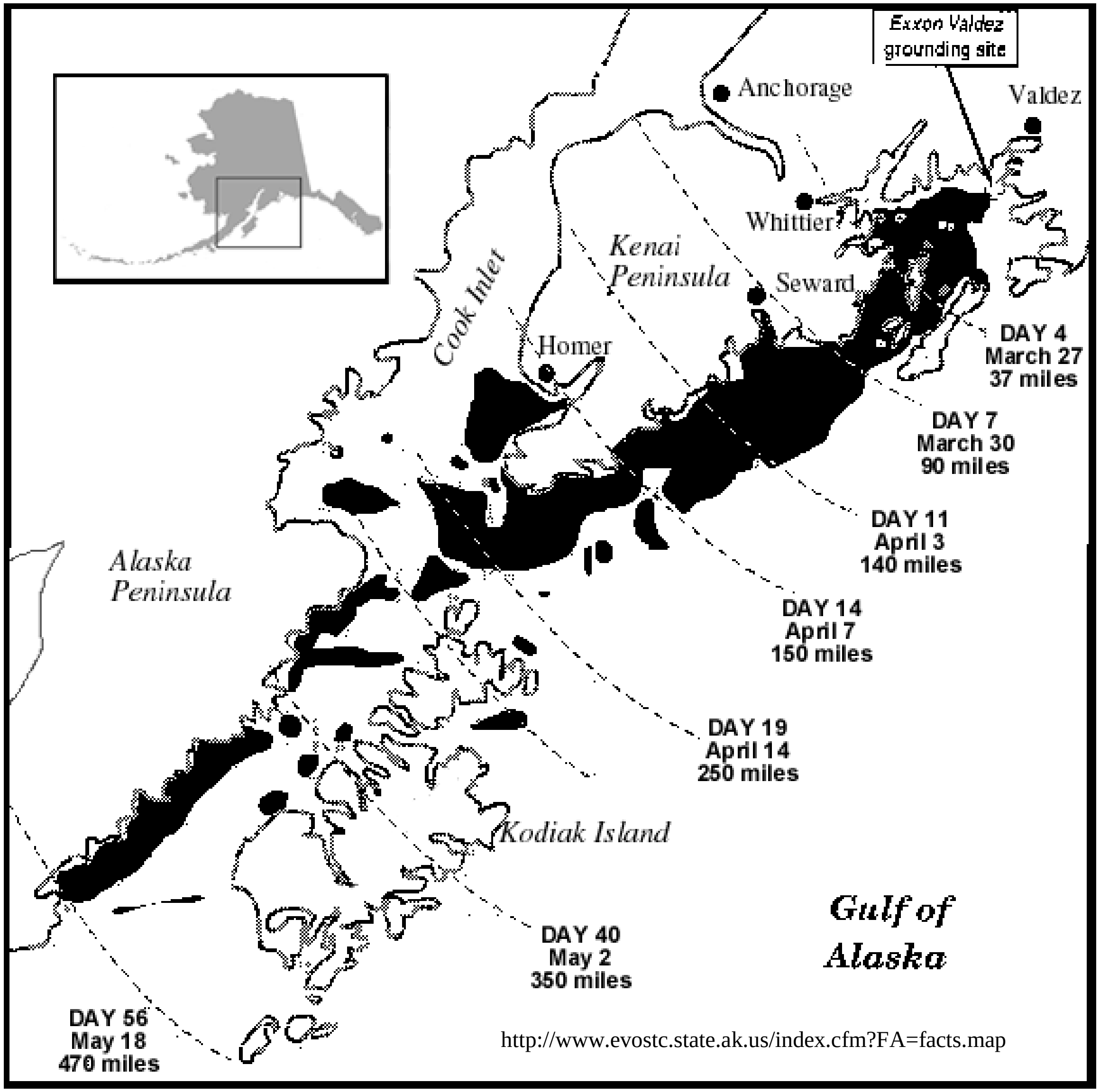


Figure 22. Current and proposed human activity occurring in or adjacent to the waters of Upper Cook Inlet, Alaska.



http://www.evostc.state.ak.us/index.cfm?FA=facts.map

Figure 23. Distribution of crude oil from the *Exxon Valdez* oil spill on March 24, 1989.

