Beluga, *Delphinapterus leucas*, Habitat Associations in Cook Inlet, Alaska

SUE E. MOORE, KIM E. W. SHELDEN, LAURA K. LITZKY,
BARBARA A. MAHONEY, and DAVID J. RUGH

Introduction

The small population of belugas, *Delphinapterus leucas*, in Cook Inlet is geographically and genetically isolated from four other populations (also called stocks) that occur around Alaska (Hazard, 1988; O'Corry-Crowe et al., 1997). Unlike the other Alaska stocks, Cook Inlet belugas occupy a relatively restricted body of water, during at least the ice-free months, and are exposed to comparatively intense perturbations associated with human activities. In this way, they may be considered a corollary to the small population of belugas that inhabits the St. Lawrence River estuary in eastern Canada (Sergeant, 1986; Kingsley, 1998; Lesage et al., 1999). However, unlike the Canadian population, the ecology of belugas in Cook Inlet is poorly understood because, until recently, their viability was not a concern. A recent decline in abundance (Hobbs et al., 2000), distribution (Rugh et al., 2000), viability (Hill and DeMaster, 1998), and availability to Alaska Native hunters (Huntington, 2000) has aroused concern for the Cook Inlet beluga stock. As a result, NOAA's National Marine Fisheries Service (NMFS) published a notice of intent to conduct a status review for this population (NMFS, 1998), a part of which is the investigation of habitat use and potential human impacts.

Belugas are seen in Cook Inlet most months of the year, but little information on distribution is available except for summer (Rugh et al., 2000). Recent surveys show that the summer range of Cook Inlet belugas is contracting, with very few whale sightings in the central and lower portions of the inlet in the 1990's compared with the mid 1970's (Rugh et al., 2000). Specifically, during June and July 1974–79, aggregations of belugas numbering from the 10's to 100's of individuals were seen in the central inlet (Calkins[1]), where none have been reported since summer surveys began in 1993 (Rugh et al., 2000). Belugas were seen in the central portion of the inlet during recent winter surveys, but were few in number (Hansen and Hubbard, 1999). Finally, while the full range of the Cook Inlet beluga stock may extend from the inlet to Yakutat Bay and Shelikof Strait (Hazard, 1988), sightings outside Cook Inlet are extremely rare (Laidre et al., 2000).

To characterize patterns of beluga habitat use, we stratified Cook Inlet into three regions based on sightings during summer surveys conducted from 1993 to 1999 (Rugh et al., 2000). Areas of high, moderate, and low beluga occur-

Sue Moore (sue.moore@noaa.gov), Kim Shelden, Laura Litzky, and David Rugh are with the National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115-6349. Barbara Mahoney is with the NMFS Alaska Regional Office, 222 W. 7th Ave., Box 43, Anchorage, AK 99513.

ABSTRACT—A review of available information describing habitat associations for belugas, Delphinapterus leucas, *in Cook Inlet was undertaken to complement population assessment surveys from 1993–2000. Available data for physical, biological, and anthropogenic factors in Cook Inlet are summarized followed by a provisional description of seasonal habitat associations. To summarize habitat preferences, the beluga summer distribution pattern was used to partition Cook Inlet into three regions. In general, belugas congregate in shallow, relatively warm, low-salinity water near major river outflows in upper Cook Inlet during summer (defined as their primary habitat), where prey availability is comparatively high and predator occurrence relatively low. In winter, belugas are seen in the central inlet, but sightings are fewer in number, and whales more dispersed compared to summer. Belugas are associated with a range of ice conditions in winter, from ice-free to 60% ice-covered water. Natural catastrophic events, such as fires, earthquakes, and volcanic eruptions, have had no reported effect on beluga habitat, although such events likely affect water quality and, potentially, prey availability. Similarly, although sewage effluent and discharges from industrial and military activities along Cook Inlet negatively affect water quality, analyses of organochlorines and heavy metal burdens indicate that Cook Inlet belugas are not assimilating contaminant loads greater than any other Alaska beluga stocks. Offshore oil and gas activities and vessel traffic are high in the central inlet compared with other Alaska waters, although belugas in Cook Inlet seem habituated to these anthropogenic factors. Anthropogenic factors that have the highest potential negative impacts on belugas include subsistence hunts (not discussed in this report), noise from transportation and offshore oil and gas extraction (ship transits and aircraft overflights), and water quality degradation (from urban runoff and sewage treatment facilities). Although significant impacts from anthropogenic factors other than hunting are not yet apparent, assessment of potential impacts from human activities, especially those that may effect prey availability, are needed.*

[1] Calkins, D. G. 1984. Susitna hydroelectric project final report: big game studies, vol. IX, belukha whale. Alaska Dep. Fish Game, Anchorage, Doc. 2328, 17 p.

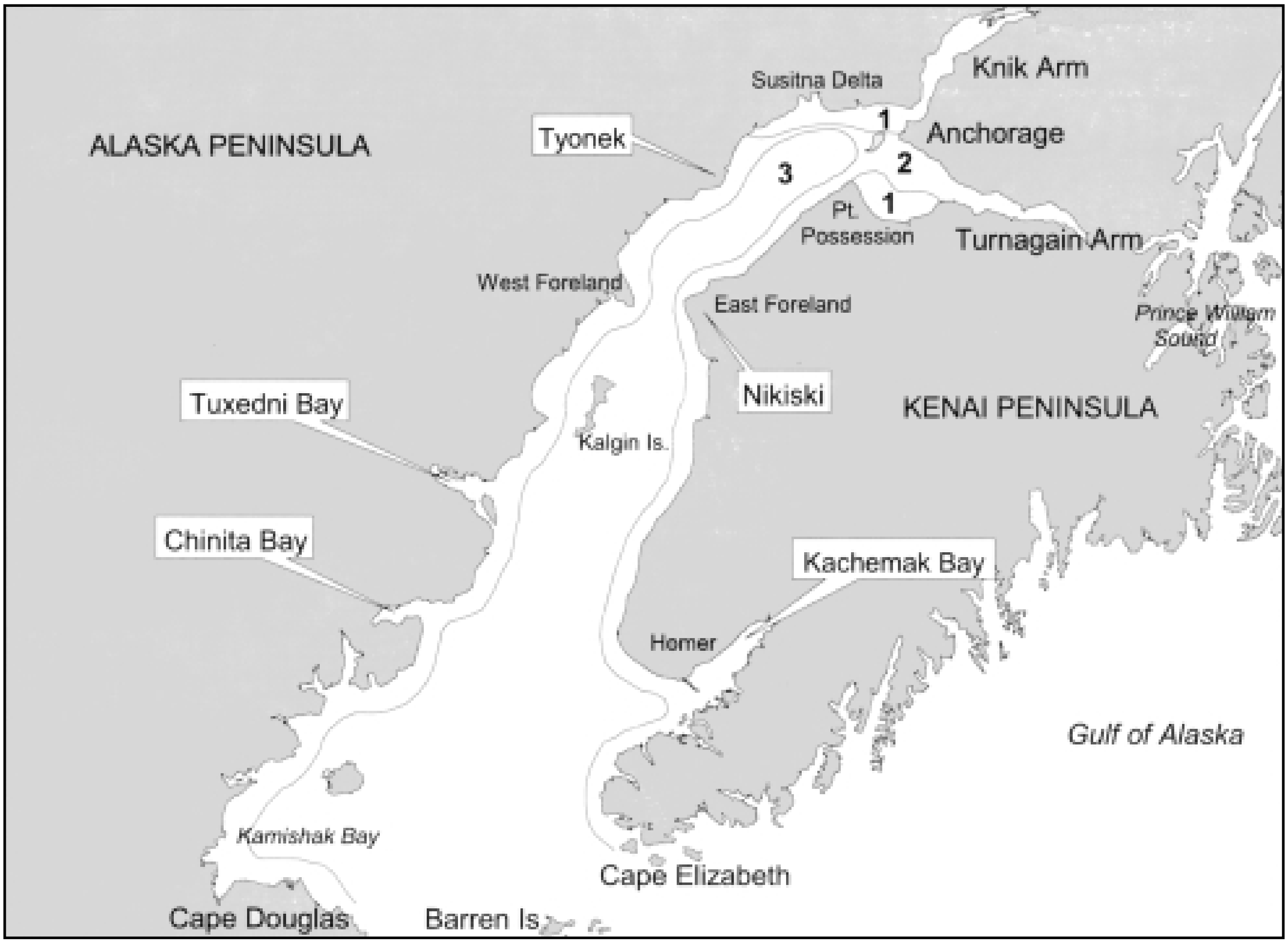

Figure 1.—Designation of three habitat regions based upon June and July distribution of belugas in Cook Inlet, Alaska; and place names mentioned in the text.

rence were defined, based upon whale distribution in June and July, and designated as Regions 1, 2, and 3, respectively (Fig. 1). Environmental information was summarized from published and unpublished data and a regional sampling survey carried out in the upper inlet in 1994 (Shelden and Angliss[2]).

Habitat associations are presented in three sections: 1) Physical Factors, including summaries of bathymetry and substrate; tides and current; salinity, turbidity, and temperature; tides and currents; natural catastrophic events (e.g. volcanoes, earthquakes, and fires), and ice cover associated with observed beluga distribution, 2) Biological Factors, including prey species and availability, predators, and natural mortality, and 3) Anthropogenic Factors, including fishing, oil and gas activities, transportation, and water quality.

Physical Factors

Cook Inlet is a semienclosed tidal estuary, extending roughly 370 km (200 n.mi.) southwest from Knik and Turnagain Arms to Kamishak and Kachemak Bays. The inlet has marine connections with Shelikof Strait and the Gulf of Alaska (GOA), and freshwater input from many large rivers (Muench et al., 1978). The shoreline of Cook Inlet is irregular, comprised of a series of channels, coves, flats, and marshes. To better characterize the estuarine environment used by Cook Inlet belugas, limited hydrographic and benthic sampling was conducted in June 1994, in the Susitna River delta during a beluga tagging study (Shelden and Angliss[2]). Measurements were taken opportunistically at sites close to beluga groups and at fixed stations (Fig. 2). Attempts were made to conduct repeat sampling at fixed stations at different times in the tidal cycle. Data collected during this short study supplement the section describing salinity, turbidity, and temperature.

Bathymetry and Substrate

Bathymetry of lower Cook Inlet (south of the Forelands) consists of an

[2] Shelden, K. E. W., and R. P. Angliss. 1995. Characterization of beluga whale (*Delphinapterus leucas*) habitat through oceanographic sampling of the Susitna River delta in Cook Inlet, Alaska, 11–18 June 1994. Int. Whal. Comm. Unpubl. Doc. SC/47/SM13, 10 p.

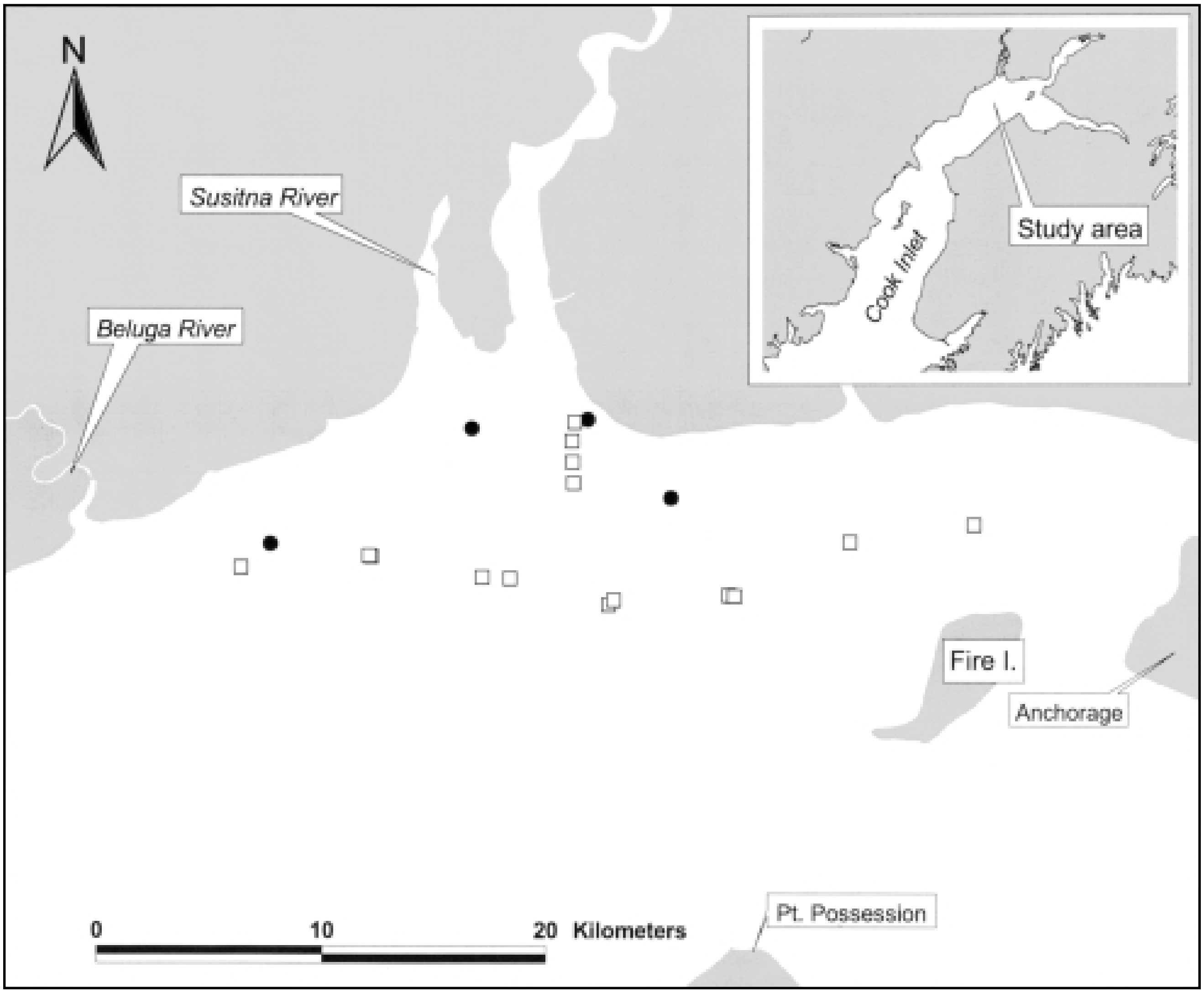

Figure 2.—Sites sampled for salinity and turbidity in upper Cook Inlet, June 1994. Dots are opportunistic sites, squares are fixed stations.

elongated trough (15–30 m deep) that bifurcates around Kalgin Island, with shallow platforms (≤10 m) on either side (Fig. 3). Northwest of Kalgin Island, a single narrow trough extends northwest mid inlet to about Trading Bay. South of Chinitna Bay, the main channel deepens to roughly 70–100 m and widens to extend across the mouth of Cook Inlet from Cape Douglas to Cape Elizabeth; it then slopes downward into Shelikof Strait. In contrast, the bathymetry of the inlet north of the Forelands is predominated by shallow river deltas.

