Anthropogenic and environmental stressors in Cook Inlet beluga whales (*Delphinapterus leucas*)

Literature Review and Assessment

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The intent of this report is to help inform scientists and administrators with NOAA, National Marine Fisheries Service in their efforts to conserve and advance the recovery of Cook Inlet beluga whales (*Delphinapterus leucas*). This report is advisory in nature and does not obligate any actions be taken based on its findings.

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Introduction

This review provides information about anthropogenic and select environmental factors that are believed to have a potentially negative impact on the Cook Inlet, Alaska beluga whale (*Delphinapterus leucas*) population and identifies significant gaps in the existing data. At reduced numbers and with contraction of their range, this population is far more vulnerable to losses due to nonlethal anthropogenic stressors than it was at a population level similar to the 1300 belugas seen in the 1970s. Disturbances that cause belugas to temporarily or permanently abandon summer feeding and calving areas could reduce their ability to reproduce or survive through the winter months. The anthropogenic and environmental stressors that are discussed include:

- Pressure on fish stocks from commercial, sport, and subsistence fishing,
- Human population growth (vehicular traffic serving as a proxy),
- Vessel disturbance (non-noise),
- Ambient noise,
- Nonpoint source pollution,
- Land use and development,
- Water temperature (fresh and marine waters), and
- Freshwater input into Cook Inlet from feeder rivers and creeks.

These stressors were selected as they have been documented to be the potential risk factors of most concern for Cook Inlet beluga whales and other cetacean species and are not presented in any particular order, but rather are grouped into two divisions, anthropogenic and environmental (Krahn et al. 2002, Hobbs et al. 2006, 2008; NMFS 2008a, b; Jefferson et al. 2009). Belugas may be one of the best sentinels for aquatic and coastal environments since they have long life spans, feed at a high trophic level, and have extensive fat stores that may serve as depots for anthropogenic toxins (Reddy et al. 2001). Most threats to marine mammals, and thus Cook Inlet belugas, may be related to the human population size and growth rate, behaviors and consumption patterns (MMC 2004). Thus, Cook Inlet belugas may serve as an ideal approach to better understanding the intersection of ecosystem health and human impacts.

This report was constructed from a review of available literature regarding sublethal stressors and their potential impact on Cook Inlet belugas. In those instances in which data specifically referring to Cook Inlet and belugas, comparable studies from other species (both aquatic and terrestrial) and locales that are relevant were reviewed
Data gaps are identified and described within the report and are identified at the end of each stressor section. Recommendations for further research based on needs identified in the data gaps sections are provided. The purpose of the recommendations is to provide NMFS with guidance on prioritization for additional data collection, study, and evaluation.

A. Anthropogenic stressors

Pressure on fish stocks

Beluga whales are viewed as top predators in the food chain and, from a global perspective, their diets vary regionally and seasonally (Stewart and Stewart 1989). Cook Inlet beluga whales appear to feed on a wide variety of prey species, focusing on specific species when they are seasonally abundant. Stomachs collected from beluga carcasses that stranded in Cook Inlet during the spring, summer, and fall provide evidence of prey availability and possibly preferences (Hobbs et al. 2008). Based on stomach contents from two carcasses, selected seasonal prey items were identified (Hobbs et al. 2006). In the spring, eulachon (*Thaleichthys pacificus*) and saffron (*Eleginus gracilis*) and Pacific (*Gadus macrocephalus*) cod species were consumed (NMFS Alaska Regional Office, unpublished data). In summer, salmon species are the preferred prey, particular chum (*Oncorhynchus keta)* and coho (*Oncorhynchus kisutch*). In the fall, as anadromous fish runs begin to decrease, fish species found in nearshore bays and estuaries again return to the beluga diet. This includes species observed in the spring diet as well as other flatfish spp (Hobbs et al. 2006).

Of 17 mostly complete stomachs with food that were examined, 14 contained fish, primarily salmon (71%), cod (43%), smelt (14%), and flounder (14%) (Quakenbush and Bryan 2010). Of the salmon that could be speciated, 36% were Coho, 21% chum, and 7% Chinook *(Oncorhynchus tshawytscha)*. Cod species included saffron and walleye Pollock (21% each), and Pacific cod (7%). Of the smelt identified, all were eulachon and yellowfin sole (14%). Starry flounder (7%) comprised the observed flounder. Nine stomachs contained invertebrates, mostly shrimp (78%), but also included polychaetes, amphipods, mysids, crab, echiurids, and sponges. Stable isotope studies on bone obtained from the skulls of 24 Cook Inlet belugas (1965-2007) used carbon and nitrogen isotope signatures to identify general diet alterations over the animal's lifetime (Quakenbush and Nelson 2010). Preliminary results demonstrated the trophic level at which the belugas are feeding has decreased from 1965 to the present which could indicate a change in prey availability.

Although some uncertainty remains, the limited data on free-ranging energetics for odontocetes suggest that captive animal feeding rates are a reasonable approximation to actual rates of food consumption in the wild (Perez et al. 1990). Food consumption of male and female adult and juvenile beluga whales held in captivity is summarized in Hinga (1979). Sergeant (1969) reported that beluga whales maintained in captivity consumed an equivalent of 4% of their body weight daily. Other sources have reported captive belugas eat approximately 2.5% to 3% of their body weight per day, about 18.2 to 27.2 kg (SeaWorld 2011). Hunt et al. (2000) calculated the total estimated energy value of the Cook Inlet beluga whale diet (93% comprised of fish of unspecified species) to be 1.3 kcal/g based on a mean weight of 303 kg. For a corrected population of ~800 individuals (Hill and DeMaster 1998), the authors calculated the summer energy requirements of this population (over 101 days in June-September), to be 9,726,300 kilojoules based on an individual daily allometric energy requirement of 96,300 kilojoules/day (Perez and McAlister 1993). Perez and McAlister (1993) estimated the total biomass of fish consumed by Cook Inlet belugas during the summer to be 2,500 metric tons. Of this total, benthic invertebrates (4kj/g) comprised 0.5 metric tons, small epipelagic fish (7kj/g) 0.5 metric tons, and miscellaneous fish species (5kj/g) 1.5 metric tons (Hunt et al. 2000). Based on these values, and of a mean abundance of ~350 individuals, the total biomass of fish consumed by CIBW during the summer would be approximately 1250 metric tons. Chum, coho and other salmonid species constitute >54% of the CIBW summer diet (Hobbs et al. 2008).

In Puget Sound, Chinook salmon are known to comprise a high percentage of the diet of Southern Resident killer whales (*Orcinus orca*) from May to September (Hanson et al. 2010) and is consistent with previous studies of Southern and Northern Resident diet composition (*i.e.*, Ford and Ellis 2006). Resident killer whales may favor Chinook salmon because Chinook have the highest lipid content (Stansby 1976), largest size, and highest caloric value per kg of any salmonid species (Ford and Ellis 2006). The preference for Chinook salmon may also relate to the whales' ability to detect or catch large fish (Au et al. 2010), or may be a constraint of their culturally inherited foraging strategies (Ford et al. 2010). There is speculation that Cook Inlet beluga whales may also be dependent on lipid-rich Chinook salmon earlier in the summer after a winter spent feeding on lesser quality fish (Hobbs et al. 2006).

Based on the average size of an adult chum (26 kg) and coho (3.6 kg) salmon, and their energetic content (502 kjoules/100g and 610 kjoules/100g, respectively) (NMFS 2011a), an average adult chum salmon would contain 130,520 kjoules and an adult coho, 21,960 kjoules, requiring an estimated range of at least 1 (chum) – 4 (coho), or combination, daily provided these mean weights do not decrease. Coho salmon weights have remained steady in Alaskan waters in contrast to decreases observed in more southerly areas of the Pacific Rim (Shaul et al. 2007). Therefore, the beluga population (~340 whales based on the 2010 count) would conservatively require approximately 35,350 – 141,400 adult salmon during the summer to maintain current numbers and metabolic rates. However, this number of salmon may be elevated, since during its calculation one assumes juveniles and calves are also eating adult salmon. It is unlikely that smaller beluga can swallow an adult chum salmon, consequently the diet of younger beluga may be more heavily dependent on coho salmon. This age dependent consumption by species would require adjustments to the average diet depending on the annual growth (larger fraction of juveniles and calves) /decline (smaller fraction) rate of the beluga population.

Fisheries may compete with belugas for salmon and other prey species. Any reduction in the ability of belugas to reach or utilize spring/summer feeding habitat, or any reductions in prey availability, may impact the energetics of these animals and delay recovery (Williams et al. 2006, Ford et al. 2010). There is strong indication these whales are dependent on access to relatively dense concentrations of high nutritional value prey such as eulachon and salmon species throughout the spring and summer months, respectively (Hobbs et al. 2006). Pinniped studies have demonstrated that top level predators may compensate for decreased access to, or availability of, prey species by making behavioral adjustments at the scale of individual dives. For example, lactating Antarctic fur seal (*Arctocephalus gazella*) females fitted with harnesses to simulate added drag during dives were able to compensate for the additional foraging costs brought on by slower swimming speeds by diving at a steeper angle (Boyd et al. 1997). Captive Steller sea lions (*Eumatopias jubatus*), also fitted with harnesses to simulate drag, compensated for changes in the cost of foraging and maintenance of foraging efficiency by altering their dive strategy over an entire bout of dives when operating within their aerobic scope (Cornick et al. 2006).

Cook Inlet belugas may also be heavily dependent on oil-rich eulachon (*Thaleichthys pacificus*) as a prey source early in the spring (preceding salmon migrations) and that large eulachon runs may occur in only a few upper Inlet streams. If belugas are heavily dependent upon the energy-rich eulachon in early spring, and the runs are very short in duration, a reduction in total availability of eulachon could be detrimental to belugas. Eulachon are caught in commercial, sport, and subsistence fisheries in the upper Inlet. A commercial fishery located in high-use beluga habitat in the Susitna Delta (Rugh et al. 2010), has occurred sporadically over the years (1978, 1980, 1998, 1999, and 2006 (Shields 2005, P. Shields, ADFG, pers. comm.). NMFS made recommendations to the Alaska Board of Fisheries (BOF) to discontinue the commercial fishery for eulachon, now occurring from May 1 to June 30 between the Chuitna and Little Susitna Rivers, and is limited to 100 tons (BOF 2005) as no quantitative assessment of the Susitna River smelt stocks has been conducted (Shields 2005), nor has an evaluation of this fishery's effects on belugas been conducted in terms of disturbance/harassment or competition for these fish. Personal use fishing for eulachon also occurs and there are no bag or possession limits.

The two most significant areas where eulachon are fished in personal use fisheries occur in the 20-Mile River (and shore areas of Turnagain Arm near 20-Mile River) and Kenai River. Other eulachon fisheries include the Placer River, Susitna and Little Susitna River, and Deshka River and Yentna River (tributaries to the Susitna River), and shoreline areas along Turnagain Arm and Cook Inlet north of the Ninilchik River. Annual removals have ranged from 2.2 to 5 tons during the past decade (NMFS 2008a). The personal use fishery for eulachon is possibly under-reported as some participants may confuse their removals as being subsistence and not personal use. Currently, no subsistence records are kept for eulachon or herring fisheries (Shields 2005).

The estimated number of sport fishing (personal use) anglers for all species of fish in south central Alaska has ranged from 280,000-325,000 over the years 1996-2009 (Alaska Department of Fish and Game 2011). Most of the fisheries occur before anadromous fish reach the river mouths and estuaries where belugas typically feed, consequently they intercept prey before the beluga have an opportunity to feed While the

State of Alaska manages the salmon fisheries to meet escapement goals for various waters, and fisheries are opened and closed throughout the season, presenting opportunities for adequate numbers of salmon to reach their spawning streams (NMFS 2008a), it is unknown if the amount of escapement into these rivers is sufficient to maintain the beluga population (Goetz et al. in review). Escapement data are not comprehensive, many rivers emptying into Cook Inlet are not monitored, and data have been collected by multiple methods, so may not be entirely comparable. ADFG currently does not have escapement data for Cook Inlet fisheries listed on their website.

The mean number of salmon caught in commercial fisheries in upper Cook Inlet from 1956-2009 was 4,191,748 salmon, with fluctuations ranging from 1,064,485 (1959) to 10,564,618 (1992) salmon (Shields 2010) (Fig. 1), and in lower Cook Inlet ranged from a low of 103,936 salmon in 1974 to 3,737,393 salmon in 1982 (Fig. 2) (Bucher and Morrison 1990, Hammarstrom and Ford 2010). It is not known how fluctuations in salmon run strength affect belugas or how fishing pressure is impacting beluga prey stocks. It is also unknown what proportion the fish targeted by the upper and lower inlet fisheries constitute prey species in the diet of Cook Inlet belugas. In addition to the indirect effects from fishing, direct effects include entanglement, ship strike, and displacement from feeding areas which will be discussed in the following section.

Data Gaps:

- Salmonid runs: Current and historic escapement biomass, species mix and timing for most rivers or watersheds emptying into Cook Inlet are not available.'
- Eulachon: population status, biomass and records of removals by fisheries (including subsistence and personal use), specifically, quantitative assessment of

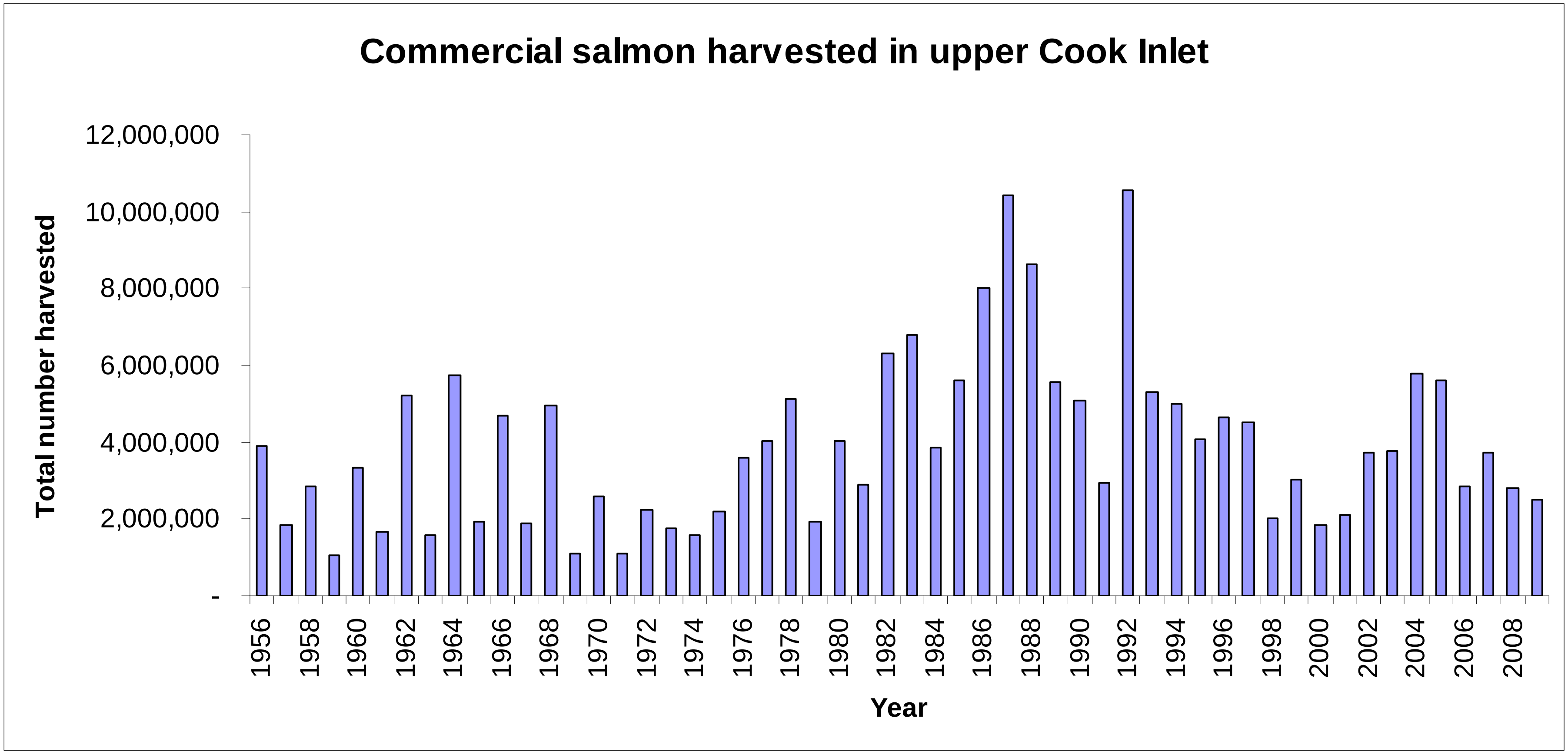

Figure 1. – Commercial salmon catch for all gear and harvest types in numbers of fish, upper Cook Inlet, 1956-2009 (Shields 2010).

