A Review of the Current and Future Threats and Conservation Measures Needed for the Recovery of the Endangered Cook Inlet Beluga (*Delphinapterus leucas*) Stock

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Introduction

Within Alaskan waters there are five genetically and geographically distinct beluga whale (*Delphinapterus leucas*) stocks: Beaufort Sea stock, eastern Chukchi Sea stock, eastern Bering Sea stock, Bristol Bay stock and Cook Inlet (CI) stock (**Fig. 1a**). Compared to the other stocks, the Cook Inlet beluga (CIB) stock is the only one endangered under the Endangered Species Act (ESA). The eastern Chukchi Sea stock and Beaufort Sea stock are migratory, allowing them to escape some threats. They also occupy a large range as does the eastern Bering Sea stock. This supports a large carrying capacity and their large population numbers allow for subsistence and sustainable harvesting (**Table 1**). Despite being non-migratory and having a smaller range, the Bristol Bay stock is increasing (Quakenbush et al., 2015). Due to CIBs inhabiting the most isolated range, their population is the smallest of the five stocks at 279 individuals; even if the CIB population was not endangered, the estimated carrying capacity is only 1,664 individuals, which is less than the population numbers of the other Alaskan beluga stocks (**Table 1**; Castellote et al., 2020; Jacobson et al., 2020).

Unlike the migratory behavior of the eastern Chukchi Sea stock and Beaufort Sea stock, satellite tagging has shown that CIBs occupy and stay in the Cook Inlet year-round (Castellote et al., 2020; Goetz et al., 2012). During late spring to early fall, the entire CIB population is found in the upper CI (**Fig. 1b**). This is classified as their primary habitat and is suggested that predator occurrence is low while prey availability is high (Castellote et al., 2020). The upper CI is also suggested to be an important habitat for calves. The shallow and turbid waters provide shelter from predators, specifically orcas (*Orcinus orca*), sharks, and bears (*Ursus* spp.). The water temperature also plays a role as calves have a thinner blubber layer than adults and was found to be 6-17 ˚C warmer than the lower CI. The upper CI also has weaker tides which is beneficial for birthing and nursing of calves (McGuire et al., 2022).

Within the upper CI, CIBs inhabit the Susitna River Delta during specific times of the year; a photo-ID study determined that CIBs use the Susitna River Delta from mid-May to early June and again from mid-July to mid-August (**Fig. 2**; McGuire et al., 2022). This is suggested to be due to prey availability during this time; eulachon (*Thaleichthys pacificus*) has seasonal migrations to the Susitna River Delta in May and early June and salmon (*Oncorhynchus* spp.) in late May and mid-July. The Kenai River is also found to be an important feeding area for CIBs (**Fig. 2**): they feed on eulachon, herring (*Clupea pallasii*), smelt (*Spirinchus thaleichthys*), and Chinook salmon (*Oncorhynchus tshawytscha*) from March-May, silver salmon (*Oncorhynchus kisutch*) from September-October, and sculpin (Cottidae), flounder, and halibut (Pleuronectidae) from November-March. Despite Chinook salmon being present in the Kenai River from mid-May to July, belugas are not seen in this area due to the large presence of fishing vessels and nets (McGuire et al., 2022).

Even before fishing threats, humans have had significant impacts on CIB populations. Hunting of CIBs has been around since prehistoric times by Native villagers, trappers, homesteaders, sportsmen, and commercial operators. After the enactment of the Marine Mammal Protection Act (MMPA) in 1972, Native villagers were the only ones who could legally hunt belugas for subsistence (Shelden et al., 2021). In 1979, the estimated CIB population number was ~1,293 individuals. Subsistence hunting by Native hunters resulted in six to seven belugas per year being harvested in the early 1980s (Carter and Nielsen, 2011). By 1991, the CIB population declined to ~1,000 individuals (Shelden et al., 2021). As a result, the Potential Biological Removal (PBR) was calculated to determine sustainable harvest levels of CIBs. PBR was calculated to be 14 belugas, using an abundance estimate (N_{min}) of 712, half the maximum theoretical net productivity rate (R_{max}) (0.02), and a recovery factor (F_r) of 1 (Moore et al., 1999). From 1994-1998, a 47% decline in CIBs was recorded with ~653 CIBs in 1994 to ~347 CIBs in 1998 which was five times the PBR (Carter and Nielsen, 2011; Moore et al., 1999). This was due to an increase in annual CIB takes with 49 CIBs being taken and up to 96 being “struck and lost” in 1994, meaning the beluga was shot and never recovered (Carter and Nielsen, 2011).