Substrate in Cook Inlet is comprised of a mixture of cobbles, pebbles, sand, silt, and clay (Karlstrom, 1964). The inlet receives immense quantities of glacial sediment from the major rivers that empty into it (e.g. Knik, Matanuska, Susitna, Kenai, Kasilof, Beluga, McArthur, and Drift; Fig. 4). Rain and melting snow also contribute to the outflow of sediments. In addition, sediments of the Copper River drainage are carried into lower Cook Inlet and Shelikof Strait by the Alaska Coastal Current (ACC) (Schumacher et al., 1989). Longshore transport of sediment is generally into Cook Inlet, although this trend can be reversed by eddy features in Kamishak, Tuxedni, and Kachemak Bays. Sediment is then redistributed by intense tidal currents and often deposited on the extensive mud flats found in the upper inlet.

Salinity, Turbidity, and Temperature

Freshwater from rivers and land drainage, and seawater from the ACC, dominate the upper and lower portions of Cook Inlet, respectively. Salinity increases rapidly and almost uniformly from Anchorage to East and West Foreland (Fig. 4). During summer and autumn, salinity varies from about 26‰ at the Forelands to roughly 32‰ at the entrance to Cook Inlet (Gatto[3]). There

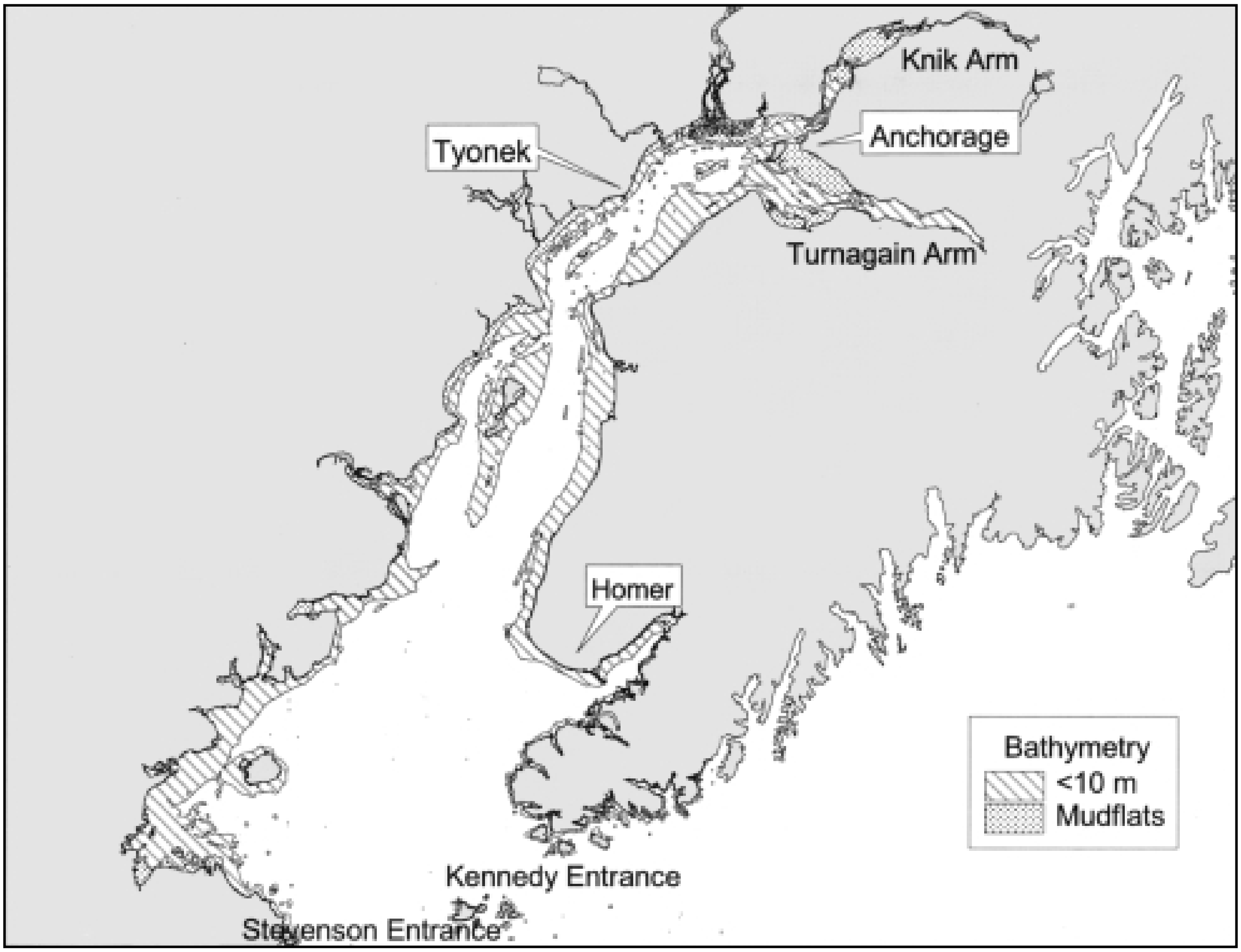

Figure 3.—Bathymetry of Cook Inlet, Alaska.

are characteristic isohalines (lines of equal salinity) resulting from high-salinity water on the eastern side and low-salinity water on the western side of Cook Inlet. In the lower inlet, isohaline contours vary with tidal currents, with local areas of depressed salinity near the mouths of large rivers and from glacially fed streams.

During our 1994 hydrographic study, beluga groups were generally found near river mouths in Regions 1 and 2 (Beluga, Susitna, and Little Susitna Rivers) where freshwater discharge and sediment loads strongly influence the hydrography. Samples obtained from stations close to beluga groups (which tended to be in water <3.5 m deep) had on average lower salinity and more suspended sediment than stations farther offshore (Fig. 5), similar to results obtained near the Port of Anchorage (Everts and Moore[4], USACE[5], Kinney et al.[6]). In June 1994, water temperatures were fairly uniform in nearshore and offshore waters of the upper inlet (Fig. 5). By July, temperatures in upper Cook Inlet usually warm to 14°–17°C (Bakus et al., 1979; USACE[5]) compared to the 8°–10°C sea surface temperatures at the mouth of the inlet and 11.5°–15°C in Kachemak Bay (Piatt, 1994).

Tides and Currents

Tides in Cook Inlet are semidiurnal, with two unequal high and low tides per tidal day (tidal day = 24 h 50 min). The mean diurnal tidal range varies from roughly 6 m (19 ft) at Homer to about 9.5 m (30 ft) at Anchorage. Three tidal rips (west, midchannel, and east)

[3] Gatto, L. W. 1976. Baseline data on the oceanography of Cook Inlet, Alaska. CRREL Rep. 76-25 prep. for NASA by U.S. Army Corps Engr., Cold Reg. Res. Engr. Lab., Hanover, N.H., 81 p.

[4] Everts, C. H., and H. E. Moore. 1976. Shoaling rates and related data from Knik Arm near Anchorage, Alaska. U.S. Army Corps Engr., Coast. Engr. Res. Cent., Fort Belvoir, Va., Tech. Pap. 76-1, 84 p.

[5] USACE (U.S. Army Corps Engr.). 1993. Deep draft navigation reconnaissance report: Cook Inlet, Alaska. Dep. Army, U.S. Army Engr. Dist., Anchorage, 120 p.

[6] Kinney, P. J., J. Groves, and D. K. Button. 1970. Cook Inlet environmental data, R/V *Acona* cruises 065, May 21–28, 1968. Univ. Alaska, Fairbanks, Inst. Mar. Sci., Rep. R-70-2, 122 p.

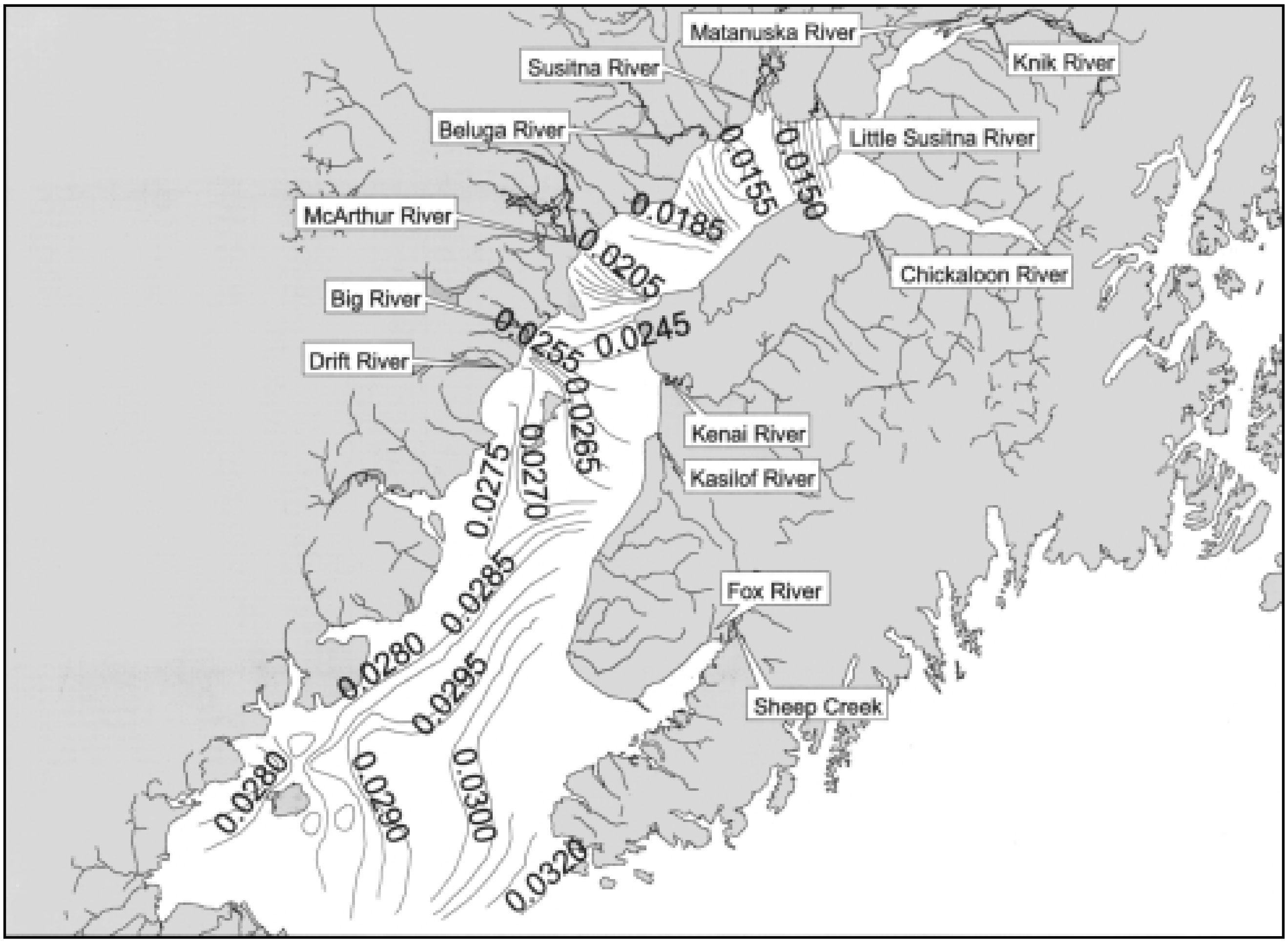

Figure 4.—Major rivers and salinity isohalines of Cook Inlet, Alaska.

are commonly observed east of Kalgin Island, extending south to about Chinitna Bay (Fig. 6) (Burbank, 1977). Tidal bores of up to 3.2 m (10 ft) occur in Turnagain Arm (Region 2). Surface circulation in upper Cook Inlet is driven by the mixing of incoming and outgoing tidewater combined with freshwater inputs (Fig. 6). A southward flow along western lower Cook Inlet is due to the Coriolis Force acting on freshwater entering the upper inlet from rivers.

Current velocities average about 3 kn but are locally influenced by shore configuration, bottom contour, and winds (USACE[5]). For example, currents may exceed 6.5 kn between East and West Forelands, and speeds of up to 12 kn have been reported near Kalgin Island. The tidal flats in upper Cook Inlet provide some protection from the strong currents that predominate in the central inlet. Lower Cook Inlet connects to the GOA through Kennedy and Stevenson Entrances and Shelikof Strait. The ACC flows along the inner shelf in the western GOA and flows northward along the eastern side of Cook Inlet. The relatively fresh turbid upper Cook Inlet outflow meets and mixes with incoming ACC water in the central inlet. This mixture flows along western Cook Inlet and outflows to Shelikof Strait.

Natural Catastrophic Events

Volcanoes

Five volcanoes along the western shore of Cook Inlet have erupted since the Holocene (10,000 years ago). These mountains are, from north to south, Spurr, Redoubt, Illiamna, Augustine, and Douglas. Three of these (Spurr, Redoubt, and Augustine) have erupted more than once during the 20th century (Riehle, 1985; Alaska Geographic, 1991). Floods generated by volcanic ejecta coming into contact with snow and ice on the volcano can impact any drainage on a volcano. Massive debris flows (consisting of several hundred million cubic feet of melted snow and glacial ice combined with sediment) that occurred during the 2 January and 15 February 1990 eruptions of Redoubt Volcano flooded the Drift River valley and damaged logistical support facilities at the Drift River Oil Terminal (Alaska Geographic, 1991). Potential hazards other than flooding are: debris avalanches, mudflows, lava flows, hot gas surges, and ashfall. Dozens of ashfall events were produced by Cook Inlet volcanoes in the

20th century, most of which were a few millimeters or less in thickness (Alaska Geographic, 1991; DNR[7]). The overall effect on fish spawning streams and rivers is not known.

Earthquakes

Active seismic zones beneath Mt. Illiamna, Mt. Douglas, and Mt. Augustine have produced clusters of deep earthquakes ranging from 5 to 6 on the Richter scale (Pulpan and Kienle, 1979). Since 1902, the Cook Inlet area has experienced over 100 earthquakes of magnitude 6 or greater (Hampton, 1982). The second largest earthquake ever recorded, magnitude 9.2 and centered 10 km east of College Fiord in Prince William Sound, resulted in landmass subsidence along much of the east coast of Cook Inlet (Noerenberg, 1971). Subsidence in the Portage area of Turnagain Arm allowed high tides to extend about 2 mi farther upstream resulting in considerable loss of fish spawning habitat (Noerenberg, 1971). Mud deposits and silting covered Pacific salmon, *Oncorhynchus* spp.; trout, *Salmo* spp.; and smelt (Osmeridae), spawning areas along streams on the south side of Turnagain Arm and pink salmon habitat in the Chickaloon River. Minor damage to intertidal spawning streams was observed between the Knik River and Bird Creek. Dewatering and loss of freshwater habitat occurred at Ship Creek near Anchorage which stopped flowing for 18 h and farther south in Cook Inlet at the Kasilof River which slowed to a trickle. The Susitna River experienced landslides but tributaries and streams were not blocked. Some loss of intertidal Pacific salmon spawning habitat also occurred in streams in Kachemak Bay.

Fires

Fire statistics for 1990 through 1998 for the Anchorage/Matanuska-Susitna (Anc/Mat-Su) region and the Kenai/Kodiak region are summarized in Table 1. The largest fires, in terms of acres burned, occurred adjacent to both the upper (Anc/Mat-Su) and lower (Kenai/Kodiak) portions of Cook Inlet in 1996. Only 3 incidents of fire were reported in the Cook Inlet Keeper (CIK[8]) database which contains information from 1990 through 1997. Fires that occur in watersheds can cause increased runoff. Debris from this runoff could cover gravel spawning beds of salmon. Decreased shading along stream banks resulting from fire may expose adult salmon to greater numbers of predators. Overall, the ramifications of fire may cause decreased Pacific salmon numbers in the short term.

