Annual Calf Indices for Beluga Whales, *Delphinapterus leucas,* in Cook Inlet, Alaska, 2006–12

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ABSTRACT—Beluga whales, Delphinapterus leucas*, in Cook Inlet, Alaska, form an isolated, depleted population that is now listed as endangered. Calving rates are an indicator of population health and the potential for recovery. Most births in Alaska beluga whale populations occur by late July; therefore, systematic aerial surveys were conducted in August covering primary habitat in upper Cook Inlet and compared to similar surveys conducted in June. Paired video cameras, one capturing the entire beluga group and the other magnified to detect smaller, darker whales, provided images used in laboratory analysis. Calves were found in 27 of 82 groups video-sampled in June and 22 of 54 groups in August. Calves were identified by their small size, skin color (darker than adults), behavior, and proximity to adults, using images captured in zoomed video. Proximity to an adult beluga (five categories) determined two calf indices, one represented young-of-the-year calves (Index 1) and the other all dependent calves up to about 3 years of age (Index 1–5). Biases associated with this method include: 1) surfacing frequency of calves, 2) verification of relative image size assumptions, and 3) the unknown fraction of mature females.*

In both June and August, the smallest calves were found in the proximity 1 category (i.e., calf touching adult). Indices suggest that most calves were born between June and August, with smaller calves (likely 0–2 months old) in all proximity categories in August. In June, the indices were similar across years with a 7-yr average for Index 1 of 1.2% (SD = 0.5%). August had significant variation. In August 2006, Index 1 was 12% suggesting that it was a good year for new calves. From 2007 to 2012, Index 1 in August ranged between 0.5 and 3.5% suggesting that these were poor calving years. June indices did not correspond to the previous August, therefore, video data from June 1995 to 2005 could not be used for a calf index. Knik Arm had the highest index values for both indices in June and August, with more than twice the values in the Susitna area, and indices were lowest in the Turnagain area.

The average per capita calving rate was 3.5% (SD = 4.3%) compared to a minimum estimate of mortality of 2% (SD = 1.2%; 2006–12) from carcass counts, suggesting the birth rate was probably at or below the replacement level. If adult females make up about 30% of the Cook Inlet population, then on average 12% gave birth each year which was one-third the maximum rate estimated for other Alaska beluga populations

Introduction

Alaska's Cook Inlet is home to a group of beluga whales, *Delphinapterus leucas*, which is genetically distinct and geographically isolated from beluga whale populations in western Alaska and the Arctic (O'Corry-Crowe et al., 1997; Laidre et al., 2000). After a period of unregulated Native subsistence hunting, the Cook Inlet beluga whale (CIBW) stock was determined to be depleted under the U.S. Marine Mammal Protection Act in 1999 (NOAA, 2000). In 2008, this distinct population segment (DPS) was listed as endangered under the U.S. Endangered Species Act (ESA) (NOAA, 2008).

As of 2012, the CIBW population has failed to show any signs of recovery, with an abundance trend showing a continued decline (Hobbs et al., 2015). ESA Recovery Plans require criteria defining benchmarks for extinction risk as part of the recovery efforts (NMFS[1]). One indicator of recovery or decline in a population is change in calving rates. For example, a decline in calving rate would result in a shortage of replacements and an ensuing decline in population size.

In the Saint Lawrence estuary (SLE), Canada, belugas inhabit an environment similar to Cook Inlet. The SLE population has not shown appreciable recovery since the end of hunting in 1979 (DFO, 2012, 2014). Females give birth between June and August after a gestation period of a little over 14 months (Béland et al., 1990, 1992). Calves may nurse up to 2.5 yr (Brodie, 1971; Sergeant, 1973; Seaman and Burns, 1981) resulting in a 3-yr calving cycle.

In Cook Inlet, traditional knowledge from Native hunters indicated calving occurs from April through August (Huntington, 2000). Hunters described calving areas and timing: in the lower inlet along the northern side of Kachemak Bay in April and May; and in the northwestern portion of the upper inlet near the Beluga and Susitna rivers in May, and Chickaloon Bay and Turnagain Arm in summer (Huntington, 2000:138).

In the late 1970's, calves were not observed during mid-June aerial surveys (Shelden et al., 2015; Murray[2]).

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[1]NMFS. 2015. Draft recovery plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Alaska Reg. Off., Protected Resour. Div., Juneau, 274 p.

[2]Murray, N. K. 1979. Belukha whales in lower Cook Inlet. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. Princ. Invest. 1(1979):192-208 *In* D. Calkins and K. Pitcher (Princ. Invest.). Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska, Res. Unit 243, p. 144-208 (avail. at

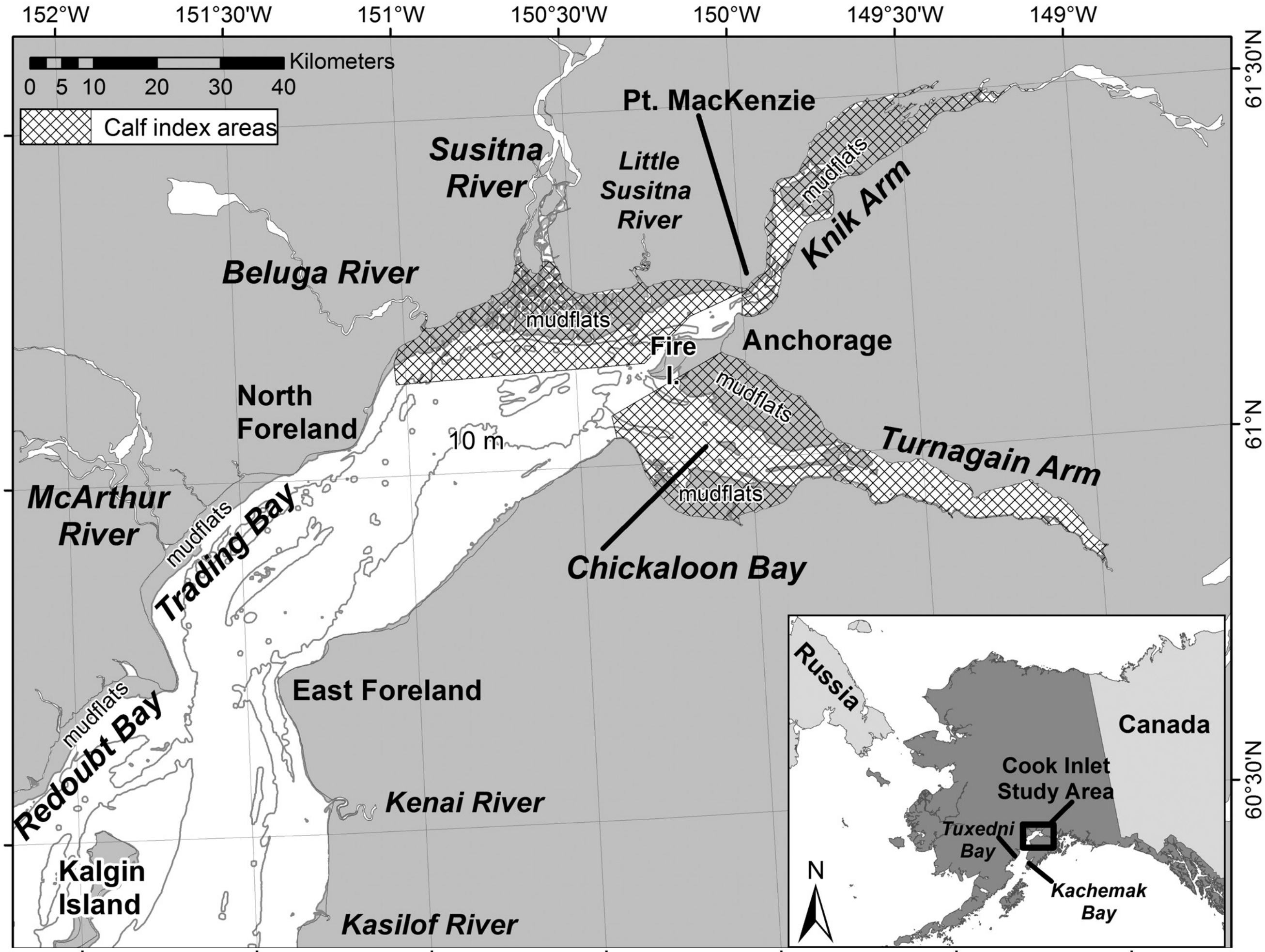

Figure 1.—Study area for the Cook Inlet, Alaska, calf index aerial surveys, August 2006–12. Three shaded regions: Susitna (from Beluga River to Pt. MacKenzie), Knik (Knik Arm), and Turnagain (including Chickaloon Bay and Turnagain Arm) denote where most beluga groups were observed during the study period.