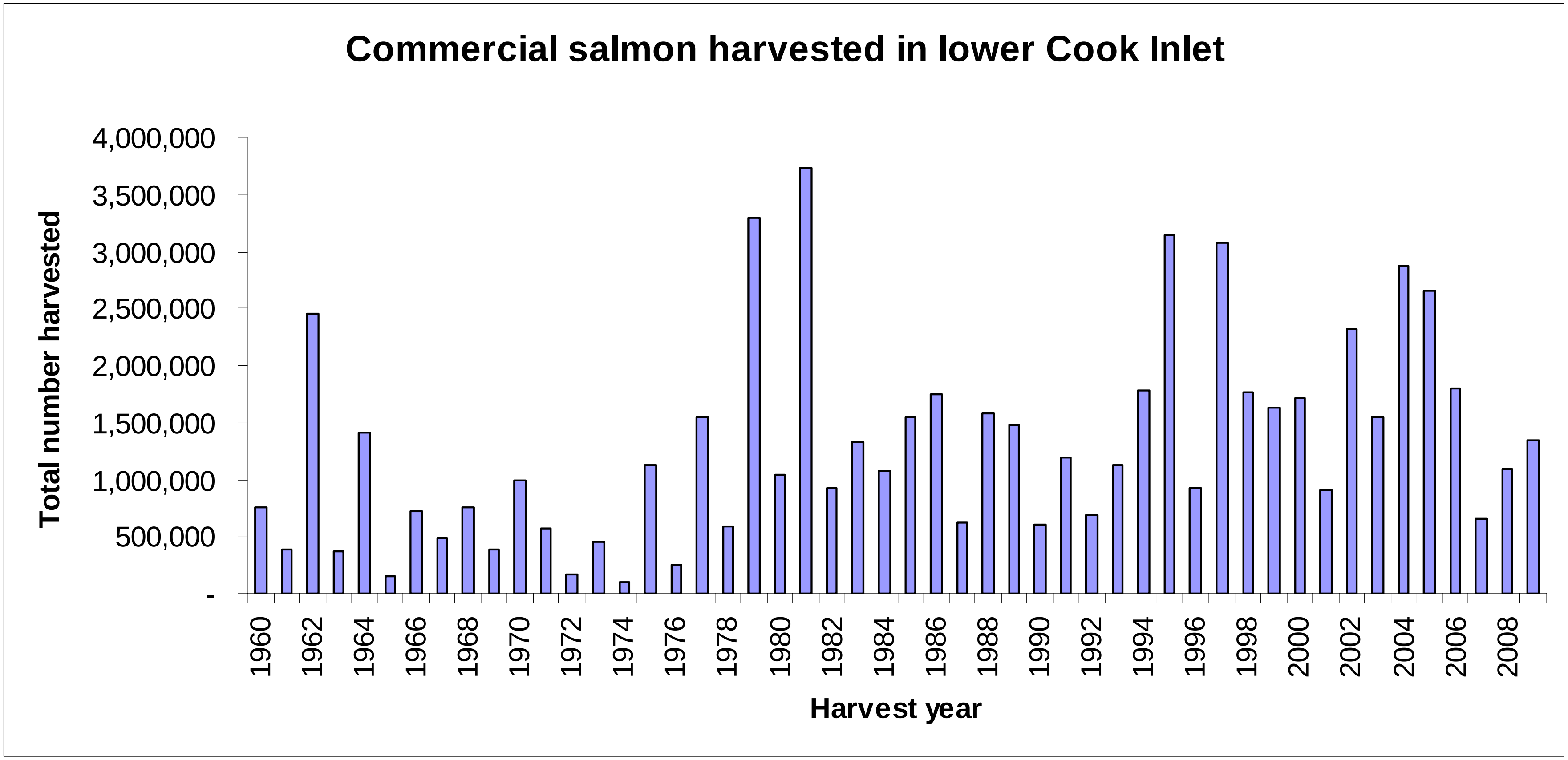

Figure 2. – Commercial salmon catch for all gear and harvest types in numbers of fish, lower Cook Inlet, 1960–2009 (Bucher and Morrison 1990, Hammarstrom and Ford 2010.

Susitna River eulachon/smelt stocks and evaluation of effect of this fishery on belugas in terms of disturbance/harassment or competition.

- Other prey species: Distribution, abundance and seasonality is not known for most species and areas within Cook Inlet. Energetic value of other preferred beluga prey items, such as cod and other flatfish is little known.
- Further stable isotope studies to better determine changes in a prey consumed by beluga whales before, during, and after the population decline.
- Beluga: Seasonal prey preferences and prey switching of Cook Inlet belugas are little known. Variation in regional and life stage prey selection is unknown and energetic requirements for various life stages of Cook Inlet belugas is unknown.

Recommendations:

- Comprehensive salmonid in-migration study to determine timing and size of runs by species and river or watershed.
- Assessment of Susitna and 20 mile eulachon runs.
- Prey base surveys of CI by season through the year.
- Continue and extend studies of stable isotope data and fatty acid composition of beluga skin and blubber and potential prey items at different times of the year to identify prey species and quantify importance (Dahl et al. 2000).
- Conduct feeding studies of fatty acid/stable isotope signatures in beluga blubber/skin using captive animals with, known diets to understand “cofactors” and “conversion factors”.
- Quantify metabolic requirements of different beluga life stages by captive animal studies and tagging of wild beluga.

Ship/vessel Disturbance (Non-acoustic)

Direct effects

Disturbances caused by fishing, such as entanglement in fishing gear and set nets impeding travel, and shipping vessels may also be a factor in the Cook Inlet beluga whale decline, and seems to increase over time (NMFS 2008a). Vessel traffic can directly cause marine mammals to alter their behavior, change movement patterns, or can even collide with them (Gubbins 2002). National Marine Fisheries Service researchers have often witnessed avoidance and overt behavioral reactions by belugas such as head-lifting and slow-rolling when approached by small vessels such as set net, sport fish or recreational boats (Lerczak et al. 2000). While noninjurious consequences, such as beluga avoiding an area of boat traffic, may seem unimportant, displacement from feeding or calving habitats could be very harmful to the recovery of this population. Daily shore-based, and occasionally boat-based, opportunistic visual and acoustic observations were made of beluga whales during the summer of 2007 in lower Knik Arm (Stewart 2010). Although interactions between small boats and beluga whales were uncommon in this area, whales did respond to close moving or approaching boats (up to several hundred meters away) with a change in behavior when boats passed. Behavioral responses varied with distance, speed, and boat bearing relative to the whales, and whales behavior prior to contact. The whales either maintained their course, but swam quickly away from stationary or pursuing boats or evaded boats and changed direction. In both cases, whales spent more time underwater while boats were nearby than before the encounters (Stewart 2010).

Effects of behavioral responses of whales and dolphins to boat traffic, the effects at the population level generally remain unclear. Behavioral studies need to be carried out alongside more detailed research on individual survival, reproductive rates and movements in order to assess whether vessel traffic that occurs around the animals has a significant impact at the population level. Investigations should attempt to determine whether problems caused by vessels are largely caused by boat acoustics and their effect on the whales, or non-acoustic in nature such as exposing the animals to harmful chemicals or causing bodily injury. Numerous study methods can be employed, but the use of controlled experiments, and land- and boat-based observations and acoustic techniques are particularly appropriate.

Vessel pollution

Vessels of all sizes and uses may be a pollution source from leakage of oil and other engine fluids into the water. The volume of leaked fluids into the Cook Inlet ecosystem is unknown, as is the impact on beluga health and that of its prey.

Vessel strikes

Although ship strikes have not been definitively documented in Cook Inlet, they may pose a threat as most of Cook Inlet is navigable and used by a variety of water craft classes. Presumed boat strike and propeller marks have been documented on individual whales during photo-identification studies (McGuire et al. 2011a). Commercial shipping occurs year round at several port facilities (*e.g.*, Anchorage, Point MacKenzie, Tyonek, Drift River, Nikiski, Kenai, Anchor Point, and Homer), along with bulk cargo freighters and tankers. Various commercial fishing vessels utilize Cook Inlet, the most intensive associated with salmon and herring fisheries (NMFS 2008a). Because of their straight line movements and slower speed, ship strikes from large vessels (e.g., over 30 meters) are not thought to pose a significant threat to belugas, but smaller boats traveling at higher speeds and making frequent directional changes may pose a bigger threat. Several areas where small vessel traffic and high whale density intersect have been identified such as the mouths of the Susitna and Little Susitna Rivers (NMFS 2008a). Jet skis use has also increased in Cook Inlet and these lighter, highly maneuverable craft can readily reach preferred beluga habitat not accessible to other mariners (NMFS 2008a).

Behavioral impacts of vessels

Although high speed approaches usually elicit escape responses in beluga whales, their behavior may be altered by slower boats too. A limited number of studies on the effects of boats on cetaceans have been published (Au and Perryman 1982; Janik and Thompson 1996; Bejder et al. 1999; Nowacek et al. 2001; Mattson et al. 2005). The impacts from vessel activity on cetaceans are of particular concern along coastal areas due to the large number of boats, high noise level, speed and mobility, and their widespread use (Richardson et al. 1995). Some studies have reported that the dominant behavioral response of cetaceans to vessel traffic has been increased swim velocity, spatial avoidance, and diving pattern changes (Janik and Thompson 1996). The probability and specific way a cetacean would avoid a vessel is expected to vary greatly by species, the population and its experience with water craft, and the specific behavioral activity demonstrated by the group upon encountering a vessel. The type of vessel and environmental conditions may also impact avoidance behavior (Au and Perryman 1982). Mattson et al. (2005) noted that multiple boats had a greater impact on bottlenose dolphin (*Tursiops truncatus*) behavior and movements than a single boat. Dolphin group size, behavior, and movement direction were all altered by several types of vessels, with jet skis eliciting the most dramatic effect. Ships (defined by Mattson et al. 2005 as slow-moving vessels up to 26 m in length), however, rarely caused a response, and when they did, behavior but not travel direction was affected. The ships rarely came within 5 m of dolphin groups and if they did, they reduced their speed to idle. The authors found that as the number of boats in the study area (Hilton Head, South Carolina) increased, both behavior and movement direction of cetacean groups were changed. Mattson et al. (2005) found that dolphin groups (n = 814 total individuals) responded to dolphin-watching vessels during 20% of observations with a change in both behavior and direction of movement primarily. Motorboats elicited responses in dolphins during 55% of observations, with a change in behavior or behavior and direction. The most dramatic effect on dolphin groups was noted with jet skis, with 56% of groups changing their behavior and 11% changing both behavior and direction.

Nowacek et al. (2001) attempted to quantify specific behavioral responses of individual bottlenose dolphins to boat traffic by conducting focal animal behavioral observations during experimental and opportunistic boat approaches on known, identifiable dolphins using small outboard powered vessels and jet-drive personal watercraft. They observed longer interbreath intervals in dolphins approached by boats versus control dolphins (*i.e.*, no boats within 100 meters). During experimental boat approaches, an underwater video system captured subsurface responses of focal dolphins, which included decreased interanimal distance, heading changes, and increased swim speed compared to control periods (no boat approaches).

The responses of belugas and narwhals (*Monodon monoceros*) to ice-breaker ships in the Canadian high Arctic were studied over a 3-year period by Finley et al. (1990). Beluga whales tended to move rapidly along ice edges away from approaching ships, while narwhals did not display an overt panic reaction. This evasive swimming behavior has also been observed in Cook Inlet belugas (Stewart 2010). Beluga pod integrity broke down and diving appeared asynchronous during the "flee" response, whereas narwhals showed subtle responses to approaching ships. Although it is generally agreed that marine mammals are more likely to show strong avoidance reactions to vessels that make sudden changes in course, speed and noise levels (Richardson et al. 1989), other studies have shown that some cetacean species may not be obviously affected by regular vessel traffic in their habitat (Failla et al. 2004). However, one cannot be certain that lack of behavioral response implies lack of a physiological response (Bejder et al. 2009). Alaska Native beluga whale hunters with the Cook Inlet Marine Mammal Commission have said that Cook Inlet beluga whales are very sensitive to boat noise, and will leave areas subjected to high use. In less pristine, more heavily trafficked areas belugas may habituate to vessel noise. For instance, beluga whales appear to be relatively tolerant of intensive fishing vessel traffic in Bristol Bay and are commonly seen during summer at the Port of Anchorage, Alaska's busiest port (NMFS 2008a).

