Potential Natural and Anthropogenic Impediments to the Conservation and Recovery of Cook Inlet Beluga Whales, *Delphinapterus leucas*

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Introduction

Cook Inlet beluga whales, *Delphinapterus leucas*, belong to a genetically distinct and geographically isolated population (O'Corry-Crowe et al., 1997, 2002) (Fig. 1). This small and declining population was listed as endangered under the U.S. Endangered Species Act (ESA) in October 2008. It is thought that this population originally numbered close to 1,300 animals; however, the population has declined significantly from its historical abundance to approximately 312 in 2012 (Hobbs et al., 2015a). At reduced numbers and with contraction of their range (Rugh et al., 2010; Shelden et al., 2015), this population is vulnerable to losses due to natural and anthropogenic (human-caused) influences.

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ABSTRACT—The endangered population of beluga whales, Delphinapterus leucas*, found year-round in the waters of Cook Inlet, Alaska, is exposed to a variety of natural and anthropogenic processes that, alone or combined, could compromise their conservation and recovery. Natural risks include stranding, killer whale,* Orcinus orca*, predation, diseases and parasites, and environmental change. Anthropogenic factors include pressure on beluga whale prey species from commercial, sport, and subsistence fishing, pollution (other than contaminants), chemical contaminants, vessel traffic, underwater noise, and habitat alteration from development and land use. This review provides a summary of current and potential factors and key gaps in existing knowledge of these factors as they relate to Cook Inlet beluga survival and recovery.*

We present current information on potential natural and anthropogenic factors that may play a role in the decline and long-term viability of Cook Inlet (CI) beluga whales. A number of these factors identified in the Marine Mammal Protection Act (MMPA) conservation plan (NMFS[1]) and ESA status reviews (Hobbs et al.[2,3]; Hobbs and Shelden[4]) of CI belugas are of particular concern, given the lack of baseline data on their occurrence and relevance, coupled with substantial gaps in existing information on their effects on mortality and reproduction. When applicable for comparison purposes, we also consider the possible impacts of these factors on other populations of beluga whales in Bristol Bay (BB), Alaska, and the St. Lawrence Estuary (SLE), Canada.

Beluga whales in BB represent a healthy, growing population that inhabits ecological niches similar to Cook Inlet (Lowry et al., 2008). Belugas in SLE were chosen because they also represent a small, geographically- and genetically-isolated stock of beluga whales (DFO[5]). Although SLE belugas have been protected from hunting since 1979, little sign of recovery has been observed, and they face many of the same natural and anthropogenic factors as CI beluga whales (DFO[5]).

Review of Natural and Anthropogenic Factors

Natural factors include, but are not limited to, stranding, killer whale, *Orcinus orca*, predation, diseases and parasites, and environmental perturbations such as changes in sea surface temperatures. Anthropogenic factors include pressure on beluga whale prey species from commer-

[1]NMFS. 2008. Conservation Plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). Natl. Mar. Fish. Serv., NOAA, Juneau, Alaska, (avail. at http://www.alaskafisheries.noaa.gov/protectedresources/whales/beluga/mmpa/final/cp2008.pdf), accessed 5 Apr. 2010.

[2]Hobbs, R. C., K. E. W. Shelden, D. J. Vos, K. T. Goetz, and D. J. Rugh. 2006. Status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Proc. Rep. 2006-16, 74 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE., Seattle, WA 98115-6349, (avail. at http://www.afsc.noaa.gov/Publications/ProcRpt/PR%202006-16.pdf), accessed 5 Apr. 2010.

[3]Hobbs, R. C., K. E. W. Shelden, D. J. Rugh, and S.A. Norman. 2008. Status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Proc. Rep. 2008-02, 116 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-6349, (avail. at http://www.nmfs.noaa.gov/pr/pdfs/statusreviews/belugawhale_cookinlet.pdf), accessed 5 Apr. 2010.

[4]Hobbs, R. C., and K. E. W. Shelden. 2008. Supplemental status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Proc. Rep. 2008-08, 76 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-6349 (avail. at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2008-08.pdf), accessed 5 Apr. 2010.

[5]DFO. 2012. Recovery strategy for the beluga whale (*Delphinapterus leucas*) St. Lawrence Estuary population in Canada. Species at Risk Act Recovery Strategy Ser. Fish. Oceans Can., Ottawa, 88 p. (avail. at http://www.sararegistry.gc.ca/virtual_sara/files/plans/rs_st_laur_beluga_0312_e.pdf), accessed 28 Feb. 2014.

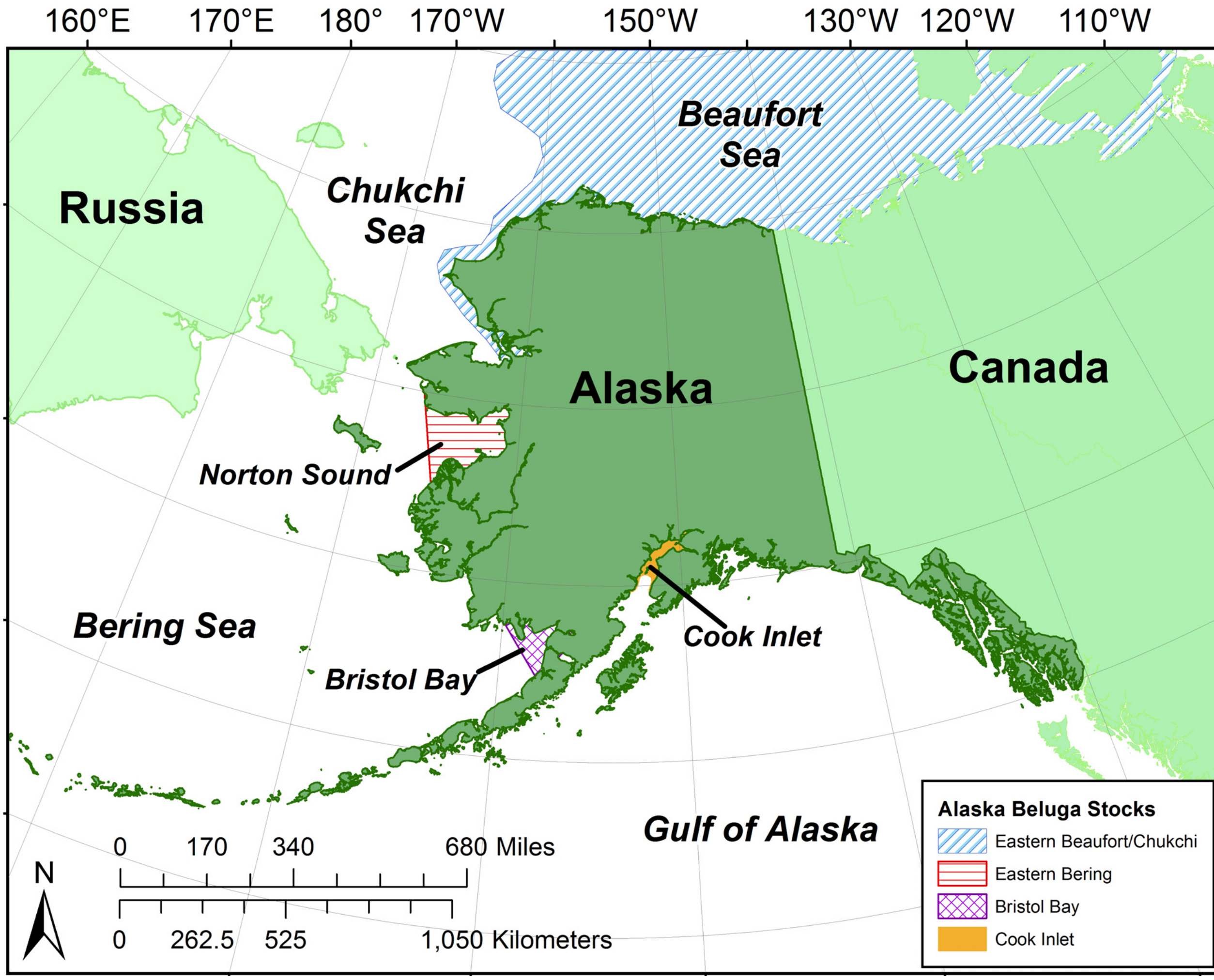

Figure 1.—Summer locations of beluga whale stocks

cial, sport, and subsistence fishing; toxicants (including contaminants), stormwater/surface runoff, vessel traffic, noise, and habitat alteration from land use and development (Norris, 1994). The proximity of CI belugas to nearshore ecosystems places them at particular risk for interactions with human-related activities that may negatively influence their survival (Perrin, 1999).