By the mid-July surveys, Nancy Murray reported calves at Beluga River, in Trading and Redoubt bays, and in mid-inlet waters south of Fire Island (Shelden et al., 2015). She noted on one occasion:

> "There were several (8–10) very large white animals, and about 12 small grey animals about ¼–⅓ the length of the larger white 'females' they swam alongside. These small animals were very dark slate grey, darker than any juveniles I've seen so far. I can't help but think that these are recently born calves which have been born since the June 18th flight" (Shelden et al., 2015: Appendix 1).

Murray[2] also reported calves in the central inlet between Kalgin Island and Kasilof River in mid-August, and in Tuxedni Bay in mid-October (Fig. 1).

During aerial surveys conducted in upper Cook Inlet waters in the early 1980's, Calkins[3] noted:

> "No neonates were positively identified on any of these surveys due to the turbid water conditions. However, on both the May 17 and the June 4, 1982 surveys, very dark, small belukhas were sighted. These could have been newborn calves although this was not determined because newborn calves and yearlings differ in length by approximately 30 cm (John Burns, pers. comm.); determining 30 cm difference between animals from an aircraft at 100 to 200 m altitude and moving at an airspeed of approximately 80 kts with the belukhas in highly turbid water proved to be an impossible task" (p. 3).

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http://www.arlis.org/docs/vol1/OCSEAP2/Annual/5721406/A1979%20V01.pdf and accessed 4 Mar. 2015).

[3]Calkins, D. G. 1984. Belukha whale. Vol. IX of Susitna hydroelectric project; final report; big game studies. Alaska Dep. Fish Game., Doc. 2328, 17 p. (avail. at http://www.arlis.org/docs/vol1/Susitna/23/APA2328.pdf and accessed 4 Mar. 2015).

Since the early 2000's, the entire CIBW population, with the exception of a few whales, has remained in or moved into upper inlet waters from the lower inlet by early June (Shelden et al., 2015). Based on the May calving time hunters identified for the Susitna area (Fig. 1), and the mid-July calf sightings during aerial surveys in the 1970's, we assumed most calves had been born by August. Thus, the location and timing of our calf study focused on upper inlet waters in August, but we also compared results to the early June surveys conducted each respective year.

A few small, dark belugas have been observed on occasion during the June surveys. On 10 June 2010, the NMFS aerial team (including three of the coauthors: KEWS, DJR, LVB) witnessed what appeared to be a birth along the unexposed mudflat edge between the Little Susitna River and Fire Island. An adult whale accompanied by two adults was observed rolling at the surface, there appeared to be blood in the water, then the whale, presumably the mother, lifted a small, dark calf to the surface on its back.

Young-of-the-year remain in close proximity to their mothers, and even at 1–2 months post-partum they are nearly always in contact with their mothers (Krasnova et al., 2006; Suydam, 2009). This proximity to an adult, and the size and color of these small whales (dark gray compared to the white adult), makes them more readily identifiable as calves. Given the difficulty of identifying calves in the turbid waters of the upper inlet, we developed a method using video recording of beluga groups that were counted during aerial passes. Here, we describe techniques used to create a calving rate index and discuss the implications for the conservation and recovery of the depleted and isolated CIBW population.

Methods

To develop a calf index for CIBWs, the NMFS National Marine Mammal Laboratory (NMML) conducted aerial surveys in August annually, beginning with a pilot study in August 2005 (Rugh et al.[4]; Shelden et al.[5,6,7,8,9], Sims et al.[10]). These surveys followed the same protocols used during the June abundance surveys (Rugh et al., 2000, 2005; Shelden et al., 2013). In this respect, the data sets would be comparable between June and August and would allow for a retrospective calf index analysis of video data collected during June surveys for the period 1995–2005. Data collection methods in August were largely proscribed by the methods used for the June survey and innovation focused on development of new analysis methods to assign age classes (calf, subadult, and adult) to the video images. The analyses were developed over a period of years and in some cases went through a series of trial and refinement steps before arriving at the methods presented here (Hobbs et al.[11], Sims et al.[12,13]).

Study Area

Cook Inlet is a long bay and estuary north of the Gulf of Alaska. Currently, the CIBW population inhabits three primary areas during the month of August, denoted as the following for the purposes of this study (Fig. 1):

"Susitna" which includes the northwestern portion of the upper inlet between Point MacKenzie and Beluga River;

"Knik" which is Knik Arm, north of Anchorage, the largest city in Alaska; and,

"Turnagain" which includes Turnagain Arm and Chickaloon Bay, in the northeast portion of upper Cook Inlet.

Data Collection

Aerial surveys were flown in twin-engine, high-wing aircraft at an altitude of 244 m (800 ft) and speed of 185 km/h (100 kn). The forward right and left observer positions had bubble windows to maximize the search area. The data recorder used a laptop computer[14] connected to a handheld portable Global Positioning System (GPS) to record survey effort and sighting data.

[4]Rugh, D. J., K. T. Goetz, C. L. Sims, and B. K. Smith. 2006. Aerial surveys of belugas in Cook Inlet, Alaska, August 2006. Unpubl. field rep., 9 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2006.pdf), accessed 19 July 2011).

[5]Shelden, K. E. W., K. T. Goetz, and J. A. Mocklin. 2007. Aerial surveys of belugas in Cook Inlet, Alaska, August 2007. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2007.pdf), accessed 19 July 2011).

[6]Shelden K. E. W., K. T. Goetz, L. Vate Brattström, B. A. Mahoney, M. Migura-Krajzynski, and B. S. Stewart. 2008. Aerial surveys of belugas in Cook Inlet, Alaska, August 2008. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2008.pdf), accessed 19 July 2011).

[7]Shelden K. E. W., K. T. Goetz, L. Vate Brattström, and B. A. Mahoney. 2009. Aerial surveys of belugas in Cook Inlet, Alaska, August 2009. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august09.pdf), accessed 19 July 2011).

[8]Shelden K. E. W., L. Vate Brattström, and C. L. Sims. 2010. Aerial surveys of belugas in Cook Inlet, Alaska, August 2010. Unpubl. field rep., 12 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august2010.pdf), accessed 19 July 2011).

[9]Shelden K. E. W., L. Vate Brattström, and C. L. Sims. 2011. Aerial surveys of belugas in Cook Inlet, Alaska, August 2011. Unpubl. field rep., 10 p. (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/survey/august2011.pdf), accessed 28 May 2015.

[10]Sims, C. L., L. Vate Brattström, and K. T. Goetz. 2012. Aerial surveys of belugas in Cook Inlet, Alaska, August 2012. Unpubl. field rep., 11 p. (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/survey/august2012.pdf) accessed 28 May 2015.

[11]Hobbs, R., C. Sims, K. Shelden, L. Vate Brattström, and D. Rugh. 2012. Annual calf indices for beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, 2006-2010. AFSC Proc. Rep. 2012-05, 29 p.

[12]Sims, C. L, R. C. Hobbs, and D. J. Rugh. 2003. Developing a calving rate index for beluga in Cook Inlet, Alaska using aerial videography and photography. Abstr. (poster) in Fifteenth Biennial Conference on the Biology of Marine Mammals, Greensboro, N.C. 14-19 Dec. 2003.

[13]Sims, C. L., R. C. Hobbs, K. T. Goetz, and D. J. Rugh. 2007. Using advanced techniques to determine age categories of belugas. Abstr. presented at the First International Workshop on Beluga Whale Research, Husbandry and Management in Wild and Captive Environments, 9-11 Mar. 2007, Valencia, Spain.

[14]Starting in 2006, survey data were entered using a new software program specifically developed for the Cook Inlet beluga aerial survey by Niel Goetz and Kimberly Goetz, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Natl. Mar. Mammal Lab., 7600 Sand Point Way NE., Seattle, WA 98115-6349.

Survey software routinely recorded time and location from the GPS every few seconds, as well as when sightings or comments were entered. Other data collected included percent cloud cover, sea state (Beaufort scale), glare (on the left and right sides), visibility (on the left and right sides), beluga group count data, and other marine mammal sightings. Because belugas in Cook Inlet tend to be found near shore during the summer months, aerial surveys included coastal tracklines within 1.4 km of the apparent waterline in addition to offshore transects. The survey also included searches up rivers until the water appeared to be too shallow for belugas (as indicated by Native Alaskan hunters who participated in past surveys).

