Anthropogenic Scarring in Long-term Photo-identification Records of Cook Inlet Beluga Whales, *Delphinapterus leucas*

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ABSTRACT—Vessel strikes, entanglement, poaching, intentional harassment, and invasive research are possible direct anthropogenic threats to the endangered Cook Inlet beluga whale, Delphinapterus leucas, *population (CIBW) according to the CIBW Recovery Plan. Establishing the prevalence of such threats is necessary for understanding impact and monitoring future trends. We examined records of individual belugas photographed during 2005–17, along with stranding records during this time, to determine prevalence of scars indicative of anthropogenic trauma, and classified these scars according to their likely sources (e.g., entanglements, vessel strikes, puncture wounds, and research). In this combined dataset, 37.7% of 106 individuals had scars classified as either confirmed or possible anthropogenic origin. In the photo-ID records, 15% of individuals had signs of confirmed or possible entanglement, 14% had signs of confirmed or possible vessel strikes, 5% had signs of possible puncture scars, and 24% had research scars. Out of 33 necropsied belugas, 6% had scars from satellite tagging, 6% had signs of entanglement, 3% had possible signs of a vessel strike, and 3% had possible signs of puncture scars. We also examined wound healing, reproduction, and survival of individuals with scars consistent with anthropogenic trauma. One important result from this work is that trauma from anthropogenic sources may take years to manifest. From our limited sample we cannot directly infer the population-level prevalence of anthropogenic trauma, but our assessment shows the source and prevalence in the sample; this is a preliminary step in understanding how anthropogenic trauma may be contributing to the population's continued decline.*

Introduction

Vessel strikes, entanglement, poaching, intentional harassment, and invasive research are among many possible threats to Alaska's endangered Cook Inlet beluga whales (CIBW), *Delphinapterus leucas,* according to the Recovery Plan (NMFS[1]) for this population. Geographically and genetically isolated from other beluga populations around Alaska, the CIBW population is listed as an "endangered" Distinct Population Segment (DPS) by NOAA's National Marine Fisheries Service (NMFS), the Federal agency responsible for its protection.

The designation under the U.S. Endangered Species Act (ESA) occurred in October 2008 (NOAA, 2008) and was preceded by a steep decline in the CIBW population during the 1990's and a designation as "depleted" in 2000 under the Marine Mammal Protection Act (NOAA, 2000). An unsustainable level of hunting by Native Alaskans (Mahoney and Shelden, 2000) was thought to be the primary cause of the initial population decline. Cooperative agreements between NMFS and subsistence users suspended CIBW hunting after 2006 (NOAA, 2008). If subsistence hunting was the only factor limiting population growth, the population was expected to have recovered in the following decade. However, a survey by NMFS conducted in June 2018 found the population has continued to decline at a rate of about 2% per year since the ESA listing in 2008 (Wade et al.[2]).

The reasons for this decline remain unknown. The CIBW Recovery Plan lists ten likely threats to CIBW recovery, including injury and death from anthropogenic activities (referred to collectively in the Plan as "unauthorized take," although this category also includes NMFS authorized take for research). Unauthorized take is categorized as a threat of medium concern in the CIBW Recovery Plan, with the level of concern affected, in part, by uncertainties about magnitude and trend.

Establishing a baseline estimate of the current magnitude of this threat is necessary for establishing and monitoring future trends. The shores of Cook Inlet are inhabited by most of Alaska's human population and in-

[1]NMFS. 2016. Recovery plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). NMFS Protected Resources Div., Alaska Region, Juneau, AK (https://repository.library.noaa.gov/view/noaa/15979).

[2]Wade, P. R., C. Boyd, K. E. W. Shelden, and C. L. Sims. 2019. Chapter 2: Group size estimates and revised abundance estimates and trend for the Cook Inlet beluga population. *In* K. E. W. Shelden, and P. R. Wade (Editors). 2019. Aerial surveys, distribution, abundance, and trend of belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2018. AFSC Proc. Rep. 2019-09, 93 p. (https://apps-afsc.fisheries.noaa.gov/documents/PR2019-09.pdf).

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cludes Anchorage, the largest urban area in the state. Humans use Cook Inlet for fishing, hunting, shipping, timber harvest, mining, dredging, renewable energy, discharge of wastewater, military activities, oil and gas development, transportation, and residential and industrial development (Fig. 1). Belugas are not uniformly distributed throughout Cook Inlet, but are predominately found in nearshore waters of upper Cook Inlet, overlapping areas of high human activity (Shelden et al., 2015). With the exception of subsistence hunting of northern and western beluga stocks, the potential for injury and death from anthropogenic activities is likely higher for CIBW's than for other beluga populations found in more remote areas of Alaska and likely to increase with a growing human population around the inlet (NMFS[1]).

Longitudinal studies of individual belugas who have experienced anthropogenic injury may provide insight into the prevalence and consequences of these threats through time and how such injuries may affect the CIBW population. Image analysis from photo-identification (photo-ID) catalogs has been successfully used for health assessment and threat risk analysis of cetaceans, including endangered baleen whale stocks such as North Atlantic right whales, *Eubalaena glacialis* (Moore and van der Hoop, 2012; Rolland et al., 2016), Okhotsk Sea bowhead whales, *Balaena mysticetus* (Shpak and Stimmelmayr, 2017), Bering-Chukchi-Beaufort Sea bowhead whales (George et al., 1994; 2017), and western gray whales, *Eschrichtius robustus* (Bradford et al., 2009). It has also been used for the long-term monitoring of small cetaceans in an estuarine environment (Wells et al., 2008) and for evaluating the effects of research activities such as satellite tagging on individual cetaceans (Gendron et al., 2015).

The CIBW Photo-ID Project began developing a photo-ID catalog of individually identified belugas in 2005 to establish a long-term, noninvasive data set to monitor the CIBW population. With approximately 400 individuals in the catalog as of the end of 2017, it consists of most of the adult and subadult CIBW population over the last 13 years, as well as calves who were too young to be identified by their own marks. Marks used for identification are long-lasting and allow information on individual survival and reproduction to be collected over time. Photographs also allow for examination of scars resulting from anthropogenic injury on those parts of the body visible above water while the whale is alive, and on all visible areas of carcasses. Photographs of live whales following an injury provide information on wound healing and body condition, and long-term photographic sighting records of injured individuals can be assessed for survival and reproduction. We therefore examine both datasets, but present some results separately.

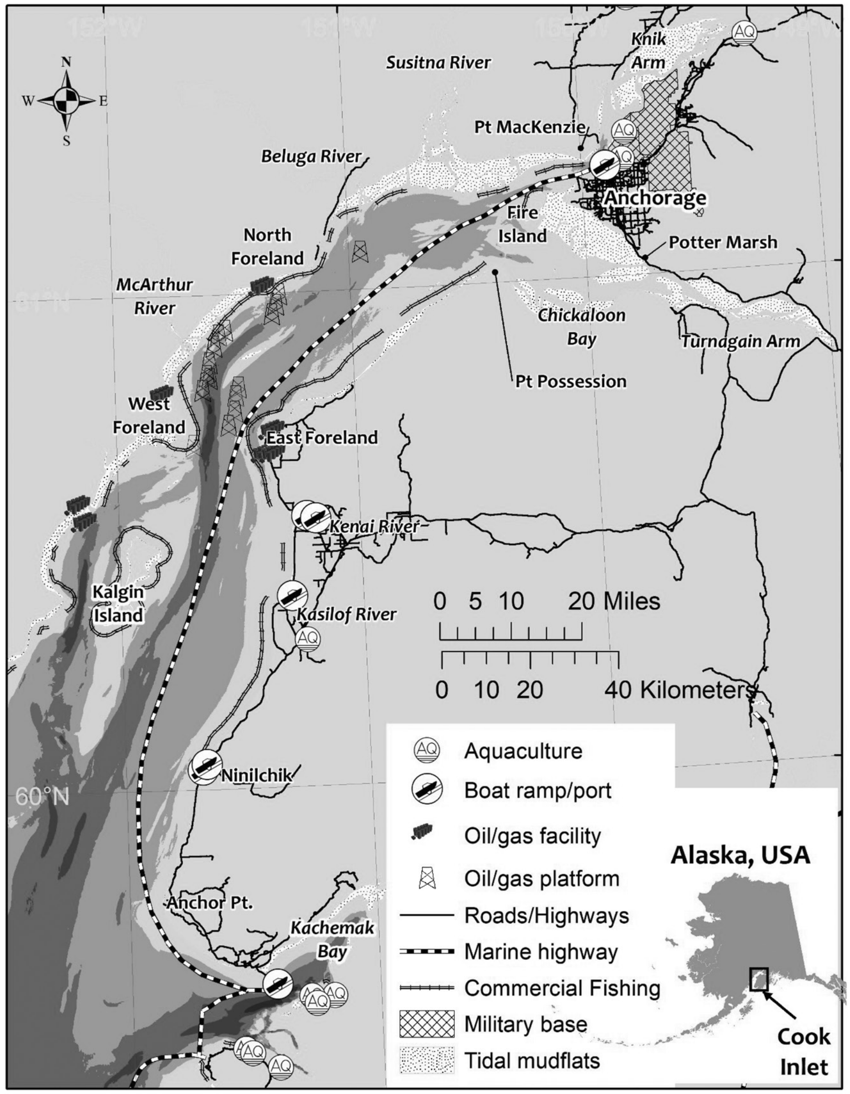

Figure 1.—Cook Inlet, Alaska.

In this paper, we

1) review photographic records of belugas in the photo-ID catalog and stranding database to identify scars indicative of anthropogenic injury;
2) classify these scars according to their likely sources (entanglement, vessel strike, hunting/

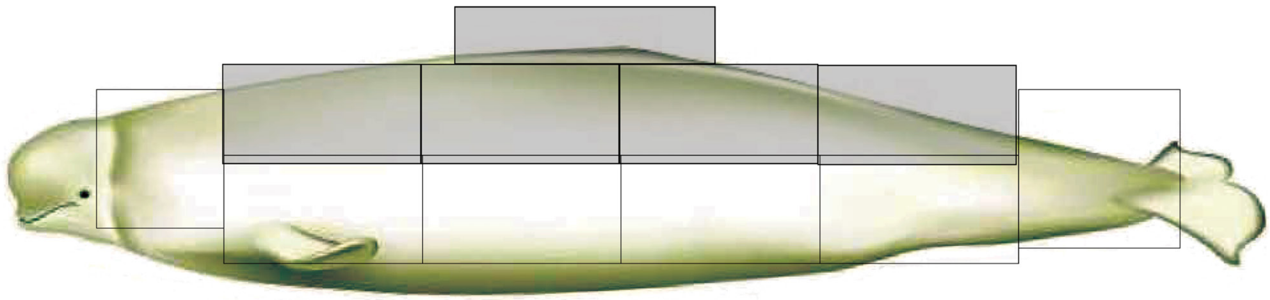

Figure 2.—Beluga body segments used for cataloging photographs for identification. The five shaded areas are the critical sections used in classifying anthropogenic scars. Beluga illustration courtesy of Uko Gorter.

poaching/harassment, and invasive research) and their location on the body;

3) estimate the prevalence of each anthropogenic scar type in the photo-ID catalog; and
4) examine the photographic sighting histories of belugas with anthropogenic scarring to document their subsequent healing, survival, and reproduction.