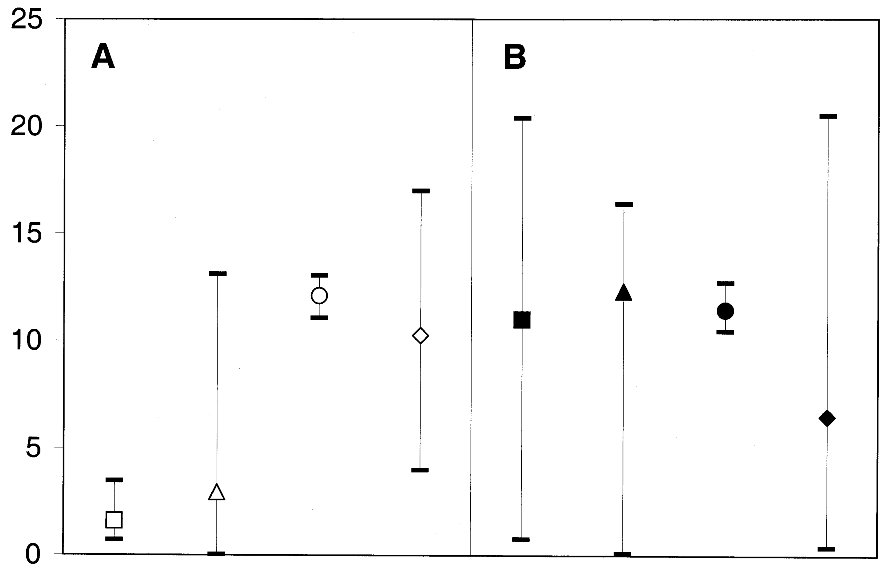

Figure 5.—Comparison of results from hydrographic sampling of nearshore areas occupied by belugas (A: open symbols) to offshore sites (B: closed symbols). Error bars indicate minimum and maximum readings for water depth (m) (squares), salinity (ppt) (triangles), temperature (°C) (circles), and turbidity (mg/l × 10) (diamonds).

Table 1.—Summary of fire statistics for the Anchorage/Matanuska-Susitna and the Kenai/Kodiak regions. Source: State of Alaska, Division of Forestry website [http://www.dnr.state.ak.us/forestry/] accessed 12 February 2000.

	Anc/Mat-Su Region		Kenai/Kodiak Region	
Year	No. of fires	Acres burned	No. of fires	Acres burned
1990	96	55.0	55	135.0
1991	116	1,267.4	47	7,930.1
1992	111	155.3	94	205.0
1993	121	164.7	94	42.5
1994	95	36.2	69	3,818.0
1995	90	163.1	50	411.8
1996	186	37,781.0	101	28,219.7
1997	149	155.9	80	14,246.5
1998	77	52.9	33	19.3

Ice Cover

Sea ice generally forms in October–November, reaches its maximum extent in February (generally from West Foreland to Cape Douglas), then recedes and melts in March–April (Fig. 7) (Mulherin et al., 2001). Ice formation in upper Cook Inlet is driven by air temperature, while the air/water temperature and inflow rate of the ACC influence sea-ice formation in the lower inlet (Poole and Hufford, 1982). Tidal action and tidal currents often shatter sea ice

[7] DNR. 1999. Cook Inlet areawide 1999 oil and gas lease sale: final finding of the director, vol. I. Alaska Dep. Nat. Resour., Div. Oil Gas, Anchorage, v.p.

[8] The Cook Inlet GIS Atlas with annotated bibliography and watershed directory is available on CD from Cook Inlet Keeper, P.O. Box 3269, Homer, AK 99603 [e-mail: keeper@xyz.net or website: www.xyz.net/~keeper].

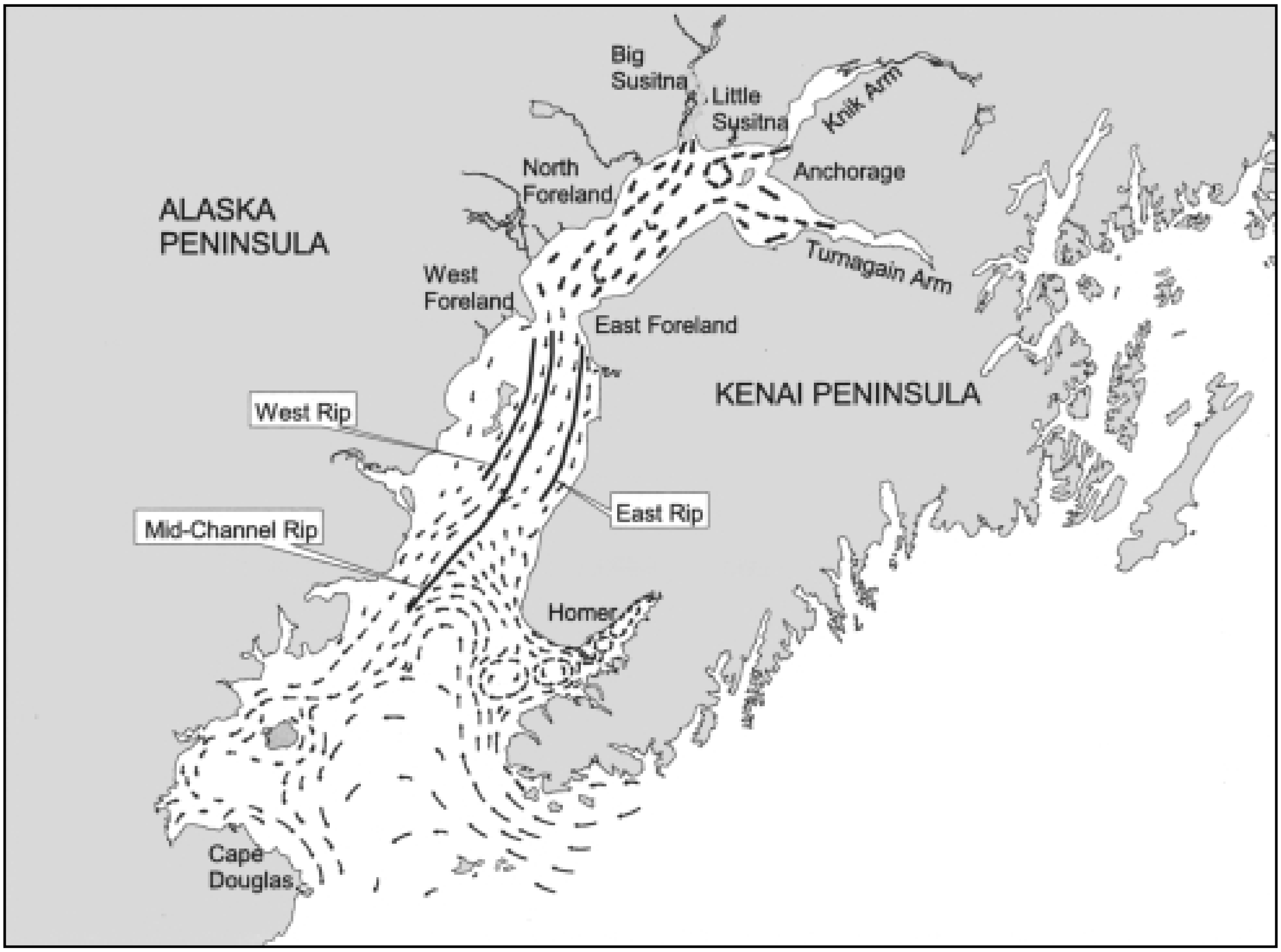

Figure 6.—Surface circulation including tidal rips in Cook Inlet, Alaska.

in Cook Inlet to the extent that there is seldom uniform cover.

Potential Effects on Belugas

There are no clear correlations between any single physical factor and beluga distribution in Cook Inlet. Tides and resulting water depths and temperature may influence beluga distribution near the river deltas. Much of the literature on belugas and their use of coastal estuaries focuses on the movement of these animals relative to tides (summarized in Kleinenberg et al., 1964). Where water levels fluctuate markedly, inshore migrations primarily occur during high tide. In Russian waters, belugas migrate along the shore during the high spring tides (Kleinenberg et al., 1964), with movement into rivers driven by prey availability (see section on Prey Variability). In Canadian waters (i.e. Nastapoka Estuary), herd position was also found to correlate with tide (Caron and Smith, 1990). Beluga groups moved into the upper reaches of the estuary during flood tide and departed during ebb tide. Similar movement patterns have been observed in Cook Inlet. Traditional knowledge and beluga whale hunting techniques suggest that these patterns have changed little since prehistoric times (Huntington, 2000; Mahoney and Shelden, 2000).

The temperature range in Cook Inlet is similar to that reported for other estuaries used by belugas. For example, beluga studies conducted in Canadian estuaries reported water temperatures from 10° to 18°C, while surrounding waters registered from 0° to 7°C (Finley et al., 1982; Hansen, 1987). While belugas in Cook Inlet appear to favor warm, turbid, low-salinity waters in summer, studies in other areas suggest that belugas are as likely to be found in clear water estuaries as in turbid habitats (Bel'kovich and Shchekotov, 1990; Caron and Smith, 1990; Smith et al., 1994). However, clear water estuaries in the lower inlet (such as Kachemak Bay) are now rarely occupied by belugas during the summer months (Rugh et al., 2000). One study conducted in the Churchill River estuary of Hudson Bay, Canada, found no significant correlation between beluga abundance and turbidity; however, water temperature affected both beluga abundance and distribution (Hansen, 1987).

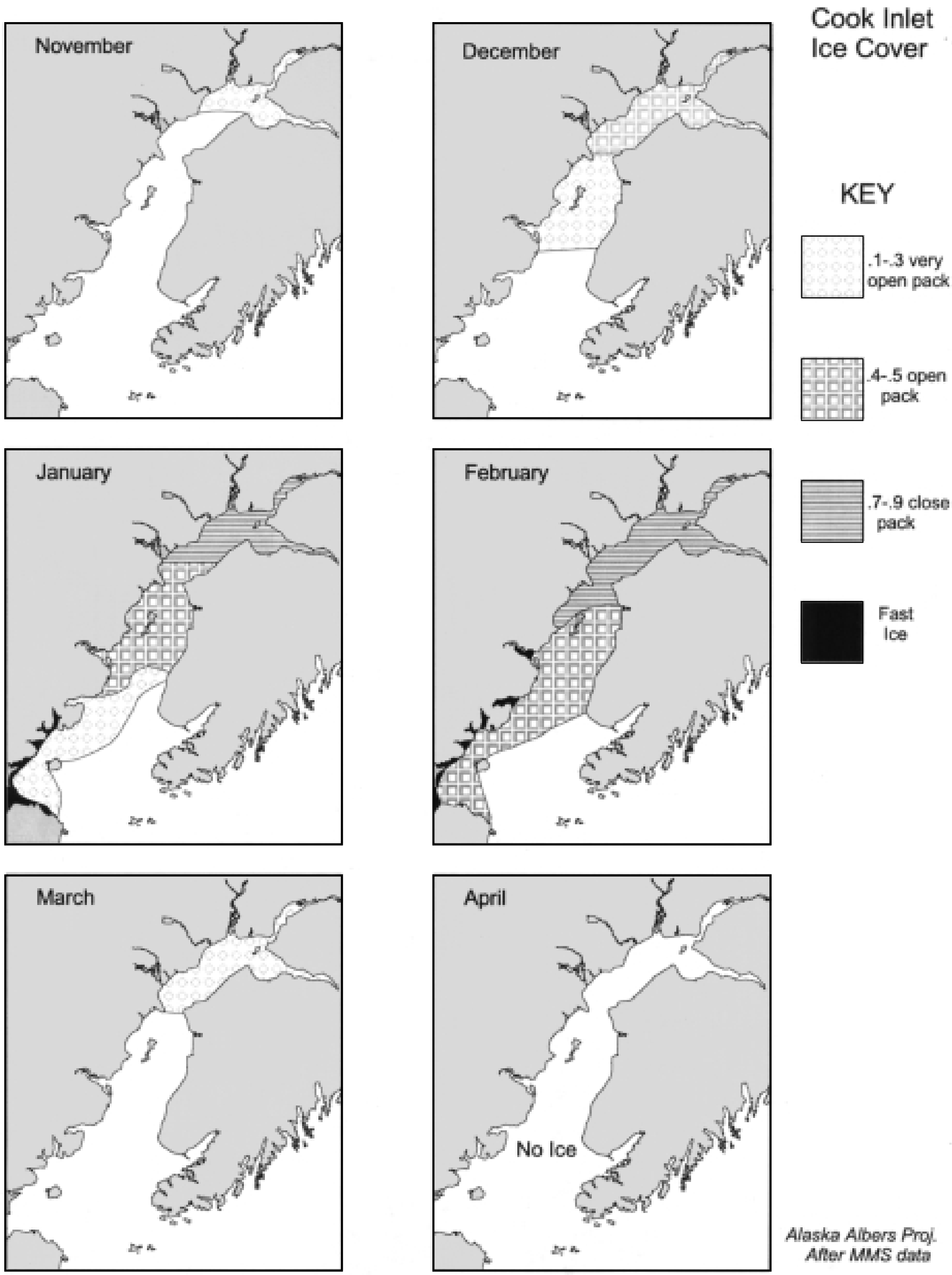

Figure 7.—Seasonal extent of sea ice in Cook Inlet, Alaska (from MMS[20]).

The blubber layer of newborn belugas can be ten times thinner than that of an adult (Kleinenberg et al., 1964). Adults with calves are present in Cook Inlet during summer and it is possible that the warmer water reduces thermal stress to newborns (Hansen, 1987), and facilitates the molt of the thick, horny layer of skin they are born with (Watts et al., 1991). Warmer water may also provide a thermal advantage to adults undergoing seasonal molt (Watts et al., 1991). Yellowing skin is a characteristic of this epidermal molt (St. Aubin et al., 1990), and Alaska Natives in Cook Inlet reported that old belugas are yellow (Huntington, 2000). As belugas enter warmer water, epidermal growth is stimulated and older, rough skin is shed. Thus water temperature, and by association salinity, may play a role in habitat selection of belugas during summer months.

In northern Cook Inlet, belugas have been seen in open leads and in 40–60% ice cover in winter (Hansen and Hubbard, 1999), suggesting that ice cover is not a limiting factor to their distribution. From habitat associations in the Beaufort Sea (Moore, 2000; Moore et al., 2000) and elsewhere, it is clear that belugas are an ice-adapted species capable of transiting vast areas nearly covered by sea ice (e.g. Suydam et al., 2000).

As discussed in the next section, occupation of coastal areas, particularly near river mouths, seems more likely driven by prey availability than specific hydrographic conditions. Elsewhere, large beluga herds have been reported associated with large prey aggregations in comparatively small feeding areas (Bel'kovich, 1960; Welch et al., 1993). Thus, in Cook Inlet, physical factors may influence beluga assemblages indirectly by affecting the distribution of prey, or directly only in terms of tides, currents and resultant water depth and temperature.

Biological Factors

Prey Species and Availability

Although the diet of belugas in Cook Inlet is largely unknown, elsewhere belugas prey on a wide variety of fish, crustaceans, and cephalopods (Seaman et al., 1982). Cook Inlet is host to a wide range of fish species, including year-round residents and many anadromous species that return seasonally to spawn in rivers. Alaska Natives have expressed concern over reports of declining fish runs and the potential negative impact this may have on the Cook Inlet beluga population (Huntington, 2000). However, determining the prey available to belugas is a complex task that has yet to be accomplished, both because fish run data are assimilated for purposes unrelated to beluga research and because not all potential prey species are counted. The data available for review tell an equivocal story.