The August survey design was similar to that of the June abundance surveys (Rugh et al., 2000, 2005; Shelden et al., 2013) with the exception that tracklines were not flown south of Kalgin Island. Since the early 2000's, almost all beluga sightings (systematic and opportunistic) have occurred in the upper inlet during the summer (June–August) (Shelden et al., 2015). During the period 2006–12, we compared beluga group distributions and raw counts collected each June (Shelden et al., 2013) to the respective August survey while underway, to ensure large portions of the population were not missed. After the field season, opportunistic sighting reports were reviewed to verify that no large groups of belugas were seen outside of the survey area (Shelden et al., 2015; Vate Brattström et al.[15]). Video data were collected during each respective June and August survey using the same camera system to facilitate within-year comparisons which would be used to determine when most young-of-the-year calves were born.

[15]Vate Brattström, L., C. Sims, R. Hobbs, and B. Mahoney. 2010. The Cook Inlet beluga whale opportunistic database: A summary of opportunistic sightings during the past 35 years. Poster pres. at Alaska Mar. Sci. Symp., Anchorage, AK, Jan. 2010 (avail. at: http://access.afsc.noaa.gov/pubs/posters/pdfs/pVate-Brattstrom01_cook-inlet-beluga-db.pdf and accessed 22 Jan. 2014).

Counting and Video Passes

When beluga groups were seen, each observer reported the sighting to the data recorder. As the aircraft passed abeam of the whale group, the observer(s) informed the recorder of the inclinometer angle and notable group behaviors but not group size. Whale group locations were marked via GPS with the survey program before the onset of the counting passes. Counts of each whale group were made by following an extended oval (racetrack pattern) around the group. Counting passes of the beluga groups were made on each pass down the long axis of the oval following procedures used during abundance surveys (Rugh et al., 2000, 2005; Shelden et al., 2013). Daily aerial counts of beluga groups were represented by medians of each observer's median counts on multiple passes (typically 4–8 passes) over each whale group.

Video Procedures

Paired, video cameras that were mounted side-by-side on a hand-held board were used to document beluga whale groups. One camera lens was set at wide angle to view the entire beluga group (referred to hereafter as "standard" video) and was used to assess the number of belugas in a group. The second camera lens was zoomed to approximately 10–15X magnification to enlarge a subsample of individual whales in the group (referred to hereafter as "zoomed" video). The zoomed video was used to examine color ratios of white adults relative to dark juveniles (Litzky, 2001; Sims et al.[12,13]) and to determine correction factors for missed animals (Hobbs et al., 2015).

Calf index surveys began in August 2005 with an experimental survey to test video camera resolution compared to still camera photography. A high-speed digital single-lens reflex (SLR) camera (Nikon D1X[16]) was used for the zoomed data collection, paired alongside a mini-digital video camera (Sony DVCAM, DSR-PDX10 Model L10A). Although clear images of calves were captured, the camera would pause after several frames to write to memory and was unable to fire fast enough (approximately 3 frames per second) to ensure adequate sampling. Consequently, the still camera was less than ideal because it could not reliably capture enough frames of a surfacing event to determine the midpoint of a whale's surfacing (i.e., the maximum image size as described below in the video analysis section).

[16]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

In 2006, both the standard video camera and the zoomed still camera were replaced with high-definition (HD) video cameras (JVC GR-HD1, 1290 × 720 pixels) to collect both standard and zoomed video. While the resolution of the JVC HD video cameras (1290 × 720 pixels) was lower than the resolution of the Nikon still camera (3008 × 1960 pixels), the jump in resolution was an improvement over the Sony DVCAM video resolution (720 × 480 pixels).

A test of the system in May 2006 (Rugh et al.[17]) demonstrated that the continuous zoomed HD video gave a better sampling of beluga surfacings than the Nikon still camera. The HD video provided sufficient resolution for calf detection as well as more frames of each surfacing for image size comparisons. Therefore, the HD video was used for the zoomed sampling in 2006 and later, and data collected with the Nikon still camera during the 2005 survey were not used in subsequent analysis. In 2011, the JVC HD cameras were replaced with higher resolution (1920 × 1080 pixels) Sony HSR-NX5U HD video cameras.

Video Analysis

Post-survey, video recordings were digitally streamed into a computer, edited, and exported so that each count-

[17]Rugh, D. J., K. T. Goetz, and C. L. Sims. 2006. Aerial surveys of belugas in Cook Inlet, Alaska, May 2006. Unpubl. field rep., 8 p. (avail. at: http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/report0506.pdf), accessed 19 July 2011).

ing pass was saved as an individual video file. During the editing process, video passes were reviewed to ensure each video clip was sufficient quality for counting whales. Quality ratings were excellent, good, fair, poor, or unacceptable, as defined in Hobbs et al. (2000), based on factors that could affect the quality of the image such as camera focus or factors that affect the visibility of whales in the field of view such as presence or absence of whitecaps or glare. Only aerial passes with excellent or good ratings were used in the analysis.

After each video was assessed for quality and exported, the clip was analyzed using the "Beluga Dots" program, software designed specifically to analyze video of beluga groups collected during these surveys.[18] The Beluga Dots program, used on Macintosh computers, allowed an analyst to mark and number each individual whale image, track the individual whales across the screen, and use tools to measure whale image size and assign color. The computer program electronically recorded all relevant information (surfacing and diving time of each whale, size and color of individual whales, and total count of the group) to a database. The program allowed analysts to review the video frame by frame or in slow motion an unlimited number of times, compare time synchronized standard and zoomed video from the same pass over a group, and enter and edit data collected during the video review whenever necessary.

Each standard video sequence was examined by a primary analyst who cataloged individual whales, noted surfacing time (the first frame where a whale was visible), diving time (final frame where a whale was visible), measured whale images (pixel size), and noted color (bright white, dull white, light gray, medium gray, and dark gray using a color scale in the analysis program). Image size was measured at the midpoint of a surfacing (halfway between surfacing time and diving time) when the largest portion of the beluga was exposed above the muddy water. If the whale midpoint image was blurred due to motion of the camera, the analyst would search forward and backward frame by frame to find a clear image of equivalent size. Whales that surfaced prior to appearing on-screen or did not dive before going off-screen, and whose midpoint occurred near the edge of the screen, were not included in the analysis as the true midpoint may have occurred off-screen.

After the primary analyst completed the first review, a second analyst reviewed each video clip and corresponding data file to confirm the primary analyst's whale count and individual whales, searched for any missed whales, and completed second measurements of each whale image size and color. The computerized analysis of video allows for thorough, documented counting of groups compared to counting real time during the aerial survey. When possible, multiple video passes of the same group were sampled.

Once the analysis of a standard video pass was completed, if there was a usable zoomed video sequence for that pass, the zoomed video was synchronized to the standard video and analyzed. The two cameras were aligned such that the zoomed video frame was centered and contained within the standard video field of view. Using the time stamp and objects that appeared at the surface in both the standard and zoomed video, the analyst could estimate the relative magnification within a video frame. The zoomed video captured higher magnification images of the animals seen in the standard video and often included small, gray-colored beluga whales that were undetected in standard video due to size (much smaller than adults), dark color (blending with the muddy water), or surfacing behavior (only a small portion of the whale broke the water surface). The proportions of these missed beluga were used to correct the group counts for missed whales when estimating group sizes (Hobbs et al., 2000, 2015), and the calf index was then derived from whales found in the zoomed video using the images that met specific criteria presented below.

A feature in the Beluga Dots software program allowed the analysts to compare the synchronized zoomed and standard video clips frame by frame. The whale images in the zoomed video were cataloged and measured then compared to images in the standard video to determine if they were also found in the standard video. If a whale was also visible in the standard video, the midpoint, if available, was used to determine if the zoomed image was at the maximum size. Midpoints that occurred more than one second outside the boundaries of the zoomed frame were considered unmeasurable in the zoomed video. For smaller whales that were visible only in the zoomed video, the portion of the surfacing was reviewed and a maximum point was identified only if the whale was clearly visible at the surface. The exposed back was measured along the longitudinal axis (in pixels) and used for size comparisons between whales.

Identifying Calves, Subadults, and Adults

Whale images in zoomed video were initially identified as calves, subadults, adults, uncertain, or unusable, based on their color, size relative to large, white belugas, and behavior. The methods were largely objective but require experienced video analysts to apply. Zoomed video with inconsistent lighting or glare patches was not used, consequently, the color measurement was thought to closely correspond with the color of the beluga itself.

Typical surfacing behavior for adults, subadults, and calves older than one year was a slow roll, which appeared in the video as exposure of the back of the head followed by the dorsal surface with the caudal peduncle submerging last (belugas rarely exposed flukes). The maximum longitudinal length exposed above the muddy water was between the blow-

[18]Starting in 2004, video data were analyzed using a new software program, "Beluga Dots", specifically developed for the Cook Inlet beluga aerial survey by Steven Hentel, 6170 NE 187th Pl., Kenmore, WA 98028.

hole and the caudal peduncle. These surfacings took between 2 and 5 sec. Less typical behavior was the headlift in which the beluga exposed just the head and blowhole to breath and submerged without exposing the back. Calves showed more varied behavior and included surfacing behavior in which the calf was partially supported or lifted by an adult.