Methods

Photo-ID Data

The photo-ID catalog was created from photographs taken during 477 photo-ID surveys conducted over 13 consecutive field seasons (2005–17) in Cook Inlet, an estuary in southcentral Alaska (Fig. 1). At the time of this study, the summer CIBW range had contracted to the area north of East and West Foreland (Rugh et al., 2010; Shelden et al., 2015), hereafter referred to as the Upper Inlet. Most of the photo-ID survey effort was concentrated in the Upper Inlet, with some effort in and around the Kenai River (Fig. 1).

Surveys were conducted during the ice-free season (April–October), with most effort in August and September, and least effort in April. Surveys were conducted from small vessels (58%) and from shore (42%). Free-swimming beluga whales were photographed with digital SLR cameras with a telephoto image-stabilized zoom lens (100–400 mm) with auto-focus. We also reviewed and cataloged photographs of live belugas shared with us from the public and colleagues. These shared photos were taken with a variety of cameras, cell phones, and other digital devices, and were held to the same quality standards as those collected during photo-ID surveys.

Marks used to identify individuals consisted of pigmentation patterns, scars from disease or anthropogenic injury, and scars that likely came from other sources such as competition (among conspecifics, or interspecific from harbor seals, *Phoca vitulina*), social interactions among conspecifics, predation (sharks: *Carcharodon carcharias, Somniosus pacificus, Lamna ditropis*; killer whales, *Orcinus orca*; and possibly brown bears, *Ursus arctos*), natural debris in high currents, or scraping themselves against rocks, sea ice, or other hard substrates (LGL[3]).

Turbidity in Cook Inlet is high from glacial sediments and prevents visibility below the waterline in the Upper Inlet. As a beluga surfaces and submerges, different portions of its body are available to be photographed. Side-profile images were used to identify individuals and were divided into 11 sections along the right and left sides of the whales. The five body sections along the spine (Fig. 2) are those used for identification because the six sections containing the head, tail, and ventrum of the whale are not commonly captured in photographs.

A right- or left-side profile set was considered complete and included in the catalog, given a unique ID number, and considered an individual if it contained high-quality images of all five sections along the spine of the whale, beginning just behind the blowhole and extending to the base of the tail (i.e., shaded sections in Figure 2). An individual could also be accepted into the catalog if it was photographed in multiple years, even if it did not have high-quality images from all five body sections, but only after photo-analysts ensured that it could not be matched to existing individuals in the catalog. All matches in the existing catalog were reviewed and verified by at least two experienced photo-analysts. Further details of the photo-ID methods are presented in McGuire and Stephens.[4]

Because photographs taken from vessels or shore were lateral views of one side of a beluga's body, separate catalogs were created for the

[3]LGL Alaska Research Associates. 2009. Photo-identification of beluga whales in Upper Cook Inlet, Alaska: mark analysis, mark-resight estimates, and color analysis from photographs taken in 2008. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, AK, 99 p. (avail. online at https://87e3476c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ugd/ af2fcb_7113cf2e054547009605bf8884568b1e.pdf).

[4]McGuire, T., and A. Stephens. 2017. Photo-identification of beluga whales in Cook Inlet, Alaska: Summary and synthesis of 2005–2015 data. Rep. prep for National Marine Fisheries Service, Alaska Region. LGL Alaska Res. Assoc., Inc., Anchorage, AK, 229 p. (avail. online at https://87e3476c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ugd/ af2fcb_4a6dbde631be4de685f764a73cf16908.pdf).

right-side images, the left-side images, and the dual-side images. Photo-ID studies of other cetaceans, such as bottlenose dolphins, *Tursiops truncatus*, often use images of the dorsal fin to identify individuals, and these individuals can be recognized by fin shape and marks along the trailing edge that are visible from either side. Belugas do not have a dorsal fin, and therefore could only be classified as dual-side individuals if 1) they met the criteria to be classified as individuals in both right- and left-side catalogs, and 2) if marks that spanned both sides of the body could be seen and used to link the two sides.

Aerial photography from drones was not feasible from 2005 to 2016 due to research permit restrictions from NMFS and flight restrictions from the Federal Aviation Administration. However, in 2017, NMFS began photographing CIBW's from drones and has made some of these images available to us, which has facilitated the matching of right and left sides and allowed for the addition of 23 dual-side linkages to our previous count of 55. The 2005–17 CIBW photo-ID catalog contains records for 423 individuals identified from photographs of their right sides, 431 individuals identified from their left sides, and 78 "dual" individuals (i.e., matched between both catalogs, and also contained within the left- and right-side catalogs).

Stranding Data

Between 2005 and 2017, 95 dead CIBW's were reported to NMFS and photographs were taken of 41 of these (McGuire et al., 2020b). Necropsies (conducted by the Alaska Marine Mammal Stranding Network under the authorization of NMFS) were performed on 33 of the 41 individuals that were photographed. Five of the necropsied whales were matched to individuals in the dual-side photo-ID catalog. Tissues and teeth were collected from some individuals ($n = 34$), either during necropsy or during brief examination without necropsy. For these individuals, ages were estimated from growth layers in the teeth, assuming one growth layer group (GLG) per year (Vos et al., 2019). A retrospective analysis of the reproductive status of dead females ($n = 16$) was conducted based on laboratory examination of their reproductive tract (Shelden et al., 2019a). The sex of necropsied individuals was confirmed using genetic methods. In brief, total DNA was extracted from tissue samples by established protocols (e.g., O'Corry-Crowe et al., 1997), and the genetic sex of each sample was determined by PCR-based methods (Fain and LeMay, 1995). In addition to collecting biological data and samples, examining veterinarians attempted to determine the cause of death (COD) during necropsy.

Classification of Anthropogenic Scarring

Categories of scars were developed by comparing scars and deformities seen on individuals in the CIBW photo-ID catalog and stranding photos to descriptive classifications and photographs of injuries of other marine mammal species (e.g., George et al., 1994; 2017; Read and Murray, 2000; Rommel et al., 2007; Azevedo et al., 2008; Bradford et al., 2009; Byard et al., 2012; Moore and Barco, 2013). Marks that likely came from non-anthropogenic sources such as competition, predation, disease, and the physical environment are not included in this paper. Scars appearing to be consistent with anthropogenic sources were classified as five types: puncture, vessel strike, entanglement, research tagging, or research remote biopsy. Scars from permitted research came from satellite tags, flipper bands applied during tagging, biopsy of restrained belugas during tagging, and remote biopsy of free-swimming belugas.

Punctures

Puncture scars were consistent with marks made from bullets (either single bullet or shot pellets; Read and Murray, 2000; Moore and Barco, 2013), harpoons, and arrows. Such scars can vary from single wounds to multiple clusters, and from round to irregularly shaped. Those classified as puncture scars were isolated on the body, deep, and surrounded by relatively clean skin, unlike dispersed, relatively shallow puncture wounds caused by scavengers.

Other indicators of puncture scars were those with a relatively small entrance scar on one side and a larger exit scar on the other, or those with a protruding arrow shaft. Biopsy scars, while technically puncture scars, were categorized separately under research scars. Biopsy scars are shallower than puncture scars, have sharper edges, and are smaller. Furthermore, they can be definitively classified as biopsy scars because they occur on identified individuals who were photographed during the time of biopsy.

Vessel Strikes

Vessel-strike scars were consistent with marks made from blunt trauma from a vessel bow strike or from lacerations made by a propeller. Small-boat propeller strikes typically leave a series of parallel, cupped-shaped marks that are thicker toward the centers (George et al., 1994; Read and Murray, 2000). Each propeller leaves a different shaped mark based on several factors, including trajectory, propeller pitch angle, torque, and speed at impact (Rommel et al., 2007), and scars can be straight, z- or s-shaped, curved, or open in the middle with thin trails (Moore and Barco, 2013). Scars from bow strikes were consistent with external signs of blunt trauma, such as dents, abrasions, and misshapen areas (Moore and Barco, 2013).

Entanglements

Entanglement scars were consistent with marks made from rope, monofilament line, and nets. Entanglement could result during active fishing, or from entanglement in derelict fishing gear and other anthropogenic marine debris. Read and Murray (2000) state that the physical evidence associated with entanglement is specific to each combination of cetacean and fishing gear but that scars from entanglement include indentations and lacerations.

Satellite Tagging

Satellite-tag scars were matched from photographs collected during live-captures of 20 belugas by NMFS-led research teams between 1999 and 2002 (18 of the 20 captured were satellite-tagged). Details about the capture and tagging, including tag types and whale movements during the life of the tags, are presented in Shelden et al. (2018). Belugas in the photo-ID catalog were classified as "confirmed satellite-tagged" individuals if the following types of tag-induced scars were visible in photographs: scars with a distinct shape (circular, crescent-shaped, or band-like); scars in an obvious pattern (depending on the tag type and attachment used in different years, tags caused scars in pairs, trios, or up to five); and/or scars in known tagging locations on the body (details can be found in McGuire and Stephens[5]).

In some cases, scars from biopsies that were taken to determine genetic sex were also visible in photos and were used as additional evidence of a tagging event (biopsy samples were taken with a trocar while whales were restrained during tagging). Individuals with photographs of scars that were similar to confirmed tagging scars but were less distinct in shape, pattern, or placement were classified as "possible satellite-tagged" individuals. Individuals classified as satellite-tagged whales were differentiated from one another based on photographs showing a combination of marks, tag scars, and tag placement, to avoid mistakenly matching similar scar patterns caused by the same tag type.

We verified that the genetic identification of any dead satellite-tagged individuals matched the genetic information from the individuals' tagging samples obtained during the original handling. Although scars from satellite tagging were technically also puncture scars (from tag holes) or entanglement scars (from flipper bands), they were considered separately under research. Flipper bands were placed around either left, right, or both pectoral flippers of tagged whales in 1999 and in 2002, and all catalog and stranding photographs were examined for signs of flipper band attachment or scarring.

Biopsies

Biopsy scars are visible on 20 belugas remotely biopsied by NMFS-led research teams in 2016 and 2017. Details are available in McGuire et al.[6,7] and from Wade[8]. Genetic sex was determined from skin samples, and levels of reproductive hormones (for females) were obtained from blubber samples. Photographs were taken of whales at the time of biopsy in order to match them to previously identified individuals in the 2005–17 photo-ID catalog.

Assignment of Anthropogenic Scar Type Labels to Identified Individuals

Three experienced photo-analysts independently examined all photos (~38,000) of the 78 dual-side whales in the 2005–17 catalog for signs of anthropogenic scars and assignment of scar type. Photo-ID protocols, presented earlier in the methods section, made it possible for an individual to be accepted into the catalog if photos matched across years, even if it did not have a complete profile set of high-quality photos. The exception to the complete profile set requirement was intended for animals that have readily identifiable scars but might not have images of the whole length of the dorsum, with the multiple-year requirement to ensure that the scar was lasting. We therefore reexamined photographic records of the dual-side whales and determined that complete profile sets were available for all 78 dual-side whales, on both sides, with photo-quality sufficient to ensure that any scars within those sections could be seen if present. Analysts also examined photographs of belugas photographed during surveys and strandings that were never identified in the catalog.

The review for anthropogenic scars focused on the dual-side catalog because individuals photo-identified on both sides of their body have the most complete sighting records in the catalog and are therefore the most useful for obtaining information about survival and reproduction. Combining sighting records and associated reproductive histories from both sides of an individual provides a more complete sighting record, and reduces the risk of missing an individual sighting because only one side was photographed in a year, or that a sighting of an individual with a calf was missed because the calf was only observed on one side of the mother.