Though several known and potential effects are described in this review, the degree to which they affect CI beluga whales is unknown. Individual factors are discussed in this review; however, cumulative factors may affect these whales at any time.

Natural Factors

Live-stranding

It is uncertain why beluga whales live strand in Cook Inlet. Belugas in some Canadian populations are known to intentionally ground themselves during molting while rubbing their skin against rocky bottoms (Smith et al., 1992), though CI whales do not appear to go through molt as observed in other higher latitude beluga populations. Beluga whales may also strand purposely or accidentally to avoid predation by killer whales (Shelden et al., 2003), when chasing prey during ebbing tides, or due to injury or illness (Moore et al., 2000). Beluga stranding events in upper Cook Inlet are not unusual (Vos and Shelden, 2005) and may, in part, occur because of extreme tidal heights and long shallow tidal estuaries found in their primary habitat (Goetz et al., 2012), or may be precipitated by anthropogenic-related events such as ship strikes or fishery interactions.

NMFS has compiled reports of approximately 1,076 dead and live stranded whales in Cook Inlet since 1987, when it began actively investigating stranding reports (NMFS[6]). A majority of the strandings involved

[6]NMFS. 2015. Draft recovery plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). Natl. Mar. Fish. Serv., NOAA, Juneau, Alaska,

live whales (n = 874) (NMFS[6]:Table 5, p. 62). Thirty-six live stranding events were reported, with a majority (n = 22; 61%) of these occurring in Turnagain Arm, an area of extensive tidal flats that results in nonlinear flooding and ebbing and strong tidal bore currents with speeds up to 5 m/s (Ezer et al., 2008). These live-stranding events involved both adult and juvenile belugas that were apparently healthy, robust animals. Although many of these events do not appear to directly cause mass mortality, prolonged stranding events that last more than a tidal cycle, such as a result of coastal flooding or tsunamis, may result in an unusual mortality event (UME) (Hobbs et al., 2015b).

Beluga whales are usually able to survive through a stranding event and escape to deeper water on the rising tide. However, some deaths during these events do occur. Once a whale strands, death may result from stress and/or hyperthermia from prolonged exposure. Years with mass strandings (total stranded; mortalities associated with that event) include: 1992 (2; 2), 1996 (60; 4 and 20–30; 1), 1999 (58–70; 5), 2003 (46+; 5), 2005 (7; 1), 2008 (28–30; 2), 2014 (UNK; 2) (NMFS[6]:Table 5, p. 62). The event in 2003 occurred on 28 August, during which at least 46 belugas live-stranded in Turnagain Arm for over 10 h; five whales were suspected to have died as a result of this stranding event (Vos and Shelden, 2005), and one was confirmed by necropsy (Burek-Huntington et al., 2015). In 2014, the NMFS received a report of two stranded beluga whales in Turnagain Arm; however, no live stranding report was received, but necropsy findings suggested they had recently live-stranded which may have contributed to their deaths (Burek-Huntington et al., 2015).

Whales stranding high on a sand bar during an outgoing tide may be exposed for 10 h or more. Unless caught in an overflow channel or ponded area and partially covered with water, the whale may have difficulty regulating body heat. An extensive network of capillaries within the flukes and flippers allows belugas to lose excess body heat to the environment, and these structures must be submerged for this mechanism to function properly and regulate body temperature, preventing overheating (Geraci and Lounsbury, 2005). Additional stress is placed on internal organs and breathing may be difficult without the support provided by water. Overall, live-stranding may contribute to reduced fitness in CI whales.

Delayed physiological consequences from stranding may include rhabdomyolysis and cardiomyopathy, resulting in kidney damage and decreased immune function (Turnbull and Cowan, 1998; Herráez et al., 2007; Moore et al., 2013). Of 38 stranded belugas, the majority (n = 25; 66%) were adults, with 8 of 11 mature females either pregnant, post-partum, or lactating, and 9 thought to have restranded dead following a prior live stranding. Four of the adults were single strandings with no significant findings detected. It is hypothesized that large, particularly pregnant, belugas may be more susceptible to mortality following a live stranding event (Burek-Huntington et al., 2015) due to the increased cardiovascular stresses.

Predation

Cook Inlet beluga whales are preyed upon by killer whales, their only known natural predator. Mortality occurs through direct predation, or indirectly by increasing live stranding events as belugas flee into shallow water to escape. Killer whales are more commonly found in lower Cook Inlet and the Gulf of Alaska (Shelden et al., 2003; Matkin et al., 2012; Matkin et al.[7]) where they may feed on a variety of prey, while the number visiting the upper inlet appears to be small. They occur infrequently, with no more than six individuals in each sighting reported to NMFS since 1982 (Shelden et al., 2003; Matkin et al.[7]).

Killer whale ecotypes include resident, transient, and offshore. Transients feed exclusively on marine mammals and have dorsal fins distinct in shape from resident and offshore orcas. Photographs of the dorsal fins of killer whales that stranded in Turnagain Arm revealed that they were transients (Shelden et al., 2003); however, resident types (fish eaters) also occur in the inlet. Therefore, a sighting of killer whales in proximity to belugas does not necessarily mean they are feeding on them.

No confirmed killer whale sightings were noted in the upper inlet from 2004 to 2012 by researchers who spent many hours on the water during the CI beluga photo-identification project (McGuire et al.[8]). Since 1982, NMFS has received reports of killer whales in the vicinity of Turnagain Arm, Knik Arm, between Fire Island and Tyonek, near the Chuitna River, near rivers along the Susitna Delta, and near the Kenai River (Shelden et al., 2003).

Native hunters report that killer whales are usually found along the tide rip that extends from Fire Island to Tyonek (Huntington, 2000). Recent directed studies of killer whales during 2008–09 did not observe any beluga predation; however, weather, tidal conditions, and scarcity of encounters precluded adequate detection of the former (Matkin et al.[7]).

Although only opportunistic data exist on the removal of beluga whales in Cook Inlet due to killer whale predation, a detailed review of stranding and suspected killer whale predation reports from this region (1982–2013), appears to suggest a minimum esti-

(avail. at http://www.nmfs.noaa.gov/pr/recovery/plans.htm#mammals), accessed 30 Jul. 2015.

[7]Matkin, C. O., L. B. Lennard, R. Andrews, and J. Durban. 2011. Predation by killer whales in Cook Inlet and western Alaska: an integrated approach 2008-2009. Proj. R0303-01 Final Rep. – Rev. April 2011 (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/killerwhales/reports/predation_ci_042011.pdf), accessed 22 Apr. 2012.

[8]McGuire, T., A. Stephens, and L. Bisson. 2014. Photo-identification of Cook Inlet beluga whales in the waters of the Kenai Peninsula Borough, Alaska. Final Rep. Field Activities Belugas Identified 2011–2013. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for the Kenai Peninsula Borough, 92 p, (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/reports/2011_2013photoid0114.pdf), accessed 10 Apr. 2014.

mate of approximately one predation event per year, which does not include three CI belugas suspected to have died as a direct result of killer whale predation in which calves accompanied adults that were attacked (Shelden et al., 2003). Injuries on additional belugas were deemed possible killer whale interactions (Burek-Huntington et al., 2015; Hobbs and Shelden[4]). On 23 Sept. 2000, an NMFS enforcement agent observed 3–5 killer whales chasing beluga whales in Turnagain Arm (Shelden et al., 2003). Within the next few days, two lactating female beluga whales were found dead with teeth marks, internal hemorrhaging, and other injuries consistent with killer whale attacks. Though the impact of killer whale predation on the CI beluga population remains unknown, if killer whale predation occurs at a rate equivalent to or greater than beluga reproduction, it could prevent recovery or reduce the beluga population, as demonstrated in population viability analysis modeling (Hobbs et al., 2015b).

Infectious Diseases

Infectious diseases include diseases caused by pathogenic bacteria, viruses, and parasites. Epidemiological theory suggests that species are driven to extinction by pathogens only under specific conditions: 1) the pre-epidemic host population size is small (i.e., the species is endangered), 2) the pathogen/parasite relies on non-density dependent transmission between hosts, or 3) when the pathogen reservoir is the abiotic environment (de Castro and Bolker, 2005). While infectious disease may not cause the complete extinction of the species, it can produce enough mortality to threaten the species or trigger the disappearance of local stocks or populations, increasing the risk posed by other mechanisms (de Castro and Bolker, 2005). Small population size is the most widely cited driver of disease-induced extinction of the three previously mentioned conditions. Lack of genetic variability is another feature of the risk associated with small population size. The lack of genetic variability in a species, or stock, may reduce the range of immune responses in the population, leaving it more susceptible to disease (O'Brien and Evermann, 1988).