Relative size was calculated as the ratio of the pixel size of a gray beluga to the average pixel size for white adults showing typical surfacing behavior in a counting pass. This was then averaged for each survey period (year) and study area (Susitna, Knik, and Turnagain). The turbid water in Cook Inlet precluded measuring full body lengths of whales, so we assumed that the maximum size of an image was proportional to the standard length of the whale. From Suydam (2009), we note that the size of a 3-yr old female (i.e., the point at which most calves have weaned (Matthews and Ferguson, 2015)) is about 60% of the size of an average adult female and 50% of the size of an average adult male. In most cases, calf sizes could be compared to only one or two adults in the same pass and same frame. With uncertainty as to the sex of the adult, and other issues such as camera angle and movement, as well as variation in the surfacing behavior of calves, relative size was used as a guideline only. We used 60% of the relative size as the breakpoint between smaller gray individuals that were more likely to be a calf and larger gray individuals that were more likely to be a subadult.

All large, bright-white and dull-white individuals were classed as adult whales and considered usable if their maximum size could be measured within the zoomed video. Where large adult whales were easily identified in the zoomed video, smaller gray whales were harder to differentiate from the water and by behavior. An analyst followed a list of four criteria to first determine if a questionable whale was in fact a whale and perhaps a calf.

First, did the movement of the questionable whale in the video appear to be surfacing or diving? This movement was detected by a change in the size of the portion of the whale that was visible above the water. Second, was the part of the whale that was visible shaped like that of other whales (oblong or tear drop shaped) depending on what portion of the surfacing was visible? Third, did the amount of time the whale was visible on screen allow enough time to detect movement and shape of the whale? Finally, did enough of the surfacing of a small, gray beluga occur within the zoomed video to allow a size measurement so that the analyst could compare the relative size of the whale to adults in the pass?

Small, dark to medium gray individuals showing behavior typical of calves (breaking the surface then quickly disappearing) were classed as calves. Intermediate sized, medium or light gray individuals showing behavior more similar to adults (slow roll surfacing) were classed as subadults. Adults showing behavior other than a slow roll were considered unusable. Whale images of gray belugas that could not easily be put into an age class were marked as uncertain. These were then reviewed by both analysts again and additional analysts were consulted. If the images remained uncertain, usually because they appeared for too short a time, they were considered unusable.

Calf Proximity and Selection of Images for Calf Index

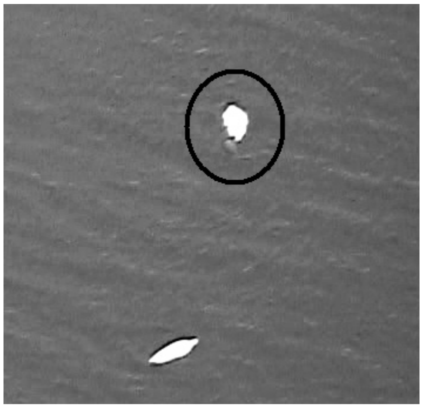
Whales identified as calves by their behavior and darker coloration were then categorized by their proximity to an adult whale based on distance in body lengths to the nearest adult in the field of view of the zoomed video. Because the entire body of a beluga was not visible, given the turbid waters of the upper inlet, a "body length" was an approximation based on the average adult image size (i.e., amount of an adult's dorsal surface that was visible above the water).

Krasnova et al. (2006) examined the spatial relationship between beluga calves and their mothers within the first 2 months post-partum. They found the most common positions during this developmental period were near the mother's flukes and at her side after comparing 11 behavioral elements. They used three categories for calf proximity: 1) "near the cow" which was within 1.5 m of the mother, 2) "at a distance from the cow" which was 1.5 to 5 m from the mother, and 3) more than 5 m away. Given the turbid conditions in Cook Inlet, we modified these categories into five proximity codes (1–5) as follows (Fig. 2):

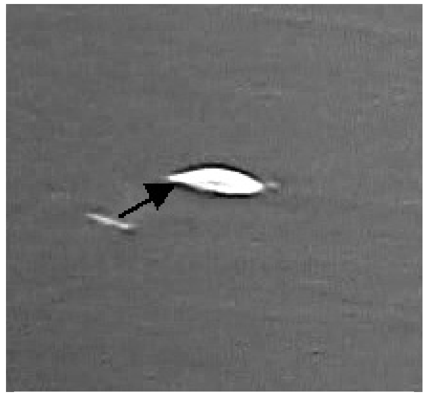
1) Calf touching an adult whale,
2) Calf within one body length of an adult whale,
3) Calf 2 or 3 body lengths from an adult whale,
4) Calf > 3 body lengths from an adult whale, and
5) Calf alone in field of view.

Due to water opacity, it is possible that an attendant adult was submerged, and therefore, undetectable in the muddy water. Krasnova et al**.** (2006) observed that very young calves may surface with the support of a submerged (thus invisible in Cook Inlet) mother, and therefore would appear to be alone (proximity 5) or if another adult was nearby to fall into proximity codes 2, 3, or 4. In addition, proximity codes 2, 3, and 4 could be affected by group behavior and density. The likelihood that random adult whales will happen to be near young whales would be expected to increase when groups are compact and milling than when whales are dispersed and travelling. In this respect, the proximity 1 sample may not contain all of the young-of-the-year calves that were recorded.

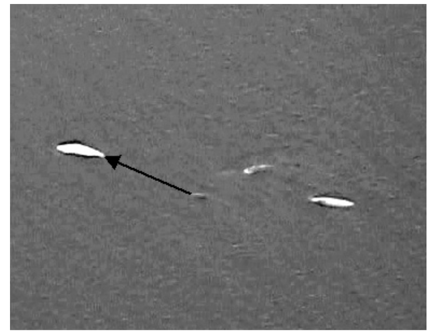
The narrow field of view for the zoomed video means a point on the water passes through the zoomed video in about 1–2 seconds. The surfacing time for calves is one-half to one-third that of the accompanying adult (which would be visible at the surface for 2–5 seconds). To avoid bias in the sampling from this longer surfacing interval, we further subsampled the measurable adults and only used adult images that were near their maximum size (i.e., measurable in the



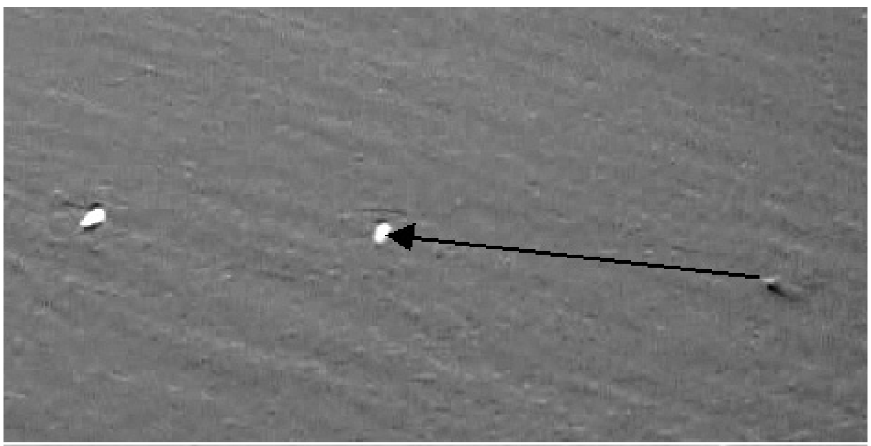
Code 1. Calf touching an adult whale.



Code 2. Calf within one body length of an adult whale.



Code 3. Calf 2 or 3 body lengths from an adult whale.



Code 4. Calf > 3 body lengths from an adult whale.

Code 5. Calf alone in field of view.

Figure 2.—Beluga whale still images captured from video showing codes used to estimate proximity (Code 1–5) of calves to nearest adult.

zoomed video). To ensure a consistent sample, the following criteria were applied to select whales to include in the calf index analysis:

1) Adult whales in both the standard and zoomed video were used if the image in the zoomed video was within 20 or fewer frames (i.e., +/- 0.66 sec) from the estimated midpoint of their surfacing in the standard video. This ensured that the size measured for the adult was near its maximum size.
2) All whales that were found in the zoomed video that met the size (smaller relative to white adult whale) and color (medium to dark gray) criteria for calves and subadults and that appeared to be near the midpoint of surfacing.

Surfacing intervals for large adult belugas could be determined from the standard video but many calves and subadults were only visible in the zoomed video. For these small whales, 3–5 frames was usually adequate for the analysts to determine if the largest portion of the calf or subadult was visible for measurement. Therefore if a small, gray beluga was not visible for enough of a surfacing to confirm it as a calf or subadult, it was not used in the analysis.