Scar types were incorporated into the photo-ID database via scar-type labels that were applied to individual photos and later queried to generate summaries of individual whales with particular scar types. A matrix was created of the five types of anthropogenic scars (i.e., puncture, vessel strike, entanglement, satellite-tagging, or biopsy) and each dual-side whale's identification number. Each identified whale was scored as "confirmed" (unambiguous evidence, such as an attached rope), "possible" (ambiguous, the mark also could have been from another source), or "no" (without any evidence of anthropogenic trauma) in

[5]McGuire, T., and A. Stephens. 2016. Summary report: status of previously satellite-tagged Cook Inlet beluga whales. Rep. prep. for Natl. Mar. Fish. Serv., Alaska Reg. by LGL Alaska Res. Assoc., Inc., Anchorage, AK, 92 p. (avail. online at https:// 87e3476c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ugd/ af2fcb_6a8302766d9544208e9465bce0a928c1.pdf).

[6]McGuire, T., R. Michaud, M. Moisan and C. Garner. 2017. Cook Inlet beluga whale biopsy: field report for 2016 feasibility study. Rep. prep. for Natl. Mar. Fish. Serv., Mar. Mammal Lab., Alaska Fish. Sci. Center and Alaska Reg., Protected Resour. Div. by LGL Alaska Res. Assoc., Inc., Anchorage, AK, 80 p. (online at https://87e3476c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ ugd/af2fcb_1f214afc7d034220a2a2b7b2128be610.pdf).

[7]McGuire, T., A. Stephens, and J. McClung. 2018. Photo-identification of beluga whales in Cook Inlet, Alaska: inclusion of biopsy and hexacopter photographs from 2017. Rep. prep. for Natl. Mar. Fish. Serv., Mar. Mammal Lab. The Cook Inlet Beluga Whale Photo-ID Project, Anchorage, AK, 91 p. (online at https://87e3476 c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ugd/ af2fcb_21893dbfcdf344818314477 a3c340c75.pdf).

[8]P. R. Wade. Unpubl. data on file at Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

each of the scar type categories. The location of each scar that had been assigned a "confirmed" or "possible" was then noted, using the sections illustrated in Figure 2, as well as the year in which a scar was first photographed.

Sighting Histories of Individuals with Anthropogenic Scars

Sighting histories (i.e., dates and locations of photographed sightings) were compiled for all belugas in the 2005–17 dual-side catalog who had confirmed or possible signs of anthropogenic scarring. The photo-ID resighting data of individual whales was augmented with biological data (e.g., sex, age, reproductive status) from whales that were photographed during necropsies (Burek-Huntington et al., 2015), satellite-tagging studies (Shelden et al., 2018; McGuire and Stephens[5]), and remote biopsy (McGuire et al.[6]).

Healing Histories

Scar condition was noted throughout an individual's sighting history. Scar condition describes what can be seen in photographs of a scar (from all sources), such as probable infection of the scar, changes in shape, size, and margins of the scars over time, and condition of the area around the scar. The presence of probable infection was inferred from discolored and/or swollen irregular looking tissue in or around the scar(s) (Geraci and Smith, 1990; St. Leger et al., 2018). We also noted visible signs of abnormal body condition (e.g., concavity around head and neck, prominent dorsal ridge, and/or concavity of the dorsal crest over satellite-tag attachment sites (McGuire and Stephens[5]).

Reproductive Histories

Identified belugas were classified as "presumed mothers" (and were therefore presumed to be females) if they appeared in the same uncropped photo frame with a calf or neonate alongside and their association was unambiguous (i.e., there were not multiple adults in close proximity to the calf). When the relationship between an individual calf and individual adult was ambiguous, either because of multiple adults near the calf, little difference in relative color or size, or distances of more than several meters between the adult and the calf, the individual was classified as "possible mother" (and therefore possible female).

Belugas were classified as calves in photos if they were gray, relatively small (i.e., < 3/4 the total length of adult belugas), and photographed near or alongside a larger, lighter-colored beluga. Neonates (i.e., newborns, up to 2 mo old) were distinguished in photographs by visible fetal folds and often a peanut-shaped head (McGuire et al., 2020a). If a presumed mother was seen with a calf in multiple years, and high-quality photos showed the calf clearly appearing progressively larger with respect to its mother in subsequent years, it was assumed to be the same calf maturing over time. We noted if a presumed female had a record of calving before and/or after tagging and biopsy events or estimated dates of anthropogenic trauma.

Survival Histories

We used stranding records and photo-ID records to determine survival, asking the question: how many dual-side whales in the 2005–17 catalog with signs of anthropogenic trauma were still alive in 2017? Unambiguous information on mortality was provided by photographs of carcasses (2005–17) and live individuals in 2017.

We also used cessation of photographic re-sightings to infer if an identified whale was dead by 2017. Time intervals that demarcated a cessation rather than an interruption in resights were determined based on the distribution of re-sight frequencies of all whales in the catalog. All photo-ID cataloged whales that had not been seen since 2006 (i.e., more than the maximum gap in the re-sight distribution of 10 years) were presumed dead. We also confirmed that those individuals presumed dead were not later photographed in 2018 or 2019. We then compared survival records according to scar type and sex of affected individuals.

Results

Prevalence of Anthropogenic Scars

We reviewed photographic records of 106 individual belugas, obtained by combining the datasets from the dual-side photo-ID catalog (n = 78) and necropsies (n = 33), including 5 whales that were common to both datasets. In this combined dataset, there were 40 individual belugas (37.7%) with scars that were classified as being of either confirmed (n = 23) or possible (n = 28) anthropogenic origin (these numbers will sum to more than 40 because some individuals had scars in more than one category). Sighting records of 24 individuals with anthropogenic scars attributed to punctures, vessel strikes, and entanglements are summarized in Table 1. Sighting records of 18 individuals with scars attributed to research (biopsies, satellite tagging, and flipper bands) are summarized in Table 2.

In our sample, research scars accounted for the majority of confirmed anthropogenic scars, followed by entanglement scars, and vessel-strike scars (Fig. 3). There were no confirmed puncture scars. Most of the scars classified as possibly anthropogenic appeared to be from possible entanglement or possible vessel-strike, followed by possible puncture. As we later discuss, our sample is biased toward animals with research scars because the dates and source of these scars are known.

In the dual-side photo-ID catalog (n = 78), 15% of individuals had signs of confirmed or possible entanglement, 14% had signs of confirmed or possible vessel strikes, and 5% had signs of possible puncture scars (Table 1). For research scars, 15% of the individuals in the dual-side photo-ID catalog had satellite-tag scars, 9% had scars from remote biopsy, and 3% had flipper-band scarring (Table 2).

Table 1.—Summary of 24 Cook Inlet beluga whales in the 2005–17 stranding and dual-side photo-ID datasets with scars indicative of anthropogenic trauma from entanglement, vessel strikes, and punctures (non-research). n=scar not detected, p=scar possibly detected, c=scar confirmed. COD=cause of death assigned during necropsy, D=denotes photo-ID number, N=necropsy id number. Adults are presumed to be female if they were photographed with an accompanying calf.

ID #	Puncture scar	Vessel-strike scar	Entanglement scar	Trauma source (confirmed or presumed)	Year first identified	Year trauma scar first photographed and status (* indicates scar fresh)	Sex	Female seen with calf post-trauma?	Year last seen	Dead by 2017? (COD)	Wound-site history?
D100	n	p	p	Vessel strike or entanglement	2005	1994 (during NMFS suction cup tagging study)	Presumed female	Yes	2016	No	No
D102	n	p	p	Possible entanglement in line or rope, or ship strike; infection in fold	2005	2005	Presumed female	Yes	2016	No	Infection in folds intermittently throughout sighting history
D106	p	n	n	Gunshot, possible entrance wound right, exit wound left; could also be from orca bite	2004	1994 (during NMFS suction cup tagging study)	Confirmed male	N/A	2013	Confirmed dead in 2013 (COD choked on flatfish)	Infection in holes and folds intermittently throughout sighting history
D107	n	p	p	Vessel strike or entanglement	2005	2005	Presumed female	Yes	2017	No	No
D108	n	p	p	Vessel strike or entanglement	2005	2005	Presumed female	Yes	2017	No	No
D112	n	n	p	Monofilament line or net	2005	2005	Presumed female	Yes	2017	No	No
D113	n	p	p	Vessel strike or entanglement	2005	2005	Presumed female	Yes	2017	No	No
D1220	n	p	p	Vessel strike or entanglement	2005	2005	Presumed female	Yes	2107	No	Infection in holes and folds intermittently throughout sighting history
D135	n	n	p	Line around tailstock, could also be predation attempt	2005	2015 (body section with scar not photographed before 2015)	Presumed female	Yes	2017	No	No
D14	n	p	n	Vessel strike or predation attempt	2005	2005	Presumed female	Yes	2017	No	No
D195	n	p	n	Vessel strike or predation attempt	2005	2008 (body section with scar not photographed before 2008)	Presumed female	Yes	2017	No	No
D2052	n	n	p	Monofilament line	2005	2005	Presumed male	N/A	2017	No	No
D206	n	c	n	Propeller scars	2005	2005	Presumed female	Yes	2017	No	No
D2303	n	n	c	Necropsy noted old net injury; also confirmed this whale satellite tagged in 2002	2006	2015 during necropsy (not from ID photos)	Confirmed male	N/A	2015	Confirmed dead 2015 (COD severe lung infection, associated infection of tag scar)	N/A (entanglement scars not seen while alive)

Table continued

Table 1.—*Continued.*

ID #	Puncture scar	Vessel-strike scar	Entanglement scar	Trauma source (confirmed or presumed)	Year first identified	Year trauma scar first photographed and status (* indicates scar fresh)	Sex	Female seen with calf post-trauma?	Year last seen	Dead by 2017? (COD)	Wound-site history?
D3846	n	n	c	Heavy braided line visible	2010	2010	Presumed male	N/A	2013	Presumed dead[1]	Rope appears tighter and cutting into flesh more every fall compared to every spring, and with every year
D419	n	n	p	Rope and/or monofilament line	2005	2005	Presumed female	Yes	2017	No	No
D516	p	p	n	Possible gunshot, entrance wound on left, exit wound on right; could also be from vessel strike	2006	2006	Sex unknown	No	2006	Presumed dead[2]	n/a (only photographed 1 day)
D68	n	p	n	Vessel strike, or predation attempt	2005	2005	Presumed female	Yes	2017	No	No
D7244	n	p	n	Necropsy noted possible propeller injury left flank and probable blunt trauma, head and neck	2007	2012* when dead (body section with scar not photographed before)	Confirmed male	N/A	2012	Confirmed dead in 2012 (COD undetermined)	n/a
D75	p	n	n	Possible gunshot: exit wound on right and entrance wound on right; possible satellite tag scar	2005	2005	Presumed female	Yes	2017	No	Infection in scars intermittently throughout sighting history
D85	n	n	p	Rope and/or monofilament line	2005	2005	Presumed female	Yes	2017	No	No
D86	p	n	n	Possible shaft of arrow stuck in skin	2005	2006*	Presumed female	Yes	2017	No	No
N 2017206	p	n	n	Necropsy noted possible trauma to the side and head, possible gun shot with positive metal detection from metal detector, but no metal found	Not photo-identified; no photos	2017* during necropsy	Confirmed female	N/A	2017	Confirmed dead 2017 (COD undetermined, possible gunshot)	n/a
N2012106	n	n	c	Entangled in gill net	Not photo-identified (<2 years old; too young)	2012* during necropsy	Confirmed male	N/A	2012	Confirmed dead 2012 (COD entanglement complicated by malnutrition and a variety of chronic parasitic infections)	n/a

[1]Presumed dead after abrupt end to robust sighting records
[2]Presumed dead after >10 years without resighting

Table 2.—Summary of 18 Cook Inlet beluga whales in the 2005–17 stranding and dual-side photo-ID catalog datasets with scars indicative of anthropogenic trauma from research (biopsy, satellite tagging, and flipper bands). COD=cause of death assigned during necropsy.