Williams et al. (2006) and Lusseau et al. (2009) documented behavioral changes in northern and southern resident killer whales, respectively, in the Pacific Northwest, in response to vessel traffic of various types. In the presence of vessels, foraging behavior of fish-eating killer whales was inhibited, which could lead to decreased energy acquisition. Killer whales reduced their time spent feeding from 13% to 10% when boats were present and increased their travel budget by 12.5% (Williams et al. 2006). Killer whales near boats shortened their feeding bouts and initiated fewer of them than in the absence of boats. This has also been found in studies of terrestrial mammals, where feeding activity is easier to observe than in free-ranging cetaceans. Amur tigers (*Panthera tigris altaica*) in Krai, Russia showed strong vulnerability to human disturbance in the form of road traffic (Kerley et al. 2002). Tigers at undisturbed sites further away from roads spent more time at kills and consumed more of the kill than tigers disturbed by humans and nearby traffic. Ultimately, disturbance to tigers was linked to lower reproductive success and higher adult mortality than tigers that occupied sites far from roads (Kerley et al. 2002). However, they did note that strong behavioral responses to disturbance, seen in individual animals, do not always imply population-level effects. It is difficult to infer population-level consequences from inter-individual variability in sensitivity to disturbance (Gill et al. 2001). It is, therefore, important to show the link between short-term behavioral effects and resulting population dynamics. Williams et al. (2006) proposed a sensitivity analysis to provide preliminary evidence that disturbance can carry higher costs to killer whales in terms of reducing energy acquisition rather than increasing energetic demand. The approach they outlined could serve as a model to integrate physiological information into behavioral studies aimed toward conservation of the species, by modeling data from captive and free-ranging animals. They viewed their sensitivity analysis as particularly useful for conducting pilot studies to quickly and non-invasively assess whether the magnitude of a particular stressor is sufficient to justify investing resources into more sophisticated studies (Williams et al. 2006). Extreme within-species variation in responsiveness to boat noise is evident in data from beluga whales. Belugas in Bristol Bay display little reaction to many fishing boats (Frost et al.1984). These belugas feed on the fish, and have presumably habituated to repeated human activity that rarely has negative consequences for the belugas.

Indirect effects

Vessel traffic may also alter beluga habitat indirectly due to increased ship traffic from expansion of the ports at Anchorage and Point MacKenzie, new boat launches and the potential installation of a commercial ferry in lower Knik Arm (NMFS 2008a). Other indirect effects of vessel traffic may include habitat quality degradation from pollution such as engine fluid leaks, influencing prey movement and behavior, and causing avoidance of critical breeding or feeding habitat by the belugas (Richardson et al. 1995).

The Alaska Department of Environmental Conservation (ADEC) has funded the Kenai Peninsula Borough to conduct a detailed vessel risk assessment for Cook Inlet with regard to vessel traffic and the risk of major accidents or incidents and the potential for release of a hazardous substance from a vessel to the Inlet waters (ADEC 2010; Nuka Research and Planning Group 2010). The risk from vessel traffic is compounded by extreme tidal currents in the Inlet, and seasonal ice conditions. The risk assessment study is underway and will maintain a website with current updates on the study progress (Alan Wien, ADEC, Project Manager, personal communication via e-mail, 7 April 2011).

Data Gaps:

- The impact a given type and level of vessel disturbance has on behaviors such as resting, socializing, and parental care activities, lost foraging opportunities and habitat use is unknown.
- Population level data on survival and reproductive rates are needed to assess whether vessel traffic that occurs around the animals has a significant impact.

- Amount of leaked/spilled vessel fluids and fuel and potentially toxic cargo into Cook Inlet is unknown as is their impact on beluga health and their prey species.
- Unknown if Cook Inlet belugas display any habituation to vessel presence, and if habituation involves displacement to habitats of lesser value, reduced foraging effectiveness, or other impacts.
- It is unknown whether interference from vessels causes significant and/or permanent behavioral changes or physical injuries among belugas, and if so, whether these effects are serious enough to reduce survival or reproduction in the population.
- Impacts from vessels on foraging efficiency and energy acquisition are unknown.
- Whether energy expenditures increase in the presence of vessels is unknown.
- Metabolic rates required when incrementally increasing swimming speed and differing breathing/surfacing rates are unknown.

Recommendations:

- Behavior studies which relate changes in behavior to levels and kinds of disturbance should be conducted in high and low disturbance areas in Cook Inlet and in a similar population in different areas such as Bristol Bay or the St. Lawrence River.
- Gather population level data on survival and reproductive rates to assess impact of vessel traffic around the animals.
- Conduct water sampling and contaminant studies that help determine the amount of leaked/spilled vessel fluids and fuel, and potentially toxic cargo that may spill

or has spilled into Cook Inlet, and determine their impact on Cook Inlet beluga health and that of their prey species.

- Determine whether Cook Inlet belugas display habituation to vessel presence, and if habituation involves displacement to habitats of lesser value, reduced foraging effectiveness, or other impacts.
- Observational studies similar to those in southern resident killer whales to determine any impacts from vessels on foraging efficiency and energy acquisition, and whether increased energy expenditures increase occurs in the presence of vessels.
- Studies relating behavioral changes and chronic or intermittent stress to increased metabolic requirements and changes in fecundity or survival are required to quantify impacts to populations.

Roads and Vehicular Traffic

Changing land-based vehicular traffic patterns may occur in response to changes in human population totals, workplace, and construction during summer peak months, which may cause changes in routes taken. Increases in both peak and winter traffic indicate changes in resident usage, while increases in peak summer traffic likely indicate increased tourism or summer workers. While patterns of road traffic may not directly impact Cook Inlet beluga survival and recovery, motor vehicle use growth rates and patterns provide some indications of human population growth, increased development, natural resource exploitation, and production of nonpoint source pollution. For instance, increases in human populations concentrate in certain areas such as ports like Anchorage. This major urban center that has developed around Anchorage and its outlying areas has resulted in severe reduction of coastal habitat along the inlet coastline which in turn may have an adverse impact on wildlife and fish species due to habitat reduction or modification. Permanent Traffic Recorder (PTR) data indicate vehicular traffic has grown from 0.8% (Anchorage area) to 2.9% (Eagle River area) over the past three decades, greater than in any other region in the state (Alaska Department of Transportation [ADOT] 2011a). The number of land-based transportation improvement projects in the Cook Inlet area is projected to increase in the near- and long-term (ADOT 2008).

Threats to wildlife from conflicts with the transportation system result in several types of impacts. These can be characterized by direct habitat loss when roadways are built mainly in low elevation areas, where the concentrations of wildlife are the greatest and opportunities for habitat loss the greatest, particularly for returning salmon (Transportation Research Board 1999). Bridges, highways, and roads are also potentially significant sources of pollutants to waterways, with the amount of potential pollutant contributions being a function of traffic volume. As rainwater and snowmelt wash off these surfaces, the water picks up dirt, dust, small pieces of rubber and metal, engine oil, grease, heavy metals such as zinc, road salts and/or other deicing agents, antifreeze drippings, and miscellaneous solid litter and debris. In studies looking at the long-term effectiveness of permeable pavement as an alternative to traditional impervious asphalt pavement in a parking area, mean concentrations of copper, zinc, and motor oil detected in stormwater samples were 7.98 μg/L, 21.6 μg/L, and 0.164 mg/L, respectively (Brattebo and Booth 2003). The zinc concentration was increased from a mean concentration of 12.0 μg/L from studies conducted in 1996 (Booth and Leavitt 1999).

The effects of road construction across rivers and streams include short term elimination of benthic life and fish population for some distance below the crossing site due to siltation and turbidity, as well as obstruction of adult and juvenile upstream migration due to poorly installed and maintained culverts, floods etc. (Barton 1977). Additionally, disturbance during bridge construction in-water work for highway expansion, and noise from traffic over bridges and/or adjacent to the water may impact Cook Inlet beluga whales.

Data Gaps:

- Amount of vehicular fluids, fuel, heavy metals, other pollutants, debris and trash released onto road surfaces remains unknown.
- Of the amount pollutants deposited on road surfaces by vehicles, the percentage that is washed into streams, creeks and other bodies of water that empty into the Inlet is unknown.
- Acoustic and behavioral impact of noise from bridge construction and traffic over bridges and adjacent to the water on Cook Inlet beluga whales is unknown.

Recommendations:

- Assess the amount of vehicular fluids, fuel, heavy metals, other pollutants, debris and trash released onto road surfaces through simulation studies, and determine what percentage of those substances is washed into waterways emptying into Cook Inlet.
- Studies quantifying impacts of toxic exposure to increased metabolic requirements and changes in fecundity or survival are required to quantify impacts to populations

Noise/Sound

Upper Cook Inlet is the most industrialized and urbanized regions of Alaska. As such, ambient anthropogenic noise levels are high (Blackwell and Greene 2002) and appear to be increasing as more construction and improvement projects are undertaken and vessel and aircraft traffic increase (NMFS 2008a). An overview of anthropogenic sounds Cook Inlet belugas must compete with acoustically is given in Hobbs et al. (2006) and in the conservation plan (NMFS 2008a). They include marine seismic surveys, aircraft, vessels, pile driving, oil and gas drilling, and dredging (Moore et al. 2000). The impacts of these anthropogenic sounds on marine mammal populations are not fully understood at this time. However, an understanding of the behavioral significance of vocalizations emitted by undisturbed beluga whales can provide important comparative data for future research on the vocal behavior of beluga whales during migration and breeding season (Sjare and Smith 1986). If enough is learned about the vocal behavior of undisturbed whales, changes in the type and rate at which vocalizations are emitted could be used to quantitatively evaluate how they respond to various types of disturbances.

Pervasive underwater sound from commercial shipping increases levels of background noise, which may mask acoustic signals that are important for marine mammal communication, foraging, predator avoidance, and navigation (Kruse 1991; Miller et al. 2000; Croll et al. 2001; Foote et al. 2004). Noise may affect developmental, reproductive, or immune functions, and cause more generalized stress. Some studies show that long-term exposure to anthropogenic noise may cause marine mammals to abandon their essential habitat (Bryant et al. 1984; Morton and Symonds, 2002).

Based on captive research it is known that beluga whales hear best at relatively

Based on captive research it is known that beluga whales hear best at relatively high frequencies, in the 10-100 kHz range (Blackwell and Greene 2002), which is above the range of most industrial activities. Studies within Knik Arm have identified underwater sound levels as high as 149 dB re: 1µ Pa., associated with a tug boat docking a barge (Blackwell and Greene 2002). Sounds associated with offshore oil platforms were also investigated and were found to generally be below 10 kHz. Beluga whales off the Port of Anchorage did not appear to be harassed by such sounds, but it cannot be determined if they were tolerating the sounds in order to continue to feed or if the efficiency of their feeding was reduced. The lowest ambient (anthropogenic and "natural" environmental underwater sounds levels in upper Cook Inlet were located at two locations heavily frequented by beluga whales, the mouth of the Susitna River and east Knik Arm near Birchwood (Blackwell and Greene 2002). In 1994, the Marine Mammal Protection Act section 101(a)(5) was amended to establish an expedited process by which U.S. citizens can apply for an authorization to incidentally take small numbers of marine mammals by "harassment," referred to as Incidental Harassment Authorizations (IHA). This process will be amended to include criteria for acoustic harassment (NOAA 2011).

Fish are also considered vulnerable to intense underwater sounds. Increased levels of background sound can mask sounds critical to fish survival, decrease auditory sensitivity, and modify behavior. Research is needed to determine whether prey populations change their behavior in response to anthropogenic sound, making the capture of individual fish more difficult for the beluga whales.

Marine geophysical seismic surveys

There is relative lack of knowledge about the potential impacts of acoustic energy from seismic surveys on marine fish and invertebrates, several of which may make up part of the beluga's diet. Available data suggest that there may be physical impacts on eggs and on larval, juvenile, and adult stages of fish at very close range (within meters) to seismic energy source. Further discussion of this can be found in Guan and Payne (2007). A study by Blackwell and Greene (2002) did not address marine geophysical seismic activity in Cook Inlet, which has been described as one of the loudest man-made underwater sound sources and has the potential to harass or harm marine mammals, including belugas (LGL 2001; Gordon et al. 2004; Richardson et al. 2005). Strong acoustic signals from seismic activity have been known to cause behavioral changes such as reduced vocalization rates (Goold 1996), avoidance (Richardson et al. 1986, 1987; Malme et al. 1988; Richardson et al. 1985, 1990, 1995; Harris et al. 2001), and blow rate changes (Richardson et al. 1995) in several species of marine mammals such as bowhead whales (*Balaena mysticetus*), gray whales (*Eschrichtius robustus*), common dolphins (*Delphinus delphis*) and ringed seals (*Phoca hispida*). Compared to mysticetes such as bowhead and gray whales, behavior of odontocetes exposed to seismic pulses has received little study.

Other than beluga whales, odontocetes such as killer whales, pilot whales (*Globicephala* sp.), white-beaked and white-sided dolphins (*Lagenorhynchus* sp.), among others have been observed near operating airgun arrays by seismic operators (Arnold 1996; Stone 1997, 1998, 1999). Odontocetes showed no change in behavior when a 3,959-in^3, 18-airgun array was firing off California (Arnold 1996). Rather many dolphin species seem to be attracted to the seismic vessel, and its associated floats, and swim toward them. In Puget Sound, however, Dall's porpoises (*Phocoenoides dalli*), observed when a 6,000-in^3, 12 – 16 airgun array was firing, tended to head away from the survey boat (Calambokidis and Osmek 1998). Seismic vessel observers off the United Kingdom showed variable results among species of odontocetes and years. Various species of dolphins, however, often showed more evidence of avoiding operating airgun arrays than has been previously reported for small odontocetes. Alaska Native beluga hunters have said that Cook Inlet belugas are at times very sensitive to anthropogenic sound and will leave high-use areas (Huntington 2000).

In addition to behavioral responses, exposure to high intensity sound for an extended period of time may also result in auditory effects such as hearing threshold shifts (TSs) (Richardson et al. 1995). Studies conducted on captive bottlenose dolphins and beluga whales exposed to single underwater impulses from a seismic watergun showed no temporary TS in the dolphin at the highest exposure conditions (Finneran et al. 2000, 2002). Effects of various sound exposures depend not only on the pressure alone, but also on the exposure duration. Bowles et al. (1994) found that sperm (*Physeter macrocephalus*) and pilot (*Globicephala melas*) whales tended to be quiet when exposed to weak pulses from a distant seismic ship.

Aircraft Noise

Response of marine mammals to aircraft vary with aircraft altitude, distance from aircraft and the social context of the animals (Richardson and Würsig 1997). Marine mammals will often react to an aircraft as if startled, turning or diving abruptly when the aircraft is overhead (Richardson et al. 1995). This reaction is thought to occur because the underwater noise produced by the aircraft is greatest within a 26-degree cone directly under the aircraft (Richardson et al. 1995). Beluga whales were reported to not react to aircraft flying at 500 m (1,640 ft), but at lower altitudes around 150-200 m (492-656) ft, they dove for longer time periods and occasionally swam away (Richardson et al. 1995). Beluga whales that were feeding appeared to be less prone to disturbance. Aerial surveys of belugas in Cook Inlet are consistently flown by NMFS at an altitude of 244 m (800 ft), use fixed-wing twin engine aircrafts. At this altitude Cook Inlet beluga whales are rarely observed to react, even to repeated overflights, as aircraft are very common in this area (NMFS 2003).

Beluga and bowhead whales often seem less responsive to passing aircraft when the whales are actively engaged in feeding, social activities or mating than when resting (Bel'kovich 1960; Richardson and Malme 1993). Patenaude et al. (2002) opportunistically observed responses of beluga and bowhead whales to helicopters and twin-engine aircraft during four spring seasons in the Beaufort Sea. The helicopter elicited a greater number of detectable responses by belugas (38% of 40 groups) than by bowheads (14% of 63). Belugas reacted significantly more frequently during overflights at lateral distances ≤ 250 m than at longer lateral distances. When in the vicinity of fixed-wing aircraft, few belugas were observed to react to overflights at altitudes 60-460 meters. When measured underwater at depths 3 m and 18 m, a Bell 212 helicopter was shown to be 7-17.5 dB noisier than a Twin Otter (10-500 Hz band) (Patenaude et al. 2002). While the dominant low-frequency components of aircraft sound are presumed to be readily audible, for belugas these components may not be audible, or only weakly audible. Mid-frequency sound components, visual cues, or both, are probably more important in eliciting reactions to aircraft in beluga whales (Patenaude et al. 2002).