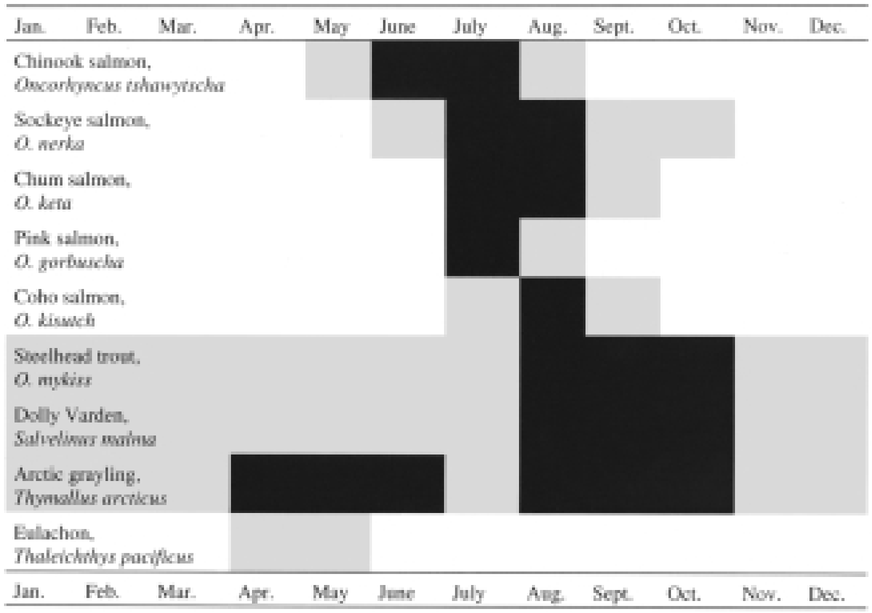

Figure 8.—Approximate timing of the presence (gray shading) and peak availability (black shading) of fish species entering fresh water drainages in upper Cook Inlet (from AOJ[9]).

The fish fauna of upper Cook Inlet is primarily characterized by the spring to fall availability of migratory eulachon, *Thaleichthys pacificus*, outmigrating Pacific salmon smolt, and returning adult Pacific salmon (Fig. 8, also see AOJ[9]). Moulton (1997) documented 18 fish species in upper Cook Inlet (Table 2) and noted that species abundance and distribution vary greatly throughout the summer. Since 1990, commercial fisheries for sockeye salmon, as well as sport fisheries for chinook and coho salmon, have reported declines in a number of fish runs in upper Cook Inlet (Rutz and Sweet, 2000; ADFG[10]). Interannual fluctuations in escapement counts for coho, pink, chum, and sock-

Table 2.—Fish species found in upper Cook Inlet, Alaska, June–September 1993 (Moulton, 1997). Species are listed from most to least abundant based on catch data.

Common name	Scientific name
Threespine stickleback	*Gasterosteus aculeatus*
Pacific herring	*Clupea pallasi*
Pink (humpback) salmon	*Oncorhynchus gorbuscha*
Eulachon (candlefish, hooligan)	*Thaleichthys pacificus*
Chum (dog) salmon	*Oncorhynchus keta*
Walleye pollock	*Theragra chalcogramma*
Longfin smelt	*Spirinchus thaleichthys*
Saffron cod	*Eleginus gracilis*
Chinook (king) salmon	*Oncorhynchus tshawytscha*
Sockeye (red) salmon	*Oncorhynchus nerka*
Coho (silver) salmon	*Oncorhynchus kisutch*
Arctic lamprey	*Lampetra japonica*
Pacific sandfish	*Trichodon trichodon*
Pacific sand lance	*Ammodytes hexapterus*
Snake prickleback	*Lumpenus sagitta*
Capelin	*Mallotus villosus*
Starry flounder	*Platichthys stellatus*
Ninespine stickleback	*Pungitius pungitius*

[9] Data on fish run timing obtained from the Alaska Outdoor Journal (AOJ) website [http://www.alaskaoutdoorjournal.com/References/matsutime.html] and the Alaska Dep. Fish and Game website [http://www.state.ak.us/adfg/sportf/geninfo/runtim/runtim.htm], 26 February 1999.

[10] Data obtained from Alaska Dep. of Fish and Game websites for commercial fisheries [http://www.cf.adfg.state.ak.us/region2/ucihome.htm] and sport fisheries [http://www.state.ak.us/adfg/sportf/region2/projnci.htm], 4 November 1999.

eye salmon at the Yentna River and chinook at the Deshka River of the Susitna River drainage occurred between 1993 and 1998 (Fig. 9). However, on a decadal scale there appeared to be no overall change in sockeye escapements (Fig. 10a) for the Susitna River drainage, though chinook (Fig. 10a), pink (Fig. 10b), and chum salmon (Fig. 10c) appeared to decline, and coho appeared to increase (Fig. 10c) from the 1980's to the 1990's.

These data are difficult to interpret with reference to prey available to belugas, both because changes in commercial and sport fishing patterns may be masking trends in salmon escapement, and the status of salmon stocks is so variable from drainage to drainage. In addition, some of the recent salmon stock declines may be due to flood-related mortality, northern pike, *Esox lucius*, predation on juvenile salmon, and poaching (Rutz and Sweet, 2000). Additional concerns for salmon stocks in the upper inlet include: urbanization, stream bank erosion caused by foot traffic and power boats, litter accumulation, and proposed timber sales and logging activity near juvenile salmon rearing habitat (Rutz and Sweet, 2000).

Lower Cook Inlet supports a diverse fish community, with 50 different species identified in Kachemak Bay and 24 species for waters near Chisik Island (Robards et al., 1999). Notably, the Kachemak Bay fish community changed significantly between 1976 and 1996 (Robards et al., 1999), coincident with a large-scale climate change (also called regime shift) in the North Pacific in the late 1970's (Francis et al., 1998; Anderson and Piatt, 1999). There has been a noticeable decline in marine species in this region resulting in the closure of commercial fisheries for shrimp, *Pandalus* sp., and king crab, *Paralithodes camtschatica*, and artificial enhancement of Pacific salmon runs (Alaska Geographic, 1994; Bechtol, 1997; Kruse, 1998), while other species such as walleye pollock, *Theragra chalcogramma*, have dramatically increased (Bechtol, 1997).

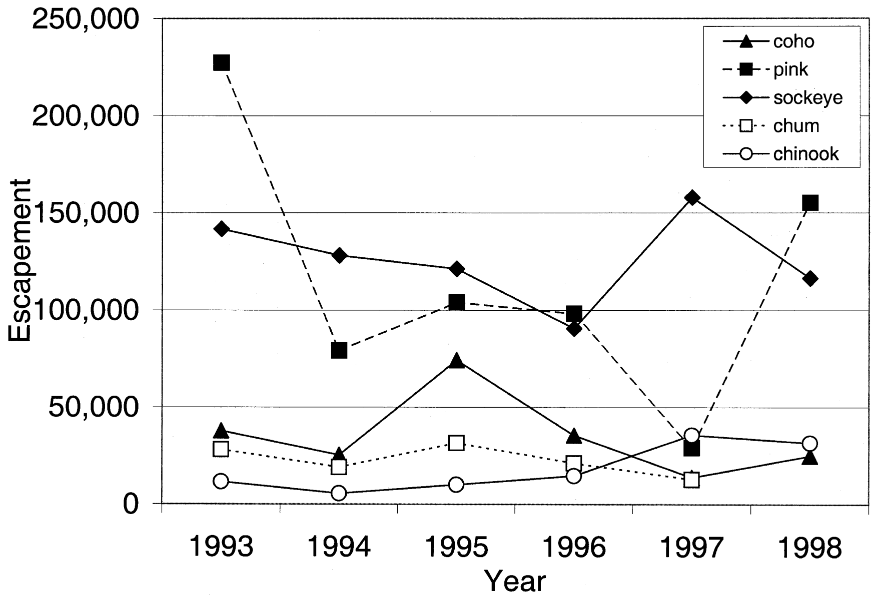

Figure 9.—Annual salmon escapement for the Yentna (coho (▲), pink (■), sockeye (◆), and chum (□)) and Deshka Rivers (chinook (○)), 1993–98 (from Davis (1998) and Fried (1999)). These rivers are main tributaries of the Susitna River complex. Yentna counts were obtained using side-scanning sonar and Deshka counts were obtained using aerial surveys and weirs.

Predators

Killer whales, *Orcinus orca*, sometimes prey on belugas in Cook Inlet, although the extent of predation is unknown (Morris[11]). There are only four confirmed (and one unconfirmed) reports of killer whales in upper Cook Inlet since 1988, although these opportunistic sightings probably underrepresent actual killer whale occurrence. In May 1991, a pod of six killer whales (2 males, 3 females, 1 juvenile) were stranded at low tide near Girdwood in Turnagain Arm (NMFS[12]). On 20 June of that same year, a dead beluga was found with teeth marks and a piece of its tail missing (Table 3). In August 1993, a pod of five killer whales, including a male that later died, stranded at Bird Point, Turnagain Arm. This male regurgitated beluga whale parts before dying (NMFS unpubl. data). In June 1994, there was an unconfirmed report of "killer whales in the area" when a group of roughly 190 belugas stranded during a low tide at the mouth of the Susitna River (Table 3).

[11] Morris, B. F. 1988. Cook Inlet beluga whales. Unpubl. rep. on file at NMFS Alaska Reg. Off., Anchorage, 34 p.

[12] NMFS. 1992. Status report on Cook Inlet belugas (*Delphinapterus leucas*). Unpubl. rep., 22 p., on file at Alaska Reg. Off., Natl. Mar. Fish. Serv., 222 W. 7th Ave. #43, Anchorage, AK 99513.

On 29 August 1999 at least three killer whales were seen chasing belugas just south of Bird Point roughly 2 h before about 60 belugas stranded there (NMFS unpubl. data). In late September 2000, 3–5 killer whales were seen near Bird Point and at Peterson Creek in Turnagain Arm. They killed (but did not eat) at least two lactating belugas and may have consumed their calves. Frequent sightings of killer whales in lower Cook Inlet, in Shelikof Strait, and along the south side of the Kenai Peninsula to Prince William Sound (Dahlheim, 1997) suggest the potential for predation there may be somewhat higher.

Natural Mortality

Stranding records for belugas in Cook Inlet include animals that presumably died of natural causes and those that were released alive on the incoming tide (Table 3), as well as animals taken by Alaska Native hunters (Mahoney and Shelden, 2000). The stranding reports are opportunistic and therefore do not necessarily represent the actual number of occurrences.

Belugas sometimes strand during low tide cycles in upper Cook Inlet, possibly

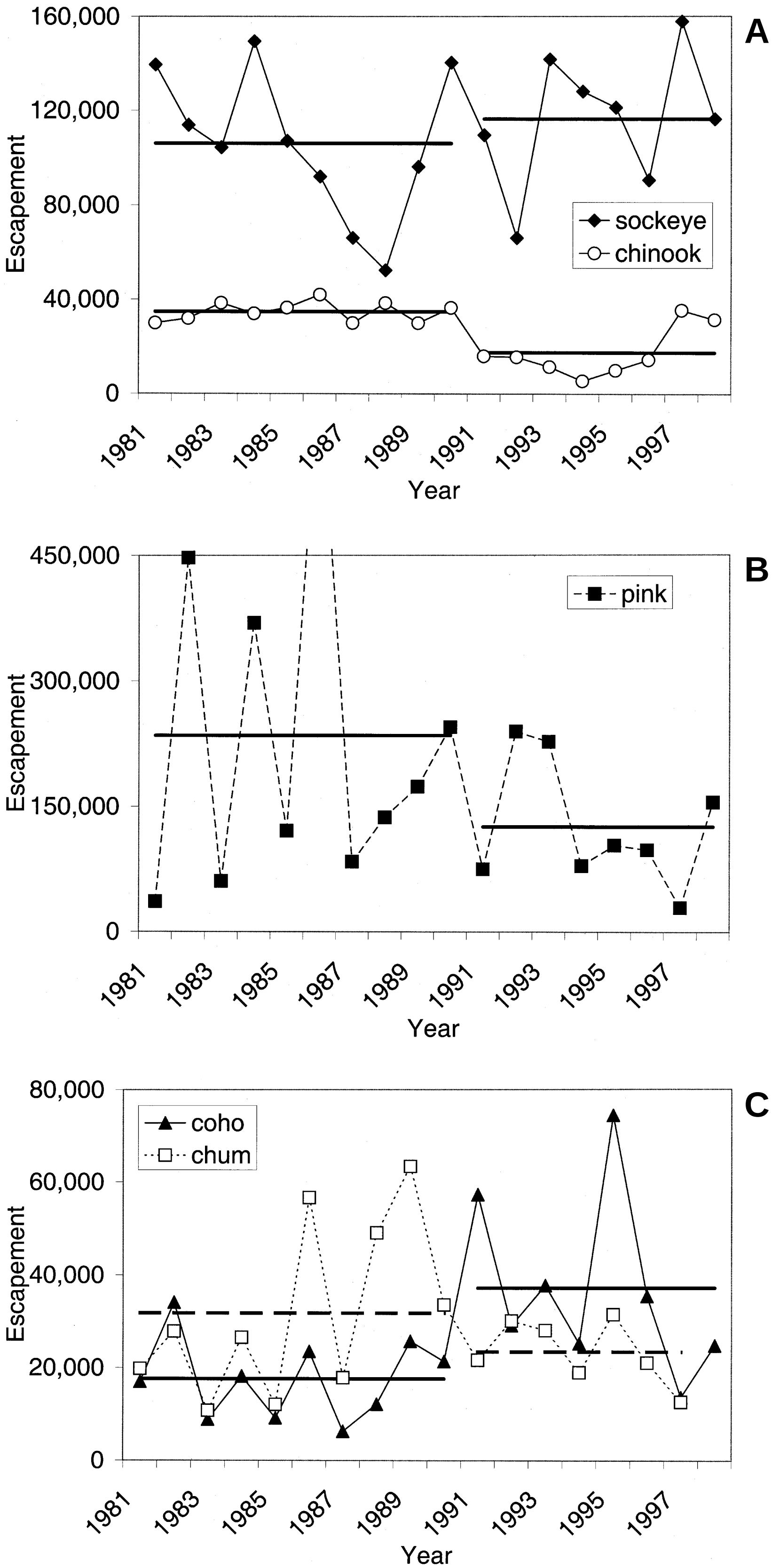

Figure 10.—Annual escapement of: a) sockeye (◆) and chinook (○), b) pink (■), and c) coho (▲) and chum (□) salmon for tributaries of the Susitna River, 1981–98 (Davis, 1998; Fried, 1999). Sockeye, pink, coho, and chum counts were obtained using side-scanning sonar and chinook counts were obtained using aerial surveys and weirs.

while avoiding predators or when following prey upriver. Most strandings are of single whales, although live groups of 10–190 individuals have been reported (Table 3). There is no evidence that strandings are the result of viral or parasitic infections. However, in a few cases deaths have occurred, possibly from the stress of stranding in combination with such an infection (Table 3; Burek-Huntington[13]). While most strandings do not result in mortality, it is important to note that there is the potential for a single event to result in the death of a significant proportion of this relatively small stock.