Photo-ID # (NMFS biopsy or tagging ID #)	Research scar (confirmed or presumed)	Year beluga first identified in photo-ID catalog	Year trauma scar first photographed and status (* scar fresh)	Sex (confirmed or presumed)[1]	Year whale last seen	Dead by 2017?	Female with calf post-tagging or biopsy (2005-2017)?	Wound sighting history
D16873 (DL-CIB16-32)	Confirmed remote biopsy 2016	2010	2016* during biopsy	Confirmed male	2018	No	N/A	Wound closed, no signs of swelling or infection
D154 DL-CIB16-35)	Confirmed remote biopsy 2016	2005	2016* during biopsy	Confirmed female	2018	No	Yes (pregnant at biopsy[2])	Biopsy site not visible when whale photographed days after biopsy
D220 (DL-CIB16-36)	Confirmed remote biopsy 2016	2005	2016* during biopsy	Confirmed female	2018	No	Possible (pregnant at biopsy[2])	Scar seen 2 weeks post biopsy, wound open but did not appear infected or swollen, wound closed by 2017
D19173 (DL-CIB17-02)	Confirmed remote biopsy 2017	2016	2017* during biopsy	Confirmed female	2017	No	No (not seen with calf pre-biopsy either)	Not seen after 2017 biopsy
D2379 (DL-CIB17-03)	Confirmed remote biopsy 2017	2005	2017* during biopsy	Confirmed male	2018	No	N/A	Scar visible in 2018; wound closed, no signs of swelling or infection
D103 (CI-01-0)	Confirmed satellite tag from 2001	2005	2001* during biopsy	Confirmed female	2017	No	Yes	Tag scars conspicuous but no signs of infection in 2017
D2303 (CI-02-05)	Confirmed satellite tag and flipper band	2005	2002* during tagging	Confirmed male	2015	Confirmed dead 2015 (COD severe, chronic bronchopneumonia and secondary infection of tag scar)	N/A	Scars conspicuous, worsening infection of tag holes, body around tag site becoming concave; signs of flipper damage from flipper band;
D111 (CI-00-02)	Confirmed satellite tag	2005	2000* during tagging	Confirmed female	2017	No	Yes	Tag scars inconspicuous and no signs of infection; abrasions across dorsal ridge
D115 (CI-02-08)	Confirmed satellite tag and flipper band	2005	2002* during tagging	Confirmed male	2014	Confirmed dead 2014 (COD live stranding)	N/A	Tag scars conspicuous but no signs of infection; signs of flipper damage from flipper band
D2204 (CI-02-06)	Confirmed satellite tag	2005	2002* during tagging	Confirmed male	2007	Presumed dead	N/A	Scars conspicuous and appeared infected and deteriorating 2005-2007
D243 (CI-01-01)	Confirmed satellite tag	2005	2001* during tagging	Confirmed female	2017	No	Yes	Conspicuous tag scars, one scar appears healed, infection in two scars intermittently throughout sighting history
D49 (unable to match)	Confirmed satellite tag, tag year unknown	2005	2005	Presumed female	2017	No	Yes	Conspicuous tag scar; infection in tag scar intermittently throughout sighting history
D549 (unable to match)	Confirmed satellite tag, tag year unknown	2005	2005	Presumed female	2017	No	Yes	Tag scars conspicuous but becoming smaller over time; no signs of infection
D875 (unable to match)	Confirmed satellite tag, tag year unknown	2005	2005	Presumed male	2017	No	N/A	Tag scar inconspicuous and becoming smaller over time; no signs of infection
D403 (unable to match)	Confirmed satellite tag, tag year unknown	2005	2005	Presumed female	2017	No	Yes	Conspicuous tag scar; infection in tag scar intermittently throughout sighting history
D3024 (unable to match)	Confirmed satellite tag, tag year unknown	2009	2009	Presumed female	2017	No	Yes	Tag scar conspicuous but no signs of infection
D5319 (unable to match)	Confirmed satellite tag, tag year unknown	2007	2007	Presumed female	2017	No	Yes	Tag scar conspicuous but no signs of infection
D75 (unable to match)	Presumed satellite tag, tag year unknown; presumed gunshot	2005	2005	Presumed female	2017	No	Yes	Conspicuous scars; infection in scars intermittently throughout sighting history

[1]Genetic sex from satellite tag samples determined by Greg O'Corry-Crowe, Florida Atlantic University; genetic sex from biopsy samples determined by Nick Kellar, NMFS Southwest Fisheries Science Center, and Kim Parsons, NMFS Northwest Fisheries Science Center.
[2] Pregnancy status at biopsy determined from hormones by Nick Kellar, NMFS Southwest Fisheries Science Center.

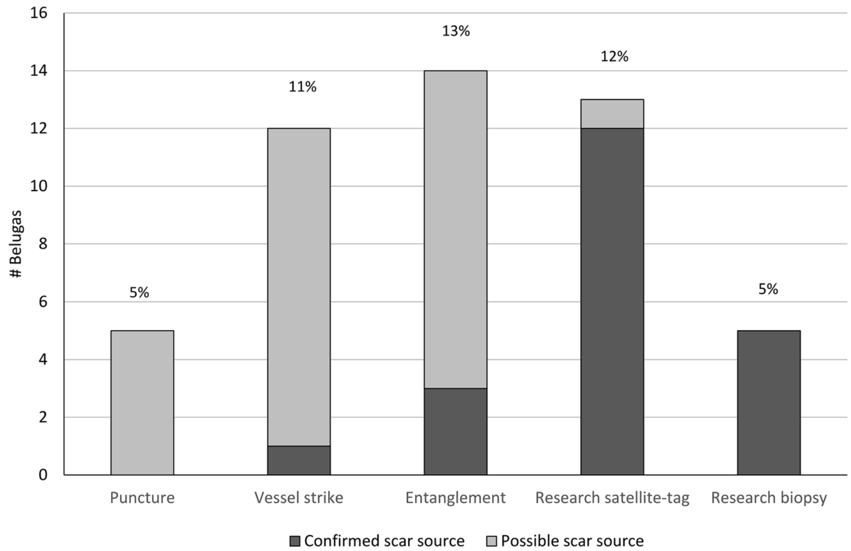

Figure 3.—Number of individual Cook Inlet beluga whales from the combined 2005-17 dual-side photo-ID catalog and necropsy datasets with signs of anthropogenic scars, according to scar type (i.e., punctures, vessel strikes, entanglement, or research). Of 106 whales examined, 24 had signs of anthropogenic scarring. Numbers are not additive across scar types as some individuals had scars of more than one type. Numbers above each bar refer to the percent of the total sample that had confirmed or possible scars from each source.

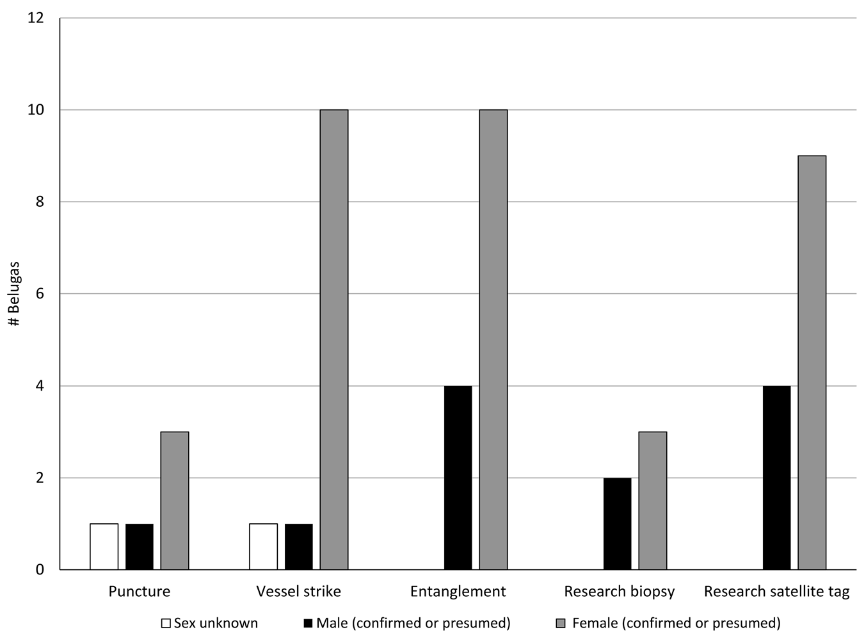

Figure 4.—Sex of individual Cook Inlet beluga whales from the combined 2005-17 dual-side photo-ID catalog and necropsy datasets with signs of anthropogenic scars, according to scar type (i.e., punctures, vessel strikes, entanglement, or research). Numbers are not additive across scar types as some individuals had scars of more than one type. Whales in the confirmed and possible scar type categories have been combined.

Out of the 33 necropsied belugas, two (6%) had scars from satellite-tagging (both tag scars and flipper band scars), two (6%) had signs of entanglement, one (3%) had possible signs of a vessel strike, and one (3%) had possible signs of puncture scars consistent with gunshot wounds (Table 1, 2). In the majority of the necropsy cases of individuals with anthropogenic scars, COD was attributed to something other than the confirmed or possible source of the scar (e.g., an individual with healed satellite-tag scars who died from aspiration of muddy water after live-stranding). There were no cases in which COD was confirmed to be from anthropogenic trauma. There were three cases in which COD was listed as undetermined but of possible anthropogenic origin: possible vessel strike (n = 1; 3%), possible gunshot (n = 1; 3%), and possible entanglement (n = 1; 3%).

In the combined photo-ID and necropsy datasets there were more females than males in each of the scar-type categories (noting some whales fell into more than one category; Fig. 4). However, considering the necropsy dataset separately, there were more dead males with confirmed or possible anthropogenic scars than dead females (Table 3).

Puncture Scars

Four of the five possible puncture scars may have been from gunshot wounds, based on patterns of presumed entrance and exit wounds on opposite sides of the body (Table 1; Fig. 5). All of the possible gunshot scars visible in the first year individuals were photographed and persisted throughout their sighting histories. None of the possible gunshot wounds were fresh when first photographed. The fifth beluga with a possible puncture wound had what appeared to be an arrow protruding from one side. The possible arrow was not seen when the whale was photographed a month prior and was also not seen on the whale when it was photographed again six days later.

Table 3.—Number of dead (confirmed or presumed) Cook Inlet beluga whales with scars indicative of anthropogenic trauma, according to scar type (confirmed and presumed) and sex (confirmed and presumed). Presence of a scar type on a carcass does not necessarily mean that it was the cause of death (COD).