By only using zoomed video images of whales that were near the midpoint of surfacing and, therefore, close to their maximum size at the water's surface, we removed the bias resulting from longer surfacing times of large adults and ensured that the measurements were consistent in representing the relative size of both large and small animals.

Calculation of the Calf Index

The probability that a surfacing beluga was a calf was estimated for each year (2006–12), and for each geographic area (Susitna, Knik, and Turnagain) with all years combined. The probabilities were estimated using logistic regression in a generalized linear model (glm) (McCullagh and Nelder, 1989). The glm routine in the software package R was used to run the calculations. Each individual whale was treated as a sample drawn at random from the population with a sample weighting of the estimated group size divided by the number of samples from the group. This strategy prevented a single heavily sampled group from dominating the analysis.

Each sample was scored as a "1" if it was a calf and a "0" if it was not a calf. The logistic regression estimated a probability that a surfacing animal was a calf, *p(x)*, as

$$p(x) = \frac{e^{B(x)}}{1+e^{B(x)}},$$

where *B(x)* was a normally distributed parameter with standard error, SE(*B(x)*), estimated iteratively during the logistic regression, and *x* was either year or area. A 95% confidence interval for *B(x)* was *B(x)*±1.96SE*(B(x))*, which was transformed to an interval for *p(x)* as

$$\frac{e^{B(x)-1.96\mathrm{SE}(B(x))}}{1+e^{B(x)-1.96\mathrm{SE}(B(x))}},$$
$$\frac{e^{B(x)+1.96\mathrm{SE}(B(x))}}{1+e^{B(x)+1.96\mathrm{SE}(B(x))}}.$$

In cases where the number of calves was zero, logistic regression cannot estimate the probability. Instead, we used the empirical logistic transform (Cox and Snell, 1989) to estimate the probability and an upper bound, so that

$$B(x) = ln\left(\frac{1/2}{m+1/2}\right)\text{and}$$
$$\mathrm{SE}(B(x)) = \sqrt{\frac{m+2}{m}},$$

where *m* is the number of non-calves (subadults and adults) found, and *ln* is the natural logarithm. In this case, we calculated an upper bound using a one-sided 95% interval because the lower bound was clearly zero:

$$\frac{e^{B(x)-1.65\mathrm{SE}(B(x))}}{1+e^{B(x)-1.65\mathrm{SE}(B(x))}}.$$

The resulting estimate was the probability that an animal drawn at random from the population in a given year or area was a calf. This became the calf index for that survey period or area. Indices were developed to assess the relative number of calves in the population. Using the proximity data and the interpretation of age groups, we developed two indices:

1) Index 1. This index included only proximity 1 calves assumed to represent primarily young-of-the-year.
2) Index 1–5. This index included all proximity codes as a proxy for all dependent calves.

We can estimate a per capita birthrate, *q(x),* in other words the probability that an individual in the population will have a calf in a year as

$$q(x) = p(x)/(1-p(x)).$$

It was not possible to distinguish males and females during our surveys; consequently, the calf indices were a measure of population level relative to reproductive success from year to year but not an actual measure of the reproductive success of mature females. At the population level, the number of births per capita can be compared to the number of mortalities per capita to estimate the growth rate. A crude estimate of mortalities per capita was calculated using the number of stranded carcasses found annually in Cook Inlet (NMFS[1]) divided by the population abundance estimate for that year (Hobbs et al., 2015).

To convert the index to an annual calving rate for adult females, we would need to know the number of adult females in the population. Currently, this information is not available for the Cook Inlet population. We instead present a scenario assuming that adult females make up about 30% of the population.

Results and Discussion

Aerial Surveys

Abundance surveys and calf index surveys were conducted each June and August from 2006 through 2012. Beluga whale groups were observed primarily in the Susitna area, Knik Arm, and Turnagain Arm (Fig. 3). The daily median counts in August (collected over 1–3 days) compared favorably to the range of daily median counts obtained during the June surveys (collected over 4–6 days: see Shelden et al. (2013)). Based on these results, and the lack of reports from other sources (Shelden et al., 2015), it was unlikely that any large groups of whales were missed during the August surveys (Fig. 4).

Video Analysis

Multiple surveys of the upper inlet were conducted in June and August, with beluga whale groups being resampled each day; therefore, totals represent the number of groups with usable samples rather than total number of groups in the inlet. Calves were found in 27 of the 82 groups video-sampled in June (195 counting passes) and 22 of the 54 groups video-sampled during the August surveys (165 counting passes). Only two calves, one from each month, were not included in the proximity analysis because a relative size could not be determined due to lack of usable adult images in the zoomed video pass. In most cases, calves and subadults were classified using coloration, behavior, and relative size, with all three in agreement. In 21 cases (June: 13; August: 8) where relative image size was greater than 60% of adult size, further review resulted in reclassification as subadult. In 23 cases (June: 16, August: 7), with relative image size less than 60% of adult size, further review resulted in reclassification as calves and assigning a proximity code. For June, 966 images were used in the calf index analysis, comprised of 48 calves, 74 subadults, and 844 adults (Table 1). August had 1,004 useable images which included 64 calves, 36 subadults, and 904 adults

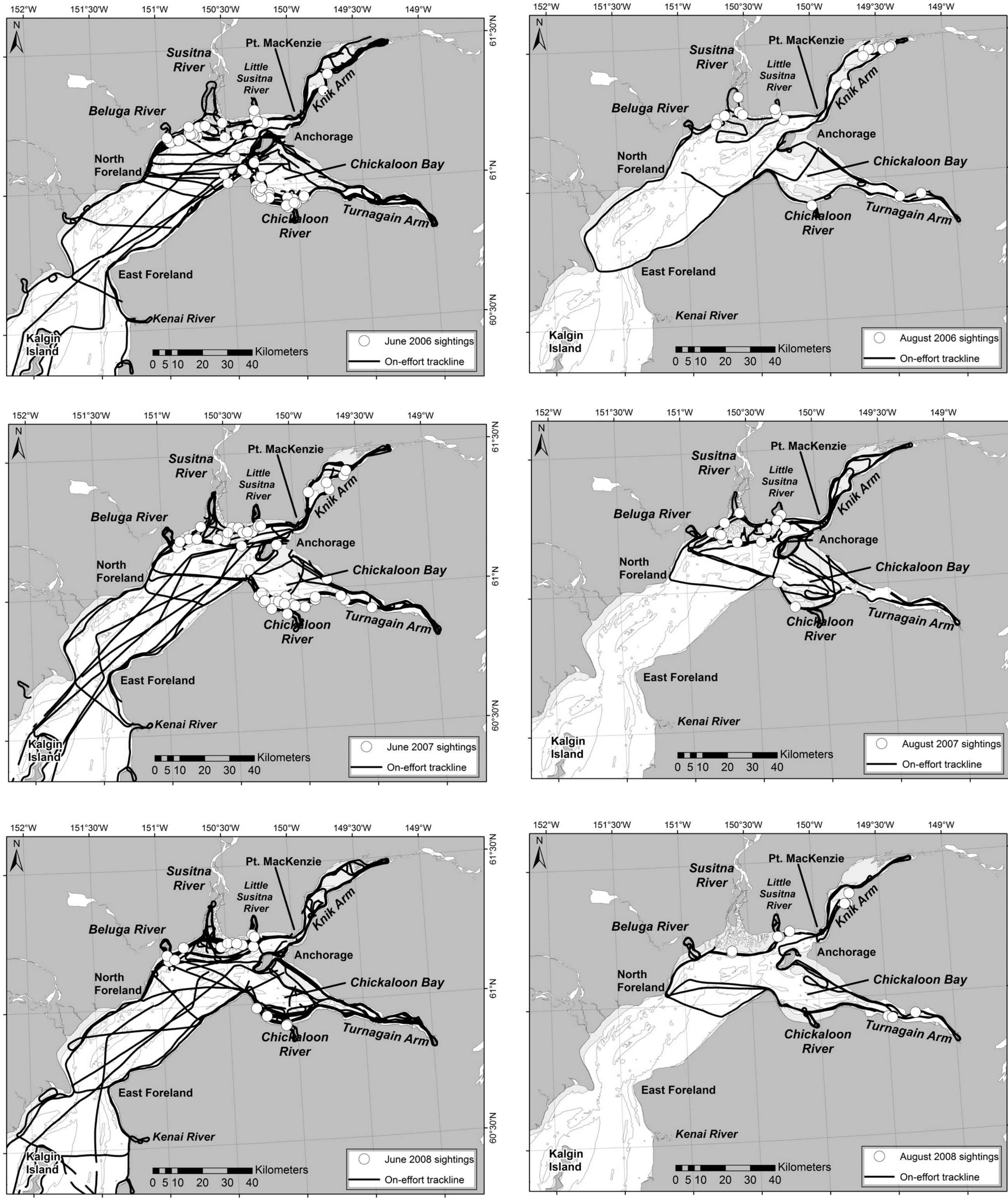


Figure 3.—Survey effort and beluga whale group locations in Cook Inlet, Alaska, documented during annual abundance (June) and calf index (August) aerial surveys, 2006–12. The white circles include initial sampling and resampling locations of beluga groups over multiple survey days.