As a result, the National Marine Fisheries Service (NMFS) listed the CIB stock as depleted under the MMPA (Shelden et al., 2021). In 1999, Alaskan Natives voluntarily agreed to stop subsistence hunting of CIBs and, in 2000, was formalized as a cooperative agreement. As a result, the expected recovery rate was 2-6% yr^{-1}, but instead, the population further declined at a rate of 1.45% yr^{-1} and was therefore listed as endangered under the ESA in 2008 (Burek-Huntington et al., 2015). A recovery plan was put into place, and critical habitat was established by the NMFS (**Fig. 3**). Despite these efforts, CIB population numbers continued to decline (Burek-Huntington et al., 2015; Shelden et al., 2021). As of 2018, their population is estimated to be 279 individuals (Castellote et al., 2020). Due to the COVID-19 pandemic and unfavorable weather conditions, abundance estimates have been limited from 2020-2021. A survey done in early 2022 surveyed for 3 consecutive days of the upper CI and found the median range to be between 186-224 CIBs, showing further decline of the stock (Shelden et al., 2022).

Threats

Despite a reduction in subsistence hunting, CIBs still face a variety of threats including strandings, orca predation, parasites and disease, environmental change, illegal harvest, fishery competition for beluga prey, pollution, oil and gas activities, coastal development, vessel traffic, anthropogenic noise, tourism, whale watching, and effects of climate change. Three major threats affecting the recovery of CIBs include noise pollution, prey reduction, and parasites and pathogens (Carter and Nielsen, 2011).

Noise pollution

Studies have found that anthropogenic noise not only poses a high threat for CIBs, but it is a reason that their population has not recovered (Castellote et al., 2018). The CI is a region with high noise compared to other parts of Alaska and is the most industrialized and urbanized body of water in the state. Some sources of noise include marine seismic surveys, aircrafts, boating vessels, pile driving, oil and gas drilling, dredging, military detonations, and shore construction. Even without anthropogenic noise, currents and tides create noise and the shallow waters make acoustic communication challenging (Norman et al., 2015). Despite natural noise, belugas rely on acoustic communication to find prey, avoid predators, navigate, find breathing holes in the ice, and communicate as CI has very turbid waters (Small et al., 2017; Norman et al., 2015).

Belugas can hear at frequencies in the range of 45-80 kHz and can hear better at higher frequencies. Most industrial activities occur at lower frequencies, but belugas are still affected by this noise. Communication between individuals is often masked in the presence of noise and temporary or permanent hearing loss can occur (Norman et al., 2015). Belugas can also change their call in the presence of boat noise which is suggested to be due to stress (Lammers et al., 2013). Avoidance of areas is another response if loud noises such as ice breakers or seismic activities are present (Norman et al., 2015). Even small noises such as those from four-wheel-all-terrain vehicles can cause belugas to flee the area. When boat engines are turned off, belugas have been known to approach the boat, suggesting that noise from the engine is affecting them as opposed to boat presence. Coastal development is an increasing threat that also creates harmful noise. This not only causes belugas to stay further from shore and abandon their traditional sites, but it causes other problems like making them more vulnerable to orca predation and abandoning key feeding areas (Carter and Nielsen, 2011).

Their prey may also be impacted by noise, and it has been shown that intense and prolonged sound can mask fish sounds imperative for their survival and cause a change in behavior, resulting in lower foraging behavior. This decreases fish reproduction and health, which negatively impacts beluga health (Norman et al., 2015).

Prey reduction

Belugas are highly dependent on high nutritional value prey and a decline in prey populations can cause belugas to have reduced energetics, affecting their recovery (Norman et al., 2015); they rely on this prey in the summer to build up their fat reserves as prey is less available during the winter months (Goetz et al., 2012). Major fisheries compete with belugas for salmon and other fish species. Throughout the years, both fisherman and Alaskan Natives have reported a decline in fish runs in the upper CI (Carter and Nielsen, 2011). This not only reduces beluga prey, but also increases competition between other species; due to the low diversity of prey in the upper CI, harbor porpoises (*Phocoena phocoena*) and harbor seals (*Phoca vitulina*) are feeding on the same fish species as CIBs (NMFS, 2016).

The health of fish also appears to be in decline; fishermen report fish, especially salmon, to have tumors, parasites, crooked spines, less oil content, and are of smaller size. This is suggested to be due to warmer water temperatures from climate change (Carter and Nielsen, 2011). Chinook salmon, for example, are very vulnerable to warming temperatures: juveniles have poor body condition, are less productive, and do not return to their birth habitat as adults (Daly and Brodeur, 2015). Embryos will not survival if the water temperature exceeds 17.5-20 °C. In addition, warmer water causes a higher likelihood for salmon to contain parasites (Carter, 2005). This not only causes a reduction in prey and nutritional value, but also exposes belugas to harmful, if not life-threatening, parasites and pathogens (Burek-Huntington et al., 2015).