This suggests that disease alone is unlikely to drive a species to extinction, but may be much more likely to do so when a highly virulent and transmissible pathogen is introduced into the population in combination with other contributing risk factors such as high toxin exposures, habitat loss, and human disturbance (Smith et al., 2006; Anthony et al., 2012). Relatively few published reports are available on infectious disease exposure and occurrence in wild belugas with most reports coming from studies of SLE belugas (Wazura et al., 1986; Martineau et al., 1988; Barr et al., 1989; De Guise et al., 1995a; Mikaelian et al., 2000; Nielsen et al., 2001; Martineau et al., 2003; Maggi et al., 2008; Lair et al.[9]).

In SLE beluga whales, infectious disease was the most common cause of death with 32% attributed to a variety of bacterial, parasitic, and viral infections (Lair et al.[9]). In Cook Inlet, characterization of infectious disease threats has been complicated by small sample sizes, lack of access to live animals, and the poor quality of most of the carcasses examined up to this point (Burek-Huntington et al., 2015).

An analysis of necropsy results from 38 beluga whales that stranded from 1998 to 2013 revealed that in 11 (29%) cases, a definitive cause of death was not determined due to moderate to advanced decomposition (Burek-Huntington et al., 2015). Infectious disease is one of the factors that is difficult to histologically evaluate in carcasses in poor condition due to the loss of ability to detect pathogens and their effects on tissues. However, three (8%) CI beluga deaths were attributed to infectious disease; one was due to systemic herpesvirus causing widespread vasculitis, and two had multiple mixed bacterial and parasitic diseases (Burek-Huntington et al., 2015).

Parasites are commonly found in wild mammals, but their role in causing morbidity and mortality depends on load and pathology produced in the particular host. The extent of tissue involvement and associated host response led to the designation of parasitic infections as contributory and/or incidental disease findings in stranded CI beluga whales (Burek-Huntington et al., 2015). Mild (i.e., incidental) lungworm infections were reported in 14 of the 38 (37%) necropsied whales and were identified as *Stenurus arctomarinus* (Burek-Huntington et al., 2015).

In hunter-killed belugas from the Churchill River basin in Manitoba, Canada, 89% (8 of 9) were parasitized with the lungworm *Pharurus pallasii* in the lung, accessory sinuses, ear canal, and cerebral spinal fluid (Kenyon and Kenyon, 1977). In another study on SLE whales, lungworm prevalence in adults and juveniles was 88 and 72%, respectively (Houde et al., 2003), and included *Pharurus pallasii* as well as *Stenurus arctomarinus* (Measures et al., 1995, 2001).

The hunter-killed whales were assumed to represent normal healthy animals with parasite loads representative of endemic levels. The lungworms in the SLE whales were thought to commonly contribute to mortality. Since pneumonia is a common finding in stranded cetaceans, it is unclear whether lungworms alone, or in combination with secondary bacterial infections, are the causative factor in mortality due to pneumonia in these strandings (Leeney et al., 2008).

The nematode, *Crassicauda giliakiana,* was detected in the majority (74%) of CI beluga cases in which the kidneys were examined (Burek-Huntington et al., 2015). In these infections, there was tissue damage and formation of large mineralized granulomas in the kidneys, at times extensive. It is unclear whether this results in functional damage to the kidneys (Burek-Huntington et al., 2015); how-

[9]Lair, S., D. Martineau, and L. N. Measures. 2014. Causes of mortality in St. Lawrence Estuary beluga (*Delphinapterus leuca*) from 1983 to 2012. DFO Can. Sci. Advis. Sec. Doc. 2013/119. Iv + 37 p.

ever, it is possible that with very heavy infestation, there could be replacement of enough of the kidney (66–75% of the kidney tissue) to affect function or obstruction of urine outflow.

Another related parasite, *C. boopsis* is thought to limit population growth in fin whales, *Balaenoptera physalus* (Lambertsen, 1986, 1992). This parasite also causes granulomas in the kidney similar to *C. giliakiana*; however, it also causes extensive thromboembolism and inflammation in the blood vessels (phlebitis) systemically. Severe secondary effects of thromboembolism to other organs with *C. giliakiana* have not been observed to date in CI whales, so it is most likely that under usual circumstances and levels of infestation, these animals live with this parasite with no clinical effects (Burek-Huntington et al., 2015).

Parasites of the stomach (*Anisakis* sp.) were often present in CI beluga whales with little significant pathology. These infestations were not considered extensive enough to cause clinical signs, although *Anisakis* sp. nematodes were associated with perforating stomach ulcers in Canadian belugas and attributed as cause of death in 4% of cases (Lair et al.[9]).

Other incidental parasitic infections in CI belugas included protozoa encysted in the skeletal muscle, morphologically consistent with *Sarcocystis* sp. and nematodes surrounded by parasitic granulomas at the blubber–muscle junction (Burek-Huntington et al., 2015). All have been previously reported in other populations (De Guise et al., 1993; Lair et al.[9]). CI beluga whales were free of ectoparasites, although both the whale louse, *Cyamus* sp., and acorn barnacles, *Coronula reginae*, have been observed on beluga whales located outside of Alaska (Klinkhart[10]).

While a variety of infectious diseases occur in CI belugas, relatively little indication exists that their occurrence has had any measurable negative impact on the health of this population with such few cases available for analysis. It is possible that the difference in rates of mortality due to infectious disease between CI and SLE belugas is due to the immunosuppressive effects of much higher contaminant loads in SLE whales (Martineau et al., 2003; Burek-Huntington et al., 2015). Even if currently not thought to be a significant factor, the increased incidence of existing diseases or emergence of previously unknown diseases could cause a significant impact on the survival and fecundity of this small population, ultimately impacting its status and recovery.

Epidemiology of infectious disease is expected to change due to climate change (Beugnet and Chalvet-Monfray, 2013), for a variety of reasons including changes in host density due to reduced habitat, increased survival of pathogens in the environment, range extensions of host species and vectors, and changes in body condition due to changes in predator-prey relationships (Burek et al., 2008). More beluga whales strand than are reported and/or necropsied. Given the challenges of responding to reported strandings and the often delayed response due to remoteness or inaccessibility, the data gathered from the few that have been necropsied, though inconclusive, provide extremely important clues in determining the potential consequences of disease, parasitism, poor nutrition, and environmental stressors on this vulnerable population.

Noninfectious Diseases

Noninfectious diseases, such as neoplasia and exposure to biotoxins, have not been found in examinations of CI beluga whales. Small numbers of animals have been tested for the presence of harmful algal bloom toxins, domoic acid, and microcystins, and all have been either negative or at clinically insignificant levels (Burek-Huntington et al., 2015). Neoplasia, which was listed as a common finding in SLE beluga causes of death, was not detected in the 38 cases examined in Cook Inlet. Neoplasia seen in SLE whales included adenocarcinomas of the salivary gland, uterus, and gastrointestinal tracts (Girard et al., 1991; Lair et al., 1998; Martineau et al., 2003; Lair et al.[9]). The hypothesis for this high rate of occurrence in SLE belugas was the extremely high levels of contaminants (De Guise et al., 1994, 1995b; Martineau et al., 1988, 1999, 2002; Lair et al.[9]).

Climate Change

The Cook Inlet ecosystem is very dynamic and experiences continual change in its physical composition, with strong currents, extreme tidal changes, and large silt volumes deposited from glacial scouring. Climatic changes in this region are driven by the Alaska Coastal Current (Di Lorenzo et al., 2008; Weingartner[11]). The environment in which belugas reside make them susceptible to entrapment in ice and more vulnerable to entrapment during sudden ice formations, freeze-ups, and when winds change, driving ice into once open areas (Armstrong, 1985; Heide-Jørgensen et al., 2002). Though entrapments appear to rarely result in mass mortalities, under-reporting is possible given these incidents occur during the winter months. In general, CI beluga whales appear to prefer ice-covered waters during the winter period, and the likelihood of entrapment is low as no entrapments have been reported (Shelden et al., 2015). However, as weather patterns become more unpredictable and extreme as a result of climate change, CI belugas may face greater risk of ice entrapment with increased frequency and scale of mortality.

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 impli-

[10]Klinkhart, E. G. 1966. The beluga whale in Alaska. State of Alaska Dep. Fish. Game, Juneau, Fed. Aid Wildl. Restor. Proj. Rep. Vol. VII, Proj. W-6-R and W-14-R, 11 p.

[11]Weingartner, T. 2007. Long-term oceanographic monitoring of the Gulf of Alaska ecosystem. Exxon Valdez Oil Spill Trustee Counc. Annu. Proj. Rep., Proj. 070340, 2 p. (avail. at http://www.evostc.state.ak.us/Store/AnnualReports/2008-070340-Annual.pdf), accessed 1 May 2012.

cations 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 have 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., 1991). 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.