Anthropogenic scar type (confirmed and presumed)	No. of belugas	No. confirmed dead	No. presumed dead	No. dead (confirmed and presumed)	% of all 11 dead (confirmed and presumed)
Puncture	5	2 (1 male, 1 female)	1 (sex unknown)	3	27%
Vessel	12	1 (male)	1 (sex unknown)	2	18%
Entanglement	14	2 (male)	1 (male)	3	27%
Biopsy	5	0	0	0	0
Satellite tag	13	2 (male)	1 (male)	3	27%

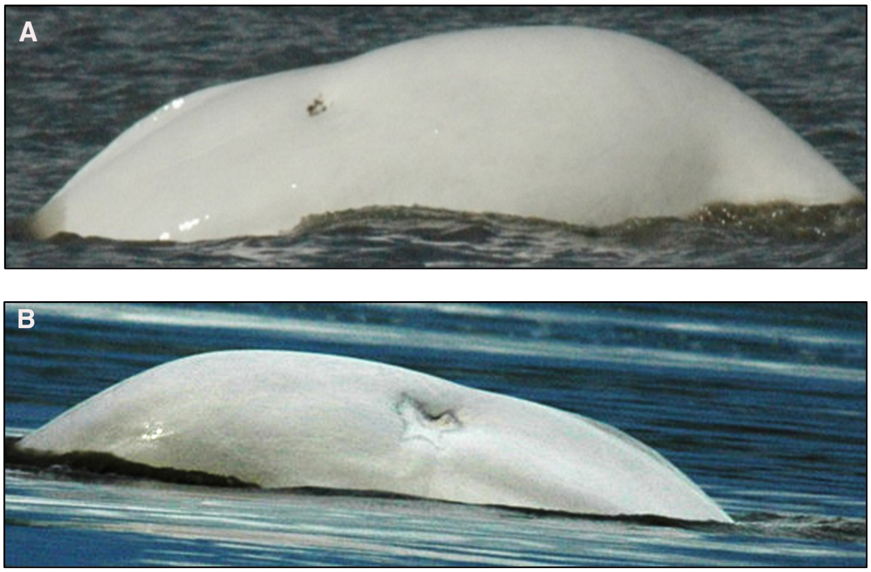

Figure 5.—Beluga D75, with possible puncture scars. The scars may be from a gunshot, with the possible entrance wound on the left side (A) and the possible exit wound on the right side (B). It is also possible these scars were made from a satellite tag, although the scar pattern and location do not match those from the confirmed satellite tags.

Figure 6.—Beluga D206, with a confirmed propeller scar along its right side.

There were three females with possible puncture scars vs. one male. All of the females with possible puncture scars were observed with calves that would have been born after they were first photographed with a puncture scar. Three whales with possible puncture scars were later confirmed or presumed dead (Table 3). In the case of one confirmed dead whale, necropsy determined the COD was from choking on a large flatfish (Rouse et al., 2017).

Vessel-strike Scars

The one case of a confirmed vessel strike showed clear signs of propeller marks along the right flank of the live whale (Fig. 6). These propeller scars were already healed when the whale was first photographed in 2005, and they did not appear to change in later years. Ten belugas had signs of possible vessel strikes in photographs taken while they were alive, but these marks could also have been made by entanglement (Fig. 7, 8), predation attempts, or shotgun blasts that damaged large areas of tissue (similar to being struck by the bow of a vessel). Most of the confirmed or presumed vessel-strike scars were on females (Fig. 4). All of the females with vessel-strike scars were observed with calves that would have been born after they were first photographed with the scar (Table 1).

Two whales with possible vessel-strike scars were later confirmed or presumed dead (Table 3). One was a male and one was of unknown sex. The dead male had fresh signs of a possible vessel strike that were detected during necropsy, with the examining veterinarian (co-author KBH) noting possible propeller injury on the left flank and probable blunt trauma on the head and neck; all areas of the body that wouldn't have been photographed while the whale was alive. The COD for this male was listed as blunt trauma from possible ship strike (McGuire et al., 2020b).

Entanglement Scars

There were three cases of confirmed entanglement. We documented one live whale entangled in heavy, braided line (Fig. 9). This whale was already entangled when it was first photographed throughout the 2010 field season and was photographed annually through 2013. NMFS and the Alaska Marine Mammal Stranding Network were updated annually with sighting information and photographs of this entangled whale. Based on how frequently this whale was seen during 2010 through 2013 and the abrupt cessation of sightings post-2013, it is assumed this whale died undetected. It is also possible it became disentangled and was no longer recognized; however, the identification marks (i.e., marks other than the line) were quite distinct on this whale, and it seems likely it would still have been recognized if it had been photographed without the entanglement.

The second confirmed entanglement was encountered when necropsy of a dead, previously satellite-tagged whale, D2303, revealed it also had signs of old net injuries on the flukes, which were not visible in photos of the whale while it was alive. The third beluga confirmed to have been entangled was a young male found dead in a gillnet near the mouth of the Kenai River, and fisheries interaction (entanglement) was noted as the COD, complicated by malnutrition and a variety of chronic parasitic infections (Burek-Huntington et al., 2015). A live beluga was photographed in 2005 entangled in what may have been a tire or a culvert liner but was never resighted or photo-identified and is not included in Table 1 (Fig. 10).

The belugas with signs of possible entanglement (n = 11) displayed marks that could have been made from monofilament line or rope around the body or tailstock, and none of these marks appeared to be fresh (Fig. 7, 8). Possible entanglement scars differed from tooth-rake marks in that possible scars from monofilament line were thinner and straighter than tooth-rake marks, and scars from other types of line were wider with rougher edges. Most of the entanglement scars were on females, although the three dead individuals with confirmed or possible entanglement scars were confirmed or presumed male. All of the females with signs of entanglement were observed with calves that would have been born after they were first photographed with the scarring (Table 1).

Biopsy Scars

All 20 belugas remotely biopsied in 2016 and 2017 were also identified individuals in the photo-ID catalog. Five of these were identified individuals in the dual-side catalog; two were males and three were females. There is no evidence that any of these individuals

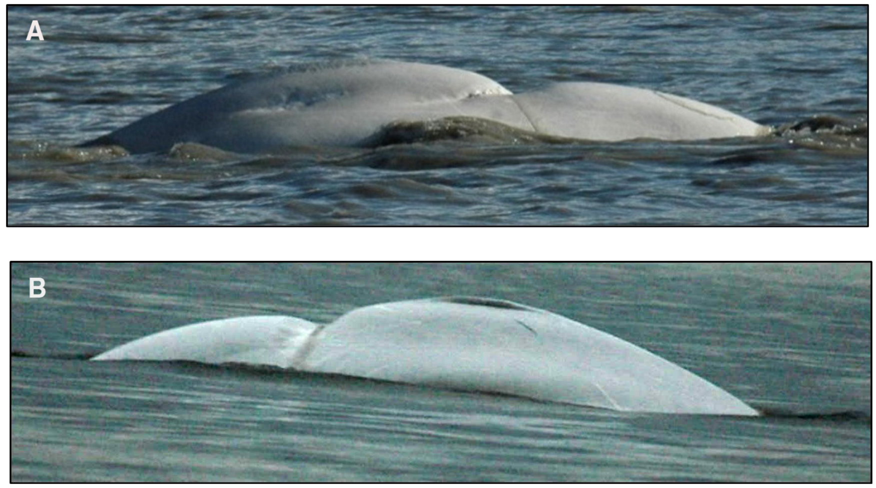

Figure 7.—Left (A) and right (B) sides of beluga D100, with scars possibly from entanglement, vessel strike, or both.

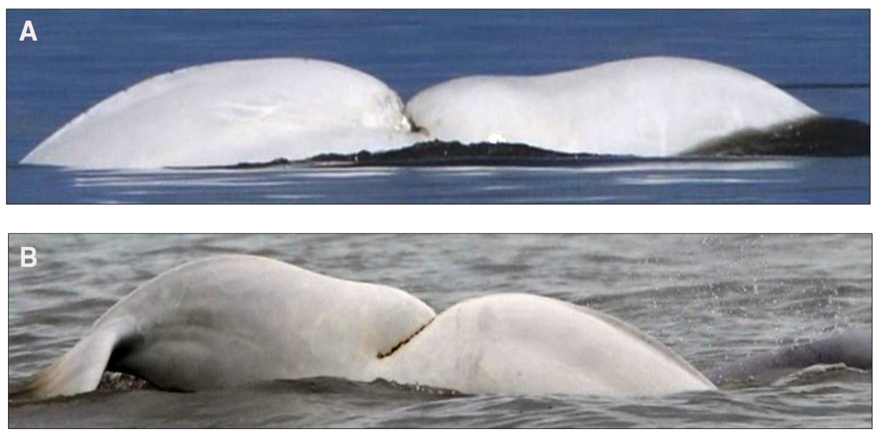

Figure 8.—Left (A) and right (B) sides of beluga D102, with a scar classified as possible entanglement or possible vessel strike. Note the infection in the scar folds in both photos, which occurred intermittently throughout the sighting history of this whale.

Figure 9.—Left-side photographs of beluga D3846, entangled in heavy braided line.

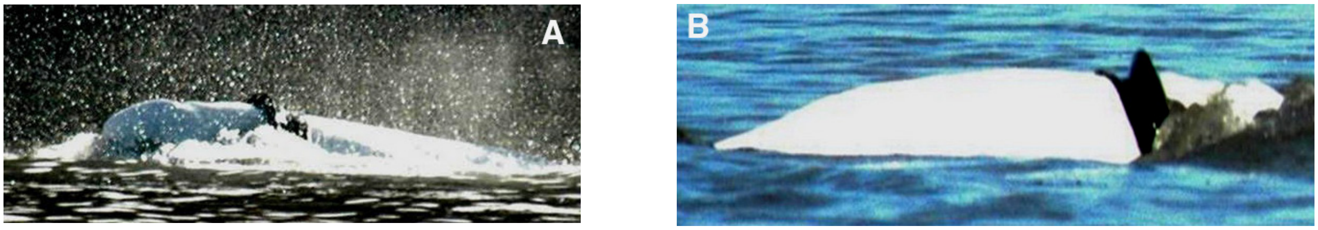

Figure 10.—Left (A) and right (B) sides of an unidentified entangled beluga whale, only seen on one occasion. The object causing the entanglement remains unknown but may be a culvert liner or tire.

have since died. Four of the five dual-side individuals were photographed on days and years following biopsy, and none had signs of infected biopsy scars (Table 2; Fig. 11).

Satellite-tagging Scars

Twelve of the 20 whales captured for satellite-tagging were identified in the dual-side photo-ID catalog. Scars on a 13th individual in the dual-side catalog may have been from a satellite-tag, although the scarring also could have been caused by gunshot wounds. Confirmed satellite-tag scars ranged from conspicuous to almost undetectable in photos of belugas in the photo-ID catalog.

Seven of the 12 (58.3%) dual-side satellite-tagged belugas had no signs of infection throughout their sighting history (e.g., Fig. 12, 13). Beluga D111, satellite-tagged in 2000, is an example of satellite-tag scars that were inconspicuous and without signs of infections (Fig. 12). Beluga D115 (Fig. 13, and Figure 16D) is an example of satellite-tag scars that were conspicuous but showed no signs of infection (shown both in photos while alive and during necropsy). Beluga D115 was tagged in 2002 and photographed annually during the period 2006–14. This male beluga was found dead with an unidentified dead adult female in 2014, possibly following a live stranding event as compacted, aspirated mud was found in their lungs (Shelden et al., 2019b; McGuire et al., 2020b).

Three tagged belugas (25%) appeared to have possible intermittent infections within the indentations and folds made by the tag scars, although the scars themselves appeared healed. Over the years, the appearance of the scars in these cases changed to include accumulation of debris within the scar borders, irregularities to scar edges, roughening of the scar surface, and changes in surrounding skin (Fig. 14B, C, D, 15A).