A circling aircraft sometimes causes subtle changes in surfacing and respiration patterns even when there is no sudden dive or other conspicuous response, such as in bowhead whales (Richardson et al. 1985). Therefore, the absence of conspicuous responses to an aircraft (or other human activity) does not prove that the animals are unaffected. It is unknown whether these subtle effects are biologically significant. Relatively little is known about the importance of sound *vs.* vision in eliciting reactions to aircraft. Aircraft noise, especially from propeller aircraft and helicopters, is probably an important stimulus much of the time as it contains prominent tones (Richardson and Würsig 1997). However, most observations have been from the disturbing aircraft itself, greatly limiting what can be observed and largely prohibiting comparison of behaviors before, during and after the disturbance (Richardson and Würsig 1997).

The main approaches to the Ted Stevens Anchorage International Airport (TSAIC), Joint Base Elmendorf Richardson (JBEF), Hood Lake, and Merrill Field all occur at least partially over upper Cook Inlet. Commercial and military jet airplanes often overfly these waters at relatively low altitudes. The number of take-offs, and landings, from JBEF is unknown. The number of yearly commercial and cargo landings at TSAIC has increased from 92,613 in 2003 to 101,863 and is continuing to increase (ADOT 2011b). Merrill Field in northeast Anchorage is a civilian airport ranked as the 72nd busiest airport in the nation in 2010 with over 144,892 flight operations (Municipality of Anchorage 2011). Blackwell and Greene (2002) conducted an acoustic measurement study in Cook Inlet and identified peak sound levels at 2.5 dB higher at 3 m (9.8 ft) than

18 m (59.1 ft) depth. At this level, both mid-frequency sound components and visual clues could play a role in eliciting reactions by the marine mammals (Richardson et al. 1995). Despite this traffic, beluga whales occur commonly in these waters and are often observed directly under the approach corridors off the north end of the International Airport and the west end of Elmendorf AFB (NMFS 2003).

Vessel Noise

Ships and boats create high levels of noise both in frequency content and intensity level that can be detected at great distances. High speed diesel-driven vessels tend to be much noisier than slow speed diesel or gasoline engines. Small commercial ships are generally diesel-driven, and the highest 1/3-octave band is in the 500 to 2,000 Hz range (Hobbs et al. 2006). An acoustic study by Blackwell and Greene (2002) suggested that beluga whales may not hear sounds produced by large ships at lower frequencies (*i.e.*, below about 300 Hz) based on data collected by Ridgway et al. (2001). At high frequency ranges, the sounds from ships may not be sufficiently above a beluga's hearing threshold or meet the criterion for Level B harassment.

Small outboard motor driven watercraft, such as those commonly used for recreational purposes in the upper inlet, typically produces noise at much higher frequencies (*e.g.*, 6,300 Hz) and may therefore, have the highest potential to disturb beluga whales. In addition, cetaceans may need to increase their call amplitude as observed in Puget Sound, Washington killer whales, which had to increase their calls by 1 dB for every 1 dB increase in background noise levels. Furthermore, nearby vessel counts were positively correlated with the observed background noise levels (Holt et al. 2008). In contrast, when the first ship or icebreaker of the year appears in the Canadian

High Arctic approaches, belugas change calling pattern and swim rapidly away as the ship comes within 35-50 km (Richardson and Würsig 1997). Beluga reactions begin when broadband (20-1000 Hz) received levels of ship noise are ~94-105 dB re 1 uPa, near the levels at which belugas might barely hear the higher frequency components of ship noise (Richardson and Würsig 1997). Sometimes the belugas will swim 80 km from their original location in response to the ship, and remain away for 1-2 days.

Another research team has confirmed this extreme sensitivity of belugas to noise disturbance from ships over several years (Cosens and Dueck 1988). The long reaction distances may be related to partial confinement by heavy ice, scarcity of ships in the area, and good sound propagation conditions (Richardson and Würsig 1997). In the St. Lawrence estuary, beluga whale calls were monitored before, during and after exposure to noise from a small motorboat and a ferry. Vocal responses were observed after exposure to both vessel types, and were more persistent when the whales were exposed to the ferry than to the small boat (Lesage et al. 1999). Responses included a progressive reduction in call rate, brief increases in the emission of falling tonal calls, an increase in the repetition of specific calls at distances <1 km from the vessel, and a shift in frequency bands used by vocalizing whales from 3.6 kHz prior to exposure to noise to 5.2-8.8 kHz when vessels were located close to the whales (Lesage et al. 1999).

Cook Inlet belugas are exposed to increasing levels of marine sound and vessel traffic over much of their range (NMFS 2008a); however, the trend of relative vessel types and numbers is unknown, but is expected to be increasing. Excessive noise from vessels, sonar, in-water construction, and other anthropogenic sources may interfere with the whales' communication, foraging, and navigation, may increase daily energetic costs,

and may produce physiological trauma. Vessel presence regardless of sound is also potentially problematic under some circumstances and may inhibit important behaviors. For example, two to four daily barge trips (occasionally five trips), each containing approximately 1,500 cubic yards of dredged material will be made to the disposal area during dredging season (mid-May through November) for the Port of Anchorage expansion project (Army Corps of Engineers [ACOE] 2008). The impact these daily barge trips will have on belugas is unknown. However, the Corps of Engineers has indicated it will cease dredging and
move dumping operations if beluga whales are within the boundaries of the dredging operation or in the vicinity of the dump site (ACOE 2008).

Of greater concern to the well-being of the marine mammal is the reaction to repeated disturbance from noise; however, there are few data on this. Gray and possibly bowhead and humpback (*Megaptera novaeangliae*) whales have shown medium- or long-term reductions in use of some areas with much shipping and other human activity (Bryant et al. 1984; Richardson et al. 1987). The roles of repeated disturbance *vs.* natural prey fluctuations in altering bowhead and humpback distribution are uncertain. The continued presence of cetaceans in some major shipping routes and fishing grounds shows tolerance of vessels and their noise.

Pile-driving

Percussive piling usually consists of a steel pile-driving hammer that falls about 1–2m by gravity, then detonates a fuel–air mixture that drives down the pile with extra force, thereby creating a broad-band gun-shot like sound (Jefferson et al. 2009). Pile driving associated with construction work close to or within the marine environment has the potential to modify marine mammal behavior, health and population densities, and may cause concern at a number of Cook Inlet locations. The response thresholds of cetaceans are usually the lowest for pulsed sounds, and pile driving is one of the loudest sources of this type of noise (Richardson and Würsig 1997). Pile driver noise can be perceived by cetaceans over a considerable distance and may have some effect on their ability to detect vocalizations (David 2006). Cetaceans are not expected to experience permanent hearing impairment from sound pressures generated by pile-driving activity, even when the whales are located very close to the source since the threshold peak impulse sound pressure for direct physical trauma in marine mammals is generally considered to be >200 dB (Richardson et al. 1995). Effects on behavior are more likely to be expected. Pile driver noise could interfere with environmental sounds, such as that made by prey species, as well as masking of communication and echolocation signals. Bowles et al. (1984) found that sperm (*Physeter macrocephalus*) and pilot (*Globicephala melas*) whales tended to be quiet when exposed to weak pulses from a distant seismic ship. In addition, underwater noise could startle or displace whales (David 2006). Proposed expansion of the Port of Anchorage and construction of a new bridge across Knik Arm in upper Cook Inlet may result in a relatively short-term increase in noise levels due to construction, especially from pile driving activities at both locations (Guan and Payne 2007). A passive acoustic study was conducted during the 2009 Marine Terminal Redevelopment (MTR) Project construction season at the Port of Anchorage, Alaska (Širović and Kendall 2009). Findings of the study indicated that most of the energy recorded from anthropogenic noise in the vicinity of the MTR Project was less than 10 kHz, with one exception of hammer pile driving noise, which extended up to 20 kHz (Širović and Kendall 2009). At this high sound level, over a broad range of frequencies, beluga whale vocalizations could be affected by masking, the interference of a sound of interest because both it and the noise have similar frequencies (Richardson et al. 1995). These construction noises, though, do not mask echolocation clicks which could be the primary vocalization produced by beluga whales in this area because they are trying to avoid other loud frequency bands (Širović and Kendall 2009).

Some attenuation of pile driver noise has been achieved by surrounding piles with an air bubble curtain. Würsig et al. (2000) achieved a 3–5 dB attenuation of broadband pulse levels using an air bubble curtain positioned within a 25m radius of the pile. The largest reductions in sound levels (8–20 dB) were achieved over a frequency range of 400–6400 Hz. Similar levels of attenuation were reported by Longmuir and Lively (2001) using an air bubble curtain generated by placing manifolds around the pile at 7m intervals. Other mitigation measures that may reduce the effects of pile driving on cetaceans include avoiding operations when cetaceans are giving birth to and rearing calves, as young calves are likely to be particularly vulnerable (David 2006). If animals are observed in the exclusion zone (*i.e.*, is a pre-defined area around the pile-driving activities (*e.g.*, 500 m radius) that if entered by marine mammals), then in-water works should be delayed until they have left the area. If they enter the exclusion zone after piling has commenced, in-water works should cease until they have left. A larger exclusion zone may be required when any calves are observed.

Explosions/detonations

Explosions such as those related to construction and bombing ranges may be sources of noise exposure to Cook Inlet belugas. The sounds may drive belugas in to shallow water because these are areas of higher sound attenuation and thus quieter, which along with timing of tidal cycles, may affect their chances of live stranding. Peak levels of pressure pulses from the detonation of > 1 kg of high explosive exceed levels from any other man-made source (Richardson and Würsig 1997). At close ranges, the shock wave can injure or kill cetaceans; however, data on behavioral reactions by cetaceans farther away are limited. Some baleen whales show little reaction to noise pulses from large blasts (Todd et al. 1996); however, Gilmore (1978) observed that migrating gray whale behavior was altered by underwater blasts within a few kilometers of the detonation. Reactions to blasts may not be strong enough to elicit avoidance of areas in which cetaceans are at risk from future explosions.

The resumption of year-round live-firing at the Eagle River Flats Impact Area (ERFIA) on USAG Richardson in north of Anchorage was evaluated in a Biological Assessment (US Army 2010). Historically, ERFIA has been an Army artillery impact area since 1945 and is currently used for winter firing of artillery into the flats. The assessment concluded that the live-firing is likely to affect the Cook Inlet belugas, but no impacts to their habitat were anticipated (US Army 2010). Finneran et al. (2000) conducted a study in which a behavioral response paradigm was used to measure masked underwater hearing thresholds in two bottlenose dolphins and one beluga whale before and after exposure to impulsive underwater sounds with waveforms resembling distant signatures of underwater explosions. Disruptions of the animals' trained behaviors began to occur at exposures corresponding to 5 kg at 9.3 km and 5 kg at 1.5 km for the dolphins and 500 kg at 1.9 km for the beluga whale. Although the presence of masking noise may have reduced the temporary threshold shifts (TTSs) observed in this study, the extremely high pressures that are needed seem to imply high resilience and a large dynamic range of the odontocetes auditory system (Finneran et al. 2000). This makes TTS studies using impulsive waveforms that resemble distant explosion signatures very challenging. It is difficult to generate sufficient source levels to produce a threshold shift in odontocetes utilizing very short duration sounds without having to actually use impulsive sources located close to the test subject (Finneran et al. 2000).

Offshore Oil and Gas Drilling and Production

Though sound produced by oil and gas drilling may be a significant component of noise in the local marine environment, underwater noise from drilling platforms is expected to be relatively weak due to the small surface area in contact with the water, namely the platform leg (Richardson et al.1995). Vibrations from the machinery through the columns and into the bottom may be notable, accounting in part for the high levels observed at low frequencies (<30 Hz) (Blackwell and Greene 2002). Richardson et al. (1990) observed behavioral reactions of bowhead whales during playbacks of recorded drillship and dredge noise. Some, but not all, bowheads oriented themselves away when received noise levels and spectral characteristics were comparable to those recorded several kilometers away from actual drillships and dredges. Feeding ceased, call rates decreased, and patterns of diving, surfacing, and respiration may have changed and individual sensitivity to noise differed among the whales (Richardson et al. 1990).

Various studies and observations suggest that beluga whales may be relatively unaffected by these activities. Beluga whales have been regularly seen near drill sites in Cook Inlet (Richardson et al. 1995). Beluga whales in the Snake River, Alaska, did not appear to react strongly to playbacks of oil industry-related noise at levels up to 60 dB above ambient (Stewart et al. 1982). Similar experiments were conducted in Nushagak Bay, Alaska, and beluga whale movement and general activity level were not greatly affected, especially when the noise source was constant (Stewart et al. 1983).

Cable- and pipe-laying operations

Little is currently known about the frequencies and levels of noise produced by pipe- and cable-laying operations, nor how these activities influence cetacean behavior and physiology (Jefferson et al. 2009). The most serious concern is that disturbing noise may cause beluga whales to abandon eventual critical habitat, and thereby reduce their survival and reproductive prospects.

Data gaps:

Some of the following are adapted from identified data gaps outlined in the Recovery Plan for the Southern Resident killer whales (NMFS 2008b).

- Potential impact of seismic energy on marine fish and invertebrates, particularly beluga prey species is unknown.
- Impact of noise on prey capture by belugas in vessel presence is unknown.
- Virtually no data is available on the significance of repeated low-altitude overflights to the well-being of cetaceans.
- Effect of vessel traits (*e.g.*, vessel type and activity; sound-pressure and sound-exposure levels; distance, size, speed and direction of travel; duration of interaction; and density and number of vessels present) on beluga behavior is unknown.
- Determine significant calls and whether they are masked by anthropogenic noise.

- Historical trends in ambient noise levels are currently unknown.
- The characteristics of sound propagation in the areas used by whales are unknown, particularly under different tide cycles and in the presence of prey fish.
- Critical distances belugas need during construction activities and whether the whales are able to partially compensate for masking noise.
- Acoustic responses to sound, including changes in the composition, rates, lengths, and "loudness" of calls, need to be evaluated.
- Effects of human-generated marine noise on beluga prey.

Recommendations:

- Studies relating behavior and changes in behavior to received sound (e.g. D-tags that record sound and movement data together) are necessary to identify threshold levels for behavioral interference of different sounds and the cumulative impact of sound should be conducted in Cook Inlet and a control population such as Bristol Bay.
- Audiograms of Cook Inlet belugas and a control population (e.g. Bristol Bay) should be collected to determine if permanent threshold shifts have occurred.
- Acoustic surveys should be conducted over several months throughout the upper Cook Inlet and a control area (e.g., Bristol Bay) to develop a complete picture of the acoustic environment of CI and allow for inclusion in area use models.
- Testing of bubble curtains and other technology for reduction of point source sound energy in the Cook Inlet environment.