Freshwater flow into Cook Inlet from melting snow pack may be altered during climate change, affecting salinity, composition, and levels of water nutrients (Royer et al., 2001). Beluga prey density and distribution in the upper inlet may also be influenced by alterations in flow. Seasonal changes in the freshwater inputs drive seasonal changes in the salinity of the Cook Inlet region. Salinity levels are important for salmonids as they progress toward the sea from the presmolt to smolt stage (Otto and McInerney, 1970) and particularly for the maintenance of planktonic communities the young fish consume (Eslinger et al., 2001; Speckman et al., 2005). Loss of sea ice and increased ocean temperatures will likely effect changes in prey distribution, composition, and productivity, which will in turn present foraging challenges for beluga if their preferred prey is not found in their usual habitats, requiring greater energy expenditure for foraging effort or resorting to lower quality prey.

Rather than directly coming from the effects of changing weather conditions, more serious influences of climate change on CI belugas may result indirectly from the role that regional warming and decreased sea ice play in modifying human activities. In light of decreasing ice coverage, ships may reach areas in the winter that were previously inaccessible due to extensive sea ice. Reductions in sea ice that allowed an increase in ship traffic, could result in ships strikes becoming an increasingly significant cause of injury and death, as well as an increased disturbance by ship noise.

Anthropogenic Factors

The major urban center of Alaska is located within the Cook Inlet region, with over 435,000 people, or approximately 2/3 of the state's population, residing in the Anchorage, Matanuska-Susitna, and Kenai Peninsula Boroughs (U.S. Census Bureau[12]). This number of people in a relatively small area presents added concerns for CI beluga whales and their natural environment. The following anthropogenic factors were evaluated, as they are considered to be the human-related factors of most concern for the beluga and other cetacean species: pressure on fish stocks from commercial, sport, and subsistence fishing; pollution (nonpoint and point-source); vessel traffic; noise; and land use and development (NMFS[1]).

Pressure on Prey Fish from Commercial, Sport, and Subsistence Fishing

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). CI belugas appear to feed on a wide variety of prey, focusing on specific species when they are seasonally abundant. In summer, Pacific salmon are preferred, particularly chum, *Oncorhynchus keta;* coho, *O. kisutch;* and Chinook, *O. tshawytscha*. During autumn, as anadromous fish runs near their end, fish species found in nearshore bays and estuaries again return to the beluga diet. This includes species observed in the spring diet, such as eulachon, *Thaleichthys pacificus*, and sculpin, Cottidae; cod, Gadidae; and flatfish, Pleuronectidae (Quakenbush et al., 2015).

Fisheries may compete with beluga whales for salmon and other prey. The mean number of all salmon species caught annually in commercial fisheries in upper Cook Inlet from 1956 to 2012 was 4,191,748 salmon (ADFG[13]), with fluctuations ranging from 1,064,485 (1959) to 10,564,618 (1992) (Shields[14]) (Fig. 2). In lower Cook Inlet, catches ranged from a low of 103,936 in 1974 to 3,737,393 salmon in 1982 (Fig. 2) (Bucher and Morrison[15]; Hammarstrom and Ford[16]). It is unknown how fluctuations in salmon run strength affect belugas or how fishing pressure is impacting their prey stocks. It is also unknown what proportion of the fish targeted by the upper and lower inlet fisheries constitute key prey items or populations in the diet of the beluga whale.

There is a strong indication that these whales are dependent on access to relatively dense concentrations of high nutritional value prey. Any reduction in the ability of beluga whales to access or utilize spring and summer foraging habitat, or of preferred prey availability, may reduce beluga energetics and delay their recovery (Williams et al., 2006; Ford et al., 2010).

[12]U.S. Census Bureau. 2011. Basic counts/population – Alaska. Am. Factfinder (avail. at http://www.census.gov/), accessed 22 Apr. 2012.

[13]ADFG. 2014. Alaska Dep. Fish Game, Div. Commer. Fish., Central Reg., (avail. at http://www.adfg.alaska.gov/index.cfm?adfg=fishingCommercialByArea.southcentral), accessed 1 Mar. 2014.

[14]Shields, P. 2010. Upper Cook Inlet commercial fisheries annual management report, 2009. Alaska Dep. Fish Game, Fish. Manage. Rep. No. 10-27, Anchorage, 172 p. (avail. at http://www.adfg.alaska.gov/FedAidpdfs/FMR10-54.pdf), accessed 22 Apr. 2012.

[15]Bucher, W. A., and R. Morrison. 1990. Review of the 1990 lower Cook Inlet salmon fishery. Rep. to Alaska Board Fish., Reg. Info. Rep. 2H90-10, 30 p. Alaska Dep. Fish Game, Div. Commer. Fish., Central Reg., Anchorage (avail. at http://www.sf.adfg.state.ak.us/FedAidPDFs/RIR.2H.1990.10.pdf), accessed 13 Aug. 2010.

[16]Hammarstrom, L. F., and E. G. Ford. 2010. 2009 Lower Cook Inlet Annual Finfish Management Report. Alaska Dep. Fish Game, Fish. Manage. Rep. 10-17, 144 p. (avail. at http://www.adfg.alaska.gov/FedAidPDFs/FMR10-17.pdf), accessed 13 Aug. 2010.

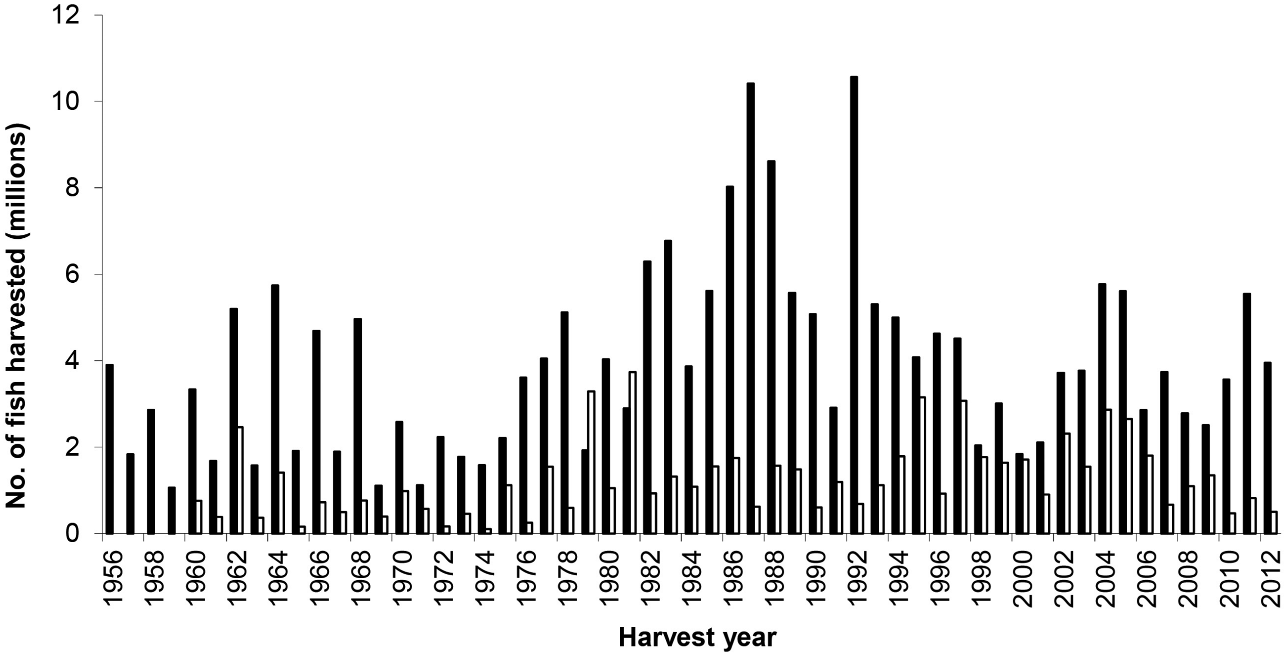

Figure 2.—Commercial salmon (coho, chum, Chinook, pink, sockeye) harvest (all gear and harvest types) for upper (black bars) and lower (white bars) Cook Inlet, 1956-2012 (Bucher and Morrison (text footnote 15); Hammarstrom and Ford (text footnote 16); Shields (text footnote 14); ADFG (text footnote 13)).

Contaminants

Exposure to contaminants and toxicants, such as persistent organic pollutants (POPs), polyaromatic hydrocarbons (PAHs), and heavy metals associated with human activities, is a concern for beluga whale health and subsistence use (Becker et al., 2000). The principal sources of anthropogenic toxicants in the marine environment are 1) discharges from municipal wastewater treatment systems; 2) accidental spills or discharges of petroleum, ship ballast, and other hazardous substances; and 3) runoff from urban, mining, and agricultural areas (Moore et al., 2000).