APPENDIX A: CORRELATIONS OF CIBW AND PREY INDICES

Correlations can indicate a relationship between two or more data sets. The relationships may indicate similar or contradictory trends in the data. I applied the Pearson product-moment correlation coefficient which produces correlation values ranging from -1.0, indicating a completely negative correlation, to 1.0, indicating a completely positive correlation with identical trends in estimates. In a negative correlation, the values or two or more data sets trend in opposite directions, such that values in one data set increase at the same time that values in a second data set decrease. For example, air temperature and glacial surface area might be expected to have a negative correlation because warmer air temperature causes more glacial melting. In contrast, a positive correlation indicates a tendency for values in two or more data sets to increase and decrease at similar times. For instance, the estimated abundances of the fish species in two adjacent river tributaries might be expected to have a positive correlation if the stream habitats and ecological conditions are similar. However, in many instances, correlation does not necessarily imply causation, which is to say that the observed similarities or differences in trends might not be the result of interactions between the factors being compared, but instead may result from secondary or tertiary factors and interactions. In addition, it is expected that some spurious relationships will be observed when comparing data sets, which is to say some positive or negative correlation may occur simply by chance. Nonetheless, observations of correlations may indicate some underlying relationship, even if the cause for that relationship cannot be identified.

Approach to Correlations

The CIBW population has failed to rebuild despite curtailment of all harvests. The reason for this failure to rebuild is unknown. To explore potential relationships among CIBWs and the available prey, we tested for correlations among CIBW abundance and selected indices of available prey. Some prey indicator data sets were excluded due to a lack of an adequate time series, either in terms of the number of years of data or the years of overlap with CIBW survey estimates. There was also an effort to focus on data sets associated with Upper Cook Inlet. Data sets included in the analysis are shown in Table A-1.

After selecting the data, the next step in the analysis was to calculate standardized annual residuals for each data set. Standardizing annual data rescales estimates to their mean and standard deviation, allowing comparisons without having very large estimates “swamp” data with smaller estimates. This step involved creating a standardized estimate for each year by subtracting the long-term average value for a data series from the values for each year, and then dividing by the standard deviation. The standardized estimates for the data set were then collectively compared for correlations among data sets and against the CIBW standardized values.

Differences exist in the seasonal timing of data collection for individual data sets. Specifically, the CIBW survey occurs in late spring to early summer, a period preceding the seasonal collection of some fisheries and escapement data. In addition, given the extended reproductive cycle of beluga whales (NMFS 2015), the effect of availability of a particular prey might not be expressed in CIBW abundance or reproductive output for several years. Thus, time lags likely exist between a change in the abundance of a particular prey type and the “observed impact” on CIBW abundance. Examination of lag effects was accomplished by shifting the time series of CIBW data by the number of lag years. For example, a lag of two years examines the relationship between available prey and CIBW abundance two years later. Replicates of paired correlations among CIBWs and the available data were examined with lag times ranging from 0 to 10 years. In all comparisons, years with missing data were ignored.

To simplify interpretations of the correlation analysis, only results with a correlation of arbitrarily-selected values ≤0.5 or ≥0.5 were considered (Table A-2). Because a correlation may be suggested for those results with such values, the statistical significance (P-value) is also presented (Table A-3).

Results of Correlations

The standardized deviations of CIBW abundance estimates were correlated across lags ranging from one to four years, although the strength and significance of the correlations declined with longer lags. For a 5-year lag and longer, the strength of the correlation and the statistical significance declined (Tables A-2 and A-3). The exception was a 7-year lag that appears to be significant, but is likely a compounding of a shorter lag period.

The Upper Cook Inlet commercial fishery for smelt/eulachon initially appears to be important at a 2-year lag and again at lags of 6¬7 years, with some shorter lags indicating a negative correlations and longer lags suggesting a positive correlation. However, these correlations were all deemed as not statically significant ($P>0.05$).

Some correlations were suggested with the offshore test fishery data. For example, the test fishery catch of sockeye appears to have a moderately strong negative relationship with CIBW estimates lagged at 6 and 7 years (correlation values of -0.60 and – 0.68, respectively). Statistically significant ($P<0.05$) negative correlations of moderate strength were also found with test fishery catches of coho at 5-, 7-, 8-, and 9-year lags. Finally, offshore test fishery catches of pink salmon were also negatively correlated with a 5-year lag of CIBW abundance estimates.