Pollutants

Since Cook Inlet belugas inhabit near-shore aquatic ecosystems, they are vulnerable to human development and its accompanying pollution. There are several sources of pollution that enter Cook Inlet waters that include: 1) wastewater treatment system discharges; 2) runoff from urban development, vehicles, aviation, human and veterinary pharmaceuticals, and activities that do not enter wastewater treatment systems, such as agriculture and mining 3) contaminants; and 4) accidental spills such as oil (Moore et al. 2000; Burkholder et al. 2007, Guan and Payne 2007). It is unknown if the volumes of pollutants are increasing within the Cook Inlet ecosystem, but the amount of pharmaceuticals is thought to be underreported and increasing (Santos et al. 2010). Most pollutants entering the inlet are likely diluted and dispersed by tides, estuarine circulation, wind-driven waves, and currents. However, it has been noted in other regions with runoff into large bodies of water that pollution generated by industrial and agricultural development near cities has unfavorably impacted the environment. For example, juvenile Chinook salmon sampled from an urban estuary in Puget Sound contained elevated concentrations of pollutants (McCain et al.1990). Other cetacean populations living in urbanized areas, such as the Saint Lawrence Estuary belugas and Puget Sound killer whales, have been found to contain elevated levels of contaminants derived from terrestrial sources (Béland et al. 1993, Grant and Ross 2002, Ross 2005).

Nonpoint source pollution, or polluted runoff, generally results from land runoff, precipitation, atmospheric deposition, drainage, or seepage. Nonpoint pollution sources refer to broad, diffuse sources of activity that generate wastes and pollutants which are applied, spilled, leaked, leached, eroded, or dumped onto or into land or water. Nonpoint sources commonly originate from urban development, roads, highways and bridges, timber harvesting, agriculture, and harbors and marinas (ADEC 2000). The term "nonpoint source" differs from "point source", which pertains mainly to industrial facilities and sewage treatment plants that discharge treated wastewater through a pipe or other discrete method. The term "point source" is defined as any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged, but is exclusive of agricultural stormwater discharges and return flows from irrigated agriculture (ADEC 2000).

In a cold climate such as that encountered in Alaska, compared to the lower 48 states, the environment interacts with chemical pollutants to make its effects more serious than would be the case for the same substance in a warmer climate (Miller 1989a). Some of this is due to the fixed (or prevailing) weather patterns which provide fixed pathways for airborne contaminants, thus limiting their diffusion over a large area. Also, there is less precipitation in the higher latitudes than in more temperature or warmer climates; precipitation allows chemicals to be transported for long distances before being deposited (Miller 1989a). In low-temperature areas, the deposition consists more of dry material (dust and small particles) than in warm-temperature areas where deposition is wetter. The result is less of a tendency for pollutants in cold temperature areas to soak into the soil and be leached away. The pollution load that comes directly in contact with soil will have a long residence time due to little subsequent leaching from rainfall, and chemical stability at low temperatures (Miller 1989a). Lastly, snow and ice on the surfaces of land

and rivers will also contain pollutant burdens from previous months. The sudden melting in spring time will release the pollutants into the waterways as a sudden large input rather than as a uniform amount spread out over the year. The impact of short-term elevated spring time pollutant levels will typically be observed when aquatic organisms such as fish are hatching out or at their period of maximum growth (Miller 1989a). The young fish will typically be more sensitive to the effects of pollutants than they would be at an older age.

There are two factors that interact to increase the length of time that a chemical persists in the same chemical form in a cold environment. The first is that any chemical process is slowed at decreased temperatures, and the second is bacterial and other biological degradations are usually reduced due to decreased biotic activity in the pollutant's microenvironment (Miller 1989b). As a general rule of thumb, a chemical reaction roughly change its rate by a factor of two when the temperature changes by ten ºC, resulting in chemical half-lives that are often double that of those in warmer temperatures (Miller 1989b), increasing persistent in the environment. A feature of cold-weather mammals such as Cook Inlet beluga whales that increases their vulnerability to environmental pollutants is their blubber accumulation. Pollutants that are lipophilic will often accumulate and reside in the blubber with relatively little effect on the animal until the animal is forced to use its lipid reserves during a period of hunger or lean food resources and reproduction/lactation for females. During this period, the lipids are metabolized and the chemical can be freed to come in contact with more sensitive organs such as liver and kidneys. The animal will acutely receive a major dose of chemical. A similar observation may be seen in fish, which may lose a great deal of their energy reserves during hungry months under the ice (Miller 1989b).

Point-Source pollution

Municipal waste

Ten communities currently discharge treated municipal wastes into Cook Inlet. This discharged waste may contain organic and inorganic pollutants including sediments, bacteria, viruses, protozoa, heavy metals, pharmaceuticals, and nutrients from agricultural and animal sources. Wastewater from the Municipality of Anchorage, Nanwalek, Port Graham, Seldovia, and Tyonek receives only primary treatment, in which is the sludge is settled, while grease and oils rise to the surface and are skimmed off, with the collected sludge driven towards a hopper in the base of the tank where it is pumped to a sludge treatment facility (Environmental Protection Agency [EPA] 2004). Wastewater from Homer, Kenai, and Palmer receives secondary treatment (NOAA 2003) in which the biological content of the sewage is substantially degraded beyond primary treatment, by using aerobic biological processes (EPA 2004). Eagle River and Girdwood have modern tertiary treatment plants (Moore et al. 2000) that provides a final treatment stage to raise the quality of the effluent before it is discharged to the receiving environment (*e.g.*, sea, river, lake, ground). An overview of wastewater treatment at the Anchorage Wastewater Treatment Facility is given in Hobbs et al. (2008). However, the impacts of discharge wastewater on beluga whales are unknown. Given the relatively low levels of contaminants such as PCBs and chlorinated pesticides found in Cook Inlet beluga whale tissues (Becker et al. 2001), municipal discharge levels are not believed to be having a significant impact on the beluga whale population (NMFS 2003), but the impact of heavy metals and waterborne pathogens is currently unknown. Experimental studies demonstrated that juvenile Chinook salmon from an urban estuarine habitat had a higher susceptibility to mortality induced by the marine pathogen, *Vibrio anguillarum*, than juvenile Chinook from the releasing hatchery (Arkoosh et al. 1998). Juvenile salmon were exposed in replicate tanks of 20 fish per tank to one of three dilutions of *V. anguillarum*, 6×10^{-5}, 1.8×10^{-4}, and 4×10^{-4} bacteria/mL seawater, which was shown to cause 30, 50, or 70% mortality, respectively, to the hatchery fish seven days after the initial 1-hour exposure.

Produced waters

Produced waters are part of the oil/gas/water mixture produced from oil wells, and are highly saline (3000 to more than 350,000 mg/L total dissolved solids [TDS]) and may contain toxic metals, organic and inorganic components, and radium-226/228 and other naturally occurring radioactive materials which may be water-, air-, or synthetic-based (Kharaka and Dorsey 2005). In oil drilling activities, chemicals are added to the fluids used in processes including: water flooding; well work-over, completion, and treatment; and the oil/water separation process. Before discharging into Cook Inlet, produced waters pass through separators to remove oil. The treatment process removes suspended oil particles from the wastewater, but the effluent contains dissolved hydrocarbons or those held in colloidal suspension (Neff and Douglas 1994). The EPA regulates the discharges from offshore gas and oil exploration platforms, which include drilling muds, drill cuttings, and production waters (the water phase of liquids pumped from oil wells).

Drilling fluids (muds and cuttings) discharged into Cook Inlet average 89,000 barrels annually (244 barrels daily), containing several pollutants such as toxic metals and other inorganic and organic compounds (Minerals Management Service [MMS] 1996). The rate of discharge is unknown, but may be consistent during periods of drilling. At the peak of infrastructure development, there were 15 offshore production facilities, three onshore treatment facilities, and approximately 368 km (230 miles) of undersea pipelines in upper Cook Inlet (MMS 1996). A key concern is the potential for acute or chronic toxic effects on aquatic organisms resulting from produced water discharges to marine and estuarine environments (Frost et al. 1998). Although the presence of these chemicals has not been specifically detected (nor tested for) in beluga whales, they may, either individually or collectively, when present in high concentrations, present a threat to aquatic life when they are ingested by invertebrates and later consumed by beluga whales and other marine species. In Oklahoma, 34% of releases of produced (saltwater and oil) waters from leaks of tanks, wellheads, dumping, storms, fires, corrosion and illegal dumping resulted in reported injury to environmental receptors including surface waters, crops, livestock, soil, fish and wildlife (Fisher and Sublette 2005).

Dredging

Dredging along coastal waterways has been identified as a concern with respect to the Saint Lawrence beluga whales, where dredging of up to 600 cubic meters of sediments resuspended contaminants into the water column and seriously impacted the belugas (DFO 1995). While the volume of dredging in Cook Inlet is comparable to St. Lawrence (more than 844,000 cubic yards in 2003 at the Port of Anchorage), the material in the former have not been found to contain harmful levels of contaminants (NMFS

2008a); however, these substances may bioaccumulate in whales over long periods of time through chronic exposure, causing potential long-term health problems. Furthermore, during dredging operations, contaminants such as heavy metals and organochlorines settled on the seabed may be stirred up and redistributed into the water column. This potential contaminant release by resuspension of environmental contaminants may increase their bioaccumulation in whales through the intake of prey items in the vicinity of the work area. Dredging may also remove benthic animals living on and in the sediments and may increase sediment loading in rivers and streams, impairing growth and survival of juvenile salmonids (Suttle et al. 2004). The release of organic rich sediments during dredging or disposal can result in the localized removal of oxygen from the surrounding water, that may lead to the suffocation of marine animals and plants within the localized area or may deter migratory fish or mammals from passing through, depending on the location and timing of the dredge. However, the removal of oxygen from the water is only temporary, as tidal exchange would quickly replenish the oxygen supply. Therefore, in most cases where dredging and disposal is taking place in open coastal waters, estuaries, bays and inlets this localized removal of oxygen has little, if any, effect on marine life (Bray et al. 1997).

Mining

Numerous current or planned mining projects are ongoing in the Cook Inlet Basin (Alaska Department of Natural Resources [ADNR] 2011). Ground water in coal mine tailings often contains elevated levels of salts and metals such as zinc which is toxic to juvenile salmonids from 93 to 815 parts per billion. Spawning salmonids use chemical cues to locate their natal streams, and therefore may be adversely affected by contaminated streams (Chapman 1978, Dittman and Quinn 1996). For instance, copper has been found to be acutely toxic to juvenile Chinook salmon and steelhead trout at levels of 17-38 ppb (Chapman 1978).

Clearing and developing land for mines, in particular increases sediment input into streams, lakes and rivers (EPA 1999, 2006, 2008). Because much or all of the vegetation in the mined areas will be removed, it is likely that stream and groundwater temperatures will increase in summer and decrease in winter negatively impacting spawning and rearing salmonids (Feller 1982, Cunjack 1996, Curry et al 2002, Beschta and Taylor 2007, Mitchell and Cunjak 2007).

Alternations in surface and groundwater temperatures and flow rates resulting from deep mining in their watersheds may decrease prey fish populations, thus negatively impacting Cook Inlet beluga whales. For example, during strip-mining operations at the Chuitna Coal Mine site, salmon may be excluded for a long period of time from the middle and upper portions of some of the area streams where most spawning and rearing occurs (Trasky 2009). The uninterrupted flow of shallow groundwater to salmonid spawning streams is essential for overwinter survival of eggs and fry. Strip-mining will interrupt this flow and destroy the shallow aquifers that currently provide groundwater to streams. Diminishing or eliminating salmon production (*i.e.*, eggs and carcasses) from a stream due to natural or anthropogenic causes such as strip mining may be self-perpetuating. Without necessary nutrients from salmon eggs and carcasses remaining downstream, certain stream stocks are likely to decline further.

Pharmaceuticals (may also be non-point source)

Pharmaceuticals are biologically active and persistent substances which have been recognized as a continuing threat to environmental stability. The occurrence of pharmaceuticals and their metabolites and transformation products in the environment is becoming a matter of concern, because these compounds, which may have adverse effects on living organisms, are extensively and increasingly used in human and veterinary medicine and are released continuously into the environment (Bendz et al. 2005, Nikolaou et al. 2007). Pharmaceuticals, and their metabolic products, may potentially enter wastewater and surface water in four ways: 1) from a pharmaceutical manufacturing facility (point-source), 2) through excretion in human urine and feces (point-source), 3) through flushing of unused medications in toilets or sinks (point-source), and 4) through the use of veterinary medications (primarily non-point source) Bendz et al. 2005, Nikolaou et al. 2007, Santos et al. 2010).

A variety of pharmaceuticals have been detected in many environmental samples worldwide and have been reported in sewage treatment plant effluents, surface water, seawater, ground water, soil, sediment and fish (Kolpin et al. 2002; Fair et al. 2009). The pharmaceuticals, which are easily adsorbed, can reach the terrestrial environment when sludge is used as an agricultural fertilizer. They can also enter agricultural land from manure from medicated, in-house reared animals and from animals raised on pastures. From the terrestrial environment the pharmaceuticals can subsequently be transported to surface water and ground water while pharmaceuticals used in aquaculture are released directly into surface water (Ashton et al. 2004). In Europe, attempts have been made to develop methods to identify highly active compounds for which potential environmental risks may exist, but at very low levels (*i.e.*, below accepted regulatory agency limits; Christen et al. 2010). The identification of pharmaceutical compounds at very low levels allows for their environmental risk assessment. Chronic ecotoxicity data as well as information on the current distribution levels in different environmental media continue to be sparse and are focused on those therapeutic classes that are most frequently prescribed and consumed. Nevertheless, they indicate the negative impact that these chemical contaminants may have on living organisms, ecosystems and ultimately, public health. Santos et al. (2010) conducted an extensive review discussing various contamination sources as well as the fate, and acute and chronic effects on non-target organisms.

The low volatility of pharmaceutical products indicates that distribution in the environment will occur primarily by aqueous transport, but may also occur by food-chain dispersal (Carlsson et al. 2006). Information about the toxic effects of many of these pharmaceuticals and their degradation by products on living organisms is also very limited and should be further investigated. Analytical methods for different environmental samples for monitoring the occurrence, transformation, and fate of pharmaceuticals in the environment need to be developed and optimized. The sensitivity of the methods must be optimized to enable easy, inexpensive, and environmentally sound analyses of these compounds (Nikolaou et al. 2007).

Nonpoint source pollution

Air pollution

Vehicular engine warm-up idle emissions may be a significant source of carbon monoxide (CO) pollution in the Anchorage Bowl (Municipality of Anchorage 2009). Since CO most impacts those individuals who suffer from cardiovascular disease, the Environmental Protection Agency (EPA) established air quality standards for CO. The

Municipality of Anchorage has had a history of air quality violations; however, there has been a dramatic decline in CO concentrations from peak levels experienced in Anchorage in the early and mid-1980s. Although high levels were experienced in the early 1970s and violations of standards occurred from 1972-1994, 1996, and from1997-2008, Anchorage obtained 12 years of compliance with EPA standards.