Potential Effects on Belugas

Prey availability likely has the strongest influence on the distribution and relative abundance of belugas in Cook Inlet. The patterns and timing of eulachon and salmon runs seems to affect beluga feeding behavior. Belugas routinely group near the Susitna River Delta in early summer (Rugh et al., 2000). Alaska Natives report that the whales feed there on migrating fish, predominantly eulachon and salmon (Huntington, 2000), which have been identified in stomach contents of harvested whales (NMFS unpubl. data). Feeding strategies are similar to those displayed in other regions. In environments equivalent to the Susitna Delta, belugas hunting salmon formed large compact groups ranging from tens to hundreds of individuals (Bel'kovitch and Shchekotov, 1990). Such group formations have been observed in the east and west tributaries of the Susitna River and in the mouths of the Little Susitna River and the Beluga River (Rugh et al., 2000).

[13] Burek-Huntington, K. 2000. Summary of lesions from beluga whale cases submitted to AVPS [Alaska Veterinary Pathology Services] in 1998 and 1999. Unpubl. rep. for Alaska Reg. Off., Natl. Mar. Fish. Serv., 222 W. 7th Ave. #43, Anchorage, AK 99513, 6 p.

Table 3.—Summary of beluga whale strandings in Cook Inlet, Alaska 1988-2000 (does not include animals killed during subsistence harvests). Animals were alive at time of stranding unless noted otherwise.

Date	Vital statistics	Location
1988		
23 Oct.	Group of 27 comprised of 3 calves, 4 yearlings, 20 adults. Released with the incoming tide.	Turnagain Arm, Girdwood.
1989		
1 Sept.	Dead female, length 360 cm.	Anchorage, Earthquake Park.
12 Sept.	Dead male, length 425 cm.	Anchorage, Campbell Creek.
1990		
18 May	Dead whale, unidentified sex, length 8′10″. Knife marks.	Anchorage, Point Woronzof.
15 June	Dead whale, unidentified sex, length ~12′.	Shirleyville.
1991		
20 June	Dead whale, unidentified sex, length 6′-6.5′. A chunk of the tail missing, orca teeth marks evident.	Turnagain Arm, MP 110.5 on Seward Highway.
31 Aug.	Group of 70-80 whales. Released with the incoming tide.	Turnagain Arm, near Twentymile.
1992		
2 June	Skeleton.	Little Susitna River.
2 Sept.	Dead male, length 14′2″.	Turnagain Arm, Potters Marsh.
6 Oct.	2 dead males, lengths 150″ and 162″. Both found sick and dying.	Kenai River, ~2 miles north.
1993		
6 July	Two groups comprised of 5 and 5+ whales. Released with the incoming tide.	Hope, MP 13 on Hope Road.
1994		
5 June	Dead female, length 348 cm.	Anchorage, ~2 miles north of Campbell Creek.
14 June	Group of ~190 released with the incoming tide. Reports of killer whales in the area.	Susitna River mouth.
10 Aug.	Dead male, length 14′8″.	Little Susitna River mouth.
19 Aug.	Skeleton.	Ivan River, north.
13 Sept.	Dead male, length 364 cm (headless).	Turnagain Arm, Bayshore.
15 Sept.	Dead male, length 474 cm.	Knik Arm, Birchwood.
23 Sept.	No data.	Nikiski, Unocal dock.
12 Oct.	Dead male, length 478 cm.	Kalifornsky Beach, Kasilof River
1995		
21 July	Dead female, length 293 cm.	Kenai River, ~ 2 miles north.
14 Aug.	No data.	Shirleyville.
13 Sept.	Dead female, length ~120″. No flukes.	Eagle River Flats, south.
31 Oct.	Grayish-white.	Nikiski, OSK Dock.
1996		
12 June	Group of 63 comprised of 24 gray and 39 white whales. Released with the incoming tide.	Susitna River, East Fork.
13 July	No data.	Little Susitna River, ~2 mi. west.
1 Aug.	Dead whale, unidentified sex, length 144″.	Susitna River, ~1 km south.
2 Aug.	Dead male, length 412 cm. Wound on dorsal.	Turnagain Arm, Bayshore.
13 Aug.	Dead whale, unidentified sex, length 155 cm.	Turnagain Arm, MP 2.3 on Coastal Trail.
28 Aug.	Group of 60 released with the incoming tide. Four dead whales included 2 males, lengths 376 cm and 438 cm, and 2 females, lengths 410 cm and 413 cm.	Turnagain Arm, Bird Point.
2 Sept.	Group of 20-30 released with the incoming tide, 1 died.	Turnagain Arm, north of Bird Point.
8 Sept.	Released with the incoming tide.	Knik Arm, ~MP 14 on Knik-Goose Bay Road.
19 Sept.	Dead whale, unidentified sex, length 144″.	Kenai, Salamantof Beach.
2 Oct.	Group of 10-20 released with the incoming tide.	Turnagain Arm, Indian Creek.
24 Oct.	Dead whale, unidentified sex, length 364 cm.	Anchorage, Ship Creek.
25 Oct.	Skeleton. Length ~150″.	Anchor Point.
1997		
? June	No data.	Anchorage boat ramp.
4 June	Dead female, length 350 cm.	Turnagain Arm, Bayshore.
27 Aug.	No data.	Anchorage city dock.
1998		
9 Apr.	Dead male, length 254 cm, ~2 years old. Pneumonia was diagnosed.	Turnagain Arm, ~3 miles south of Girdwood.
14 May	Group of 30 comprised of ~12 gray and 18 white whales. Released with incoming tide.	Turnagain Arm, ~6 miles east of Hope.
22 May	Dead male, length 14′4″.	Susitna River, East Fork.
8 June	No data.	Ninilchik, ~4 miles offshore.
13 June	No data.	Cook Inlet, off Chinitna Bay.
15 June	No data.	Lewis River
16 June	No data.	Susitna River, Big Island.
28 July	Dead male, length 11′2″. Total reported strandings for entire Island was 6 from April through July.	Fire Island, NE.
11 Aug.	Dead male, length 11′8″.	Fire Island, SW.
7 Sept.	Group of 5 whales. Released with incoming tide.	Turnagain Arm, between Hope and Beluga Point.
9 Sept.	Dead male, length 366 cm.	Turnagain Arm, Placer River.

Continued on next page.

Table 3.—Continued.

Date	Vital statistics	Location
1999		
7 July	Dead whale, unidentified sex, 191 cm.	Chuitna River, Tyonek
15 July	Dead calves (2), unidentified sex.	Fire Island, W.
26 July	Dead calf (no teeth in jawbone), unidentified sex.	Fire Island, Race Point.
25 Aug.	Dead whale, unidentified sex.	Knik Arm, Settlers Bay.
29 Aug.	Group of about 60 whales released with incoming tide. About 5 died. Killer whales seen chasing belugas 2 h prior to stranding.	Turnagain Arm, MP 100.
9 Sept.	Group of 12–13 whales released with incoming tide.	Rainbow, near Seward Hwy.
11 Sept.	Dead whale, very decomposed, 135 cm.	Turnagain Arm, near Shore Dr.
18 Sept.	Dead whale, very decomposed, 150 cm.	Turnagain Arm, N.
2000		
early April	Skeleton.	Ninilchik.
29 May	Dead whale, unidentified sex, gray color.	Point Possession.
4 June	Dead whale, unidentified sex, length 10′.	Point Possession, N. Miller Creek.
12 June	Dead male, length 437 cm.	Point Possession.
19 June	Dead male, length 242 cm.	Point Possession, Coast Guard Light.
24 June	Dead male, length 335 cm.	Knik Arm, Port of Anchorage.
23 July	Dead male, length 67 in.	Turnagain Arm, Point Campbell.
24 July	No data.	Little Susitna River, halfway between the mouth and powerlines.
11 Aug.	Dead whale, unidentified sex, length 172 cm.	Chuitna River.
27 Aug.	Group of 8 comprised of 7 adults and 1 calf. Released with incoming tide.	Turnagain Arm, 5 mi. E. of Beluga Point
1st week Sept.	Dead whale, unidentified sex. Chunks of blubber and meat missing from belly, possible orca teeth marks.	Nikiski, Unocal loading dock.
17 Sept.	Dead female, young, length 180 cm, 200 lbs.	Turnagain Arm, Peterson Creek.
25 Sept.	Dead female, lactating, length 375 cm. Orca predation.	Turnagain Arm, Indian Creek.
26 Sept.	Dead female, lactating, length 364 cm. Orca predation.	Turnagain Arm, Bird Creek.
24 Oct.	Group of 2 whales released with incoming tide.	Turnagain Arm, McCue Creek

Dispersal of the large groups of whales is usually not observed until later in the summer (Rugh et al., 2000; Calkins[1]). Dense concentrations of salmon and eulachon in early June, followed by the availability of more dispersed species later in the summer (Moulton, 1997), may account for this change in beluga group size and composition. The paucity of beluga sightings in lower Cook Inlet in the 1990's (Rugh et al., 2000) relative to the 1970's (Calkins[1]) leads to speculation that belugas no longer find preferred prey in the lower inlet (Speckman and Piatt, 2000). However, the impact on Cook Inlet belugas of a changing fish community may be difficult to quantify because the beluga diet is flexible and changes with season, location, sex, and age (Seaman et al., 1982; Stewart and Stewart, 1989).

To date, there has been no coordination between biologists counting fish runs (and thereby estimating the availability of some beluga prey) and those conducting surveys for belugas in Cook Inlet. Fish run counts are conducted to answer fishery-related questions, which limits the interpretation of available data regarding the influence of prey availability on beluga occurrence. Coordinated research is needed to correlate beluga occurrence and distribution to prey availability. The majority of beluga stranding events likely result from pursuing prey into the shallows in the upper inlet, while a few may occur when belugas attempt to evade killer whales or other potential threats (Huntington, 2000) or when a whale is ill.

Anthropogenic Factors

Fishing

The Cook Inlet area supports recreational, commercial, subsistence, and personal use fisheries (ADFG[14]). All of these fisheries are subject to regulations under Title 5 of the Alaska Administrative Code. In Cook Inlet, recreational fishing generally occurs within river drainages and is usually limited to unbaited, single hook or artificial lures depending on location and species fished. Commercial fishing occurs in Region 1 and 2 (Fig. 1) north of the Forelands in upper Cook Inlet (the Northern District commercial fishery), in Region 2 and 3 in the central inlet between the Forelands and Anchor Point (the Central District), and in Region 2 and 3 in the Kamishak Bay District (waters west of long. 152°20.00′ W and north of Cape Douglas) and the Southern District (waters east of long. 152°20.00′ W and north of Elizabeth Island).

The Northern District is made up of 5 individual set gillnet fisheries while the Central District includes both set gillnet and drift net fisheries (Fig. 11). The Southern and Kamishak Bay Districts allow the use of purse seines, hand purse seines, and beach seines. Set gillnets can also be used in the Southern District in specific locations along the south shore of Kachemak Bay between Halibut Cove and Port Graham. All four districts allow the use of groundfish gear (including pelagic trawls, hand troll gear, longlines, pots, and mechanical jigging machines) but regulate gear type by location and species fished.

Subsistence fishermen may harvest finfish (other than Pacific salmon, and rainbow and steelhead trout, *Oncorhynchus mykiss*) at any time in any area of the state by any method unless restricted by the subsistence fishing regulations under Title 5. Cook Inlet fishing seasons

[14] Data obtained from the Alaska Dep. Fish Game website, 25 August 2000 [http://www.cf.adfg.state.ak.us/].

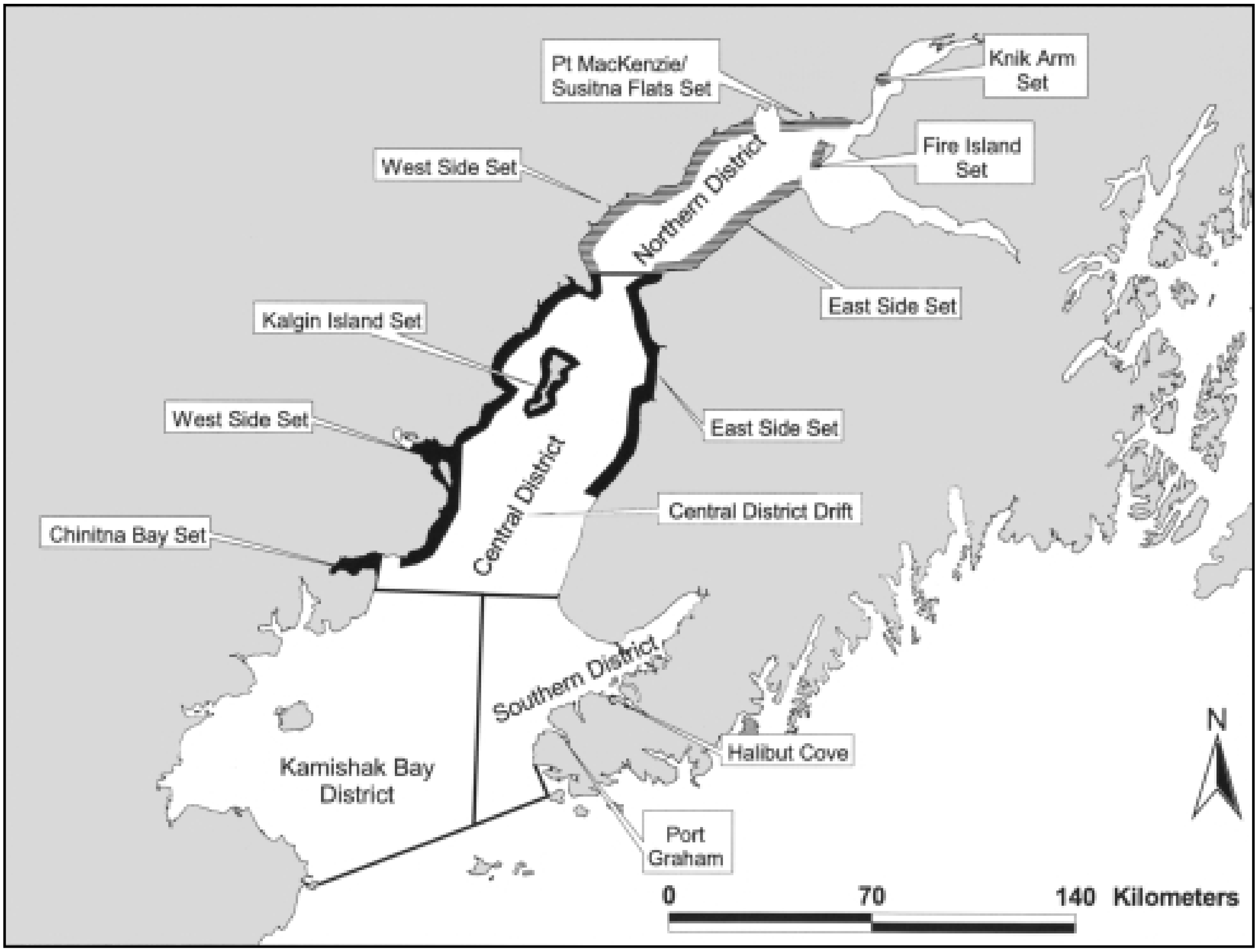

Figure 11.—Cook Inlet commercial fishing districts and individual set and drift net fisheries.

start at varying times by region (generally sometime in June) and continue until closed by an emergency order.