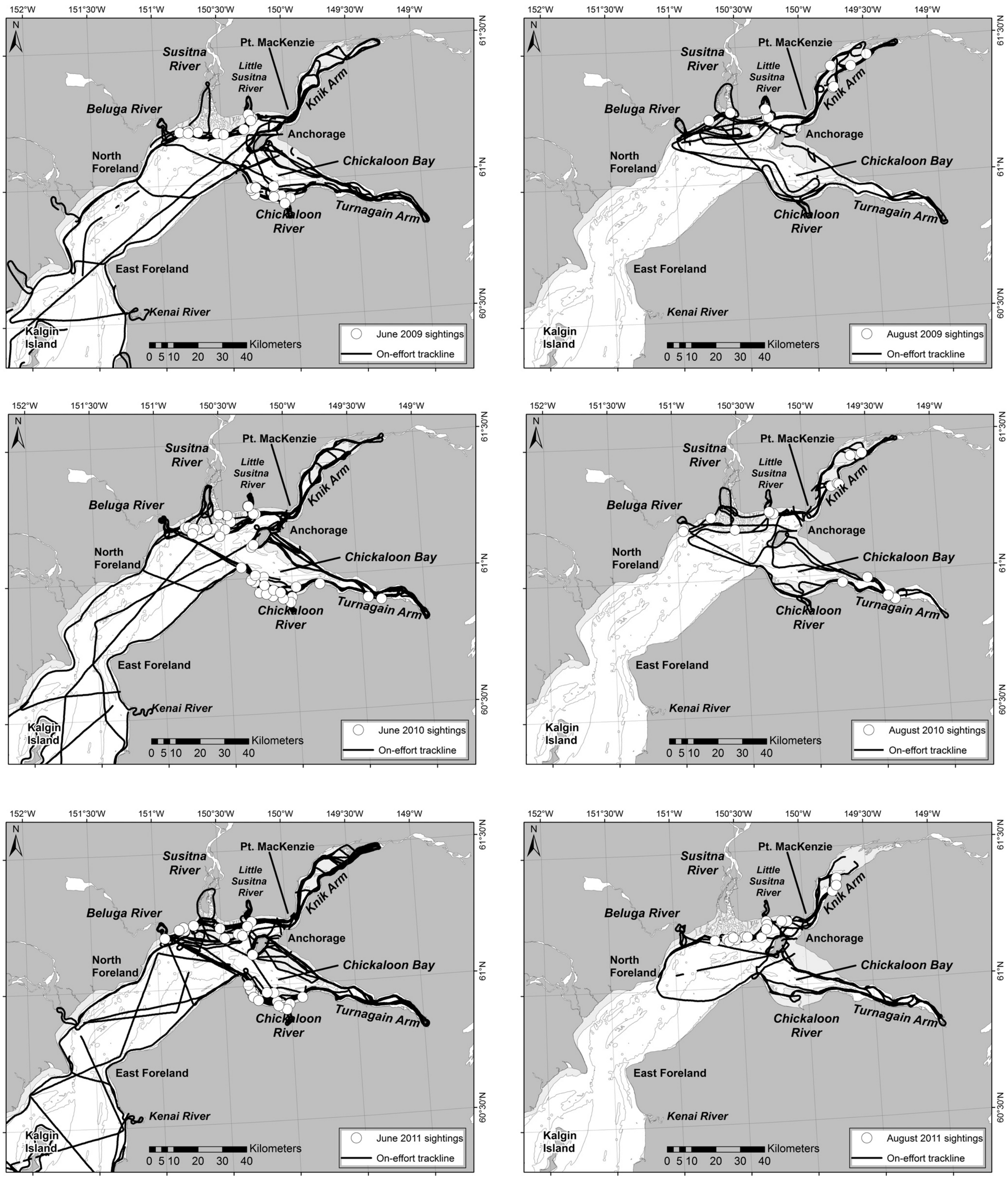


Figure 3.—*Continued*

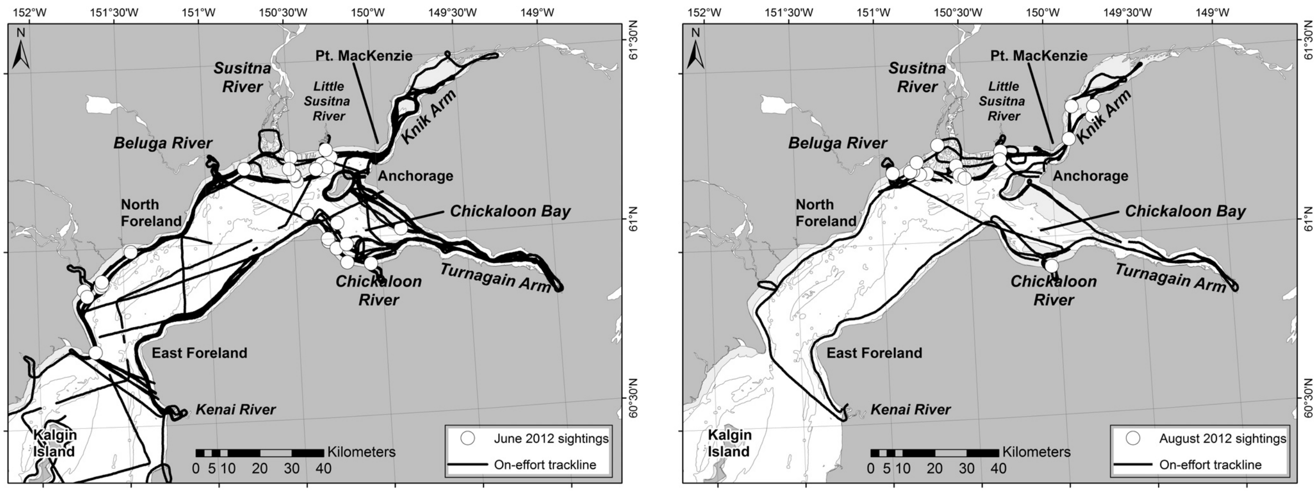


Figure 3.—*Continued*

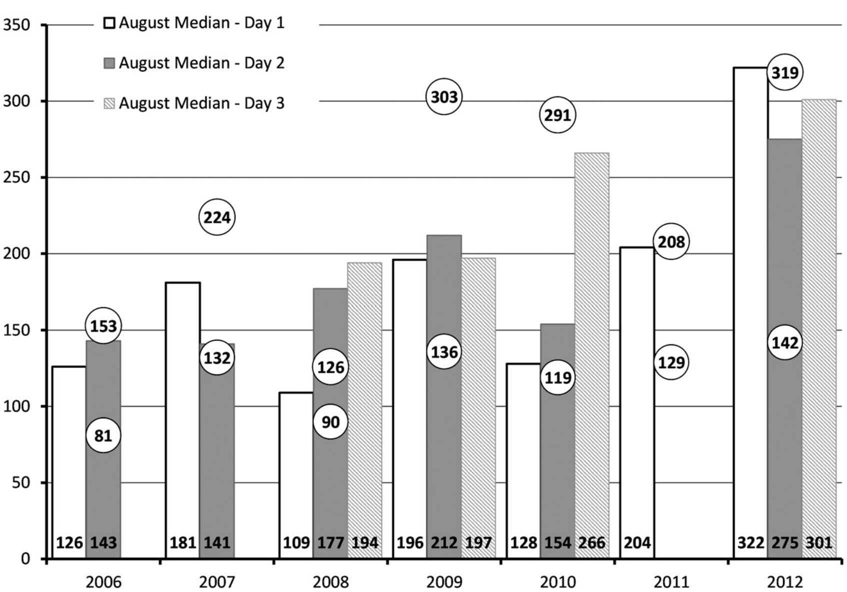


Figure 4.—Beluga whale daily median count totals for each survey day in August (2006–12) compared to the range of median counts obtained each respective June (circles) in Cook Inlet, Alaska.

(Table 2). Similar overall numbers of adults were found in zoomed video in both months, but more subadults were detected in June while more calves were detected in August.