Persistent Organic Pollutants (POPs) Persistent Organic Pollutants (POPs) include many compounds and are defined as organic contaminants that persist in the environment due to their resistance to degradation, and bioaccumulation in the food chain with the best known examples being the polychlorinated biphenyl (PCBs), dieldrins, chlorinated herbicides such as DDT, in addition to others. Detrimental effects of POPs in marine mammals include, but are not limited to, reproductive disorders (Helle et al., 1976; Béland et al., 1993; Martineau et al., 1994), immune system depression (De Guise et al., 1995b; de Swart, 1996; Ross, 1995), and subsequent greater risk of infection (Jepson et al., 1999, 2005; Hall et al., 2006).

However, the effects on the health of the animal are often difficult to discern. For instance, no experimental studies on the reproductive effects of contaminants in cetaceans have been performed, and direct evidence for the association is lacking (O'Hara and O'Shea, 2001). Nevertheless, organochlorines (OCs) are suspected to be broadly affecting the health and reproduction of cetaceans globally through disruption of endocrine receptors (Colborn and Smolen, 1996; Martineau et al., 2003).

Some contaminants and toxins have been detected in different matrices such as water column, benthic sediment, and river samples in Cook Inlet (Savoie et al.[17]). Although no cause-and-effect relationship has been established between contaminants (e.g., PCB and perfluorooctane sulfonate [PFOS]) and reproductive disorders in belugas, researchers have suspected that elevated organochlorines are associated with reproductive failure (Béland et al., 1993; Martineau et al., 1994; URS Corp.[18]). Small numbers of several classes of POPs tested in

[17]Savoie, M. A., G. Gillingham, and S. M. Saupe. 2012. Integrated Cook Inlet environmental monitoring and assessment program (ICIEMAP). Poster presented at 2012 Alaska Marine Science Symposium, Anchorage, Alaska, 16-20 January 2012 (avail. at http://www.alaskamarinescience.org/), accessed 28 Feb. 2014.

[18]URS Corporation. 2010. Chemical exposures for Cook Inlet beluga whales: a literature review and evaluation. Rep. for Natl. Mar. Fish. Serv., Reg. Office, Anchorage, Alaska, NMFS Contr. AB133F-06-BU-0058 (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/reports/cibtoxicology0310.pdf), accessed 16 Mar. 2011.

hunter-killed samples have been tested in CI beluga whales and have been found to be lower than any other North American beluga stocks, with the SLE whales at highest levels (Becker et al., 2000).

Hydrocarbons There is a diverse array of natural and anthropogenic sources of hydrocarbons to Cook Inlet (Driskell and Payne[19]) that could pose a concern for beluga health and reproduction. Large oil spills present one of the greatest short-term threats to coastal life, whereas point-source discharges and nonpoint sources of petroleum contamination pose chronic risks.

In addition, spills of hazardous substances such as urea, sulfur dioxide, and ammonia are also of concern and may occur on land and at sea (ADEC[20]). Elevated levels of the POPs BTEX (benzene, toluene, ethylbenzene, and xylenes) were detected in the water column at three locations in upper Cook Inlet (two near Trading Bay and one near East Foreland) warranting further investigation (Savoie et al. [17]). Coastal cetaceans may contact petroleum during migration, feeding, or breeding. 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 behavioral changes, lung congestion, pneumonia, inflammation of the mucous membranes, liver disorders, and neurological damage (Geraci and St. Aubin, 1990).

A recent study documented adverse health consequences in a population of bottlenose dolphins, *Tursiops truncatus*, in Louisiana subsequent to the Deepwater Horizon oil spill (Schwacke et al., 2013). Oil and petroleum product production, refining, and shipping in the inlet present a possibility for oil and other hazardous substances to be spilled, negatively impacting marine species in the inlet. As such, both the immediate and the 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[21]). Major spills of oil and other harmful substances have occurred over the past two decades (Table 1; ADEC[20]). Oil spills may also be destructive to beluga prey, and may, therefore, adversely affect the whales by reducing food availability and serving as a source of exposure through ingestion. Clinical exposure trials, used to evaluate the effect of PAHs, such as those found in crude oil, demonstrated adverse cardiac function in fish embryos (Incardona et al., 2010).

PAHs are also carcinogenic (Martineau et al., 2003). St. Lawrence belugas have a higher rate of malignant neoplasia than reported for any other cetacean population, with 18% of deaths attributed to this disease in a study of 129 examined carcasses (Martineau et al., 2003). One hypothesis is that the high levels of PAHs in substrates, along with bottom feeding of belugas on benthic invertebrates may, partially or fully, explain the exposure responsible for these neoplasms (De Guise et al., 1994, 1995b; Martineau et al., 1988, 1994, 2003; Lair et al.[9]).

With the low levels of neoplasia in CI beluga whales, it would be reasonable to hypothesize that tissue levels of these contaminants are relatively low; however, these compounds have not been tested, so the tissue levels in CI belugas are unknown, which is a significant data gap. Studies on PAHs in archived CI beluga liver and blubber tissue demonstrated the presence of PAH levels at the highest concentrations in adult females and fetuses, warranting further study of the bearing of these chemicals on reproductive success and subsequent population recovery (see Saupe et al.[22]).

Essential and nonessential heavy metals Trace elements and heavy metals have been investigated in several populations of beluga whales, including those in Cook Inlet (Becker et al., 2000). Copper concentrations in the liver were 2–3 times higher in CI whales compared to those in the Beaufort and eastern Chukchi Seas, but were more similar to levels recorded in Hudson Bay, Can., belugas (Becker et al., 2000). CI beluga liver copper levels were consistently higher (mean = 160 mg/kg) than levels at which kidney damage (mean = 29 mg/kg) was reported in bottlenose dolphins in Australia (Lavery et al., 2009; URS Corp.[18]).

However, further evaluation of hepatic copper levels is needed to provide insight into the potential for kidney damage in CI beluga whales because the toxicological implication of elevated copper levels in this species is unknown. Being an essential element, it is regulated metabolically in vertebrates and varies among and within species (Thornburg, 2000). Copper does not appear to accumulate with age, with the highest copper concentrations usually found in younger animals (Becker et al., 2000). Diversity in prey consumed may influence the differing concentrations of this element between CI and other Alaska beluga populations.

Attempts at linking disease epizootics, neoplasia, and other health effects with elevated contaminant levels in marine mammals have prov-

[19]Driskell, W., and J. Payne. 2012. Integrated Cook Inlet monitoring and assessment program (ICIEMAP): hydrocarbon fingerprinting. Poster presented at 2012 Alaska Marine Science Symposium, Anchorage, Alaska, 16-20 January 2012 (avail. at http://www.alaskamarinescience.org/), accessed 28 Feb. 2014.

[20]ADEC. 2011. Major oil spills to coastal waters. Spill prevention and response. Alaska Dep. Environ. Conserv., Div. Water (avail. at http://www.dec.state.ak.us/water/wqsar/index.htm), accessed 1 Mar. 2014.

[21]MMS. 1996. Cook Inlet planning area oil and gas lease sale 149. Final Environ. Impact Statement. U.S. Dep. Interior, Minerals Manage. Serv., Alaska OCS Reg.. (avail. at http://www.boem.gov/ak-eis-ea/), accessed 22 Oct. 2010.

[22]Saupe, S. M., T. M. Willette, D. L. Wetzel, and J. E. Reynolds. 2014. Assessment of the prey availability and oil-related contaminants in winter habitat of Cook Inlet beluga whales. Final report of field surveys and laboratory analyses (2011-2013). Rep. prep. by Cook Inlet Reg. Citizens Advisory Counc. (RCAC) for Kenai Peninsula Borough, 53 p.

Table 1.—Select spills of petroleum products in Cook Inlet (ADEC text footnote 20).