One surprise finding was a preponderance of moderate to strong positive correlations between CIBW estimate residuals and the Northern District commercial fishery catches of all five salmon species at a wide range of lags (Tables A-2 and A-3). At first glance this might suggest that CIBW estimates tend to increase and decrease on similar scales as commercial fishery catches. Although the correlations are positive, it is unrealistic to presume that increased fishing harvests results in increased CIBW abundance, or decreased harvests result in decreased CIBW abundances. Because the fisheries, and likely CIBWs, are both in the same general area targeting the same “prey,” that is, salmon, it is possible that years of strong salmon returns result in greater harvests and also greater availability of salmon as CIBW prey. This may especially be true for pink salmon which tend to have larger returns on even years. Values for correlations between CIBW estimates and Northern District pink salmon harvests do seem strongest on even-year lags. But the relationship between CIBWs and pink salmon does not seem to extend to the Deshka weir counts of pink salmon. While the Deshka weir has also tended to exhibit strong counts of pink salmon on even years, the magnitude of the highest counts and the timing of those counts in the time series was out of sync with the CIBW data; basically the years of the Deshka pink salmon counts was in the late 1990s to early 2000s, after CIBW abundance had decline. In terms of timing, it is also notable that both the CIBWs and the Northern District harvests were historically of larger magnitudes that scaled to similar values as residuals. Thus, the magnitude and timing of the declines in Northern District commercial harvests, combined with a general trend of reduced harvests in more recent years, could partly explain the strong correlation with the CIBW time series.

Little Susitna coho appeared to have a moderate positive correlation (0.60) with CIBWs at a 6-year lag. Other than aspects mentioned above, the CIBW time series does not appear to be correlated at any time lags with other prey indices as indicated by low correlation values or a lack of statistical significance in the correlations.

One other aspect that needs to be considered in examining these results is sample size. The maximum number of paired data point for the correlation analysis is 20, the number of years of CIBW data. For the different sets of prey indices, years of missing data either within or at the start of a data set reduces the potential number of correlation data points. This is particularly important, as the CIBW data are lagged against other data sets. For example, there are only 12 years of commercial smelt data, including a six-year gap during 2000¬2005 when no fishery occurred. As the CIBW data are lagged, fewer data pairs are available with which to explore for a correlation, and at 9- and 10-year lags, only two data pairs are available.

A-1. Sets of salmon data indices considered for correlations analyses.

Code	Area	Species	Method[a/]	Years [b/]
CIBW	Upper Cook Inlet	CIBW	Aerial	1994¬2014
DeshChin	Deshka	Chinook	Weir	1995¬2015
DeshPink	Deshka	Pink	Weir	1996¬2015
DeshCoho	Deshka	Coho	Weir	1997¬2015
ComSmelt	Upper Cook Inlet	Eulachon/smelt	Commercial Harvests	1998¬2015
SusSmelt	Susitna	Eulachon/smelt	PU Harvest	1996¬2014
KnikSmelt	Knik Arm	Eulachon/smelt	PU Harvest	1996¬2014
AncSmelt	Anchorage	Eulachon/smelt	PU Harvest	1996¬2014
KenSmelt	Kenai	Eulachon/smelt	PU Harvest	1996¬2014
OTFsock	Offshore Test Fishery	Sockeye	Gillnet	1984¬2015
OTFcoho	Offshore Test Fishery	Coho	Gillnet	1984¬2015
OTFpink	Offshore Test Fishery	Pink	Gillnet	1984¬2015
OTFchum	Offshore Test Fishery	Chum	Gillnet	1984¬2015
LsuCoho	Little Susitna	Coho	Weir	1996¬2015
KenSock	Kenai	Sockeye	Sonar	1984¬2015
NDistChin	Northern District	Chinook	Commercial setnet	1984¬2015
NDistSock	Northern District	Sockeye	Commercial setnet	1984¬2015
NDistCoho	Northern District	Coho	Commercial setnet	1984¬2015
NDistPink	Northern District	Pink	Commercial setnet	1984¬2015
NDistChum	Northern District	Chum	Commercial setnet	1984¬2015

[a/] Indicates the current method, although the applied method may have changed over time.

[b/] Represents the total range; some years in the listed range might not have data.

A-2. Correlations of standardized residuals of Cook Inlet beluga whale estimates against selected indices of prey availability at lags of 0¬10 years.