Parasites and pathogens

Besides impacting fish health, harmful parasites have also been found in CIBs. *Stenurus arctomarinus*, a species of lungworm, have been known to cause mortality in young St. Lawrence Estuary belugas. This species of lungworm has not historically been documented in

Alaska but was recently found in CIBs. Another parasite new to CI is the nematode *Crassicauda giliakiana*, which is not found in any other Alaska beluga stock (Burek-Huntington et al., 2015). That being said, 90% of CIBs have been found to be infected by this nematode. It mainly affects the kidneys and causes extensive tissue damage and replacement, but it is unknown if the kidney is functionally damaged (Norman et al., 2015).

Bacterial infections also occur but are poorly studied in CIBs. Bacterial infections of the respiratory tract, such as bacterial pneumonia, are the most common diseases found in marine mammals: at least one CIB was known to have died from pneumonia (Norman et al., 2015). Viruses are also not well known and only one CIB was found to have died from a viral infection. St. Lawrence Estuary belugas were found to be more susceptible to diseases when exposed to anthropogenic chemical and organic contaminants in the water. Although pollutants are also not well studied in CIBs, their habitat is near Anchorage which is the largest urban area in Alaska. Over half of their population (~710,230) uses their drainage system which goes directly into CIB habitat. They also only have primary sewage treatment and do not test for pathogens that could be entering into the water. Contaminants from sewage could make CIBs more susceptible to disease and cause other problems associated with persistent organic pollutants (POPs) and heavy metals, but these have not been studied in CIBs and their habitat (Burek-Huntington et al., 2015).

Conservation measures

Critical habitat

In 2008, CIBs were listed as endangered under the ESA which required NMFS to designate critical habitat for them (McGuire et al., 2022). Critical habitat is defined as 'specific geographic areas that contain physical or biological features essential to the conservation of the species and that may require special management considerations or protection' by the ESA. In 2011, 7,800 km^2 of the CI was designated as critical habitat by NMFS (**Fig. 3**). Essential components to the survival of CIBs are their primary prey species as well as areas near anadromous fish streams and in $\geq$ 30 ft of water. This is important because they are important feeding grounds for CIBs. Other important components include unpolluted waters, minimal noise pollution, and unrestricted travel between important habitat areas. Even with these restrictions in place, CIBs have continued to decline (McGuire et al., 2020).

Photo identification

The Cook Inlet Beluga Whale Photo-ID project started in 2005 to help identify individuals based on their individual scars and markings to help researchers determine feeding and calving grounds, rearing of calves, use of habitat, and movement of individuals to ultimately aid in their recovery (**Fig. 4**; McGuire et al., 2020). Trained personnel observe belugas from multiple places along CI and take data on belugas such as group size, age, location, behavior, anthropogenic noise, and interspecific interactions during ice-free seasons (**Fig. 5a**, **Table 2**). From these surveys, CIBs were found seasonally in different areas as opposed to showing site fidelity within their critical habitat and calves were found throughout CI. CIBs also moved with the tides and were found in the Susitna Delta River, Knik Arm, Turnagain Arm, and the Kenai Delta River, which are identified as hotspots (**Fig. 5b**). Overall, this effort was, and still is, successful in obtaining critical data to help future conservation efforts for CIBs (McGuire et al., 2020).

Recovery Plan

In 2016, the NMFS created a recovery plan by identifying threats and the degree to which they are resulting in CIB decline, as well as ways to mitigate these threats to allow for recovery of CIBs (NMFS, 2016). The goal is for CIBs to recover to the point where they are no longer considered endangered under the ESA. To achieve this, five factors were established important to their recovery: their habitat must be suitable for their recovery with prey abundance; any commercial, scientific, recreational, and educational activities do not inhibit recovery; diseases are not causing CIB decline; regulatory mechanisms are equipped to manage threats outside of the ESA; and any new threats that could affect the recovery of CIBs are monitored. A stakeholder panel was also formed to give their feedback on this plan. A list of 64 actions were created to aid in their recovery. Some of these actions include improving stranding responses, evaluating prey abundance, using photo-ID to look for disease, and engaging in abundance surveys. Although this plan has so far been unsuccessful, it is estimated that it will take 50 years for CIBs to recover (NMFS, 2016).