Oil and Gas Activities

There are seven oil producing fields supporting 15 oil and gas offshore platforms in upper Cook Inlet in Region 3 (Fig. 12). Underwater noise, habitat loss, and oil spills are generally cited as the foremost potential negative impacts of petroleum development activities on marine mammals (Geraci and St. Aubin, 1990). In 1999, the Alaska Department of Natural Resources (DNR), Division of Oil and Gas, proposed 815 tracts for lease in Cook Inlet (DNR[7]). Habitat loss due to oil and gas development was assumed by DNR to be limited to temporary displacement of harbor seals, *Phoca vitulina*, and sea otters, *Enhydra lutris*, from haulouts and nearshore foraging areas during construction of pipelines and transport facilities in Cook Inlet (DNR[7]). The possibility of disturbing and displacing belugas from similar nearshore habitats during these activities was not discussed. Although habitat loss may occur only temporarily during construction, a natural gas blowout or oil spill in upper Cook Inlet could put the beluga population at great risk.

Cook Inlet offshore oil platform spills totaled approximately 10,500 gal between 1984 and 1994 (DNR[7]). Four natural gas blowouts have occurred in Cook Inlet since 1962. The last gas blowout lasted from December 1987 until June 1988 at the Steelhead Platform well, M-26, on the McArthur River Field where escaping gas ignited, damaging the platform and injuring workers (DNR[7]). Offshore pipeline failures have not been reported since 1976. In 1987, the tanker *Glacier Bay* spilled about 210,000 gal of crude oil, interrupting commercial fishing operations near Kalgin Island during the peak of the sockeye salmon run (DNR[7]). Less than 10% of the oil was recovered. Smaller oil spills have occurred at the Drift River and Nikiski marine terminals in Cook Inlet. When ice forced the Unocal tanker *Coast Range* away from the Drift River facility dock in December 1990, about 630 gal spilled from the dock pipe (DNR[7]). Booms and skim-

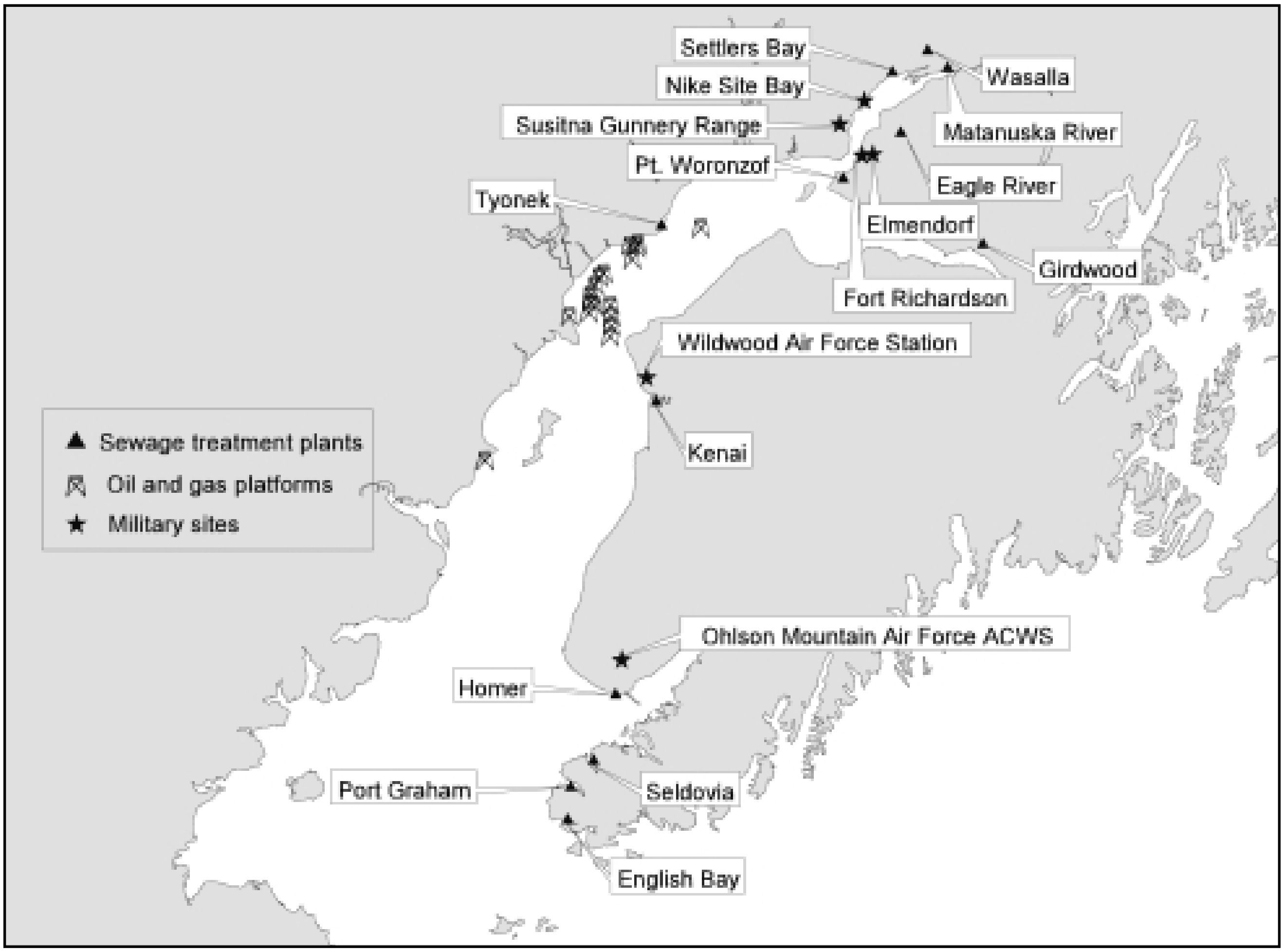

Figure 12.—Oil and gas platforms, sewage treatment facilities, and military sites of Cook Inlet, Alaska.

mers were ineffective in the heavy ice and about 300 gal could not be recovered. On 5 December 1995, between 2,500 and 2,900 gal of crude oil were released into Cook Inlet when an overflow alarm failed at Nikiski (DNR[7]). The oil traveled north into the rip currents and disappeared from view within three days.

Cetaceans are very mobile and are able to detect oil, however, they do not appear to avoid spills (Geraci, 1990). The greatest potential hazard associated with spills are the highly toxic vapors that concentrate above oil slicks and can result in sudden death if inhaled (Geraci, 1990). This phenomenon may have contributed to the loss of killer whales from AB pod during the *Exxon Valdez* spill in Prince William Sound (Harvey and Dahlheim, 1994). Several oil-spill trajectory models have been developed for Cook Inlet, however, these models have not yet been validated by more extensive direct measurements of currents, tidal rips, and water chemistry (Johnson and Okkonen, 1999).

Transportation

Vessel Traffic

Cook Inlet experiences very high volumes of vessel traffic relative to most of Alaska because the Port of Anchorage is an important distribution and transportation hub. This traffic affects parts of Regions 1, 2, and 3. Deep draft containerships and liquid-bulk petroleum vessels represent the majority of vessels berthing at the Port of Anchorage. For example, in 1992, 640 ships docked at the Port of Anchorage[15]: 319 were cargo vessels, 214 were deep-water freighters, 15 were petroleum tankers, and 92 were barges (76 of which were oil carriers). No cruise ships docked, compared to 4 port calls in 1991. There are no commercial vessel-based beluga whale-watching activities currently operating in Cook Inlet.

Vessel traffic in the upper inlet could change dramatically if plans to develop the Point MacKenzie Port in lower Knik Arm across from the Port of Anchorage are ever realized. Point MacKenzie is currently a barge port, but long range

[15] Port of Anchorage. 1992. Port of Anchorage yearly vessel arrival report for 1992. Municipality of Anchorage, Anchorage, Alaska.

plans include dredging to support a bulk loading facility for export of resources such as coal, wood chips, and logs. Commuter ferry service between Anchorage and Point MacKenzie Port has also been discussed, but recent concerns about the stability of the Point MacKenzie dock undermine the likelihood of this development in the near future (Komarnitsky[16])

Tankers must maintain a minimum distance of 5 mi from shore when transiting through Cook Inlet. Marine pilots are assigned to vessels navigating within Cook Inlet and docking at the Port of Anchorage. A deep-water Anchorage area in Kachemak Bay can accommodate up to three vessels when scheduling conflicts or weather delays occur. Since 1965, the Anchorage Harbor has been dredged to a depth of about 10 m (35 ft) below mean lower low water to accommodate deep draft vessels. Shoal movement along Fire Island and off Point Woronzof resulted in the initiation of dredging operations on the Knik Shoal in the late 1990's. Concerns expressed by environmental groups over impacts from dredging vessels operating off Fire Island have led to development of a monitoring program by the USACE (McConnell[17]).

Aircraft Overflights

Cook Inlet experiences significant aircraft traffic throughout the year. In 1998, over 40% of general aviation aircraft operating in Alaska were based in Anchorage (3,892 of 9,825) as well as 47% of licensed pilots (4,365 of 9,246) (MOA[18]). On average, 166 commercial passenger and 93 cargo planes land daily at Anchorage International Airport (Goldsmith[19]), as well as numerous private aircraft. Seaplane traffic in upper Cook Inlet is primarily based out of Lake Hood and Spenard Lake. Military aircraft regularly utilize the airfield at Elmendorf AFB. Smaller aircraft also use public runways at Birchwood and Goose Bay in Knik Arm, Merrill Field, Girdwood, the Kenai Municipal Airport, Ninilchik, Homer, and Seldovia.

Water Quality

Sewage

Ten communities discharge treated municipal wastewater into Cook Inlet or its rivers (Fig. 12), with many cases of fecal-coliform counts exceeding safe levels documented in recent years (Table 4). Sewage receives primary treatment at Point Woronzof (in Region 1), the largest wastewater management facility serving Anchorage, and at smaller facilities serving English Bay, Port Graham, Seldovia, and Tyonek (all in Region 2). Point Woronzof can treat 44 million gallons/day (mgd) versus the 10,000 gallons/day to 1.6 mgd treated at the other facilities listed above (MMS[20]). In 1993, effluent discharged from Point Woronzof averaged 30 mgd with discharges of biochemical oxygen demand (BOD) averaging 25,800 lb/day, total suspended solids (TSS) averaging 12,300 lb/day, and oil and grease averaging 5,360 lb/day (which may contain petroleum hydrocarbons) (MMS[20]). Sewage from Homer, Kenai, and Palmer receives secondary treatment, while Girdwood and Eagle River wastewater facilities (both in Region 1) are modern, tertiary treatment plants (AWWU[21]). Specifically, Eagle River was expanded in 1991 and has a capacity of 2.5 mgd. Girdwood was upgraded in 1997 to handle 0.60 mgd. Septic tanks or other individual systems are used in the other communities that border Cook Inlet.

Military Bases

According to the USACE, Alaska District, Formerly Used Defense Site (FUDS[22]) Geographic Information System database, most of the military base sites around Cook Inlet (Fig. 12) never had, or have been cleared of, hazardous/toxic waste, ordinance, and unsafe debris. However, some of these sites were never visited by USACE, and state-of-the-site summaries are based upon contractor and private property owner's reports. The Eagle River Flats area near Fort Richardson was nominated in 1996 by the EPA superfund cleanup staff for listing under Section 303d of the Clean Water Act due to the presence of white phosphorous (from artillery shell residue) and its potential lethal effect on waterfowl using this area (ADEC[23]; EPA[24]). Several remediation projects have helped to reduce waterfowl mortality from several thousand to a few hundred per migratory season.

Contaminants

Mineral discharges of zinc, barium, cadmium, and mercury are monitored at known point sources that include oil production facilities, the Point Woronzof Wastewater Treatment Plant, military bases, fish processors, and municipalities of Cook Inlet. Barium is the major component of drilling mud (63% of drilling muds are comprised of the mineral barite (barium sulphite)), and both mercury and cadmium are found in barite (MMS[20]). Mercury has also been reported in the municipal wastewater effluent of the Point Woronzof plant (MMS[20]).

In 1991, the National Toxics Campaign Fund analyzed sediment samples, collected on the west shore of Cook Inlet near the mouth of the Drift River and in Trading Bay, which contained "higher than average" concentrations of barium but no detectable levels of polycylic aromatic hydrocarbons (PAH's), beryllium, or arsenic (DNR[7]). A 1993 MMS study compared heavy metal con-

---

[16] Komarnitsky, S. J. 2001. Valley port in trouble. Anchorage Daily News, 7 Feb.:A-1:A-8.

[17] McConnell, G. R. 2000. Beluga report: upper Cook Inlet navigation project. Unpubl. rep., 2 p., to Alaska Reg., Natl. Mar. Fish. Serv., 222 W. 7th Ave. #43, Anchorage, AK 99513

[18] Data obtained from the Municipality of Anchorage (MOA) website accessed 29 June 2000 [http://www.ci.anchorage.ak.us/services/departments/merrill/].

[19] Goldsmith, S. 1998. Anchorage International Airport 1998: economic significance. Report prep. for Anchorage International Airport [available at Inst. Social Econ. Res., Univ. AK, 3211 Providence Dr., Anchorage, AK 99508], 37 p.

[20] MMS. 1996. Cook Inlet planning area oil and gas lease sale 149: final environmental impact statement, vol. 1. U.S. Dep. Inter., OCS EIS/EA MMS 95-0066, v. p.

[21] Data obtained from the Anchorage Water & Wastewater Utility (AWWU) website, 10 February 1999 [http://www.awwu.ci.anchorage.ak.us/website/default.htm].

[22] Data obtained from the U.S. Army Corps of Engineers website, 11 February 1999 [http://knik.poa.usace.army.mil/].

[23] Data obtained from the Alaska Dep. Environ. Conserv., Air and Water Quality Div. (ADEC) website, 12 February 1999 [http://www.state.ak.us/dec/dawq/wqm/wqp/303d/303dl.htm].

[24] Data obtained from the Environ. Protect. Agency (EPA) website, 2 November 1999 [http://www.epa.gov/superfund/sites/npl/ak.htm].

Table 4.—Summary of sewage outfall fecal coliform exceedances in Cook Inlet. Partial listing summarized from: Alaska Department of Environmental Conservation, Air and Water Quality Division webpage [http://www.state.ak.us/dec/dawq/wqm/wqp/303d/303dl.htm].