Studies have investigated increases in human mortality and morbidity from exposure to exhaust emissions from marine vessels (Lu et al. 2006, Corbett et al. 2007). Therefore, exhaust emissions from marine engines operating in close proximity to whales have the potential to deteriorate air quality and the health of the animals (Lachmuth et al. 2011). Atmospheric dispersion modeling was used to estimate threshold doses for adverse health effects in killer whales; findings suggested that current whale-watching guidelines (State of Washington 2008; NMFS 2011b) have been fairly effective in limiting pollutant exposure to levels at or just below those at which measurable adverse health effects in killer whales would be expected. However, it was observed that safe pollutant levels are exceeded under worst-case conditions and certain average-case conditions (Lachmuth et al. 2011). Effective 16 May 2011, new rules issued by the National Marine Fisheries Service prohibit vessels of all types in Washington's inland waters from approaching any killer whale closer than 200 yards (double the prior 100 yard distance), and forbids vessels from intercepting a whale or positioning the vessel in its path. Research is needed to determine if vessel exhaust and air quality may have adverse effects on belugas.

Stormwater/Surface runoff

Water quality is a concern for wildlife, especially since cetaceans may be vulnerable to antibiotic resistant strains of bacteria (Stoddard et al. 2005), terrestrial pathogens (Minnette 1986, Higgins 2000), aquatic pathogens (Arkoosh et al. 1998; URS 2011), and biochemical markers (Kannan et al. 2005). For example, exposure to dilutions of *Vibrio anguillarum*, a marine pathogen, at 6×10^{-5}, 1.8×10^{-4}, 4×10^{-4} bacteria/mL seawater, was shown to cause 30, 50, or 70% mortality, respectively, to the hatchery fish seven days after the initial 1-hour exposure (Arkoosh et al. 1998). When considering the development of water quality standards for coastal cetaceans, the difficulty in obtaining good scientific data to support water quality guidelines is due to the difficult logistics of collecting data from wild populations to develop cetacean-dose response relationships (Thompson 2007).

Highway runoff is a significant source of water quality degradation. Various solids, metals, and nutrients present in highway runoff have been identified as degraders of water quality. Particulate matter may transport other pollutants to receiving waters. Heavy metals are known to adsorb to fine particles and other solids, where they may be released when exposed to water, and become a threat to aquatic life (Young et al. 1996). Nutrients, such as nitrogen, may stimulate the growth of algae blooms and deplete levels of dissolved oxygen. Fine airborne particulate matter containing nitrogen. phosphorus, and metals generated from human activities, and other pollutants from vehicle emissions, may be transported to earth where they will be part of urban runoff during periods of precipitation. It is important to note that not all the pollutants in highway runoff can be attributed to transportation activities. Other sources of runoff may include particulate matter from industrial air pollution, and chemical runoff from agricultural activities (Young et al. 1996, Clausen 2007).

A review of management practices for stormwater runoff in the Municipality of Anchorage is given in NMFS (2008a). The growing problems of stormwater runoff are related to increases in impervious surface area—streets, parking lots, and buildings—and construction activities that compact the soil. Instead of soaking into the ground, rain that falls on an impervious surface quickly runs off the site via storm drains and drainage ditches, which often send the water directly into streams and rivers. Human activities can influence the types and concentrations of many surface and ground water contaminants, such as nutrients (compounds of nitrogen and phosphorus) and organic compounds. Residential and agricultural land uses can contribute nutrients and organic compounds to ground water through leaching of fertilizers, pesticides, and petroleum products (Glass 2001, Clausen 2007). Roadways and railroads can be a source of herbicides (applied to rights-of-way) and of volatile organic compounds (VOC). Chemicals used by homeowners, such as household cleaners, paints, solvents, fuel oil, and gasoline, also can be a source of VOCs in ground water (Brattebo and Booth 2003). Commercial and industrial establishments may also discharge VOCs and other substances to the atmosphere or to the ground. The Alaska Department of Environmental Conservation [ADEC] (1996) reported that petroleum products constitute the primary contaminant of water in Alaska, and commonly enter the ground through leaking of tanks and distribution lines or spilling of product on the surface.

The literature illustrates the adverse impacts of stormwater discharge from growing communities on fresh water and marine invertebrates, fish, and marine mammal populations (Becker et al. 2000, Beach 2002, Bolton et al. 2004, LaLiberte and Ewing 2006). Streams and wetlands that are dependent on stable surface and ground water flow may experience higher high flows (flooding) and lower low flows, leading to the loss of stream habitat and stresses to fish and other aquatic life. Flooding not only threatens property and the safety of residents, but can cause stream banks to rapidly erode. In addition, stormwater runoff is often contaminated with various water pollutants that are byproducts of urban and suburban activities such as construction, aircraft deicing agents (NMFS 2008a), automobile use (oil and transmission fluid leakage), and lawn care. If left unchecked, the pollutants can further stress fish and other wildlife species that depend on clean water for food and habitat (Miller and Klemens 2003). Sublethal effects from many discharges may prove more deleterious over time than the immediate lethal concentrations, because subtle and small effects on fish may alter their behavior, feeding habits, and reproductive success (Murty 1986).

A mechanistic, physically based model for pollutant release, from a surface source, such as field-spread manure, was hypothesized, laboratory tested, and field applied to demonstrate the potential applicability of a mechanistic model to pollutant release from surface sources (Walter et al. 2001). Their model predictions corroborated well with observations of runoff and pollutant delivery in both the laboratory and the field and might have applicability to sources of nonpoint source pollution in the Cook Inlet ecosystem. Despite the potential impacts of stormwater on Cook Inlet's ecosystem, there has been little research into determining if stormwater discharge has had a detrimental effect on belugas and their prey species.

Groundwater

Throughout the city of Anchorage, groundwater is pumped from hydrologic units consisting of unconsolidated surficial (*i.e.*, relating to the earth's surface) deposits and metamorphic bedrock underlying hillside areas. The superficial deposits of gravel, sand, silt, and clay range in thickness from several feet to more than 1,500 feet below land surface (Barnwell et al. 1972). The groundwater is eventually discharged into Cook Inlet. Regionally, the quality of Anchorage-area groundwater generally is good (Glass 2001). In isolated areas in Anchorage, however, oil and fuel spills and waste-disposal sites have released benzene, xylenes, arsenic, chromium, fluorescein, and sulfate into the ground water (ADEC 2005). Leachate from septic systems, landfills, and other disposal sites have introduced coliform bacteria and higher concentrations of iron, manganese, dissolved organic carbon, and chloride into local groundwater which ultimately empties into Cook Inlet (Munter 1987; Munter and Maynard 1987), causing disease in humans and aquatic and terrestrial animals (*e.g.*, cancer), organ toxicity, and immune suppression (Gauthier et al. 1998, Becker et al. 2000, Brousseau et al. 2003, Stoddard et al. 2005). Other human impacts at the groundwater freshwater stream interface from areas other than Cook Inlet are summarized in Hancock (2002) and in other sections of this review (see Contaminants).

Contaminants

Contaminants are a concern for beluga whale health and subsistence use (Becker et al. 2000). The detrimental effects of persistent organic pollutants (POPs) in marine mammals include, but are not limited to, immune system depression (De Guise et al. 1995, de Swart 1995, Ross 1995, 2005; Schwacke et al. 2005), reproductive disorders (Béland et al. 1993, Martineau et al. 1994, Ross 2005, Schwacke et al. 2005; Waring and Harris 2005), and subsequent greater risk of infection (Jepson et al. 1999, 2005; Hall et al. 2006); however, the effects on the health of the individual animal are often difficult to discern. As high trophic level organisms in the marine environment, fish consuming marine mammals may be exposed to very high levels of fat-soluble environmental contaminants (Maruya and Lee 1998). Although numerous sources of polycyclic aromated hydrocarbons (PAHs) to urban runoff have been identified, their relative importance remains uncertain (Krein and Schorer 2000). Sealed parking lots can account for a majority of stream loads of PAHs (Mahler et al. 2005). PAHs in runoff from parking lots with coal-tar emulsion sealcoat had mean concentrations of 3500 mg/kg, 65 times higher than the mean concentration from unsealed asphalt and cement lots (Mahler et al. 2005). Dissolved amounts of PAHs in washoff samples from coated parking lots ranged from 0.24 -16.0 µg/L of water.

A more thorough discussion of the potential effects of contaminants as they relate to Cook Inlet belugas is given in URS (2010). Briefly, concentrations of the chemicals (PCBs and chlorinated pesticides) detected in the Cook Inlet population are typically lower than those reported for other Arctic beluga populations, and these contaminants may represent a less significant health risk than for other populations; however, in combination with other stressors such as disease, parasites, low prey availability, noise and other anthropogenic factors, contaminants may still compromise Cook Inlet beluga health (Becker et al. 2000). The potential exists for some of the detected chemicals in the belugas, such as PCBs, to be present at concentrations associated with the possibility of impaired immune function and endocrine disruption in marine mammals (URS 2010). Endocrine disruptors may play a role in impairing reproduction and altering hormone regulation in belugas (Waring and Harris 2005). Trace elements and heavy metals have been investigated in several populations of belugas, including the Cook Inlet population

(Becker et al. 2000). Copper levels in the livers of Cook Inlet beluga whales are higher than levels at which kidney damage was reported in bottlenose dolphins (URS 2010).

Beluga whales may provide an early warning system for assessing the impact of stressors on the inlet's health. Assessing the sources, levels and patterns of contaminants found in the tissues of marine mammals, and the biological effects of these contaminants on individuals, is essential to determining population- or species-level impacts. Pulster and Maruya (2008) have been able to determine that polychlorinated biphenyl (PCB) signatures, such as the compound Aroclor 1268, may be used to distinguish among local populations of inshore bottlenose dolphins along the southeastern U.S. coast. They also found PCB signatures in dolphin blubber closely resembled those in local preferred prey fish species, strengthening the hypothesis that inshore bottlenose dolphin populations exhibit long-term fidelity to specific estuaries and make them excellent sentinels for assessing the impact of stressors on coastal ecosystem health. Significant variations in contaminant mixtures have been found to exist within localized populations of bottlenose dolphins, with life history factors such as age and sex driving individual differences (Yordy et al. 2010).

Oil spills (may also be point-source)

Large oil spills present one of the greatest short-term threats to coastal life, whereas non-point sources of petroleum contamination create chronic problems. Coastal cetaceans may contact petroleum during migration, feeding, or breeding. Usually cetaceans contact oil at the water's surface where they may inhale volatile hydrocarbons, the oil may adhere to their skin or eyes, or their prey may become contaminated. Marine mammals are generally able to metabolize and excrete limited amounts of hydrocarbons, but acute or chronic exposure poses greater toxicological risks (Grant and Ross 2002). Unlike humans, cetaceans have a thickened epidermis that greatly reduces the likelihood of petroleum toxicity from skin contact with oiled waters (Geraci 1990, O'Shea and Aguilar 2001). Inhalation of vapors at the water's surface and ingestion of hydrocarbons during feeding are more likely pathways of exposure. Acute exposure to petroleum products can cause reduced activity and changed in behavior, lung congestion, pneumonia, inflammation of the mucous membranes, liver disorders, and neurological damage (Geraci and St. Aubin 1990). However, long-term monitoring of resident and transient killer whales that came into contact with oil from the 1989 *M/V Exxon Valdez* spill in Prince William Sound, Alaska showed population declines of 33 and 41%, respectively, in the year following the spill (Matkin et al. 2008). The resident pod has not recovered to pre-spill numbers in the 19 years since the spill while the transient pod is precariously close to extinction.

A detailed discussion of oil spill threats in Cook Inlet is given in NMFS (2008a). Briefly, oil and petroleum product production, refining, and shipping in Cook Inlet present a possibility for oil and other hazardous substances to be spilled, and to impact the marine mammal species/stocks in Cook Inlet. The impact of an oil spill in this region and how it may affect marine mammals in it is unknown, as data describing behavioral or physiological effects is sparse. As such, the potential cumulative effects of such an event are considered potentially adverse. The Outer Continental Shelf Environmental Assessment Program estimated that 3,339 m^3 (21,000 barrels) of oil were spilled in the inlet between 1965 and 1975, while 1,590 m^3 (10,000 barrels) were spilled from 1976 to 1979 (MMS 1996). In July 1987, the Tanker/Vessel (T/V) *Glacier Bay* struck an uncharted rock near Nikiski, Alaska, discharging an estimated 214.6 to 604.2 m^3 (1,350 to 3,800 barrels) of crude oil into Cook Inlet (Eley 2006). Belugas are found in the area where this spill occurred. In February 2005, the T/V *Seabulk Pride* was torn from its moorings by heavy ice and tides in mid-Cook Inlet. Approximately 302.8 liters (80 gallons) of product spilled before the tanker was safely retrieved.

Oil spills may also be potentially destructive to beluga prey populations and therefore may adversely affect belugas by reducing food availability. Chronic small-scale discharges of oil into oceans greatly exceed the volume released by major spills (Clark 1997) and represent another potential concern. Such discharges may originate from many sources, such as tank washing and ballast water dumping by tankers and the release of bilge and fuel oil from general shipping. Though it is known that chronic oil pollution kills large numbers of seabirds (Wiese and Robertson 2004), its impact on beluga whales and other marine mammals is poorly documented, and the long-term effects of repeated ingestion of sub-lethal quantities of petroleum hydrocarbons is unknown.

Data gaps:

- Inventories of contaminated sites are not comprehensive or up to date.
- Impact(s) of air pollution on Cook Inlet belugas is unknown.
- Data describing the fate of pharmaceuticals in the environment is limited.
- Detailed occurrence and trends of waterborne fecal pathogens is largely unknown.
- The impacts of produced water discharges and dredging operations on beluga prey species are unknown.

- Correlation between contaminants and health effects in belugas is largely unknown.
- Little is known regarding the factors influencing contaminant patterns within localized populations of marine mammals such as belugas.

Recommendations:

- Comprehensive inventories of contaminated sites can be maintained and regularly updated, and can be used to prioritize sites in need of further investigation and remediation.
- Air sampling to identify pollutants and their potential impact on belugas.
- Environmental risk assessment studies must be performed for pharmacologically active compounds, their metabolites, and especially for mixtures of such compounds that have a high likelihood of being detected in Cook Inlet.
- Regular coastal marine and riparian environmental sampling for waterborne pathogens and their sources could be undertaken in the Cook Inlet region.
- Monitor indicator pathogens (*e.g.*, fecal, respiratory, serology) and parasites in a sympatric species such as Cook Inlet harbor seals, which maintain relatively high site-fidelity within the Inlet, would provide better insight into the extent to which Cook Inlet belugas are exposed to pathogens and parasites from terrestrial sources
- Studies quantifying impacts of toxic exposure to increased metabolic requirements and changes in fecundity or survival are required to quantify impacts to populations.
- Studies of instream flow and the impact of groundwater to streams necessary to

support salmon and other aquatic life need to be conducted in order to improve protection (and restoration) of streams utilized during mining activities

- Principal components analysis to assess the variation of contaminants among individuals in relation to age, sex, and reproductive maturity.
- Document the impact of chronic oil pollution on beluga whales and other marine mammal species in Cook Inlet and investigate the long-term effects of repeated ingestion of sub-lethal quantities of petroleum hydrocarbons.
- Hydrographic surveys in mid-to upper Cook Inlet to improve understanding of these hydrologically dynamic subregions to investigate the physical processes that might influence the behavior and trajectory of spilled oil.