Necropsies

Necropsies are important to understand CIBs cause of death, especially if there is no evident cause of death; necropsies are the main source of information on predation, parasitism, disease, and environmental change threats (Burek-Huntington et al., 2015). Between 1997-2011, the Alaska SeaLife Center tested or necropsied 59 live and dead harbor seals (*Phoca vitulina* *richardsi*) in CI to test for disease and contaminants. They used harbor seals as a surrogate species to study CIBs as they are exposed to the same diseases and contaminants. They found there to be a low presence of disease and contaminants within harbor seals and do not think this is the reason for CIB decline. It is important to note that there are some diseases that only impact cetaceans and belugas are more affected by contaminants that harbor seals (Bauer et al., 2016). That is why it is important to perform necropsies as disease and contaminants are increasing threats to CIBs; in 2011, 62% of photo-IDed belugas had evidence of disease from scarring. Climate change and pollution can weaken immune systems, worsen disease, and result in an outbreak, which could be detrimental to CIBs (NMFS, 2016).

In 2003, 20 CIBs stranded and only 2 of the 20 had a known cause of death. Without proper data from necropsies, it is unknown why this mass stranding occurred, making it hard to follow/modify the recovery plan (Vos and Shelden, 2005). New threats are also arising, and necropsies are imperative to help identify them. They provide critical understanding of trends in mortality and can focus on where conservation efforts are needed. For example, Burek-Huntington et al. (2015) found that disease was a large cause of death for CIBs in 1998, 2000, and 2001, but perinatal mortality and malnutrition were more prevalent from 2006-2008. This data allows for the recovery plan to be adjusted appropriately based on these new threats and creates an important research focus (Burek-Huntington et al., 2015).

Acoustic monitoring

Researchers have used hydrophones and other acoustic devices as a mean to study CIBs to determine seasonal habitat utilization, feeding areas, social interactions, and orca predation (Blevins-Manhard et al., 2017; Castellote et al., 2015; Lammers et al., 2013). In 2008, NOAA Fisheries started the Cook Inlet Beluga Acoustics project to detect CIB presence throughout the CI using passive acoustic monitoring. From 2008-2013, acoustic devices were deployed in 12 locations to determine summer and winter grounds of CIBs. It was determined that CIBs forage and are much more prevalent in the upper CI during the summer months as opposed to the winter (**Fig. 6**; Castellote et al., 2015).

Captive beluga calves produce pulsed calls very frequently the first seven months after being born. A similar pulsed call was found in wild CIBs and is speculated to be calves communicating with their mothers, allowing researchers to gain a better understanding of where calves are located within the CI (Blevins-Manhard et al., 2017). Another study found orcas to be present at Homer Spit and detected only one pod north of Tuxedni Bay in the fall (labeled in **Fig 6 a,b**). This suggests that CIBs are absent in these locations, specifically Homer Spit, due to the presence of these predators. Similar to necropsies, acoustic monitoring of belugas collects important data that can also be used in management applications (Lammers et al., 2013).

Discussion

Despite many conservation measures in place, CIBs have declined by 80% since the 1970s and continue to decline at around 2.3% annually (Migura and Bollini, 2022). One of the main challenges in appropriate conservation approaches is the lack of data regarding CIB habitat use, foraging behavior, use of the critical area, and threats. In addition, some threats that are known to impact other marine mammal species are not fully studied in CIBs (e.g. parasites, pathogens, contaminants). For example, *S. arctomarinus*, and *C. giliakiana* are new to Alaska, but the reason as to why this is is unknown (Burek-Huntington et al., 2015). Necropsies, acoustic devices, satellite tags, and photo ID are all methods to obtain more data, but there are challenges with each method. Satellite tags provide data on seasonal movements and diving behavior but not what they were doing at each site or the group size. Photo-ID can provide some of this data but is lacking fine-scale movements as it focuses on the site the belugas were found in that moment (McGuire et al., 2020). Acoustic devices can only be placed in certain areas and anthropogenic noise can mask beluga sound (Lammers et al., 2013). Necropsies can sometimes provide cause of death of belugas, but they are rare and often the cause of death remains unknown (Burek-Huntington et al., 2015).

Although critical habitat has been established, specific knowledge on hotspots within that habitat is limited. Without this information, key areas within the critical habitat cannot be given stricter regulations. In addition, any disturbance or modification to the critical habitat could impact recovery for CIBs; 60% of Anchorage's natural gas is delivered through a pipeline that goes through the Turnagain Arm. A leak in this pipe could cause detrimental effects to CIBs, so it is imperative to understand their habitat to take action such as redirecting the pipeline (McGuire et al., 2020).