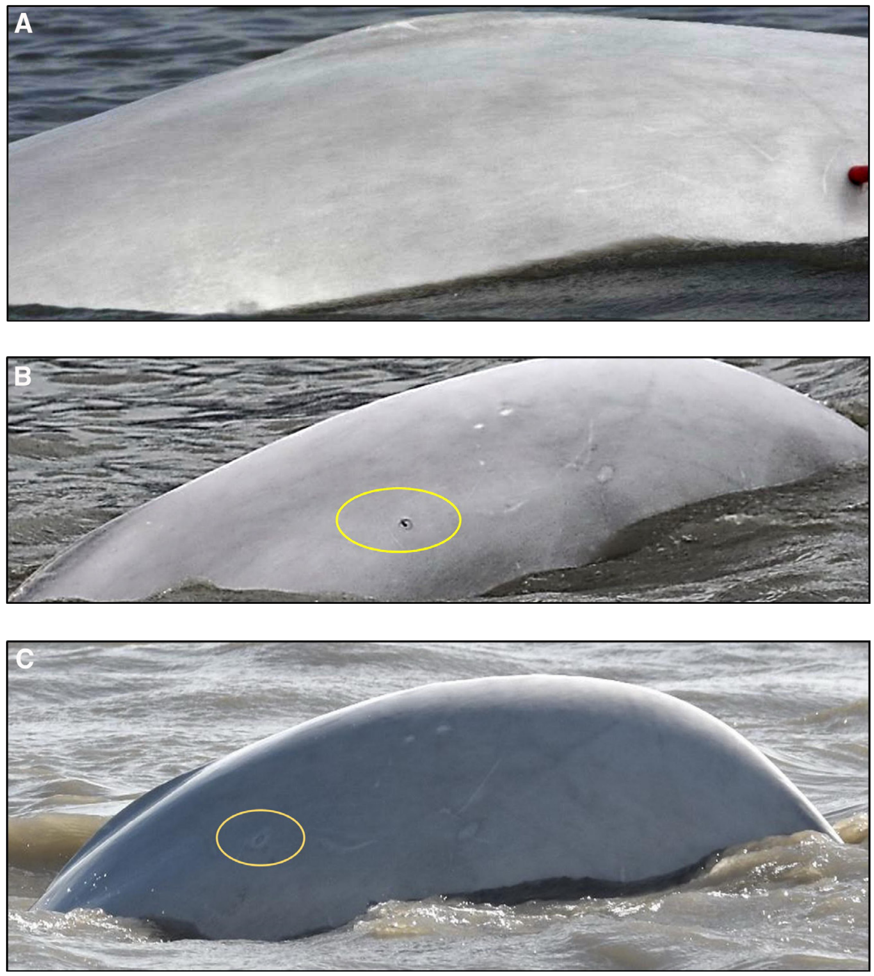

Figure 11.—Left side of beluga D220, showing (A) the biopsy dart location in 2016, (B) the biopsy scar two weeks later, and (C) the closed biopsy scar one year later. (Photo (A) courtesy of Robert Michaud, GREMM, photo (B) courtesy of Marc Weber, U.S. Fish and Wildlife Service).

Two tagged belugas (16.7%) appeared to have possible progressive tag-scar infections coupled with deteriorating body condition and death (one confirmed and one presumed death; Fig. 14, 15). Beluga D2303 was found dead in 2015 and had been satellite-tagged in 2002. Photo-ID photographs of this male showed that the conspicuous satellite-tag scars appeared to become infected in 2006 and worsened yearly thereafter, with the tag holes not only discoloring and deteriorating, but the dorsal area above the tag scars also becoming more concave each year (Fig. 14). At the time of the necropsy, the examining veterinarian (KBH) noted the infection of the tag site and the poor body condition of the whale.

Following histopathological examination of the tissues, the COD was determined to be severe lung infection leading to secondary infection of the tag scars. This was due to the lung infection being oriented around the airways with chronic inflammation, instead of a multifocal random pattern suggesting blood-borne infection to the lungs, such as would be expected if the tagging site was the site of the primary infection. A possible mechanism for secondary infection of the tag site could have been the presence of foreign material in the tagging site acting as a nidus for infection. The finding of refractile material in the tag lesion is suggestive of this. It is also possible the animal suffered from immune deficiency, however this cannot be determined through post-mortem examination. Beluga D2204 was also satellite tagged in 2002 and was photographed with infected and deteriorating tag scars (Fig. 15). A lack of photographic resightings after 2007 indicate this male may have died.

Flipper bands were placed around one or both pectorals of belugas during satellite tagging in 1999 and in 2002 (Shelden et al., 2018). Signs of pectoral-fin damage from the bands were visible in photographs taken during necropsy of the two dead satellite tagged whales (Fig. 16). One of these whales (D115) was photographed alive in 2007 with the band embedded in a damaged pectoral fin protruding from

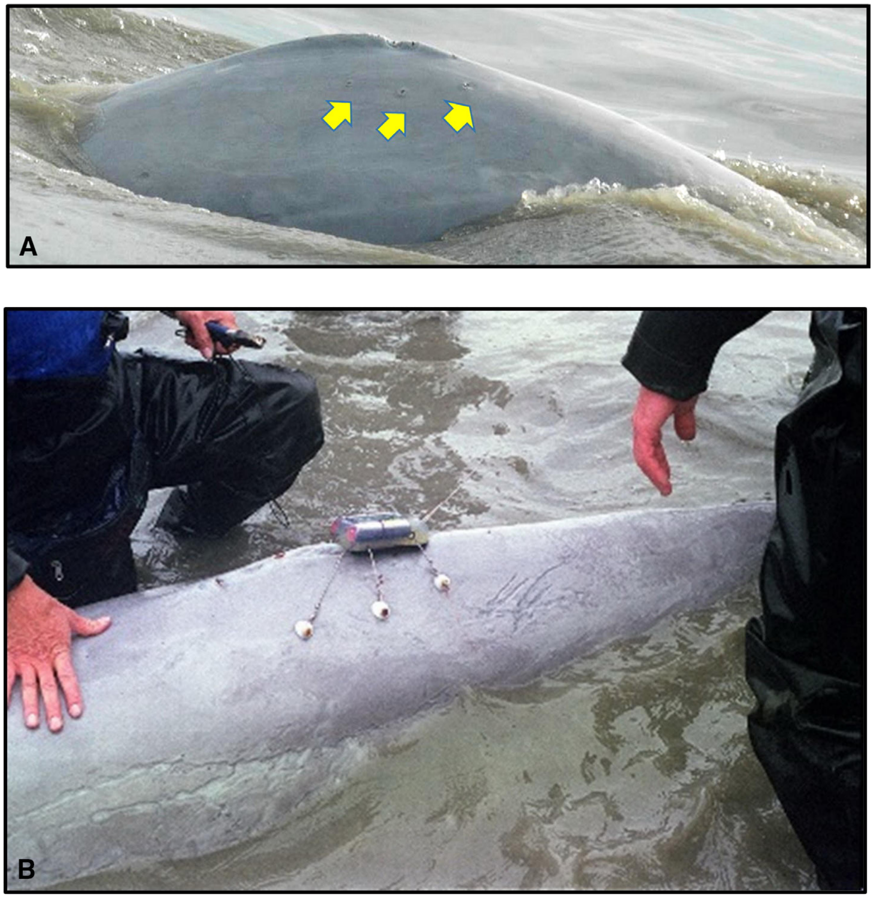

Figure 12.—Left side of beluga D111 photographed in 2005 (A), with scars from a satellite tag attached in 2000 (B). This is an example of inconspicuous and uninfected tag scars. (Photo (B) courtesy of NMFS).

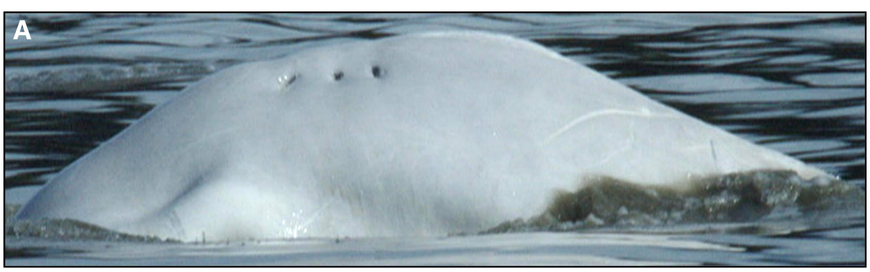

Figure 13.—Beluga D115, satellite tagged in 2002, showing scars on the left side (A) and spanning both sides (B). This is an example of conspicuous but uninfected tag scars. This beluga died in 2014, with cause of death attributed to live stranding.

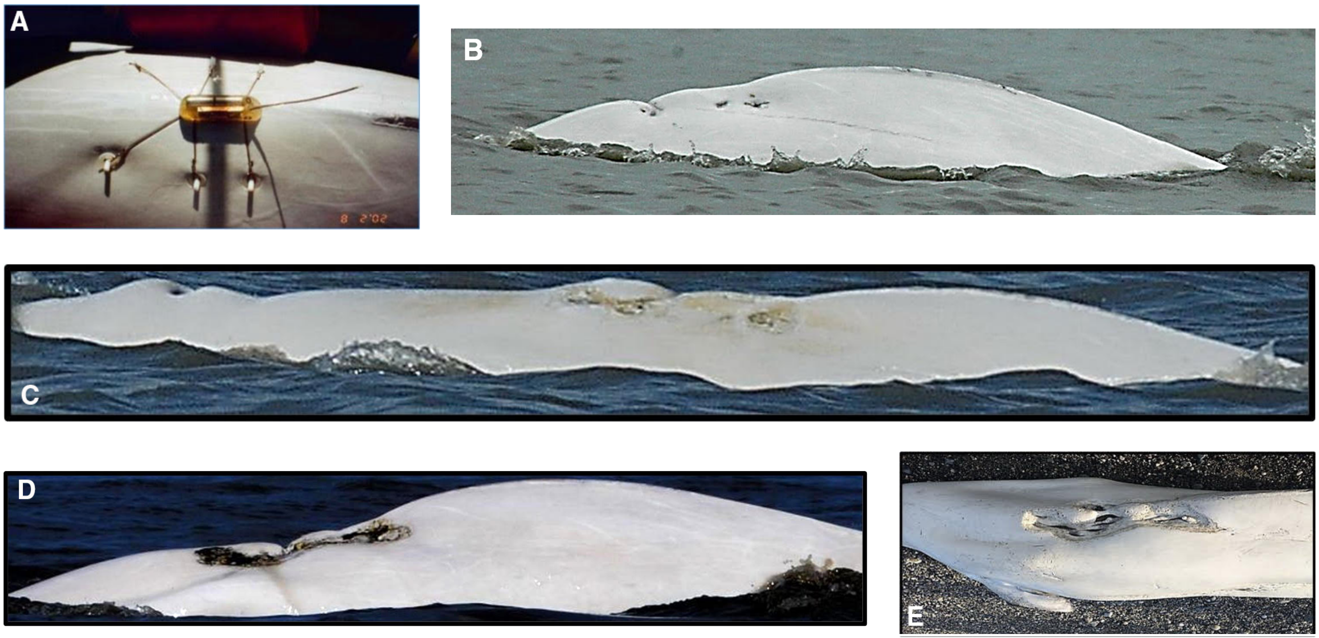

Figure 14.—Beluga D2303, satellite tagged in 2002 (A), with tag scars that were conspicuous, infected, and deteriorating. Left side in 2007 (B); 2011 (C) and 2014 (D), with progressive tag site deterioration, and increased concavity along the front of the dorsal ridge. This beluga died in 2015 (E), with cause of death attributed to severe lung infection, with associated infection of the tag scars. (Photo (A) courtesy of NMFS, photo (C) courtesy of Randy Standifer and the Alaska Marine Mammal Stranding Network).

the water while it swam on its side (Fig. 16B).