Date	Vessel	Location	Product	Amount	Notes
2 July 1987	Tanker/Vessel (T/V) *Glacier Bay*	Near Nikiski	Crude oil	214.6-604.2 m^3 (1,350-3,800 barrels)	Belugas noted in area of spill; but unknown if any adverse impacts inflicted.
21 Aug. 1989	T/V *Lorna B*	0.5 mile N of Steelhead Oil Platform, Upper Cook Inlet	Diesel	404 m^3 (2,540 barrels)	Became entangled in tow cable while towing barge supporting the platform reconstruction.
3 Jan. 1992	Oil pipeline rupture	Port Nikiski	Crude oil	36 m^3 (302 barrels)	
5 Dec. 1995	Tank overfill	Tesoro Refinery, Kenai	Crude oil	22 m^3 (181 barrels)	
6 Mar. 1997	Steelhead Offshore Platform	Upper Cook Inlet	Diesel	35 m^3 (286 barrels)	
15 Jan. 2009	M/V *Monarch*	Granite Point Platform, central Cook Inlet	Diesel; lube oil; unspecified chemicals	172 m^3 (1,080 barrels) – diesel; 3.5 m^3 (22 barrels) lube oil	An estimated 700 barrels of diesel fuels and lube oils unaccounted for.
9 Jan. 2012	XTO Onshore Facility	Nikiski	Crude oil; processed water	32 m^3 (200 barrels) mixed crude and process water	Due to faulty gasket on an access plate located on one of their tanks.

en challenging, given the relatively small number of studies; however, indirect evidence of negative effects has been documented (O'Hara and O'Shea, 2001). In the United Kingdom and Canada, several studies have investigated the potential impact of contaminants on marine mammal immunity and health status (Martineau et al., 1994, 1999, 2002; Jepson et al., 1999, 2005; Hall et al., 2006; Pierce et al., 2008), while more direct studies of contaminants and immunosuppression have been performed in harbor seals, *Phoca vitulina* (de Swart et al., 1996; Ross et al., 1996). Levels of contaminants in blubber of beluga whales can be compared to the threshold levels established for other species of marine mammals to determine the level of risk posed by exposure to these compounds. However, caution is warranted in these evaluations, as the threshold effects levels were determined for non-beluga species, and beluga whales may be more or less susceptible to the toxicological effects of these compounds.

Municipal waste and terrestrial-source pathogens In principal, sources of toxicants in the marine environment may be oil spills, runoff from urban development, vehicle and airplane drippings, human and veterinary pharmaceuticals, and byproducts of activities that do not enter wastewater treatment systems, such as agriculture and mining (Moore et al., 2000). Water quality is a concern for wildlife, with cetaceans vulnerable to infections attributable to terrestrial-source fecal pathogens, antibiotic resistant strains of terrestrial-source bacteria, and wastewater treatment system discharges. Monitoring for indicator organisms (e.g., fecal indicator bacteria) and pathogens within Cook Inlet may provide better insight into the extent to which belugas could be exposed. The ecology of fecal bacteria and protozoal organisms entering nearshore aquatic environments within the inlet is not well understood, though it is recognized that fecal by-products from humans and terrestrial animals may affect the quality of water and food resources in coastal ecosystems (Lisle et al., 2004; Miller et al., 2006).

Ten communities currently discharge treated municipal wastes into the inlet, five of which conduct only primary treatment (EPA[23]). Wastewaters from the Municipality of Anchorage, Nanwalek, Port Graham, Seldovia, and Tyonek receive only primary treatment, while wastewaters from Homer, Kenai, and Palmer receive secondary treatment (NOAA[24]). Eagle River and Girdwood have modern tertiary treatment plants (Moore et al., 2000). Wastewater entering these plants may contain a variety of organic and inorganic pollutants, and may be further dispersed in mixing zones which are areas of water downstream from or surrounding a treatment facility discharge point where the effluent plume being diluted by the water may exceed water quality standards specified by the Clean Water Act and state specifications (ADEC[25]).

Coastal human development contributes to the presence of protozoal and bacterial organisms, emergence of harmful algal blooms, and presence of antibiotic resistant organisms in aquatic ecosystems (Johnson et al., 1998; Scholin et al., 2000; Miller et al., 2002; Blackburn, 2003; Wong et al.[26]), potentially exposing CI belugas due to their preference for nearshore marine ecosystems.

[23]EPA. 2004. Primer for municipal waste water treatment systems. Environ. Protect. Agency, Doc. EPA 832-R-04-001 30 p. (avail. at http://www.epa.gov/owm/primer.pdf), accessed 9 Feb. 2012.

[24]NOAA. 2003. Subsistence harvest management of Cook Inlet beluga whales. Final Environmental Impact Statement. Alaska Reg., Nat. Mar. Fish. Serv., NOAA, 180 p. (available from https://alaskafisheries.noaa.gov/protectedresources/whales/beluga/eis2003/final.pdf), accessed 9 Feb. 2012.

[25]ADEC. 2010. Water quality standards, assessment and restoration. Alaska Dep. Environ. Conserv., Div. Water (avail. at http://www.dec.state.ak.us/water/wqsar/index.htm), accessed 9 Feb. 2012.

[26]Wong, S. K., E. Jensen, and W. Van Bonn. 2002. Ciprofloxacin resistance associated with marine mammals. Proceedings of the 42nd Interscience Conference on Antimicrobial Agents and Chemotherapy, 27-30 September 2002, San Diego, CA. American Society for Microbiology, Washington, D.C., p. 86.

A number of fecal bacteria and parasites can be transmitted through waterborne routes and are potential pathogens to both humans and animals, whereas viruses tend to be more host-specific and less likely to cross species. Fecal coliform and *Enterococcus* spp. counts are monitored by ADEC, but a rigorous survey of the microbiological quality of the water and sediment in and around Anchorage has not been attempted (ADEC[25]). Water and sediment samples collected from effluent and multiple coastal waterways in and around Anchorage were found to contain terrestrial-source fecal indicators and pathogens. In this same study, microbial source determination provided evidence of human-source pathogen pollution that could adversely affect beluga health (Norman et al., 2013).

Many current or planned mining projects are ongoing in the Cook Inlet Basin (ADNR[27]). Mined resources include coal, precious metals, and lead. The coastal zones may be developed and utilized during mining operations. Mine area runoff entering the inlet may contain organic carbon, ammonia, nitrates, oil and grease, and heavy metals (ADNR[27]). Alterations of surface and groundwater temperatures, flow rates, and nutrient or oxygen composition can result from mining operations. Mining runoffs into the surrounding Cook Inlet watershed may decrease or contaminate prey fish populations and negatively alter CI beluga critical habitat (Ward et al., 2009).

Pharmaceuticals Pharmaceuticals are biologically active and persistent substances that have been recognized as a continuing threat to environmental stability. The occurrence of pharmaceuticals and their metabolites and transformation products in the environment has become a matter of concern (Fair et al., 2009). These compounds, which may have adverse consequences 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; Santos et al., 2010). 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. Studies to determine the presence and significance of pharmaceuticals in CI belugas and their environment have not been conducted.

Emissions Vehicular, train, and aircraft engine warm-up and idle emissions may be a significant source of carbon monoxide pollution in the Anchorage area (Municipality of Anchorage[28]). Emissions may be produced as a byproduct of industrial activities such as coal plant operations, and during aerosolization of various fuels into fumes such as jet fuel. During "break-up" of ice in the spring, air quality warnings are commonly issued due to particles that have accumulated through the winter being emitted from sediment and debris stirred up by vehicular traffic and winds as surface snow melts. Exhaust emissions from marine engines operating in close proximity to killer whales have the potential to degrade air quality and the health of the animals (Lachmuth et al., 2011). However, research is needed to determine if levels of vessel exhaust and air quality over Cook Inlet are comparable or have adverse impacts on belugas.

Produced waters Produced waters, byproducts of oil and gas exploration, are a portion of the oil/gas/water mixture produced from oil wells and are highly saline (3,000 to more than 350,000 mg/L total dissolved solids) (Kharaka and Dorsey, 2005). The characteristics of the produced waters, as well as other discharges described, except drilling muds and cuttings, are based on information obtained during the Cook Inlet Discharge Monitoring Study conducted between 10 April 1988 and 10 April 1989 (EBASCO[29,30]). They may contain toxic metals, organic and inorganic components, radium-226/228, and other naturally occurring radioactive materials that may be water-, air-, or synthetic-based (Kharaka and Dorsey, 2005).

In the oil industry, chemicals are added to the fluids used in drilling processes including water flooding; well work-over, completion, and treatment; and the oil/water separation process. Before being discharged 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[31]). More recent sampling of produced waters has detected no, or very low levels of, hydrocarbon accumulations in Cook Inlet sediments or the water column from produced water discharges (Savoie et al.[17]).

The State of Alaska regulates discharges from offshore platforms, which include drilling muds, drill cuttings, and production waters (the wa-

[27]ADNR. 2011. Alaska Dep. Nat. Resourc., Div. Mining, Land, Water, Mining Resourc. (avail. at http://dnr.alaska.gov/mlw/mining/index.htm), accessed 30 Jan. 2012.