The recovery plan from 2016 is another essential conservation measure put in place to protect the CIB stock. But besides a lack of data, the amount of harassment that is allowed for CIBs is concerning; NMFS has allowed for 120,000 takes between 2017-2025, despite their population declining. A better approach would be to create yearly takes that decrease/increase based on how the population is doing and authorize takes based on what is needed (Migura and Bollini, 2022).

Stakeholders are another factor in CIB recovery. The recovery plan includes educating stakeholders to make them more aware, as boaters are not always aware that boat noise can harm CIBs. There is also a stakeholder panel consisting of individuals who are interested in CIB recovery or who will be impacted by any actions taken to protect CIBs. This panel is involved in planning on how to reduce threats to CIBs. Participation in the CIB monitoring program is a way that stakeholders have gotten involved with CIB recovery (NMFS, 2016).

There are also stakeholders who have interests in activities that may impact CIBs (Szymoniak and Colt, 2009). In 2010, it was proposed that a ferry, called the Knik Arm or Cook Inlet Ferry, would be built to transport people from the Knik Arm (labeled in **Fig. 3**) to Anchorage and other areas within the CI. There were many benefits to this project such as an increase in jobs, economic growth, shorter commute, and construction of a dock for multiple boats. One interesting benefit was that it would increase ship traffic that would allow for the Ship Creek area to be developed which would negatively impact CIBs (Szymoniak and Colt, 2009). The noise pollution from construction of the docks and increased boat noise/traffic would have harmful effects to CIBs, especially since the Knik Arm is included in their critical habitat (**Fig. 3**; Kendall and Cornick, 2015). The Knik Arm is a major foraging area for CIBs and any disturbance that causes them to be displaced will have negative population effects; seasonal pile driving has already caused belugas to be displaced in the Knik Arm. In addition, the recovery plan lists anthropogenic noise as a threat of high concern. As a result, the ferry was never built, despite many economic benefits, as it would be detrimental to the recovery of CIBs (Castellote et al., 2018).

To help CIBs, I would work with other researchers to obtain more data in areas that are missing. For example, testing Anchorage's sewer water for presence of pathogens or obtaining data on beluga contaminants by taking blubber samples from dart biopsies or necropsies. In addition, I would use the data from photo-ID, necropsies, satellite tagging, and acoustic monitoring to remodel the critical areas/recovery plan. For example, I think it is important to create more restrictions such as limited/restricted fishing in the summer in areas where belugas are feeding, as photo-ID has identified important CIB hotspots.

Another method I would use is studying the Bristol Bay stock. Bristol Bay belugas are similar to CIBs because they are nonmigratory and occupy a limited geographic area (**Fig. 1a**; Quakenbush et al., 2015). A major difference between these stocks is the Bristol Bay stock is increasing at about 4.8% per year and has been since 1996. Throughout this time, it was suggested that the population was below their carrying capacity due to hunting, research, gillnet entanglement, orca predation, and an increase in prey resulting in an increased carrying capacity. However, CIBs are not at carrying capacity and are still in decline. The reason for their increase is unknown but it is suspected to be due to a decrease in hunting and research lethal takes, increase in salmon abundance, and a decrease in orca predation (Lowry et al., 2008). In my opinion, to increase CIBs, studying the Bristol Bay stock to identify why they are increasing can potentially help to understand what is different for CIBs. For example, Bristol Bay has an abundance of salmon whereas salmon in the CI are diseased (Carter and Nielsen, 2011; Lowry et al., 2008). Determining why salmon health is declining and taking action may increase CIB overall body condition, allowing for more successful reproduction. But it is also important to look at multiple stressors as these threats together could be causing decline as opposed to a singular threat.

Overall, the CIB stock is declining at a rapid rate and has been since the 1990s (Carter and Nielsen, 2011). It is imperative to update the 2016 recovery plan and critical habitat with the new data that has been collected, as well as research new/understudied threats. I believe that stricter regulations will be needed such as limiting coastal development, and stakeholders will be key, as new restrictions will mean backlash from fishermen, coastal project workers, the public and others. But without these changes, CIBs will continue to decline until it is too late to save them.