The average relative size of apparent calves within each proximity category was estimated for June and August for each year and overall (Fig. 5). The June calves (Fig. 5a) tended to be relatively larger overall compared to those observed in August (Fig. 5b). This is consistent with our assumption that most calves are not born until later in the summer. The calves in the June sample would be 10 to 12 months old while the calves in August would be zero to 2 months old. In August, this difference is particularly evident in the proximity 1 category (i.e., calf touching adult) which represented 40% of the calf sample (compared to 25% of the June calf sample) which is consistent with observations by Krasnova et al. (2006) during which calves younger than 2 months were nearly always in contact with their mother.

For both months, the proximity 1 category produced the smallest (i.e. youngest) calves, while the other categories (excluding August proximity 5) included larger (older) calves. These results are consistent with the analysis in Suydam (2009) which showed that animals estimated to be 1 year old or older (based on size) spend less time in close proximity to an adult than smaller calves (<1 year old). The August proximity 5 calves (alone in field of view) may also include young-of-the-year based on relative size. Young-of-the-year calves are known to surface more frequently than the accompanying adult (Krasnova et al., 2006; Suydam, 2009), and given the turbid waters of Cook Inlet, the mother was likely present but submerged.

Beluga groups were found in greater numbers in the Susitna area in both June and August (Tables 1, 2; Fig. 3). This was not surprising as the Susitna area has always been an area of high occupancy even as this population has declined in numbers (Rugh et al., 2010; Shelden et al., 2015). Calves were smaller in August than June

Table 1.—Video passes reviewed for the presence of beluga whale calves in Cook Inlet, Alaska, in June 2006–12. Belugas were classified by color: adults (bright white to dull white), subadults (light gray), and calves (medium to dark gray), relative size, and surfacing behavior. Proximity codes are defined as 1) Calf touching an adult whale; 2) Calf within one body length of an adult whale; 3) Calf 2 or 3 body lengths from an adult whale; 4) Calf >3 body lengths from an adult whale; and 5) Calf alone in field of view. For the Index 1 and Index 1–5 analyses, each whale was treated as a sample drawn at random from the population with a sample weighting of the estimated group size divided by the number of samples from the group.

				Proximity codes								
Date	Area	Group ID	Passes sampled	1	2	3	4	5	Total calves	Total subadults	Total adults	Corrected group size
7 Jun 06	Turnagain	1	1								1	17
7 Jun 06	Turnagain	2	1								1	22
7 Jun 06	Susitna	4	1								1	26
8 Jun 06	Susitna	3	2							1	9	43
8 Jun 06	Susitna	6	2								2	13
11 Jun 06	Turnagain	1	1								2	7
11 Jun 06	Susitna	5	1								2	8
11 Jun 06	Susitna	6	2							1	5	181
11 Jun 06	Knik	7	1								1	15
12 Jun 06	Susitna	1	1		1				1		6	188
12 Jun 06	Turnagain	2	2							1	5	36
12 Jun 06	Turnagain	4	1								3	50
14 Jun 06	Turnagain	2	1								2	21
14 Jun 06	Turnagain	5	3								5	53
14 Jun 06	Susitna	7	3					1	1	4	18	163
14 Jun 06	Susitna	8	1	1					1		2	43
14 Jun 06	Susitna	9	2								2	31
15 Jun 06	Turnagain	2	1								1	15
15 Jun 06	Susitna	3	2								4	33
15 Jun 06	Susitna	4	1								4	51
15 Jun 06	Susitna	5	3								4	74
9 Jun 07	Knik	2	5		1			2	3	2	7	35
9 Jun 07	Turnagain	6	1								1	24
9 Jun 07	Turnagain	10	1								1	63
10 Jun 07	Susitna	2	3	1				1	2	3	9	84
10 Jun 07	Susitna	4	2								2	9
10 Jun 07	Susitna	5	2								1	54
10 Jun 07	Turnagain	6	3								6	1
10 Jun 07	Knik	7	2			1			1		3	31
10 Jun 07	Turnagain	10	2							1	3	21
10 Jun 07	Turnagain	11	3								9	42
11 Jun 07	Turnagain	4	6								7	35
11 Jun 07	Susitna	5	6			3		1	4	1	15	54
11 Jun 07	Susitna	6	5	1			1		2	1	66	223
11 Jun 07	Knik	7	1			1	1		2	1	3	40
14 Jun 07	Susitna	5	2								4	57
14 Jun 07	Susitna	6	3		1				1	2	26	177
14 Jun 07	Susitna	7	3								8	48
14 Jun 07	Susitna	8	3	1					1		6	39
15 Jun 07	Turnagain	2	1								1	9
15 Jun 07	Turnagain	3	3		1				1	2	3	5
15 Jun 07	Turnagain	4	2							1	2	15
15 Jun 07	Susitna	5	3							2	20	178
15 Jun 07	Susitna	6	1								1	17
4 Jun 08	Susitna	1	4			2	2		4	15	47	383
5 Jun 08	Turnagain	1	4				1		1	4	13	40
5 Jun 08	Susitna	2	4				1		1	2	7	77
6 Jun 08	Susitna	3	1							1	1	387
7 Jun 08	Turnagain	1	2							3	4	50
7 Jun 08	Susitna	2	2	1		1			2	8	17	313
12 Jun 08	Susitna	1	4	2					2	1	20	220
12 Jun 08	Susitna	2	5					1	1		10	64
2 Jun 09	Susitna	1	5	1		2			3	6	39	183
2 Jun 09	Susitna	2	5							3	19	90
3 Jun 09	Susitna	1	7					1	1		72	248
3 Jun 09	Turnagain	2	1								1	19
3 Jun 09	Turnagain	3	3								3	30
4 Jun 09	Susitna	1	4							5	13	87
4 Jun 09	Susitna	2	4				2		2	3	23	146
4 Jun 09	Turnagain	4	1								1	39
5 Jun 09	Turnagain	1	1								2	30
5 Jun 09	Turnagain	2	1								1	11
5 Jun 09	Susitna	4	5	2					2		29	181
1 Jun 10	Turnagain	3	2					1	1		4	51
2 Jun 10	Turnagain	1	2								7	126
2 Jun 10	Susitna	2	4	1					1		49	200
8 Jun 10	Turnagain	2	1								1	32
8 Jun 10	Susitna	3	1								1	74
8 Jun 10	Susitna	4	2								6	171
8 Jun 10	Susitna	5	1								2	69
10 Jun 10	Turnagain	2	1								1	3
10 Jun 10	Susitna	10	4								37	233
1 Jun 11	Susitna	3	2		1				1		23	271
2 Jun 11	Turnagain	1	1								5	22
2 Jun 11	Susitna	3	2		2	1			3		21	155
3 Jun 11	Turnagain	1b	2								7	77
5 Jun 11	Susitna	3	3								12	295
8 Jun 11	Turnagain	1	1								1	6
4 Jun 12	Trading Bay	2	1								5	17
4 Jun 12	Susitna	3	1								10	128
4 Jun 12	Susitna	4	1								4	173
5 Jun 12	Susitna	3	4	1	1			1	3		42	263
Totals			195	12	8	11	8	9	48	74	844	

Table 2.—Video passes reviewed for the presence of beluga whale calves in Cook Inlet, Alaska, in August 2006–12. Belugas were classified by color: adults (bright white to dull white), subadults (light gray), and calves (medium to dark gray), relative size, and surfacing behavior. Proximity codes are defined as: 1) Calf touching an adult whale; 2) Calf within one body length of an adult whale; 3) Calf 2 or 3 body lengths from an adult whale; 4) Calf >3 body lengths from an adult whale; and 5) Calf alone in field of view. For the Index 1 and Index 1–5 analyses, each whale was treated as a sample drawn at random from the population with a sample weighting of the estimated group size divided by the number of samples from the group.