Location	Outfall	Description
Cheney Lake, Anchorage	Fecal Coliform Urban Runoff Storm Drainage	On Section 303(d) list for fecal coliform since 1996. MOA 1991–94 data indicates fecal coliform criterion is being exceeded in almost every monitoring month.
Furrow Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1996. MOA data indicate levels of fecal coliform exceed the criteria for drinking water, primary contact recreation, and at times secondary contact recreation. Source of fecal coliform presumed to be human-caused from urban runoff sources.
Little Rabbit Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. Source of fecal coliform exceedances (human-caused or caused by non-human sources such as wildlife) has been an issue.
Little Survival Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. Source of fecal coliform exceedances (human-caused or caused by non-human sources such as wildlife) has been an issue.
Ship Creek—Glenn Hwy. Bridge, down to mouth, Anchorage	Fecal Coliform Petroleum Products Urban Runoff	On the Section 303(d) list for fecal coliform, biological community alteration, and petroleum hydrocarbons since 1994. MOA fecal coliform monitoring data indicates water quality criteria for drinking water and contact recreation were exceeded at times between 1989–94. EPA established a superfund site adjacent to Ship Creek. Petroleum products floating on ground water threaten the waterbody. A report for ADEC indicates the macroinvertebrate community has been altered/degraded. A recovery plan was completed in June 1998.
Campbell Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. There are several parameters of concern, i.e. temperature, turbidity, zinc, and lead, but the Creek was water quality limited for fecal coliform only.
Campbell Lake, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. The Campbell Creek water quality assessment, completed in June 1994, included an assessment of Campbell Lake. Results were similar to those found for Campbell Creek.
Chester Creek, Anchorage	Fecal Coliform Urban Runoff Industrial	On the Section 303(d) list for fecal coliform since 1994. The waterbody is water quality limited for fecal coliform only, though several other areas of concern were identified.
Fish Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform and turbidity since 1994. The waterbody was water quality-limited only for fecal coliform.
Hood/Spenard Lake, Anchorage	Dissolved Oxygen Urban Runoff Industrial Fecal Coliform	On the Tier I 1996 Section 303(d) list and proposed for Tier III for fecal coliform only because a TMDL for fecal coliform was developed and finalized on September 30, 1997. The waterbody will remain on the Tier II list for dissolved oxygen. There are four other pollutants of concern, petroleum, nitrates, lead, and ammonia, however, the data indicated no persistent violations.
Little Campbell Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. The lake is water quality-limited only for fecal coliform.
University Lake, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. The waterbody is water quality-limited for only fecal coliform.
Westchester Lagoon, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. Westchester Lagoon is water quality-limited only for fecal coliform, however, there are water quality concerns related to iron, turbidity, and petroleum products.
Jewel Lake, Anchorage	Fecal Coliform Urban Runoff Land Development	On the 1996 Section 303(d) Tier I list for fecal coliform. A TMDL was developed and finalized and the waterbody is proposed for Tier III listing.

centrations to results obtained during OCSEAP studies conducted in the late 1970's and found "no immediate evidence of heavy metal pollution in Cook Inlet" (ENRI[25]). However, concentrations of terrestrial-source mercury at sampling stations in upper Cook Inlet were higher than the EPA designated chronic level but well below the acute toxicity level (ENRI[25]). From 1993 to 1997, the Cook Inlet Regional Citizens Advisory Council (CIRCAC) initiated studies similar to the 1993 MMS study. Overall, PAH concentrations were considerably lower than the amount expected to cause adverse effects in animals (ADL[26]; KLI[27]). In their 1997 report on the state of the inlet, CIK criticized the results of these studies as being inconclusive and emphasized the need for longer-term testing.

In 1997, MMS began a project to compare the chemical "fingerprints" of pollutants from sediment samples to their possible sources (ADL[28]). Sources included Cook Inlet crude oil, natural oil seeps, Municipality of Anchorage sewage outfall, and water from Homer Harbor. Preliminary results indicate no contamination in surface sediments or specimen tissues from oil and gas production; although, elevated levels of arsenic, copper, and mercury at some sites were due to local anthropogenic inputs and need further evaluation (ADL[28]). Anthropogenic inputs, however, accounted for only a small fraction of metals found in Cook Inlet. Compared to natural loadings from rivers and streams, these anthropogenic inputs contributed less than 1% of total metal transport in Cook Inlet and beyond, the only exception being barium which was 5.5% (ADL[28]).

[25] ENRI. 1995. Current water quality in Cook Inlet, Alaska, study. Environ. Nat. Resour. Inst., Univ. Alaska, Anchorage, OCS Study MMS 95-0009, 124 p.

[26] ADL. 1995. Cook Inlet pilot monitoring study: Phase II final report. Arthur D. Little, Inc., Cambridge, Mass., Ref. 46849, v.p.

[27] KLI. 1996. Cook Inlet environmental monitoring program: final report. Kinnetic Lab., Inc., Anchorage, Alaska, 59 p.

[28] ADL. 1998. Sediment quality in depositional areas of Shelikof Strait and outermost Cook Inlet: final literature synthesis. Arthur D. Little, Inc., Cambridge, Mass., OCS Study MMS 97-0015, 69 p.

Specimen tissues were also analyzed by the EPA in 1997 to determine if subsistence food resources were being contaminated by dioxins/furans, PAH's, pesticides, PCB's, and metals including inorganic arsenic, barium, cadmium, chromium, methyl mercury, and selenium (DNR[7]). More than 100 samples of subsistence fish, shellfish, and marine plants were tested. Similar to the CIRCAC Monitoring Program results, EPA preliminary results indicated that contaminant levels (regardless of their source) in sediments and tissues were at background levels or were undetectable, and did not pose a threat to Cook Inlet biota. However, PCB's and methyl mercury in sea bass (Serranidae), cadmium in snails (Prosobranchia), chitons (Polyplacophora), and octopus, *Octopus dolfleini*, and the pesticide dieldrin in chinook salmon could pose a health risk to humans depending on the quantity consumed and type of preparation. Organocholorines, such as PCB's and DDT, are dispersed worldwide as a result of agricultural and industrial activities, and there is concern that these synthetic chemicals impair health and reduce reproductive fitness in marine mammals (reviewed in Colborn and Smolen, 1996).

Potential Effects on Belugas

Belugas in Cook Inlet are subjected to various anthropogenic activities, from fishing operations, oil and gas exploration and development, intense vessel and air traffic, sewage, and contaminants, as well as the annual hunt conducted by Alaska Natives. It is possible that commercial and subsistence fishing in the upper inlet could have an impact on belugas, either from competition for fish or displacement from foraging habitat. Reports of belugas entangled in fishing gear are sporadic and few. From 1981 to 1984, at least 3–6 whales were taken incidental to commercial salmon fishing (Burns and Seaman[29]). Since 1988, there have been only three reported entanglements: 1) one beluga caught at Fire Island on 25 July 1989; 2) one beluga caught in a set gillnet near the Susitna River on 25 July 1990; and 3) one beluga caught in a fishing net in the Kenai area on 9 August 1996 (NMFS unpubl. data). Of note, there were no reports of entanglements in 1999, the first year that NMFS fishery observers were available to monitor fishing activities in the Category II Cook Inlet salmon gillnet fishery (NMFS unpubl. data). There were four observers in the upper inlet (Fire Island, Point Possession, Tyonek, and Susitna areas) and three in the lower inlet (Kenai, Nikiski, and McArthur areas). Currently there are no data to indicate that beluga mortality due to entanglement is significant.

Beluga hearing and responses to noise generated from oil and gas activities, geophysical surveys, dredging, construction, and the operation of vessels and aircraft are reviewed in Richardson et al. (1995); with their responses to noise from an icebreaker in the Bering Sea detailed in Erbe and Farmer (1998; 2000). Underwater noise from most of these activities are at relatively low frequencies (<1 kHz) where beluga hearing is poor; belugas hear best at frequencies between 10–15 kHz (Richardson et al., 1995). In the late 1970's and early 1980's, there were numerous reports of belugas seen near oil and gas structures (Hazard, 1988). McCarty (1981) reported groups, including females with calves, passing within 10 m of active platforms. Small groups of belugas (4–8 animals) were "commonly seen" near oil and gas platforms in Cook Inlet during winter but not in summer (Dahlheim[30]). There have been no confirmed reports of belugas near oil and gas structures in recent years.

Low frequency (i.e. long wavelength) sound travels poorly in shallow water, so transmission of these sounds in upper Cook Inlet is expected to be confined to relatively short ranges. This may partially explain the lack of response of 15 belugas to seismic exploration signals in Cook Inlet in June 1995 (Morris[31]). During that observation, the whales were in shallow *ca*. 2–7 m (6–20 ft) water, and the ship was in relatively deep *ca*. 20–27 m (60–80 ft) water about 37 km (20 n.mi.) from the whale group. In 1999, belugas were observed near the docks at the Port of Anchorage and in Knik Arm between Anchorage and Point MacKenzie during transits from the dredging operation off Fire Island, but none were reported close to the dredge site (McConnell[17]). According to the USACE[5], marine birds and mammals are rarely found in the immediate vicinity of marine dredging excavation or disposal sites in Cook Inlet, and these animals can easily avoid dredging operations.

Observed responses of belugas to vessels ranges from complete tolerance to extreme sensitivity, apparently depending on whale activities, habitat, boat type, and previous experience (Richardson et al., 1995). It appears that belugas can habituate to vessels that follow consistent routes (Burns and Seaman[29]). In addition, hundreds of commercial salmon fishing vessels in Bristol Bay do not deter belugas from feeding in the area (Frost et al.[32]). Even when purposefully harassed by powerboats, belugas continue to return to traditional estuarine areas in Cook Inlet (Lerczak et al., 2000).

It is uncertain if noise or visual cues from aircraft operating in the Anchorage area affect belugas. Richardson et al. (1995) found that in the Beaufort Sea, belugas dive or swim away when low-flying (<500 m) aircraft (either fixed-wing or helicopters) pass directly overhead. Lone animals and small groups responded more often than feeding whales. However, in eastern Hudson Bay, Canada, Caron and Smith (1990) observed no changes in swim directions of belugas when aircraft passed >300m overhead, which is consistent with observations from the survey aircraft flown at roughly 244 m in Cook Inlet (Rugh

[29] Burns, J. J., and G. A. Seaman. 1986. Investigations of belukha whales in the coastal waters of western and northern Alaska: II. Biology and ecology. U.S. Dep. Commer., NOAA, Natl. Ocean Serv., Anchorage, Alaska, Final Rep., Res. Unit 612, 129 p.

[30] Dahlheim, R. F., Jr. 16126 Dubuque Road, Snohomish, WA 98290. Personal commun.

[31] Morris, R., NMFS Alaska Reg. Off., Anchorage, AK 99513. Personal commun.

[32] Frost, K. J., L. F. Lowry, and R. R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. *In* B. R. Melteff and D. H. Rosenberg (Editors), Proc. workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, p. 187–200. Univ. Alaska Sea Grant Rep. 84-1.

Table 5.–Categories defined by the National Marine Fisheries Service with specific recommendations regarding the use of proposed oil and gas development tracts in Cook Inlet. Source: Payne, text footnote 33.

Category one[1]		Category two[2]	
Location	Tract number	Location	Tract number
Chuitna River	494, 497, 498	Kustatan River	211, 257
Beluga River	485, 486, 493, 544, 547, 548, 549, 550, 551, 552, 559	Middle River	373, 376, 377
Ivan River	541	Drift River	177
Susitna River	536, 537, 538, 539, 540, 542, 543, 593, 594, 598	Big River	175, 218
Little Susitna River	529, 532, 533, 534, 535, 585, 586, 590	McArthur River	301, 320, 384
Knik Arm	575, 576, 577, 579, 581, 582, 616, 617, 618, 620, 621, 622, 623, 627, 655, 656, 657, 658, 662	Kenai River	126, 127, 129, 130, 131, 132, 161, 162
Anchorage	522, 524, 525, 526, 527, 528, 530, 531		
Chickaloon River	322, 323, 324, 325, 326, 327, 329, 331		
Turnagain Arm	320, 321, 328, 330, 333, 334, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 462, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475		

[1] Oil and gas exploration and development (permanent or temporary) should not occur on these tracts, excluding upland areas (above Mean Higher High Water).

[2] Leasing of these tracts should be conditioned such that no permanent surface entry or structures occur, excluding upland areas, and temporary activities and structures occur only between November 1 and April 1 of each year.

et al., 2000). Belugas are probably less sensitive to aircraft noise than to vessel noise, but their response may be highly variable as a function of previous experience, activity, and characteristics of the noise.

In other regions, belugas have demonstrated a strong attachment to certain estuaries, a behavior referred to as site tenacity or fidelity (Finley, 1982; Finley et al., 1982; Caron and Smith, 1990). These belugas continue to return to estuaries after a disturbance and, surprisingly, adults accompanied by calves were usually the first to return. Similar site fidelity appears to be demonstrated by belugas in Cook Inlet (Lerczak et al., 2000). Although Cook Inlet belugas continue to occupy the upper inlet despite oil and gas development, vessel and aircraft traffic, and dredging operations, the cumulative impacts of these activities are not known.

Water quality is also of particular concern to Alaska Native hunters in Cook Inlet (Huntington, 2000). Specifically, hunters maintain that, in addition to garbage along the beaches, the water itself smells bad, there is more foam along the beaches, and that effluent from oil rigs and other sources may be affecting the health of fish and therefore belugas in Cook Inlet. Belugas, harbor seals, sea otters, and their prey depend on inshore waters, areas where oil tends to accumulate (Geraci and St. Aubin, 1990). Belugas confined to small leads during heavy ice years could be especially at risk if the open water was contaminated with unweathered oil (Hansen, 1992). Concerned that oil and gas exploration and development might affect Cook Inlet belugas, NMFS recommended deleting specific tracts from the DNR's 1999 lease sale (Payne[33]). The tracts were divided among three categories. Category One tracts represented areas heavily used by belugas during summer (Table 5). It was recommended that oil and gas development (permanent or temporary) not occur in these areas, excluding those areas above Mean Higher High Water. Category Two included tracts used by belugas during summer periods (Table 5). These tracts should be leased on condition that "no permanent surface entry or structures occur, other than in upland areas, and that all temporary activities and structures (e.g. exploration drilling) occur only between 1 November and 1 April of each year." No specific recommendations were made for the remaining sale tracts which were placed under Category Three.

Additional sources of potential contamination include the EPA superfund site at Eagle River Flats. This area is of particular concern as belugas are known to congregate at the mouth of the Eagle River and at times to enter the river (Rugh et al., 2000; NMFS unpubl. data). Although Cook Inlet belugas inhabit a region of comparatively high anthropogenic development, they do not carry higher loads of PCB's and chlorinated pesticides and apparently have lower concentrations of some compounds (e.g. chlordane, HCB, and dieldrin and heavy metals) than whales from two other Alaska beluga stocks (Becker et al., 2000; Krahn et al., 1999). The principle source of PCB's, toxaphene, DDT, chlordane, HCB, and dieldrin in Arctic populations of belugas is hypothesized to be atmospheric transport from lower latitudes (Pacyna, 1995).

[33] Payne, P. M., NMFS, Office of Protected Resources, in letters 19 and 30 Nov. 1999 to Patty Bielawski, Dep. Nat. Resour.

Conclusions

Beluga habitat associations are summarized by region (Fig. 1) in Table 6. In Region 1, the largest beluga concentrations in summer are associated with very shallow, low-salinity water at the outflow of major rivers in the upper inlet. Prey availability is probably high and varies with annual fish runs. Occurrence of killer whales (predators) is low, only a small number of entanglements in fishing nets have been reported, and potential disturbance from petroleum activities is not considered a key determinant to distribution at this point. Although stranding occurs fairly often, mortality associated with it seems to be low. Vessel traffic is high (particularly near Anchorage) and due to sewage outfalls water quality comparatively poor in Region 1. Region 2 is similar to Region 1 with the exceptions of increased petroleum activities along the western shore and reduced shipping activity. In winter, belugas were seen primarily in Region 3. However, it is also possible that belugas in heavy-ice cover nearshore may have been missed by aerial observers. Water depth in Region 3 varies from shallow to the deepest channels in Cook Inlet, the water column is comparatively well mixed, and sea-ice varies from open water to >90% surface cover. Fishing activity is largely absent in winter, although potential disturbance from petroleum transportation activities continue year-round. Water quality in the central inlet is described as "good" due to mixing effects of tidal flushing.