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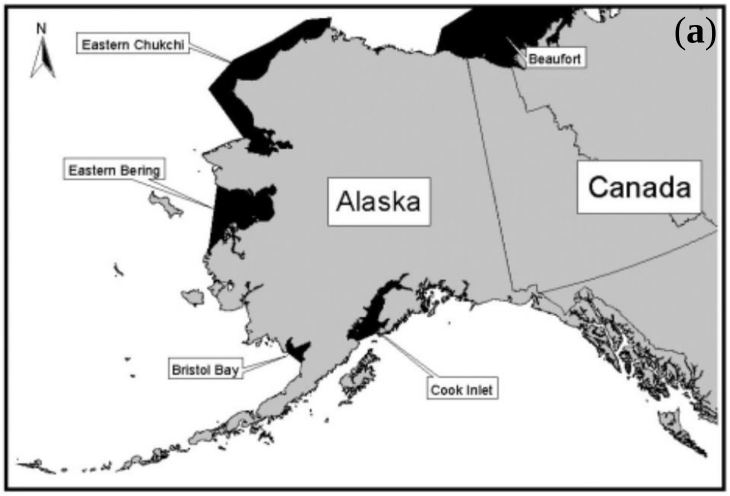
Figures



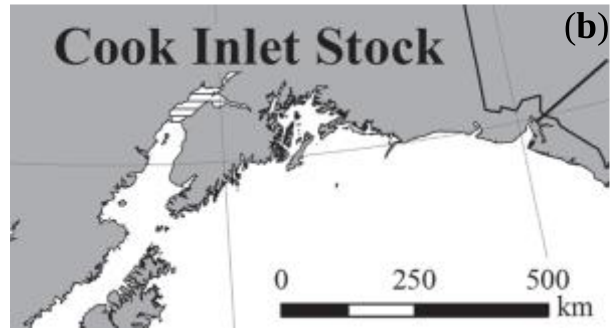


Figure 1. (**a**) Beluga stocks found in Alaskan waters (Moore and DeMaster, 2000) and (**b**) known summer areas (striped area) for Cook Inlet belugas (modified from Quakenbush et al., 2015).

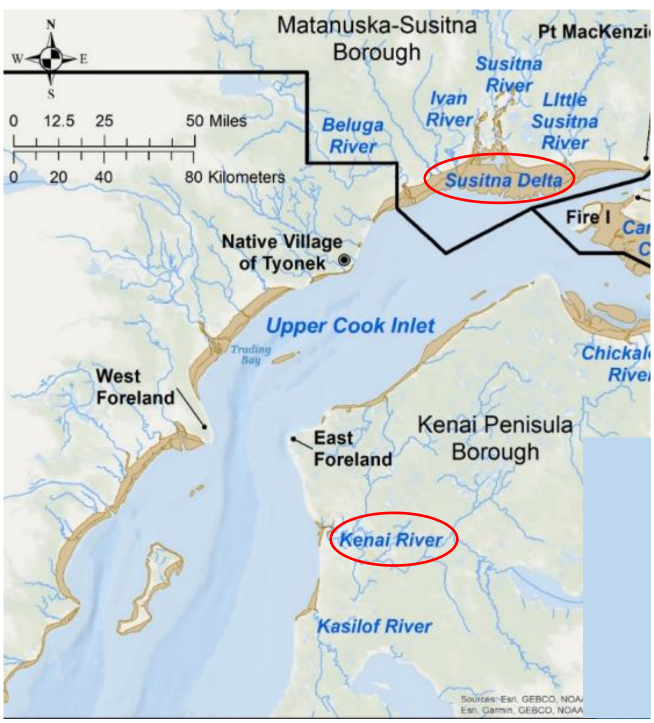


Figure 2. Map of upper CI showing the location of the Susitna River Delta and Kenai River (modified from Shelden et al., 2021).

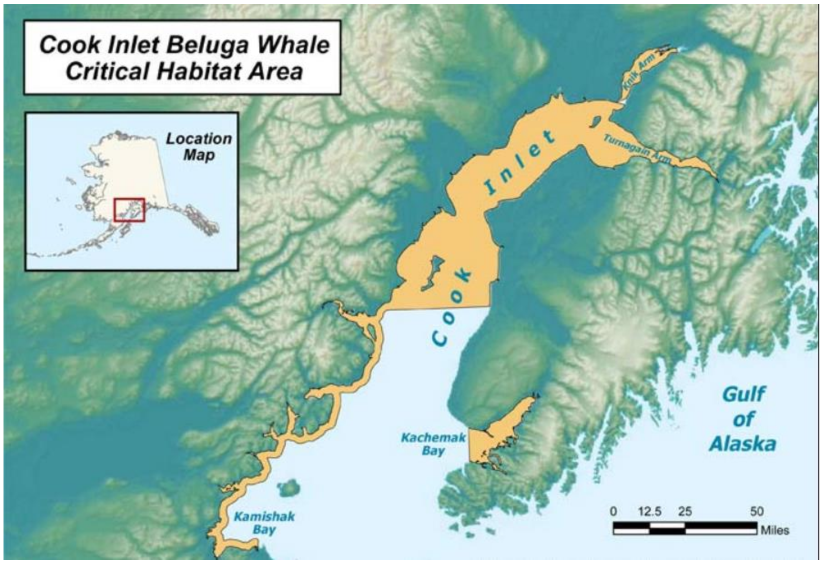


Figure 3. Critical habitat (shaded in orange) designed by NMFS for CIBs (Alaska Department of Fish and Game, 2022).