Urban Development and Habitat Loss

Alaska's most populated and industrialized area is the southcentral region. Many cities, villages, ports, airports, treatment plants, refineries, highways, military bases, and railroads are situated on or very near to Cook Inlet. In areas where belugas must compete with humans for the use of nearshore habitats, development of the coastline may lead to direct loss of habitat, or indirect alteration of habitat may occur due to bridges, vessel traffic, noise, and discharges affecting water quality, and appears to be increasing with time. The Anchorage Bowl (Anchorage and its outlying suburban areas) historically has developed land for industrial purposes at a rate of approximately 30 acres per year and will likely continue this trend at least through 2030 (Economic and Planning Systems 2009). In addition, salmon populations, an important prey of belugas may be impacted by degradation of aquatic ecosystems resulting from land use changes (*e.g.*, agriculture, hydropower, industry, resource extraction, and urban development). The urbanization of land may contribute to local hydrologic problems. The increase in impermeable structures and surfaces (buildings, paved roads and lots), watercourse channeling, and draining and filling of wetlands encourages a number of environmental problems (Markon 2003). Water runoff from these impermeable surfaces increases the risk of hazardous substances being washed into the water system and elevating bacteria in streams and rivers (Frenzel and Couvillion 2002). Channeling of small rivers and streams reduces the amount of fish habitat and allows increased flows of runoff into nearby Cook Inlet. Booth and Jackson (1997) characterized urbanization of aquatic systems in Puget Sound, Washington using contiguous hydrologic modeling and showed that approximately 10% of the effective impervious area (*i.e*., urban development) in a watershed typically yields demonstrable, and potentially irreversible, loss of aquatic-system function; however, degradation of a watershed can occur at levels below 10% of development. A proposed tidal turbine project in upper Cook Inlet off of Fire Island could degrade habitat used by the belugas (McGuire et al. 2011b).

The time period of most noticeable change in urban development for the Municipality of Anchorage occurred between the early 1970s and 2000 (Fig. 3), with lesser dramatic changes occurring after the 1980s (Markon 2003). Urban growth appeared to be more influenced by the availability of flat land near the city center, and expanding to areas that provided views of the Alaska Range and less developed wooded areas (Markon 2003). While most beluga habitat remains mostly intact, extensive construction and natural resource development projects threaten Anchorage's shorelines. Even though >90% of Knik Arm remains undeveloped, there are several planned or proposed projects that have been identified in a relatively confined portion of lower Knik

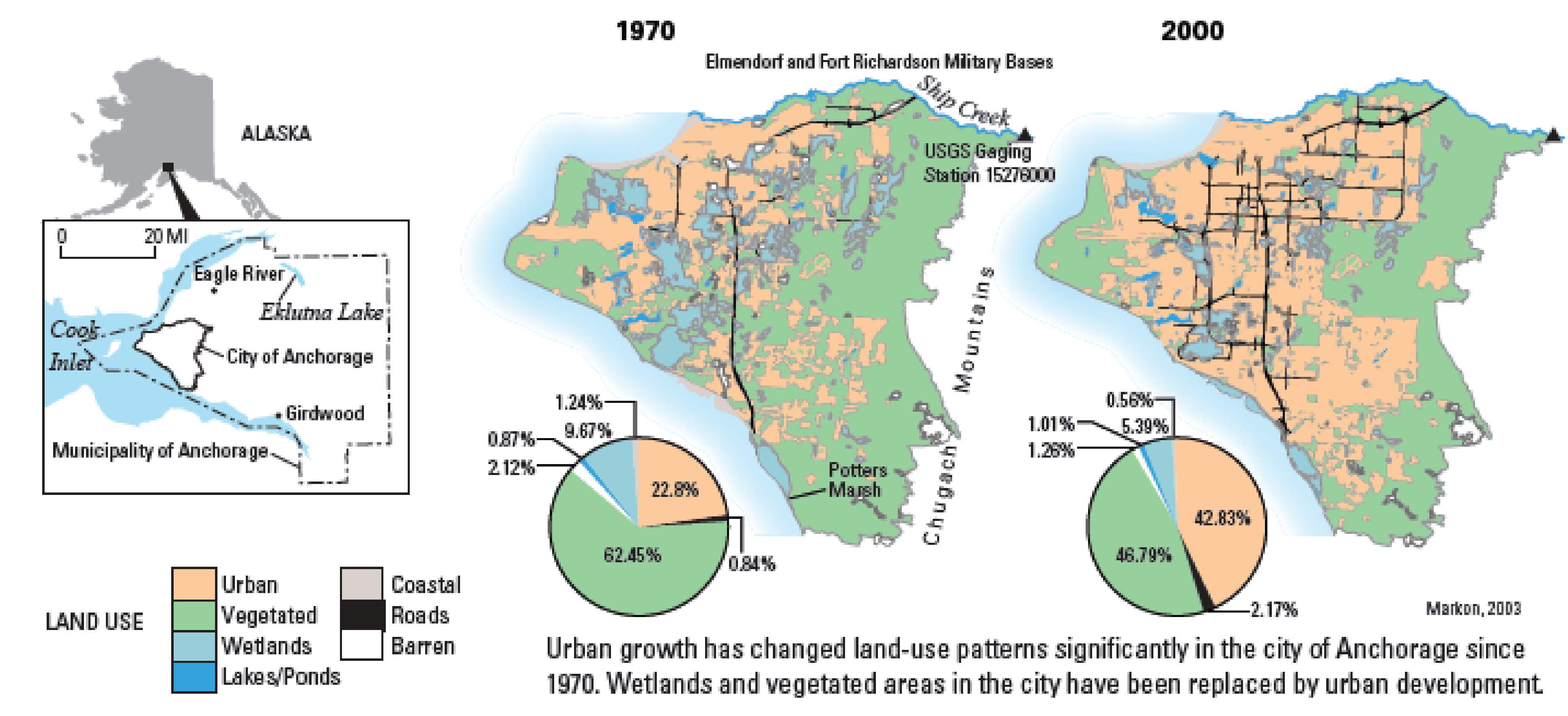

Figure 3. – Map showing changes in urban growth in the Anchorage area between 1970 and 2000. Used with permission from USGS.

Arm. Some of the potential impacts of these development projects on belugas are discussed in the Conservation Plan (NMFS 2008a), including proposed intermodal expansion of the Port of Anchorage, consisting of rail and road expansions and marine terminal redevelopment (Port of Anchorage 2011). Knik Arm is an important feeding area for beluga whales during much of the summer and fall (Hobbs et al. 2008). Whales move to upper Knik Arm on the flooding tide, feed on salmon, then move back with the outgoing tide to wait in waters off and north of the Port of Anchorage. The primary concern for belugas is that development may restrict passage along Knik Arm.

The proposed Knik Arm bridge crossing has the potential to affect oceanographic conditions in Knik Arm by causing a restriction that would alter tidal currents and thus affect sediment transport and deposition (Kinnetic Laboratories 2004). The bridge crossing may also alter the formation and movement of stamukhas (*i.e.*, broken off sea ice blocks that form due to wind, tides, or thermal expansion forces; Smith 2000) within Knik Arm. Sediment-laden stamukhas entrain and transport a large amount of intertidal sediments that may potentially contain contaminants and accumulate in intertidal and shallow subtidal areas.

During operations of dredging and dumping of spoils, an increase in suspended solids concentration is expected which may potentially influence beluga prey, and affect the whales indirectly by the loss of food supply due to disturbance of the seafloor and increased sedimentation (Jefferson et al. 2009). Seabed 'reclamation' involves creating land areas from shallow coastal areas by dumping and filling of rock and sediment to create land for human use (Jefferson et al. 2009). The filling-in of marine habitats to produce land has the effect of eliminating marine mammal and prey habitat. This is irreversible, and although the effects of construction work can be mitigated, it is virtually impossible to mitigate against the effects of complete and total loss of habitat. Planned improvements to the Seward Highway may result in habitat alterations due to dredging, in-water filling, and runoff from construction activities (Markowitz et al. 2007).

Construction of the expanded Port of Anchorage facilities will require up to 5.6 million cubic yards of dredging. After completion of the expansion, dredging requirements should decrease to maintenance levels (2-2.5 million cubic yards of dredged material annually). Dredging will occur from mid-May through November to maintain adequate water depth (-35 feet mean lower low water) that is appropriate for navigation in Anchorage Harbor and to -45 feet mean lower low water for the authorized port expansion project (ACOE 2008). Adult salmon in the project areas of Knik Arm could be subjected to suspended solids concentrations from dredging and dispersion of disposed material. However, it has been suggested by some studies that returning adult salmon tend to remain in shallow water, perhaps to reduce predation by belugas. This shallow water orientation will probably tend to keep them away from dredging and its spoils, which would tend to largely occur in deeper water (Pentec 2005).

Gravel mining can significantly alter the geomorphology, fine-particle dynamics, turbidity, and biotic communities of a river or stream. The density and biomass of invertebrates may be reduced, while total densities of fish may also be reduced. Silt-sensitive species of fish in rivers and streams may become less numerous downstream from mines, and destruction of the riparian zone during gravel extraction operations can have multiple deleterious effects on the habitat of anadromous fish (Moulton 1980, Brown et al. 1998). Environmental degradation may extend far beyond the boundaries of the immediate gravel mining areas. Attempts to mitigate or restore streams impacted by gravel mining may be ineffective because the disturbance results from changes in physical structure of the streambed over distances of kilometers upstream and downstream of mining sites (Kanehl and Lyons 1992, Packer et al. 2005). The sole source of gravel mining in the Municipality of Anchorage occurs adjacent to the Birchwood Airport, in Eagle River by Eklutna Inc. They began construction in 2008 on a 102-acre industrial park (Eklutna Inc. 2011). The company's estimate is that approximately 4 million tons of gravel can be extracted as the park is developed, and it has planned restoration of fish habitat in conjunction with the Army Corps of Engineers and Alaska Department of Fish and Game. The gravel mine is planned to run for five years. Other sources of gravel occur in the Matanuska-Susitna delta region.

Data gaps:

- Knowledge about the functional value, stability, and resiliency of many "restored" habitats not completely understood.
- The biological impacts (or recovery) associated with water management activities are unknown.
- Biotic implications of hydrologic alteration in Cook Inlet region are unknown.

Recommendations:

- Monitor functional value, stability, resiliency, and the biological impacts (or recovery) of restored habitats, associated with water management activities, particularly as they pertain to belugas.
- Assess the biotic implications of hydrologic alterations that have occurred in Cook Inlet, such as assessment of abundance and distribution of affected fauna.

B. Environmental Stressors

Correlations are commonly found between physical factors and individual ecosystem components, including phytoplankton (Li et al. 1984, Townsend et al.1994), zooplankton (Roemmich and McGowan 1995), and fish (Swartzman et al. 1992, Castillo et al.1996, Anderson and Piatt 1999). It has been shown that killer whale population trends are driven largely by changes in survival, and that their survival rates are strongly correlated with the availability of their principal prey species, Chinook salmon (Ford et al. 2010). Based on the findings of Ford et al. (2010), it is estimated that a 25% decrease in prey availability to beluga whales may result in a 1% survival rate and 15% drop in calving probability. In most cases the means by which physical factors evoke a biological response cannot be established, even when correlations are strong (Greene et al. 2003, Springer et al. 2003). Further review focuses on two of the most important: freshwater runoff from streams and rivers draining into the inlet and water temperature. Two workshops have been held that produced proceedings that describe the research (Johnson and Okkonen 2000, Schumacher 2005) which includes a pair of temperature and salinity studies that are precursors to this work (Okkonen and Howell 2003).

Freshwater runoff

Freshwater flow into Cook Inlet, specifically from the melting snow pack, may be altered during climate change, affecting salinity, water nutrient composition and levels, and prey fish density and distribution in the upper Inlet where belugas feed and reside. Increasing precipitation at high latitudes, increasing river discharge, and net melting of ice stocks on land and sea all point to an acceleration of the hydrologic cycle (Stocker and Raible 2005). Freshwater content reflects seasonal changes in snowmelt, runoff, and precipitation patterns. Freshwater discharge into Cook Inlet from slower (<1200 ft^3/second) surrounding streams and creeks overall has remained fairly constant over the past 30 years with periodic peaks and troughs (Fig. 4). Faster moving freshwater sources (>1200 ft^3/second) had high flow rates during the 1970s to early 1980s, but then showed a decline during the early 1980s through the mid-1990s, some of which was due to lack of gauge readings (Fig. 5) (USGS 2011). Seasonal changes in the freshwater inputs drive seasonal changes in the salinity field of the Cook Inlet region. Discharge measurements on the Susitna River, the largest draining into the upper Inlet, has a maximum discharge in May as the river first opens up.

Rivers discharging into the Gulf of Alaska (GOA), which include the Susitna and Little Susitna Rivers and others that empty into Cook Inlet, have recently demonstrated shifts in volume and timing of water delivered to the eastern North Pacific Ocean (Hodgkins 2009). Salmon production is affected by environmental conditions at each stage of the life cycle and is tied to nutrient production (Lawson 1993). Freshwater discharge into the GOA has been found to be correlated with primary and salmon productivity in Alaska through changes in coastal salinity and water temperatures (Hare et al. 1999, Royer 1982, Royer et al. 2001).