This descriptive account of beluga habitat associations in Cook Inlet could be greatly improved by the incorporation of quantifiable measures of habitat variability. While it is well established that belugas follow fish runs, our capability to assess the importance of prey availability to habitat selection would be greatly improved by quantification of fish runs coordinated with whale surveys. This would help determine factors critical to the belugas' known selection of only a few rivers. Similarly, measures of anthropogenic factors (i.e. fishing, underwater noise, and water quality), both within and outside of beluga concentration areas, would allow a better assessment of beluga habitat quality and selection criteria.

Table 6.—Physical, ecosystem, and anthropogenic habitat factors that may affect beluga distribution in three regions of Cook Inlet, Alaska, based on density of whale sightings.

Item	Region 1	Region 2	Region 3
Beluga distribution			
Summer	High	Moderate	Low
Winter	Occasional	Occasional	Moderate
Physical factors			
Bathymetry	Shoals and shallow	Shallow	Deep channels
Salinity (summer only)	Fresh	Fresh	Fresh, saline
Sea ice (winter only)	Ice covered	Brash ice	Brash and ice free
Tides and currents	Extreme & variable	Extreme & variable	Moderate & channeled
Ecosystem factors			
Prey variability	Dense fish runs?	Fish runs?	Dispersed fish runs?
Predators	Low	Low	Low?
Strandings	High	High	Low
Natural catastrophe	Unknown	Unknown	Unknown
Anthropogenic factors			
Fishing and bycatch	Low	Low	Low
Petroleum	Low	Moderate (west)	High (west)
Transportation	High (Anchorage)	Low	High
Water quality	Poor	Poor	Moderate

Acknowledgments

We thank K. Laidre and J. Davies for preparation of detailed maps of Cook Inlet. Reviews were provided by J. Breiwick (NMML), R. Hobbs (NMML), and two anonymous reviewers. Technical reviews were provided by G. Duker and J. Lee (AFSC).

Literature Cited

Alaska Geographic. 1991. Alaska's volcanoes. Alaska Geogr. 18(2):1–77.
________ . 1994. The Kenai Peninsula. Alaska Geogr. 21(2):1–126.
Anderson, P. J., and J. F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Mar. Ecol. Prog. Ser. 189:117–123.
Bakus, G. J., M. Orys, and J. D. Hedrick. 1979. The marine biology and oceanography of the Anchorage region, upper Cook Inlet, Alaska. Astarte 12:13–20.
Bechtol, W. R. 1997. Changes in forage fish populations in Kachemak Bay, Alaska, 1976–1995. *In* Proc. Alaska Sea Grant Coll. Program, p. 441–455. Rep. AK-SG-97-01.
Becker, P. R., M. M. Krahn, E. A. Mackey, R. Demiralp, M. M. Schantz, M. S. Epstein, M. K. Donais, B. J. Porter, D. C. G. Muir, and S. A. Wise. 2000. Concentrations of polychlorinated biphenyls (PCB's), chlorinated pesticides, and heavy metals and other elements in tissues of belugas, *Delphinapterus leucas*, from Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):81–98.
Bel'kovich, V. M. 1960. Some biological observations on the white whale from the aircraft. Zool. Zur. 30:1414–1422.
________ and M. N. Shchekotov. 1990. The belukha whale: natural behavior and bioacoustics. Woods Hole Oceanogr. Inst., Woods Hole, Mass.
Burbank, D. C. 1977. Circulation studies in Kachemak Bay and lower Cook Inlet. *In* L. L. Trasky, L. B. Flagg, and D. C. Burbank (Editors), Environmental studies of Kachemak Bay and lower Cook Inlet. Alaska Dep. Fish Game, Mar. Coast. Habitat Manage., Anchorage.
Caron, L. M. J., and T. G. Smith. 1990. Philopatry and site tenacity of belugas, *Delphinapterus leucas*, hunted by Inuit at the Nastapoka estuary, eastern Hudson Bay. *In* T. G. Smith, D. J. St. Aubin, and J. R. Geraci (Editors), Advances in research on the beluga whale, *Delphinapterus leucas*, p. 69–79. Can. Bull. Fish. Aquat. Sci. 224.
Colborn, T., and M. J. Smolen. 1996. Epidemiological analysis of persistant organocholorine contaminants in cetaceans. Rev. Environ. Contamination Toxicol. 146:91–172.
Dahlheim, M. E. 1997. A photographic catalog of killer whales, *Orcinus orca*, from the central Gulf of Alaska to the southeastern Bering Sea. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 131, 54 p.
Davis, R. Z. 1998. Upper Cook Inlet salmon escapement studies 1997. AK Dep. Fish Game, Regional Info. Rep. ZA38-91, 129 p.
Erbe, C., and D. M. Farmer. 1998. Masked hearing thresholds of a beluga whale (*Delphinapterus leucas*) in icebreaker noise. Deep-Sea Res., Pt. II 45:1373–1388.
________ and ________ . 2000. Zones of impact around icebreakers affecting beluga whales in the Beaufort Sea. J. Acoust. Soc. Am. 108(3): 1332–1340.
Finley, K. J. 1982. The estuarine habitat of the beluga or white whale, *Delphinapterus leucas*. Cetus 4(2):4–5.
________ , G. W. Miller, H. Allard, R. A. Davis, and C. R. Evans. 1982. The belugas (*Delphinapterus leucas*) of northern Quebec: distribution, abundance, stock identity, and catch history and management. Can. Dep. Fish. Oceans Tech. Rep. 1123, 57 p.
Francis, R. C., S. R. Hare, A. B. Hollowed, and W. S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the N.E. Pacific. Fish. Oceanogr. 7(1):1–21.
Fried, S. M. 1999. Upper Cook Inlet salmon biological escapement goal review: department findings and recommendations to the Alaska Board of Fisheries. AK Dep. Fish Game, Regional Info. Rep. ZA99-05, 26 p.
Geraci, J. R. 1990. Physiological and toxic effects of oil on cetaceans. *In* J. R. Geraci and D. J. St. Aubin (Editors), Sea mammals and oil: confronting the risks, p. 167–197. Acad. Press, Inc., San Diego, Calif., 282 p.
________ and D. J. St. Aubin (Editors). 1990. Sea mammals and oil: confronting the risks. Acad. Press, Inc., San Diego, Calif., 282 p.
Hampton, M. A. 1982. Lower Cook Inlet environmental geology and Shelikof Strait environmental geology. U.S. Dep. Inter., USGS Open-File Rep. 82-928, Reston, Va.
Hansen, D. J. 1992. Potential effects of oil spills on marine mammals that occur in Alaskan waters. U.S. Dep. Inter., OCS Rep. MMS 92-0012, 25 p.
________ and J. D. Hubbard. 1999. Distribution of Cook Inlet beluga whales (*Delphinapterus leucas*) in winter. U.S. Dep. Inter., OCS Study MMS 99-0024, 30 p.
Hansen, S. E. 1987. White whale (*Delphinapterus leucas*) distribution and abundance in relation to water temperature, salinity, and turbidity in the Churchill River estuary. M.S. Thesis, Laurentian Univ., Ontario, Can., 150 p.
Harvey, J. T., and M. E. Dahlheim. 1994. Cetaceans in oil. *In* T. R. Loughlin (Editor), Marine mammals and the *Exxon Valdez*, p. 257–264. Acad. Press, N.Y.
Hazard, K. 1988. Beluga whale, *Delphinapterus leucas*. *In* J. W. Lentfer (Editor), Selected marine mammals of Alaska: species accounts with research and management recommendations, p. 195–235. Mar. Mammal Comm., Wash., D.C.
Hill, P. S., and D. P. DeMaster. 1998. Alaska marine mammal stock assessments, 1998. U.S. Dep. Commer., NOAA Tech. Memo NMFS-AFSC-97, 166 p.
Hobbs, R. C., D. J. Rugh, and D. P. DeMaster. 2000. Abundance of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994–2000. Mar. Fish. Rev. 62(3):37–45.

Huntington, H. P. 2000. Traditional knowledge of the ecology of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):134–140.
Johnson, M. A., and S. R. Okkonen. 1999. Cook Inlet oceanography workshop. U.S. Dep. Inter., OCS Study MMS 2000-043, 118 p.
Karlstrom, T. N. V. 1964. Quaternary geology of the Kenai lowland and glacial history of the Cook Inlet region, Alaska. U.S. Dep. Inter., Geol. Surv. Prof. Pap. 443.
Kingsley, M. C. S. 1998. Population index estimates for the St. Lawrence belugas, 1973–1995. Mar. Mammal Sci. 14(3):508–530.
Kleinenberg, S. E., A.V. Yablokov, V. M. Bel'kovich, and M. N. Tarasevich. 1964. Beluga (*Delphinapterus leucas*): investigation of the species. Akad. Nauk SSSR, Moscow, 376 p. Transl. by Israel Prog. Sci. Transl., 1969.
Krahn, M. M., D. G. Burrows, J. E. Stein, P. R. Becker, M. M. Schantz, D. C. G. Muir, T. M. O'Hara, and T. Rowles. 1999. White whales (*Delphinapterus leucas*) from three Alaskan stocks: Concentrations and patterns of persistent organocholorine contaminants in blubber. J. Cetacean Res. Manage. 3:239–249.
Kruse, G. H. 1998. Salmon run failures in 1997–1998: a link to anomalous ocean conditions? Alaska Fish. Res. Bull. 5(1):55–63.
Laidre, K. L., K. E. W. Shelden, D. J. Rugh, and B. A. Mahoney. 2000. Beluga, *Delphinapterus leucas*, distribution and survey effort in the Gulf of Alaska. Mar. Fish. Rev. 62(3): 27–36.
Lerczak, J. A., K. E. W. Shelden, and R. C. Hobbs. 2000. Application of suction-cup-attached VHF transmitters to the study of beluga, *Delphinapterus leucas*, surfacing behavior in Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):99–111.
Lesage, V., C. Barrette, M. C. S. Kingsley, and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River Estuary, Canada. Mar. Mammal Sci. 15(1):65–84.
Mahoney, B. A., and K. E. W. Shelden. 2000. Harvest history of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):124–133.
McCarty, S. 1981. Survey of effects of outer continental shelf platforms on cetacean behavior. Appendix C, vol. II. *In* R. S. Gales (Editor), Effects of noise of offshore oil and gas operations on marine mammals: an introductory assessment, p. C1–C31. Naval Ocean Syst. Cent., San Diego, Calif., NOSC Tech. Rep. 844.
Moore, S. E. 2000. Variability of cetacean distribution and habitat selection in the Alaskan Arctic, Autumn 1982–91. Arctic 53(4):448–460.
________ , D. P. DeMaster, and P. K. Dayton. 2000. Cetacean habitat selection in the Alaskan Arctic in summer and autumn. Arctic 53 (4):432–447.
Moulton, L. L. 1997. Early marine residence, growth, and feeding by juvenile salmon in northern Cook Inlet, Alaska. Alaska Fish. Res. Bull. 4(2):154–177.
Muench, R. D., H. O. Mofjeld, and R. L. Charnell. 1978. Oceanographic conditions in lower Cook Inlet: spring and summer 1973. J. Geophys. Res. 83(C10):5090–5098.
Mulherin, N. D., W. B. Tucker III, O. P. Smith, and W. J. Lee. 2001. Marine ice atlas for Cook Inlet, Alaska. U.S. Army Eng. Res. Develop. Cent./Cold Reg. Res. Eng. Lab., Tech. Rep. 01-10, 155 p.
NMFS. 1998. Regulations governing the taking and importing of marine mammals; threatened fish and wildlife; Cook Inlet beluga whales. Fed. Regist. 63:64228–64229.
Noerenberg, W. H. 1971. Earthquake damage to Alaskan fisheries. *In* The great Alaska earthquake of 1964, vol. 3—biology, p. 170–193. Natl. Acad. Sci., Wash., D.C.
O'Corry-Crowe, G. M., R. S. Suydam, A. Rosenberg, K. J. Frost, and A. E. Dizon. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. Molecular Ecol. 6:955–970.
Pacyna, J. M. 1995. The origin of Arctic air pollutants: lessons learned and future research. Elsevier Sci., Sci. Total Environ. 160/161:39–53.
Piatt, J. F. 1994. Oceanic, shelf and coastal seabird assemblages at the mouth of a tidally-mixed estuary (Cook Inlet, Alaska). U.S. Dep. Inter., OCS Study MMS 93-0072, 33 p.
Poole, F. W., and G. L. Hufford. 1982. Meteorological and oceanographic factors affecting sea ice in Cook Inlet. J. Geophys. Res. 87(C3):2061–2070.
Pulpan, H., and H. Kienle. 1979. Western Gulf of Alaska seismic risk studies. *In* Proceedings of the 11th offshore technology conference, Houston, TX, 30 April–3 May 1979, p. 2209–2218.
Richardson, W. J., C. R. Greene, C. I. Malme, and D. H. Thomson. 1995. Marine mammals and noise. Acad. Press, Inc., San Diego, Calif.
Riehle, J. R. 1985. A reconnaissance of the major holocene tephra deposits in the upper cook Inlet region, Alaska. J. Volcanology Geotherm. Res. 261–2:37–74.
Robards, M. D., J. F. Piatt, A. B. Kettle and A. A. Abookire. 1999. Temporal and geographic variation in fish communities of lower Cook Inlet, Alaska. Fish. Bull. 97:962–977.
Rugh, D. J., K. E. W. Shelden, and B. A. Mahoney. 2000. Distribution of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, during June/July 1993–2000. Mar. Fish. Rev. 62(3):6–21.
Rutz, D., and D. Sweet. 2000. Area management report for the recreational fisheries of northern Cook Inlet, 1999. Alaska Dep. Fish Game, Fish. Manage. Rep. 00-8.
Schumacher, J. D., P. J. Stabeno, and A. T. Roach. 1989. Volume transport in the Alaska Coastal Current. Continental Shelf Res. 9(12):1071–1083.
Seaman, G. A., L. F. Lowry, and K. J. Frost. 1982. Foods of belukha whales (*Delphinapterus leucas*) in western Alaska. Cetology 44:1–19.
Sergeant, D. E. 1986. Present status of white whales *Delphinapterus leucas* in the St. Lawrence Estuary. Nat. Canadien (Rev. Ecol. Syst.) 113:61–81.
Smith, T. G., M. O. Hammill, and A. R. Martin. 1994. Herd composition and behavior of white whales (*Delphinapterus leucas*) in two Canadian arctic estuaries. Meddr Grønland, Biosci. 39:175–184.
Speckman, S. G., and J. F. Piatt. 2000. Historic and current use of lower Cook Inlet, Alaska, by belugas, *Delphinapterus leucas*. Mar. Fish. Rev. 62(3):22–26.
St. Aubin, D. J., T. G. Smith, and J. R. Geraci. 1990. Seasonal epidermal molt in beluga whales, *Delphinapterus leucas.* Can. J. Zool. 68:359–367.
Suydam, R. S., L. F. Lowry, K. J. Frost, G. M. O'Corry-Crowe, and D. Pikok, Jr. 2000. Satellite tracking of eastern Chukchi Sea beluga whales in the Arctic Ocean. Arctic. 54(3):237–243.
Stewart, B. E., and R. E. A. Stewart. 1989. *Delphinapterus leucas*. Am. Soc. Mammal. 336: 1–8.
Watts, P. D., B. A. Draper, and J. Henrico. 1991. Preferential use of warm water habitat by adult beluga whales. J. Therm. Bio. 16(1):57–60.
Welch, H. E., R. E. Crawford, and H. Hop. 1993. Occurrence of arctic cod (*Boreogadus saida*) schools and their vulnerability to predation in the Canadian high Arctic. Arctic 64(4): 331–339.