Figure 4. Organizations who created the Cook Inlet Beluga Whale Photo-ID project ("Cook Inlet Beluga Whale Photo-ID Project," 2017).

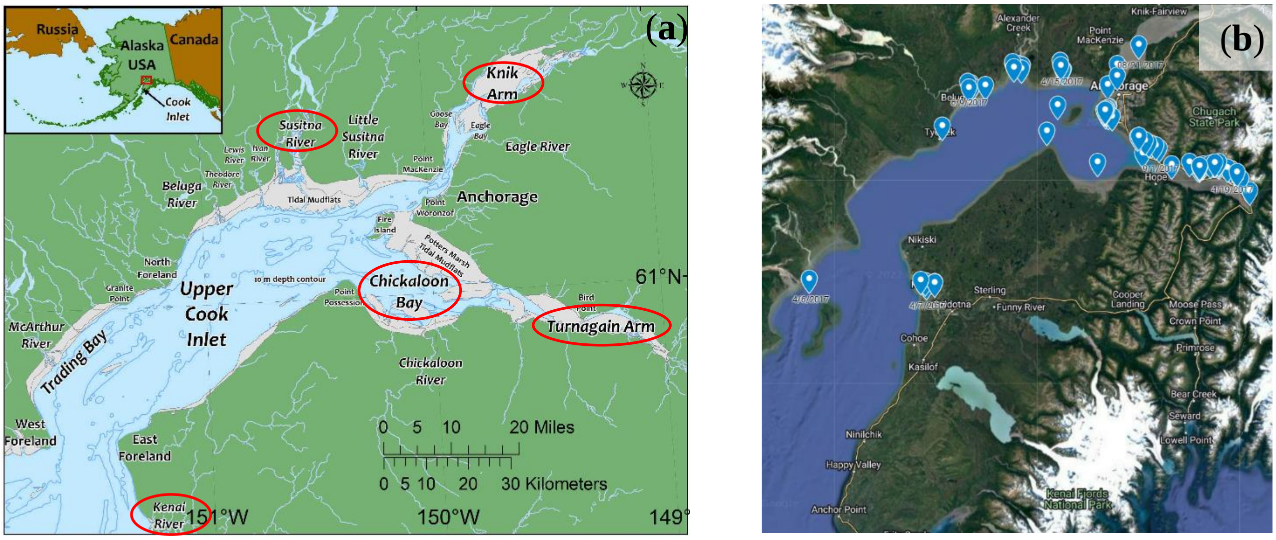
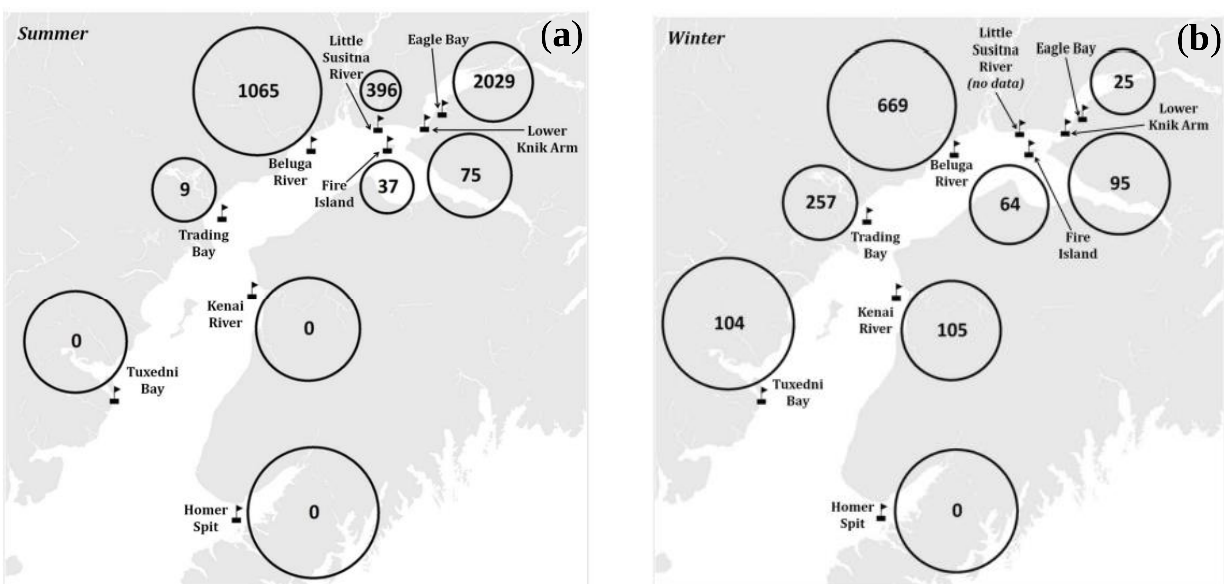