Changes in salinity can change the water column's vertical stability, which in turn affects the mixed layer depth and primary production. Changes in the mixed layer depth concurrent with phytoplankton production may provide links between freshwater discharge and zooplankton production and distribution (Royer et al. 2001). The amount of environmental salinity is important for the life cycle of salmon progressing toward the sea from the pre-smolt to smolt stage (Otto and McInerney 1970), and particularly for the

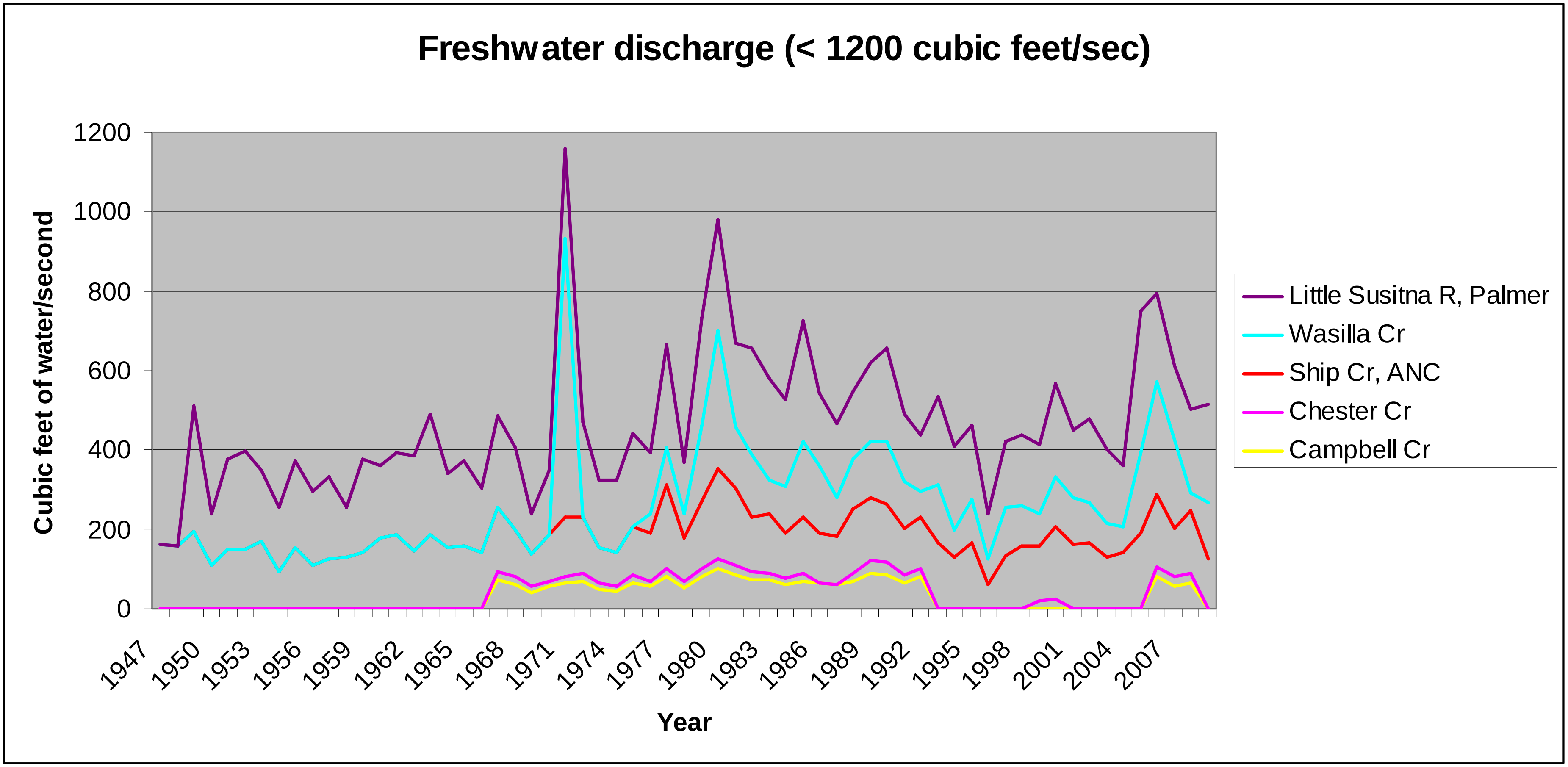

Figure 4. – Freshwater discharge (<1200 ft^3/sec) from 1947-2009 in Cook Inlet (USGS 2011).

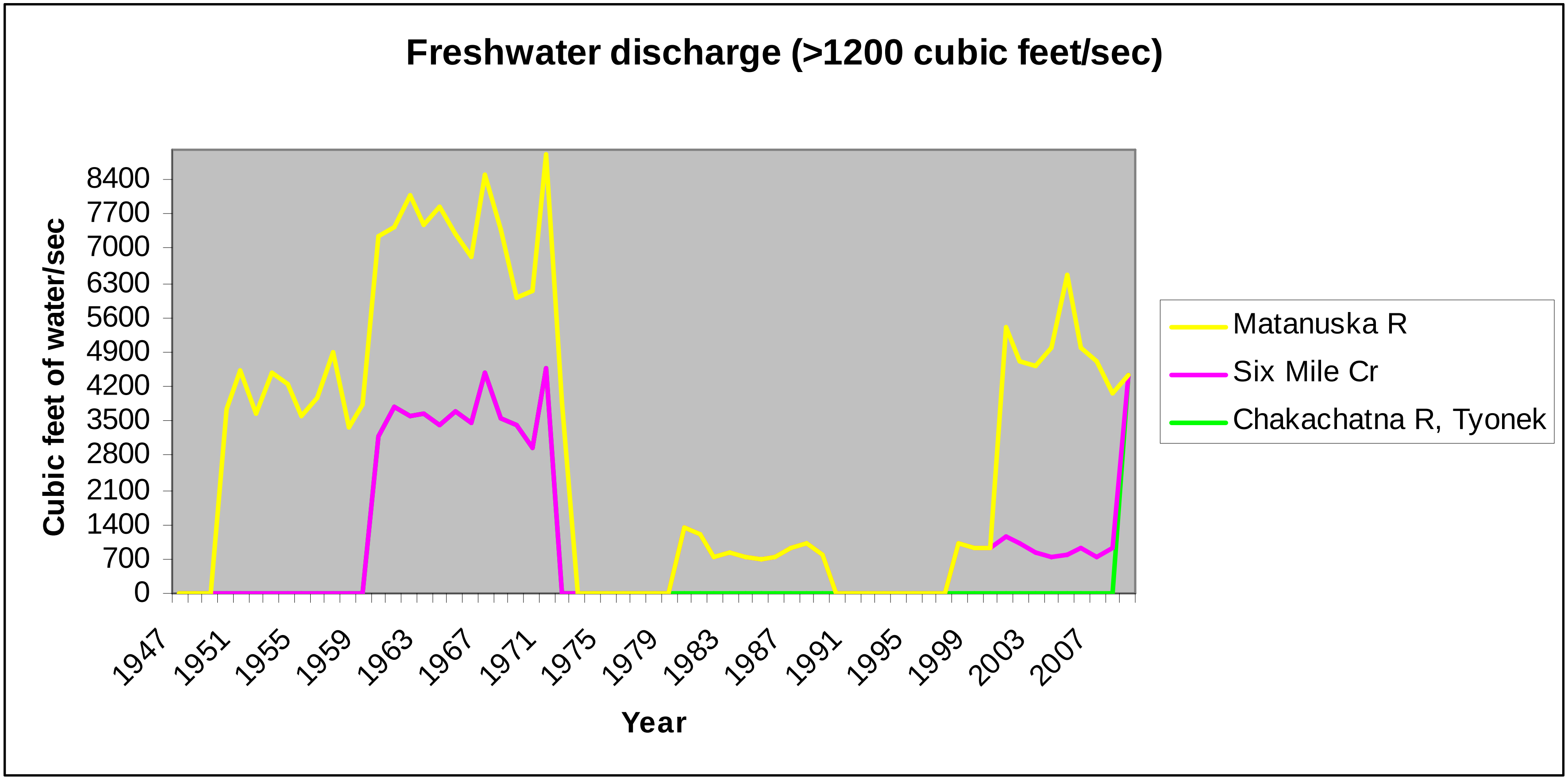

Figure 5. – Freshwater discharge (>1200 ft^3/sec) from 1947-2009 in Cook Inlet (USGS 2011).

maintenance of planktonic communities the young fish feed on (Eslinger et al. 2001, Speckman et al. 2005). In Kachemak Bay (lower Cook Inlet), increased insolation during late spring and summer has been observed to increase freshwater runoff and raise surface water temperatures, which results in a well-stratified water column in the Inner Bay (Abookire et al. 2000). Changes in fish distribution may result in foraging challenges for beluga whales if their required prey items are not found in their usual habitats, resulting in belugas expending more energy locating them, or resorting to lower quality prey items.

Water temperature

One of the most significant factors in the health of a stream ecosystem is water temperature. Altered stream temperature can have detrimental effects on various species by influencing biological, chemical and physical water properties (Smith 1972). For example, if stream temperatures are low (between 4°C and 0°C), fish growth slows (Edwards et al.1979). Maximum possible daily phytoplankton growth rates are determined as functions of temperature (Eppley 1972). Fish abundance has also been found to be significantly correlated with fluctuations in the physical environment (Nash 1988; Ward et al. 2009). The vast majority of fishes are strict thermal conformers (Fry 1968). An important physical factor of Pacific salmon habitat is stream temperature and its effects on various salmon life stages (Alderice and Velsen 1978, Murray and McPhail 1988, Groot and Margolis 1991).

Each species of Pacific salmon has adapted to specific spawning temperatures and times so that incubation and emergence occur at the most optimum time of the year, in order to maximize survival (Kyle and Brabets 2001). Since fish are cold-blooded, their metabolic rates increase with rising water temperature. Their populations are affected as natural or artificial events shift temperatures away from the optimal ranges for fish species, forcing them to actively seek habitats closer to their preferred temperature range. Increases in water temperature may impact transition from freshwater to saltwater (smolting) in juvenile salmonids (McCormick et al. 1996). Adults of cold-water fish species may stop migrating or die unspawned if exposed to extended periods of abnormally warm temperatures. Cold-water fish species are more sensitive during earlier stages of life rather than as juveniles and adults (Rombough 1996).

Temperature and salinity gradients exist between lower and central Cook Inlet, between the east and west sides of the inlet (Okkonen and Howell 2003, Okkonen et al. 2009). A study investigating stream temperatures in the Cook Inlet basin, and their implications of climate change, observed that water temperatures are a valuable measure and descriptor of biological, chemical and physical characteristics of rivers and streams in the Cook Inlet basin (Kyle and Brabets 2001). This is considered significant as fish health and populations are greatly affected by water temperature conditions. Fifteen sampling sites in Cook Inlet had a predicted water-temperature change of 3°C or more over the next 100 years, which is considered significant for the incidence of disease in fish populations (Chatters et al. 1992). Negative changes to the health or habitat of beluga prey species such as those due to abnormal or extreme water temperatures may reduce prey availability or distribution, resulting in potentially negative impacts on the health and reproduction of the beluga population due to decreased energy intake or increased energy expenditure seeking out prey.

<u>Data gaps</u>:

- Data on tidal mixing rates in different areas of Cook Inlet to better define critical beluga and fish habitat are unknown.

- Areas of the inlet with the strongest upwelling which provide the greatest nutrients for beluga prey species are unknown.
- The influences of water temperature and salinity on fish distributions on a small-scale within Cook Inlet.
- How anadromous fish survival is affected by changes in streamflow and water temperature regimes when in coastal rivers and streams is unknown.

Recommendations:

- Conduct tidal mixing studies in different areas of Cook Inlet to better define critical beluga and fish habitat.
- Hydrographic surveys of mid-to upper Cook Inlet would improve understanding of these dynamic subregions.
- Assess anadromous fish abundance and distribution within coastal inlet rivers and streams to determine how their survival is affected by stream flow and water temperature regimes.

Summary/Conclusions of the Review

This review considers anthropogenic and two environmental factors that may currently pose a risk for Cook Inlet beluga whales, as well as those that might continue into the future. Threats to quantity and quality of beluga prey species may occur due to continued development and natural exploitation, as well as climate change. In addition, levels of OC contaminants, while not appreciably elevated may start to increase in the habitat used by Cook Inlet beluga whales and their prey, if development and habitat loss increases. Therefore, Cook Inlet belugas may be at risk for chronic, serious, sublethal effects, if OC concentrations in Cook Inlet have similar effects as seen in other marine mammal species (*e.g.*, immunotoxicity in harbor seals). Other risk factors that may continue to impact Cook Inlet belugas are oil spills and habitat loss due to development. Recovery may be delayed or prevented by actions which affect the whales directly (such as ship strikes, predation by killer whales, or strandings) or indirectly by affecting their habitat (reductions in prey species, oil spills, coastal development). This review identifies non-lethal anthropogenic and environmental stressors of most concern, and identifies areas of needed research and further information on acute and long-term impacts on the recovery of the endangered Cook Inlet beluga whale.

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Table 1. Summary of non-lethal stressor knowledge and data gaps

Stressor	Knowledge gap(s)	Page(s)
Anthropogenic		
Pressure on fish stocks	• Salmonid runs: Current and historic escapement biomass, species mix and timing for most rivers or watersheds emptying into Cook Inlet not available. • Eulachon: population status, biomass and records of removals by fisheries (including subsistence and personal use) and evaluation of effect of this fishery on belugas in terms of disturbance/harassment or competition. • Other prey species: Distribution, abundance and seasonality within Cook Inlet. • Seasonal beluga prey preferences • Escapement counts for upper Cook Inlet watersheds • Stable isotope data on all beluga prey species • Quantify/update metabolic needs at all beluga life stages	12-15
Non-acoustic vessel disturbance	• The impact a given type and level of vessel disturbance has on various behaviors is unknown. • Studies which relate changes in behavior to levels and kinds of disturbance should be conducted in high and low disturbance areas in the Inlet and in a similar population in areas such as Bristol Bay or the St. Lawrence River. • Amount of leaked/spilled vessel fluids and fuel and potentially toxic cargo into Cook Inlet is unknown as is their impact on beluga health and their prey species. • Does interference from vessels cause significant or permanent behavioral changes? • Impact of vessel disturbance on foraging efficiency and energy acquisition • Does energy expenditure increase in vessel presence?	22-23
Roads and vehicular traffic	• Amount of vehicular fluids released onto road surfaces • Percentage of road runoff that reaches watersheds • Acoustic/behavioral impact of bridge construction/traffic	26
Noise/sound Seismic surveys Aircraft noise Vessel noise Pile-driving Explosions/detonations Offshore oil/gas drilling Cable and pipe-laying	• Potential impact of seismic activity on beluga prey fish and invertebrates at all life stages. • Is beluga prey capture affected by vessel noise? • Significance of repeated low-altitude overflights on well-being of cetaceans such as belugas • Impact of noise from construction and industrial activities. • What vessels characteristics most impact belugas (size, speed, sound-exposure levels, etc.) • Further determine the acoustic environment of Cook Inlet (especially historical trends of ambient noise level) • The characteristics of sound propagation in the areas used	40-41

	• by whales are unknown, particularly under different tide cycles and in the presence of prey fish. • Critical distances belugas need during construction activities and whether the whales are able to partially compensate for masking noise. • Acoustic responses to sound, including changes in the composition, rates, lengths, and "loudness" of calls, also require evaluation. • Effects of human-generated marine noise on beluga prey.	
Pollutants (Point-source) Municipal waste Produced waters Dredging Mining Pharmaceuticals **Pollutants (Nonpoint source)** Stormwater/surface runoff Groundwater Contaminants Oil spills	• Specific sites in need of remediation and cleanup. • Impact(s) of air pollution on Cook Inlet belugas • Data describing the fate of pharmaceuticals in the environment is limited. • Detailed occurrence and trends of waterborne fecal pathogens is largely unknown. • The impacts of produced water discharges and dredging operations on beluga prey species are unknown. • Correlation between contaminants and health effects in belugas is largely unknown. • Little is known regarding the factors influencing contaminant patterns within localized populations of marine mammals such as belugas. • Impact of chronic oil pollution on beluga whales and other marine mammal species in Cook Inlet (investigate the long-term effects of repeated ingestion of sub-lethal quantities of petroleum hydrocarbons). • Physical processes that might influence the behavior and trajectory of spilled oil not completely known.	61
Urban development and habitat loss	• Knowledge about the functional value, stability, and resiliency of many "restored" habitats not complete. • The biological impacts (or recovery) associated with water management activities are unknown. • Biotic implications of hydrologic alteration in Cook Inlet region are unknown.	67
Environmental		
Freshwater runoff **Water temperature**	• Tidal mixing rates within Cook Inlet and link to critical beluga and fish habitat not well understood. • Areas of the inlet with the strongest upwelling which provide the greatest nutrients for beluga prey species. • The influences of water temperature and salinity on fish distributions on a small-scale within Cook Inlet. • Impact of changes in streamflow and water temperature regimes on anadromous fish survival when in coastal rivers/streams.	73

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