[28]Municipality of Anchorage. 2009. Air quality conformity determination for the 2010-2013 Anchorage Transportation Improvement Program. Prep. by Municipality of Anchorage, Community Planning and Dev. Dep., Transportation Planning Div., and Health and Human Services Dep., Air Qual. Section, Anchorage, Alaska, 34 p. (avail. at http://www.muni.org/Departments/OCPD/Planning/AMATS/Pages/AirQualityandPM10.aspx), accessed 5 Mar. 2012.

[29]EBASCO Environmental. 1990. Summary report: Cook Inlet discharge monitoring study: produced water (discharge number 016) Sept. 1988-Aug. 1989. Prep. for Amoco Production Co., ARCO Alaska Inc., Marathon Oil Co., Phillips Petroleum Co., Shell Western E&P Inc., Texaco Inc., Unocal Corp., Anchorage, Alaska and U.S. Environmental Protection Agency, Region 10, Seattle, Wash.

[30]EBASCO Environmental. 1990. Comprehensive report: Cook Inlet discharge monitoring study: Apr. 1987-Jan. 1990. Prep. for Amoco Production Co., ARCO Alaska Inc., Marathon Oil Co., Phillips Petroleum Co., Shell Western E&P Inc., Texaco Inc., Unocal Corp., Anchorage, Alaska and U.S. Environmental Protection Agency, Region 10, Seattle, Wash.

[31]Neff, J. M., and G. S. Douglas. 1994. Petroleum and hydrocarbons in the water and sediments of upper Cook Inlet, Alaska, near a produced water outfall. Submitted to Marathon Oil Co., Anchorage, AK, by Battelle Ocean Sci. Lab., Duxbury, MA, 30 p.

ter phase of liquids pumped from oil wells). The discharge rate of drill cuttings and drilling fluids during well drilling operations varies, but drill cuttings that are washed of oil contamination, plus a small volume of drilling fluid solids are continuously discharged during drilling operations. This rate varies from approximately 25 to 250 barrels per day into Cook Inlet, which contains several pollutants such as toxic metals and other inorganic and organic compounds (MMS[32]). At the peak of infrastructure development, there were 18 offshore production and 3 onshore treatment facilities, with approximately 368 km (230 miles) of undersea pipelines in upper Cook Inlet (MMS[32]). These products of natural resource exploration and extraction may pose health threats, such as bioaccumulation and toxicity, to beluga whales and their preferred prey and thus warrant further monitoring. While the probability of an impact from chronic, long-term exposure to produced waters on an ecosystem and its attendant populations, such as Cook Inlet and the belugas, is currently considered low, this cannot be substantiated from the relatively low number of published studies in the literature (Neff et al., 2011).

Dredging Dredging activities along coastal waterways have been identified as a concern for the SLE beluga population, where dredging of up to 600,000 m^3 of sediments resulted in the resuspension of contaminants into the water column (DFO[5]). While the volume of dredging in Cook Inlet is comparable to the St. Lawrence estuary (more than 844,000 yd^3 in 2003 at the Port of Anchorage), the sediments in Cook Inlet have not been found to contain harmful levels of contaminants (NMFS[1]); however, these dredged contaminants 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 OCs, that settled on the seabed may be stirred up and redistributed into the water column. This potential contaminant release by resuspension may increase their bioaccumulation in whales through the intake of prey items in the vicinity of the work area.

Stormwater and surface runoff Cetaceans may be especially vulnerable to a variety of pollutants and pathogens from runoff. Highway runoff is a significant source of water quality degradation. Various solids, metals, and nutrients present in highway runoff have been identified as inimical to 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.[33]).

The growing problem of stormwater runoff is related to increases in impervious surface area—streets, parking lots, and buildings—and construction activities that compact the soil. Stormwater runoff may be contaminated with terrestrial fecal pathogens and various water pollutants that are byproducts of urban and suburban activities, such as construction, agricultural chemicals, aircraft and street surface deicing agents (NMFS[1]), automobile use (oil and transmission fluid leakage, brake linings), 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[34]). Despite the potential effects of stormwater on Cook Inlet's ecosystem, there has been little research to determine if stormwater discharge has had a detrimental effect on beluga whales and their prey species.

Vessel Traffic

The majority of Cook Inlet is navigable and utilized by a variety of watercraft that pose a ship strike threat to beluga whales. Ship strikes resulting in mortality of CI belugas have not been definitively confirmed. However, in October 2007, a beluga stranded with evidence of trauma along the right side of the thorax that was suggestive of a ship strike (NMFS[1]).

Various commercial fishing vessels operate throughout the inlet with some areas associated with intensive salmon and herring fishing (NMFS[1]). Ship strikes from large vessels are not expected to pose a significant threat to belugas due to these ships slower speed and straight line movement. Smaller boats that travel at high speed and frequently change directions may pose a greater threat, particularly near river mouths where the belugas often congregate to feed on fish runs. Resulting displacement from sensitive feeding or calving habitats, when avoiding areas of high watercraft traffic, could be detrimental to the recovery of this population. Multiple CI beluga whales have been photographed with external injuries and marks suggestive of vessel strikes (McGuire et al.[8]).

Underwater Noise

Upper Cook Inlet is the most industrialized and urbanized body of water in Alaska, and background noise is relatively high compared to other regions of the state (Blackwell and Greene[35]). Noise from human sources appears to be increasing as more construction and improvement projects are undertaken

[32]MMS. 2003. Cook Inlet planning area oil and gas lease sales 191 and 199, final environmental impact statement. Minerals Manage. Serv., OCS EIS/EA MMS 2003-055, Alaska Outer Continental Shelf (avail. at http://www.mms.gov/alaska/ref/EIS_EA.htm 3), accessed 1 Mar. 2014.

[33]Young, F. C., S. Stein, P. Cole, T. Krarner, and F. Graziano. 1996. Evaluation and management of highway runoff water quality. Fed. Highway Admin., Wash., D.C. (avail. at http://trid.trb.org/view.aspx?id=479031), accessed 6 Oct. 2011.

[34]Miller, N. A., and M. W. Klemens. 2003. Stormwater management and biodiversity: impacts and potential solutions. Fact Sheet, Metropolitan Conserv. Alliance, Wildl. Conserv. Soc., Bronx, N.Y. (avail. at http://eices.columbia.edu/), accessed 2 July 2010.

[35]Blackwell, S. B., and C. R. Greene, Jr. 2002. Acoustic measurements in Cook Inlet, Alaska, during August 2001. Contr. no. 40HANF100123, Greeneridge Rep. 271-1 for NMFS Protect. Resour. Div., Anchorage, Alaska, 41 p. (avail. at NMFS, Alaska Region, 222 W 7th Ave., Box 43, Anchorage, AK, 99513), accessed 21 Oct. 2010.

along with increased vessel and aircraft traffic (NMFS[1]).

Sources of noise in the inlet include marine seismic surveys, aircraft, vessels, pile driving, oil and gas drilling, dredging, military detonations, and shore construction (Moore et al., 2000; Castellote et al., 2011; Lammers et al., 2013), forcing belugas to compete acoustically with natural and anthropogenic noise. Much of upper Cook Inlet is characterized by sand/mud bottoms, shallow depth, and high background noise from currents and tides (Blackwell and Greene[35]), thereby making it a poor acoustical environment.

Wild beluga whales hear best at relatively high frequencies, in the 45–80 kHz, which is above the range of noise from most industrial activities; however, their sensitivity at lower frequencies, where industrial noise concentrates, is still very good (Castellote et al., 2014; Blackwell and Greene[35]). Noise that is above ambient levels and within the same frequency utilized by beluga whales may mask communication between individual whales. Belugas are displaced by loud sources of noise such as ice breakers or marine seismic surveys, often at considerable distances in the tens of kilometers (Finley et al., 1990; Cosens and Dueck, 1993; Miller et al., 2005). More extreme levels of noise exposure can generate physical effects on beluga whales through temporary or permanent damage to hearing capabilities (Richardson et al., 1995).

Acoustic signals that are important for cetacean communication, foraging, predator avoidance, and navigation may be masked by excess high intensity noise in the environment. Commercial shipping associated with the Port of Anchorage and construction projects, increases the levels of background underwater noise (Kruse, 1991; Miller et al., 2000; Foote et al., 2004). Considerable commercial, military, and cargo air traffic increases noise in the Cook Inlet air space from the Anchorage International Airport and the local military base, Joint Base Elmendorf-Richardson.

The base also adds the noise of live fire and explosions due to military exercises, though the base has taken measures to mitigate this effect on beluga at critical areas and times of the year. Chronic noise may affect developmental, reproductive, or immune functions, and cause more generalized stress (Rolland et al., 2012). 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).

Fish are also considered vulnerable to intense and/or prolonged underwater sounds (Popper and Hastings, 2009). Increased levels of background noise can mask sounds critical to fish survival, decrease auditory sensitivity, modify their behavior, or decrease foraging efficiency as demonstrated in terrestrial species (Siemers and Schaub, 2011).