Figure 5. (**a**) Map showing locations of beluga photo-ID survey zones (Wade, 2022). (**b**) CIB sightings map from 2017 (Cook Inlet Beluga Whale Photo-ID Project, 2017).



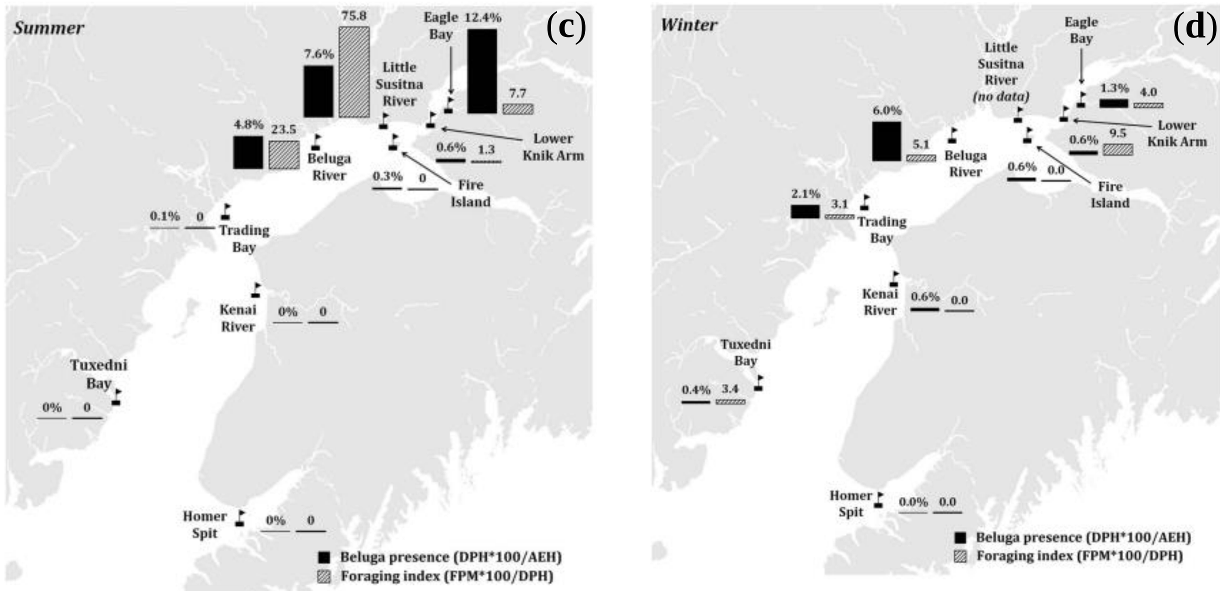


Figure 6. Relative amount of acoustic effort hours (AEH) represented as open circles and the number of beluga detection positive hours (DPH) within each circle obtained in (**a**) summer and (**b**) winter. Beluga % DPH (solid black) and foraging index (hatched) during (**c**) summer and (**d**) winter (Castellote et al., 2015).

Tables

Table 1. Estimated population size of the five beluga stocks in Alaskan waters (data from Castellote et al., 2020; Quakenbush et al., 2015).

Stock	Estimated population size
Beaufort Sea	39,000
Eastern Chukchi Sea	4,000
Bristol Bay	3,000
Eastern Bering Sea	1,800
Cook Inlet	279

Table 2. Number of beluga photo-ID surveys conducted in Cook Inlet, Alaska, between 2005 and 2017 according to survey zone and year (McGuire et al., 2020).

Zone	Total number of surveys	Month						
		Apr	May	Jun	Jul	Aug	Sep	Oct
Susitna River Delta	156	0	14	28	61	37	9	7
Knik Arm	154	1	4	14	8	61	48	18
Turnagain Arm	119	3	4	0	0	29	68	15
Chickaloon Bay/Fire Island	21	0	4	5	4	3	5	0
Kenai River Delta	27	0	9	0	0	0	8	10
Total Number of Surveys	477	4	35	47	73	130	138	50