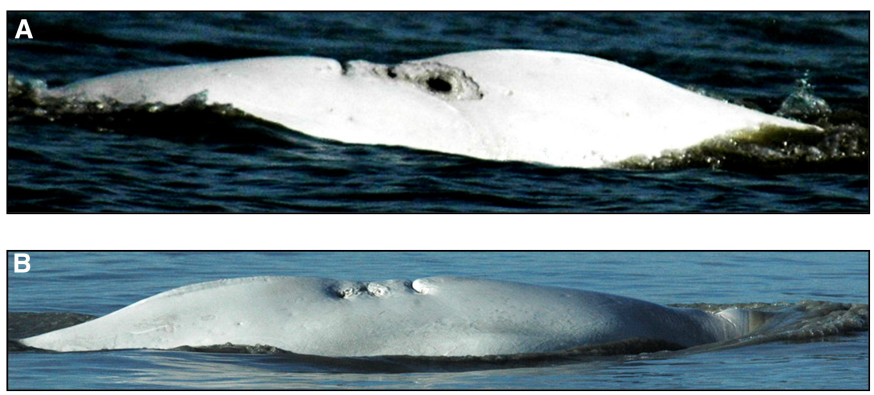

Figure 15.—Beluga D2204, satellite tagged in 2002, showing scars on the left side (A) and right side (B). This is an example of conspicuous and deteriorating tag scars. A lack of resightings after 2007 indicated this whale may have died.

Discussion

Our analysis found that anthropogenic activities identified in the CIBW Recovery Plan as potential threats to the population (i.e., entanglement, vessel strikes, and trauma from research) are in fact experienced by belugas in Cook Inlet. Over a third of the individuals in our dataset bore scars from confirmed or possible anthropogenic injury, and 9% of necropsied whales had uncertain causes of death that were potentially related to anthropogenic-induced trauma. While our data clearly demonstrates that anthropogenic injury occurs with some frequency in the CIBW population, using our findings to quantify anthropogenic injury at the population level, and inferring the population-level consequences of these injuries is more difficult.

Although the dataset has limitations for such quantitative inference, it enables us to provide a qualitative assessment on the incidence of anthropogenic injury in the entire CIBW population. Specifically, we discuss how some anthropogenic impacts are not detected in our sample, but also how our sample of individuals (n = 106, dual-side photo-identified individuals plus necropsied individuals) may not be representative of the entire CIBW population. We also discuss the sources of anthropogenic trauma in relation to other beluga populations and other whales to give a broader context to our findings.

Missed Anthropogenic Impacts

The scars documented in our dataset likely do not represent all anthropogenic impacts to the whales in our sample because some impacts are not seen for various reasons. Healed and incon-

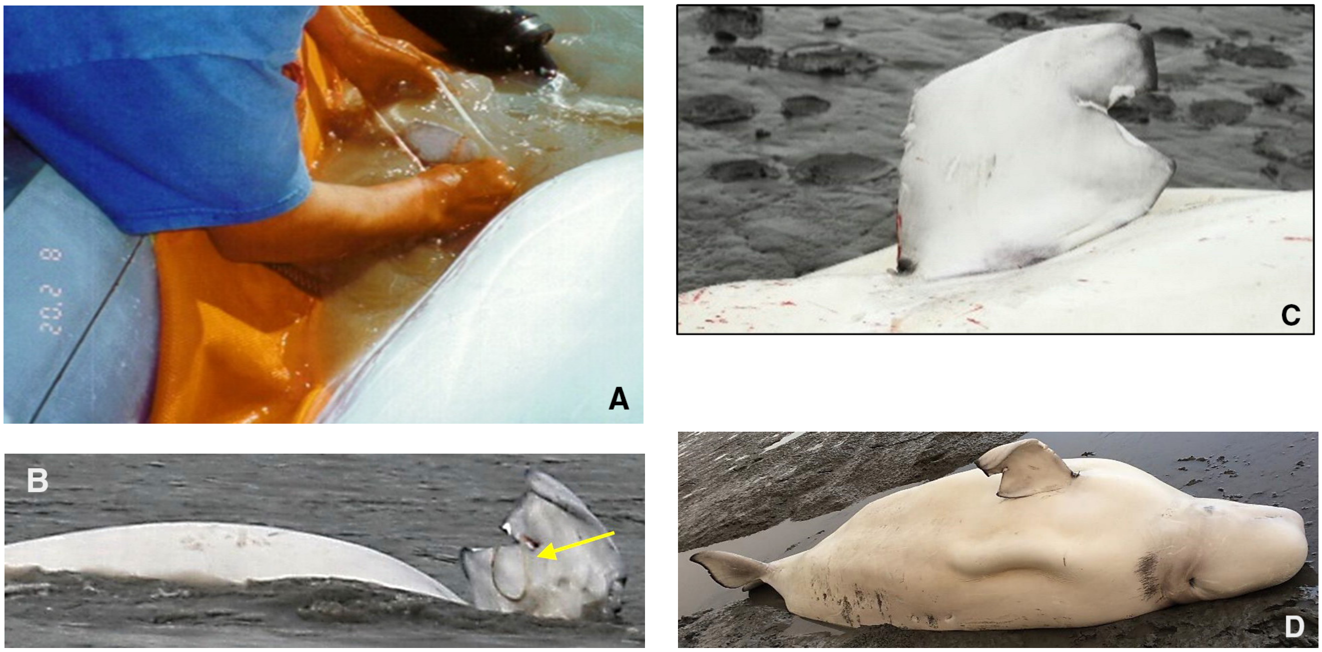

Figure 16.—Flipper bands were placed around one or both pectorals during satellite tagging in 1999 and 2002 (A). Photo (B) shows a flipper band in 2007 embedded in a damaged left-pectoral fin. Photos (C) and (D) show damage from flipper bands on dead beluga D115 (assigned name CI-0208 during tagging) in 2014. (Photo (A) courtesy of NMFS, photo (B) courtesy of Chris Garner, photo (D) courtesy of Bill Streever).

spicuous scars may be missed in identification photos and during necropsy. For example, the satellite-tag scars on D111 (Fig. 12) were only seen in photos from early in its resighting history and not in later photos. Had only the more-recent photographs been available, these satellite-tag scars would not have been detected. Because all photo-ID surveys and 96% of all reported strandings occurred during the ice-free months (April–October), any fresh anthropogenic scars and/or related mortalities occurring November through March would likely be missed in both the datasets.

Additionally, marks on most body sections of live belugas are missed during photo-ID. Because only certain body sections of free-swimming belugas are visible above the turbid water, any scars on normally submerged body sections are not detected unless the beluga is later encountered stranded or dead onshore. For instance, there were four belugas whose anthropogenic scars were only detected when normally submerged sections of their bodies were visible during necropsy.

Anthropogenic scarring is likely underestimated in the necropsy records. Delays between initial detection and necropsy may prevent examinations from being conducted while carcasses are still fresh, during which time signs of anthropogenic scars may decompose or be destroyed by scavengers, lessening the probability of detection, or the degree of confidence assigned by the examiner. Additionally, beached and floating carcasses usually have only one side visible and are too heavy to roll, so any scars on the non-exposed side of the body will be missed, especially on larger whales.

Sample Bias

Our analysis indicated that 17% of examined belugas bore scars from research, 13% exhibited signs of confirmed or possible entanglement, 11% had signs of confirmed or possible vessel-strikes, and 5% had possible puncture scars. While we likely miss some indications of anthropogenic trauma as discussed above, we cannot simply use our estimates as minimum prevalence rates within the population because our sample is unlikely to be representative of the entire population.

Anthropogenic scarring is more likely to be detected on older belugas than younger ones. The photo-ID catalog, particularly the dual-side catalog, is biased toward well-marked older individuals because they have had more time to accumulate identifiable marks over time, including anthropogenic scarring. In addition, younger whales have a faster-growing dermis and epidermis (Reeb et al., 2005). Therefore nonlethal scars obtained from anthropogenic trauma would likely heal faster and be less visible on younger whales than on older ones. At the same time, younger, smaller belugas may be more likely to die as a result of anthropogenic injury from vessel strikes or gunshots.

Younger belugas might also be less likely to break free of entanglements because they are weaker than larger belugas. If younger carcasses sink faster because of less body fat or are more rapidly destroyed by scavengers because of their relatively smaller size, then this part of the population (i.e., younger whales killed by anthropogenic activities) may be especially underrepresented in our analysis. These age-related factors, and how they relate to anthropogenic trauma, are complicated and suggest that our sample may overestimate anthropogenic trauma within the population as a whole due to a disproportionate number of older animals in the catalog, while at the same time underestimating anthropogenic impacts in younger animals.

Research was the most common cause of all anthropogenic scarring that we documented, occurring in 16% (n = 17) of our combined photo-ID and necropsy sample (n = 106); 11% were satellite-tag scars and 5% were biopsy scars. Because satellite-tagging scars can be more obvious than other types of scarring and more easily linked across both sides of a whale, satellite-tagged whales were more likely to be in our dual-side sample than whales that had not been tagged. In addition, photographs were available of several of the individuals when they were tagged, and we intentionally tried to find matches to them in the catalog. To date, a total of 18 whales have been satellite tagged, representing about 6% of the most-recent estimated population size of 279 in 2018 (Wade et al.[2]), and about 5% of the population of 357 whales estimated in 2003 (Hobbs et al., 2015a). On the other hand, we know that there were 20 whales remotely biopsied during 2016–17, which would be 7% of the estimated population in 2018, slightly more than the 5% prevalence of biopsy scars estimated with our methods.

Similarly, our methods may underestimate some types of non-research anthropogenic scars more than others because different sources of anthropogenic trauma are more likely to produce scars on different body sections. For example, scars from collisions between vessels and baleen whales are primarily found along the back and dorsal ridge (Bradford et al., 2009), and we would expect the same pattern for belugas based on our field observations of beluga surfacing behavior, including around vessels. In contrast, entanglement scars are more likely to occur on the caudal peduncle, flippers, back, or head (e.g., George et al., 1994; Read and Murray, 2000). Because images used for beluga photo-ID must include the dorsal and adjacent sections and rarely capture the head, flippers, or flukes, we would expect photos in the catalog to underestimate entanglement rates relative to vessel-strike rates.

Prevalence of Anthropogenic Trauma Scars According to Likely Scar Source

Vessel-strike scars included blunt trauma from impact and lacerations from propellers. We were unable to determine the type of vessels involved in the scarring we observed. Large ships and small vessels regularly transit near beluga whales in Cook Inlet and most often approach whales unintentionally. Watercraft observed around belugas during photo-ID surveys included container ships, cruise ships, tugs, barges, dredges, small recreational boats, seismic vessels, U.S. Coast Guard vessels, research vessels, stand-up paddleboards, and windsurfing boards.

During photo-ID surveys, we observed (and reported to law enforcement) several instances in which belugas were intentionally approached by vessels (i.e., boat drivers/occupants were seen pointing at belugas prior to approach), including at the Port of Anchorage small boat launch when a skiff of duck hunters approached a group of whales, and in the Kenai River when a small recreational vessel drove at high speed directly over a small group of belugas in shallow (< 2m) water. We also noted many occasions in which vessels appeared to pass through or over groups of belugas without realizing they were there.