	Time lag (years) between index and CIBW survey estimate [b/]										
Index [a/]	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10
CIBW	1.00	0.67	0.58	0.55	0.51	0.35	0.49	0.58	0.13	-0.06	0.05
DeshChin	-0.14	-0.35	-0.26	0.27	0.18	-0.43	-0.29	-0.07	-0.38	-0.25	0.33
DeshPink	0.07	0.14	0.07	-0.05	-0.02	-0.16	0.20	-0.03	0.33	-0.15	0.16
DeshCoho	-0.20	-0.32	-0.12	0.06	0.10	-0.39	-0.18	-0.20	0.08	-0.25	-0.29
ComSmelt	-0.33	-0.41	-0.51	-0.37	-0.03	-0.43	-0.55	0.93	0.91	NA	NA
SusSmelt	0.01	0.26	0.21	-0.03	0.11	0.20	-0.33	-0.30	0.29	0.61	-0.11
KnikSmelt	0.25	0.36	-0.16	-0.03	0.14	-0.33	-0.36	0.41	0.50	0.18	-0.10
AnchSmelt	-0.12	0.12	0.17	-0.23	-0.12	0.53	0.46	0.01	-0.17	-0.05	-0.13
KenSmelt	0.12	-0.29	-0.19	0.28	0.12	-0.26	0.29	-0.04	-0.07	-0.21	-0.06
OTFsock	-0.52	-0.26	-0.32	-0.20	-0.16	-0.47	-0.68	-0.60	-0.27	-0.26	-0.32
OTFcoho	0.08	-0.21	-0.20	-0.31	-0.44	-0.50	-0.40	-0.62	-0.50	-0.54	-0.13
OTFpink	-0.33	-0.40	-0.34	-0.43	-0.36	-0.56	-0.33	-0.45	-0.29	-0.37	-0.07
OTFchum	-0.05	0.03	0.03	-0.24	-0.06	-0.11	-0.08	-0.26	0.10	-0.12	0.42
LsueCoho	0.02	-0.29	-0.01	-0.10	-0.29	0.06	0.60	-0.17	-0.07	-0.42	-0.36
KenSock	-0.36	-0.35	-0.04	-0.15	-0.16	0.08	-0.08	0.49	-0.08	-0.09	-0.36
NDistChin	0.12	0.44	0.55	0.54	0.69	0.84	0.84	0.84	0.85	0.45	0.28
NDistSock	0.86	0.81	0.57	0.72	0.51	0.76	0.55	0.79	0.49	0.45	0.55
NDistCoho	0.88	0.72	0.72	0.72	0.67	0.77	0.79	0.65	0.45	0.25	0.25
NDistPink	0.84	0.50	0.67	0.29	0.68	0.42	0.82	0.52	0.80	0.38	0.82
NDistChum	0.73	0.81	0.74	0.64	0.61	0.86	0.80	0.81	0.78	0.54	0.59

[a/] See Table 6 for definitions of indices.

[b/] Lag is the delay, in years, between a prey value and the Cook Inlet beluga survey estimate. Lag 1 implies the data in a year is compared to CIBW data one year later.

NA – Too few corresponding data points for a comparison.

Note - Highlighted cells indicate values ≤-0.50 or ≥0.50.

A-3. Statistical significance of correlations of selected prey indices data with Cook Inlet beluga whale abundances at lags of 0-10 years.

	Time lag (years) between index and CIBW survey estimate [b]										
Index [a]	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10
CIBW	-	**	*	*	*	NS	NS	*	NS	NS	NS
DeshChin											
DeshPink											
DeshCoho											
ComSmelt			NS				NS	NS	NS		
SusSmelt										NS	
KnikSmelt									NS		
AnchSmelt						NS					
KenSmelt											
OTFsock	*						**	**			
OTFcoho						*		**	*	*	
OTFpink						*					
OTFchum											
LsueCoho							*				
KenSock											
NDistChin			*	*	***	***	***	***	***		
NDistSock	***	***	**	***	*	***	*	***			*
NDistCoho	***	***	***	***	**	***	***	**			
NDistPink	***	*	**		***		***	*	***		***
NDistChum	***	***	***	**	**	***	***	***	***	*	**

[a] See Table *** for definitions of indices.

[b] Lag is the delay, in years, between a prey value and the Cook Inlet beluga survey estimate. Lag 1 implies the data in a year is compared to CIBW data one year later.

* - P≤0.05; ** P≤0.01; *** P≤0.001; NS = not significant at P≤0.05

Note - Highlighted cells denote relationships in which the correlation value was ≤-0.50 or ≥0.50.