Land Use and Development

Coastline development along Cook Inlet includes cities and villages with associated ports, airports, roadways, and refineries in close proximity to important beluga habitat. Rather than being uniformly distributed throughout the inlet, the beluga whales are primarily found in nearshore waters. In areas where belugas must compete with humans for the use of nearshore habitats, coastline development may lead to direct loss of habitat or its indirect alteration due to bridges, vessel traffic, noise, and discharges affecting water quality. Salmonids 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.

Several port facilities are located in Cook Inlet, the largest located in downtown Anchorage. While most of Knik Arm remains relatively undeveloped, there are several planned or proposed projects that have been identified in a relatively confined portion of lower Knik Arm (Kendall and Cornick, 2015). Knik Arm is an important feeding area for beluga whales during much of the summer and fall, particularly in the upper reaches. The primary concern for beluga whales in this region of upper Cook Inlet is that development may impede their passage through Knik Arm (Kendall and Cornick, 2015).

Health Assessment

To more accurately characterize the effect of anthropogenic and environmental threats to CI beluga whale health, NMFS proposed actions that would contribute to the compilation of disease, pathological, and health indices. One of the actions included developing protocols to collect standardized baseline health data from physical examinations, blood and urine samples, and blowhole and anal swabs, to compare to other beluga populations.

Following the cessation of handling of CI beluga whales, comparative health assessments of wild belugas have been redirected toward more abundant populations (i.e., BB beluga whales) to serve as a control population for Cook Inlet. In 2008, BB beluga whale health assessment studies were initiated to develop safe, reliable, and standardized data collection and sampling protocols and have continued yearly since 2012. This population is considered relatively healthy, with a similar ecological niche (O'Corry-Crowe et al., 1997) as CI beluga whales, and serves as the most suitable surrogate group for health and disease evaluations.

Great potential exists for both observational and theoretical approaches to investigate the processes impeding survival and recovery of CI belugas; however, lack of data is often the key constraint in the application of epidemiological methods. The need for these approaches will inevitably increase in the face of the combined challenges of increasing anthropogenic pressures and climate change.

Many threats facing marine mammals, including CI beluga whales, may be related to the growth, behaviors, and consumption patterns of humans

Table 2.—Summary of key knowledge gaps for potential impediments to Cook Inlet beluga conservation and recovery, and if known, the number of animals, and year, presumed to be associated by each factor to date.

Factor	Knowledge gap(s)
Natural	
Live stranding	• Influence of climate change on water temperature, winds, and cloud cover on beluga adaptations to stranding events are unknown. • Consequences of live-stranding and refloating on long-term survivorship unknown. • Mass live stranding event with associated deaths (1992:2, 1996:5, 1999:5, 2003:5; 2005:1; 2008:2; 2014:2*) (NMFS, Table 5, p. 62 (text footnote 6)). *- 2014 live stranding mortalities suggested by necropsy findings (see Burek-Huntington et al., 2015).
Predation	• Influence on beluga population recovery and growth is not completely understood. • During 11 of 15 observed killer whale-beluga encounters, 17 belugas were injured or killed directly or indirectly through live stranding. One beluga death was assumed in each of remaining 4 encounters for total of 21 deaths during 1985-2002 (Shelden et al., 2003).
Diseases/parasites	
Infectious diseases	• Influence on beluga mortality and reproduction is not completely understood or unknown for pathogens such as *Bartonella* spp., *Brucella* sp., antibiotic resistant bacteria, and non-adapted pathogenic bacteria. • Impact of parasites such *Crassicauda giliakiana* and others on population recovery is unknown or not completely understood. • Necropsy of 38 animals (1998-2013) documented disease as cause of death in 3 cases (Burek-Huntington et al., 2015).
Changes in ice formation	• Long-term impact of increased ice cover and fast ice formation on population survival and recovery unknown.
Freshwater runoff	• Tidal mixing rates within Cook Inlet and link to critical beluga and fish habitat not well understood.
Water temperature	• Areas of the inlet with the strongest upwelling which provide the greatest nutrients for beluga prey species not delineated. • The influences of water temperature and salinity on fish distributions on a small-scale within the inlet are not well defined. • Impact of changes in streamflow and water temperature regimes on anadromous fish survival when in coastal rivers/streams and sound transmission in water.
Anthropogenic	
Pressure on fish stocks	• Salmonid runs: current and historic escapement biomass, species mix and timing for most rivers or watersheds within Cook Inlet not available. • Eulachon: population status, biomass and removal records through fisheries (including subsistence and personal use) and evaluation of fishery impact on belugas through 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.
Non-acoustic vessel disturbance	• Bearing of a given type and level of vessel disturbance on various beluga behaviors. • Relation of behavioral changes to various levels and kinds of disturbance in the Inlet and how it compares to similar populations in Bristol Bay and the St. Lawrence Estuary is unknown. • 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? • How does vessel disturbance alter foraging efficiency and energy acquisition? • Does energy expenditure increase in vessel presence?
Roads/vehicular traffic	• Amount of vehicular fluids released onto road surfaces. • Percentage of road runoff that reaches watersheds. • Acoustic/behavioral impact of bridge construction/traffic.
Noise/sound	
Seismic surveys	• Influence of seismic activity on beluga prey fish and invertebrates at all life stages.
Aircraft noise	• Is beluga prey capture affected by vessel noise?
Watercraft noise	• Significance of repeated low-altitude overflights on well-being of cetaceans such as belugas.
Pile-driving	• Bearing of noise from construction and industrial activities.
Explosions/detonations	• What vessels characteristics might most alter beluga behavior (size, speed, and sound-exposure levels)?
Offshore oil/gas drilling	• Detailed delineation of the acoustic environment in Cook Inlet (including historical trends of ambient noise levels).
Cable and pipe-laying	• Characteristics of sound propagation are unknown, particularly under different tide cycles and in the presence of prey.
	• Critical separation distances from construction activities and ability to partially compensate for masking noise is unknown.
	• Acoustic responses to sound, including changes in the composition, rates, lengths, and "loudness" of calls.
	• Effects of human-generated marine noise on beluga prey.
Pollutants (Point-source)	
Municipal waste	• Specific sites within Cook Inlet in need of remediation and cleanup.
Produced waters	• Influence(s) of air pollution on Cook Inlet belugas.
Dredging	• Data describing the fate of pharmaceuticals in the environment is limited.
Mining	• Detailed occurrence and trends of waterborne fecal pathogens is largely unknown.
Pharmaceuticals	• The effects of produced water discharges and dredging operations on beluga prey species are unknown.
Oil spills	
Pathogens	
Pollutants (Nonpoint source)	
Stormwater/surface runoff	• Correlation between contaminants and health effects in belugas is largely unknown.
Groundwater	• Factors influencing contaminant patterns within localized populations of marine mammals such as belugas.
Contaminants	• Influence 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).
Oil spills	
Pathogens	• Physical processes that might influence the behavior and trajectory of spilled oil not completely known
Urban development and habitat loss	• Knowledge about the functional value, stability, and resiliency of many "restored" habitats is incomplete. • The biological effects associated with water management activities are unknown. • Biotic implications of hydrologic alteration in Cook Inlet region are unknown.

(Marine Mammal Commission[36]). Therefore, belugas may be one of the best sentinels for aquatic and coastal environments in northern zones given their long life spans, high trophic level feeding patterns, and extensive fat stores that may serve as depositories for anthropogenic toxins (Reddy et al., 2001), and may allow for a better understanding of the intersection of ecosystem health and the influence of humans on this watershed and the various species that depend on it.

[36] Marine Mammal Commission. 2004. Annual report to Congress. Mar. Mammal Comm., Bethesda, Md., 167 p. (avail. at http://www.mmc.gov/reports/annual/welcome.shtml), accessed 30 Apr. 2010.

Conclusions

The processes discussed above have varying probabilities of occurrence. Some may be more likely to occur (e.g., fishing pressure from humans) compared to others (e.g., ship strikes). Some events may be more acute (e.g., oil spill, introduced epidemic disease) while others are chronic or long term (e.g., pollution and noise). The relative importance of each impediment to the recovery of Cook Inlet belugas depends not only on its magnitude, but also its duration. Considering these characteristics will aid in determining to which impediments a greater portion of limited research funds should be dedicated. Management may not be able to realistically mitigate the influence of a particular impact, resulting in a relatively larger effect on recovery than a factor that is more readily mitigated. A summary of key gaps in existing knowledge of natural and anthropogenic factors on CI beluga survival and recovery is presented by subcategory in Table 2.

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