Worldwide, entanglement in fishing gear is the most common source of anthropogenic mortality for small cetaceans (Read and Murray, 2000; Brownell et al., 2019). While we documented several entanglement scars that were apparently nonlethal and one mortality attributed to entanglement, our analysis supports Moore et al. (2000) who stated that direct mortalities from fishing gear, while known to occur, are probably uncommon for belugas in Cook Inlet. Moore et al. (2000) based their conclusions on no reports of mortality or serious injury being recorded by an observer program in 1999 and 2000. Potential sources of entanglement for belugas in Cook Inlet include set nets along shore, drift nets in deeper water, recreational fishing from shore and small vessels, derelict gear (line, nets), and debris. Unfortunately, unless the gear was still present, we were unable to determine the type of gear involved in most entanglements.

For a puncture scar to be confirmed as gunshot or arrow, the event would have to be witnessed, or the bullet or arrow retrieved from the carcass during a necropsy. None of the signs of puncture wounds could be confirmed, and therefore their prevalence is likely underestimated. For example, shotgun blasts can provide a variety of wounds depending upon the power of the shotgun (gauge), shell size, load (birdshot to buckshot to slugs), and distance to target, complicating the assessment of gunshot wounds. In addition, puncture wounds, even when healed, are often exploited by scavengers post-mortem, complicating classification and diminishing examiner certainty.

The possible puncture scars that were noted may have occurred during subsistence harvest (i.e., belugas that were "struck and lost" during past legal subsistence hunting that ended in 2006), poaching (illegal hunting post-2006), and intentional harassment (shooting at whales with the intent to harm or scare rather than to harvest for consumption). The CIBW Recovery Plan[1] notes that since 2006, the NMFS Office of Law Enforcement has investigated credible reports (number and details of incidents not stated) of what appeared to be fresh gunshot injuries to CIBW's, indicating that poaching and/or intentional harassment may still occur.

The potential for illegal harassment of belugas appears to be high along

Figure 17.—Photo of one of the many signs about belugas around Cook Inlet with bullet holes.

roadways, where belugas often approach within several meters of shore, as we have noted while photographing belugas from vehicle pullouts on the Seward Highway along Turnagain Arm. Many of the educational signs about belugas along the Seward Highway are riddled with bullet holes (Fig. 17). In addition, a pile of ammunition casings was encountered at the water's edge along Turnagain Arm during a land-based photo-ID survey.

Anthropogenic Trauma Scars and Survival

The CIBW Recovery Plan[1] states that photographs of belugas with healed anthropogenic scars were evidence that some individuals survived traumatic events, and therefore the NMFS classified unauthorized take as a threat of medium, rather than high, concern. We believe this assigned ranking does not consider the low carcass recovery rate (McGuire et al., 2020b) and resulting difficulty in determining how many belugas die of anthropogenic trauma. In addition, although an individual may survive the traumatic event in the short-term, we believe the previous statement ignores the possibility that the individual's long-term survival and/or reproductive output may decrease. Subsequently, this would have a delayed, but important, impact on the overall population size and trajectory.

Moore and van der Hoop (2012) present examples of cetacean entanglements that were not immediately lethal, but ultimately resulted in infection, hemorrhage, and tissue damage, as well as individual pain and suffering, all of which may eventually lead to decreased reproduction and/or survival. A population viability analysis conducted by NMFS determined that even one additional death annually can negatively affect the viability of the population and increase the risk of extinction (Hobbs et al., 2015b).

Anthropogenic trauma can affect beluga health and survival over an extended period. Although anthropogenic trauma was only conclusively established as the primary cause of death for one animal, we use the sighting history of whales that were satellite-tagged to illustrate how anthropogenic trauma can affect beluga health and survival over an extended period, despite signs of individual recovery. Considering the entire period from when satellite tagging began in 1999 to the end of our photo-ID and necropsy analysis in 2017, 3 of the 18 tagged belugas were confirmed to have died, and an additional 5 were presumed to have died. In this example, the mortality rate is 40%. Whales tagged in 2002, when larger bores and tag pins were used (Shelden et al., 2018), died at a higher rate than whales tagged in other years, although none died immediately after tagging. Flipper bands had been used on other beluga populations without incident (Orr et al., 1998; Shelden et al., 2018) but were documented to have caused extreme flipper damage to the two dead CIBW individuals on which they were photographed.

These patterns raise important questions about the impacts of anthropogenic trauma on CIBW's that our data cannot fully resolve but should be considered. For example, did the tagging injuries and/or stress of capture compromise their immune systems, leaving them more vulnerable to later infection and poor overall health or poor body condition? Did the large scars created by tagging allow pathogens already in the environment to become established in their systems? Have rising summer water temperatures in Cook Inlet, documented during our work over the last decade (McGuire[9]), contributed to an increase in scar infection rates? Is there some characteristic(s) of the immune systems of CIBW's, or the environment of Cook Inlet, in which established tagging protocols caused more harm to CIBW's than to belugas in other populations?

We use the previous example not to single out research activities, but rather because our records are strongest for research-related scarring, due to known date and type of anthropogenic activity and the relatively large sample size compared to other types of anthropogenic scarring. We are unable to compare the relative lethality of non-research anthropogenic trauma (i.e., entanglement, puncture, and vessel strikes), because both the number of individuals that have died of a type of trauma and the incidence of the trauma type in the population are unknown. We would also expect that individuals who have survived but bear scars of entanglement, puncture, and vessel strikes may still suffer long-term negative effects of these human interactions, such as chronic infections or reduced ability to feed effectively or escape predators.

For example, one live presumed female has scars indicative of entanglement or vessel strike (Fig. 8). Although she was photographed year after year and is believed to be a reproductive female due to the close accompaniment of different calves over the years, her injury appears to cause labored swimming. Her body twists with her tail coming out of the water with almost every fluke stroke, and she is almost always lagging slightly behind any group with which she is associated. Although she is surviving and apparently giving birth to and raising calves, it is unclear whether her injury may affect her in indirect ways. We do not know, for example, whether her injury may make her more susceptible to killer whale predation, if the increased energy expenditure to swim in an apparent inefficient manner results

[9]McGuire, T. Unpubl. data on file at Cook Inlet Beluga Whale Photo-ID Project, Anchorage, AK 99515.

in chronic stress and increased risk of infection, or if her reproductive rate is lower than it would have been otherwise.

Anthropogenic Trauma Scars and Reproduction

Aside from the obvious link that a dead female is no longer available to reproduce, we were unable to detect associations between anthropogenic scarring and reproductive success in the known females (from biopsy and stranding) and presumed females (inferred from photographs of calf records). We could only examine this on a very basic level, asking if a female was still seen with a calf (that was presumed to be hers) after an anthropogenic scar was acquired. In all cases the answer was yes – all known females were seen with a calf or calves (across multiple years) subsequent to documentation of a scarring event. We do not yet have enough information about individual reproductive rates to determine if reproductive success changed after a scarring event, or how reproductive rates of scarred females compared to non-scarred females.

Our findings show a clear pattern of more females than males having scars indicative of anthropogenic trauma. In contrast, of the animals found dead, more males than females had signs of anthropogenic scarring (although the source of the scarring was not necessarily the COD). There does not appear to be a sex-bias in the greater stranding dataset (McGuire et al., 2020b), or in the photo-ID catalog (McGuire et al.[4])—there are currently 45 individuals of known sex in the photo-ID dual-side catalog and 23 are females and 22 are males. Observations of live males and females in the field show they are found in the same groups and use the same habitat at the same time during the ice-free field season (McGuire et al., 2020a).

We can only speculate as to why there are differences in observed sex ratios with respect to anthropogenic scarring and death. Observations of other beluga populations suggest that pregnant females move more slowly and are less agile (Quakenbush[10]), which may make them more susceptible to vessel-strikes, entanglement, and capture for satellite tagging. Alternatively, or in addition, females may be more susceptible to injury if their attention is on their calves, if they are protecting their calf, or if females with dependent calves are less able to move out of harm's way.

Perhaps females do not heal as well as males if their energy is being used for pregnancy and lactation. During photo-ID surveys, some calves appear to be more curious about vessels, approaching them at closer distances than older animals, which may cause mothers to be drawn closer to boats and nets because of their calves. Adult males may also be experiencing other stressors (e.g., the accumulation of contaminates, which adult females offload into their calves while nursing) (e.g., Shelden et al., 2018) that leave them with compromised immune systems which may make them more susceptible to death when they do experience anthropogenic injuries.

Conclusions

Necropsy data provided information on the prevalence of lethal anthropogenic injury (when noted as the confirmed or possible COD), as well as documentation of anthropogenic scarring only visible upon examination of a carcass (even when not the COD). Photo-ID data provided information about nonlethal prevalence of anthropogenic scarring on living whales, healing/infection of scars, and the life history context for identified carcasses with anthropogenic scars. In addition, the photo-ID data provided information about potential links between anthropogenic scarring and whales that are presumed dead but were not present in the necropsy data.

Combining data from the photo-ID catalog and necropsy reports forms a more complete picture than presented by either dataset alone and allows for estimation of the prevalence of anthropogenic trauma scars according to likely scar source. While the combined datasets maximize what can be learned about anthropogenic trauma, they underestimate prevalence, particularly for extreme trauma where death may be immediate and undetectable with the methods used.

One important result from our study is that anthropogenic trauma effects may take years to manifest. For example, some past research activities, although perhaps not a substantial contribution to anthropogenic mortality in terms of absolute numbers, had unforeseen consequences, including injury from tagging activities and reduced body condition possibly due to tagging which were not apparent until 5 years or longer after the research event. Caution is therefore warranted when implementing or permitting new research techniques for this population, and concerns must be balanced with the depth and importance of the data collected with these methods. Continued annual monitoring of individuals subject to invasive or semi-invasive research methods is recommended, along with annual reporting and peer-review of results. Likewise, belugas bearing signs of non-research anthropogenic scarring could still be threatened by the activity even though they survived the immediate trauma event, and should continue to be monitored to assess long-term health, reproduction, and survival even after the threat is removed.

While our study details the physical manifestations of anthropogenic trauma, there are other direct consequences to belugas from anthropogenic activities that our findings do not specifically address, including disruption of behaviors such as foraging, navigation, communication (especially between mothers and calves), nursing, and predator detection/avoidance. Documenting the prevalence of non-lethal scarring gives some indication of how frequently CIBW's are coming into contact with some human activities, and provided qualitative information needed to help guide future efforts to quantify disruption of behaviors from

[10]Quakenbush, L., Alaska Dep. Fish Game, 1300 College Road, Fairbanks. Personal commun., Feb. 2020.

anthropogenic activities. In addition, multiple natural and anthropogenic activities may combine to pose threats greater than either alone (e.g., auditory masking from seismic activities may reduce ability to avoid ship strikes; reduction in prey may cause belugas to risk taking fish from nets and become entangled).

In summary, we have documented that injury from anthropogenic activities does occur at lethal and nonlethal levels. With over one-third of the individuals examined bearing signs of confirmed or possible anthropogenic trauma, these levels are not inconsequential. Although our sample does not allow us to reliably infer the rate of anthropogenic trauma at the population level, it provides an important index of the types and level of trauma experienced by a subset of the population. We found no evidence that unauthorized take from the anthropogenic trauma sources we examined are the primary threat to beluga recovery. However, the evidence we present here suggests anthropogenic trauma remains at least an important component of "cumulative effects," which were ranked as the threat of highest concern in the CIBW Recovery Plan[1].

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