				Proximity codes								
Date	Area	Group ID	Passes sampled	1	2	3	4	5	Total calves	Total subadults	Total adults	Corrected group size
16 Aug 06	Knik	1	2								1	16
16 Aug 06	Susitna	4	3	1		1		1	3	2	27	159
17 Aug 06	Turnagain	1	2							1	2	9
17 Aug 06	Susitna	5	3							4	3	61
17 Aug 06	Knik	6	2	1					1		5	127
17 Aug 06	Knik	8	1	1					1		1	44
1 Aug 07	Susitna	2	3	1					1		9	56
1 Aug 07	Susitna	4	3								20	71
1 Aug 07	Susitna	5	4	1					1		55	209
1 Aug 07	Susitna	6	1								12	143
2 Aug 07	Susitna	3	4	1	1		1		3	1	23	116
2 Aug 07	Susitna	4	5	2	1	2	6		11		26	153
12 Aug 08	Turnagain	1	3								4	80
12 Aug 08	Susitna	2	2					1	1		4	87
12 Aug 08	Knik	4	1								1	43
13 Aug 08	Turnagain	1	3								9	47
13 Aug 08	Susitna	2	4	4	5	1	2		12	3	41	143
13 Aug 08	Susitna	3	2							1	3	58
13 Aug 08	Knik	4	2								15	121
14 Aug 08	Turnagain	1	5			1			1		31	76
11 Aug 09	Susitna	1	5	1		1		1	3	3	53	206
11 Aug 09	Susitna	2	4								49	263
11 Aug 09	Knik	3	3								5	71
12 Aug 09	Susitna	1	3		1		1	1	3		18	205
12 Aug 09	Knik	2	4				1		1	6	11	100
13 Aug 09	Knik	1	4								7	47
13 Aug 09	Susitna	2	6	1			1		2	1	21	109
13 Aug 09	Susitna	3	3							1	8	20
13 Aug 09	Susitna	4	6	2	2	1	1	2	8	5	48	158
17 Aug 10	Turnagain	1	1								4	121
17 Aug 10	Susitna	6	2							1	4	76
18 Aug 10	Knik	1	2							2	2	206
18 Aug 10	Susitna	2	1								1	263
18 Aug 10	Turnagain	4	3								4	71
18 Aug 10	Turnagain	5	2								7	205
19 Aug 10	Knik	1	5							1	17	100
19 Aug 10	Susitna	2	7			1			1	2	29	47
19 Aug 10	Susitna	3	2								6	109
19 Aug 10	Turnagain	4	1								4	20
19 Aug 10	Turnagain	5	2								5	158
10 Aug 11	Knik	1	2								7	42
10 Aug 11	Susitna	2	5	1					1		37	128
10 Aug 11	Susitna	3	3	3					3		18	93
10 Aug 11	Susitna	4	4								12	55
11 Aug 11	Susitna	2	4								19	60
11 Aug 11	Susitna	3	5	1	1				2		48	163
11 Aug 11	Susitna	4	3	2					2		47	212
11 Aug 11	Knik	6	3								16	75
7 Aug 12	Susitna	1	2							1	20	231
7 Aug 12	Susitna	2	3							1	8	63
8 Aug 12	Turnagain	1	2								4	34
8 Aug 12	Susitna	2	4	1		1			2		37	186
9 Aug 12	Susitna	2	3	1					1		35	382
9 Aug 12	Knik	4	1								1	19
Totals			165	25	11	9	13	6	64	36	904	

within this area (Fig. 6). Similar to the annual averages, the proximity 1 category included the youngest calves while the other categories (excluding August proximity 5) were represented by older calves.

After 2007, belugas were no longer found in Knik Arm in June (Table 1; Fig. 3) but continued to be present in this area in August in all years but 2007 (Table 2; Fig. 3). Relative sizes of calves within this area were similar in June and August with most being smaller and thus likely young-of-the-year (Fig. 6). This suggests the Knik area may be an important nursery area. We do not know why belugas were no longer present in Knik Arm during the June survey period.

The Turnagain area has been consistently occupied in June, but whales were not present in 2009 and 2011 in August (Fig. 3). Few calves were found in the Turnagain area and almost all relative sizes were much larger than those in Knik Arm suggesting that these calves were older than a yearling in both June and August (Fig. 6).

Calf Indices

We used proximity 1 images as a proxy for young-of-the-year calves for Index 1. Proximity 1 calves were

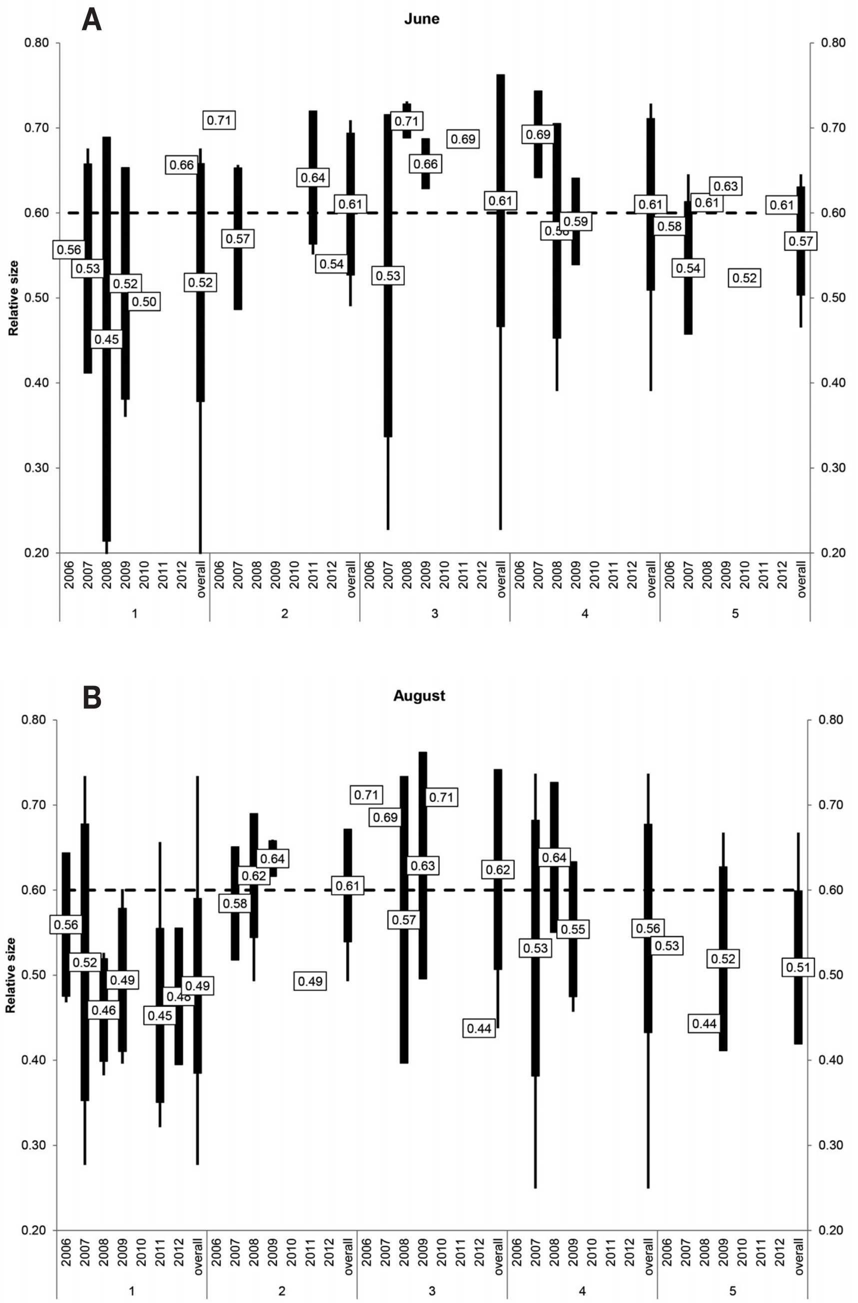


Figure 5.—Relative size for each calf proximity code per year and overall based on beluga whale video data collected during aerial surveys of Cook Inlet, Alaska, in June and August (2006–12). Bars indicate minimum and maximum ratio of calf to average adult size for the average ratio (in white box) with larger box representing +/- 1 standard deviation. Proximity codes are defined as 1) Calf touching an adult whale; 2) Calf within one body length of an adult whale; 3) Calf 2 or 3 body lengths from an adult whale; 4) Calf >3 body lengths from an adult whale; and 5) Calf alone in field of view. Estimated calf size was calculated by dividing calf pixel size by the average pixel size for all adult whales in the same counting pass. The 60% guideline (dashed line) represents maximum size of an unweaned calf.

not detected in the August 2010 or June 2011 video sample. Therefore, the probability that an animal drawn at random from the population would be a calf for those samples was estimated from the sample of adults and subadults using the empirical logistic transform. Index 1–5 included all dependent calves. Taken together, the two indices are nested, with Index 1–5 encompassing all of the young calves in Index 1.

In June, the indices were similar across years with Index 1 calves representing 0.4% to 1.5% of the population and Index 1–5 calves between 1.5% and 5.7% (Fig. 7a). The 7-yr (2006–12) average for Index 1 in June was about 1.2% (SD = 0.5%). The consistent low numbers for Index 1 suggest that the young-of-the-year calves, which by June would be 10–12 months old, no longer maintained close contact with the mother and instead behaved more like yearlings and older calves.

August was significantly different from June (Fig. 7b). In August 2006, young-of-the-year calves made up 12% of the population (Index 1) and both indices were fairly close, suggesting that it was a relatively good year for new calves (Fig. 7b). This large percentage of calves in 2006 would be encouraging for the health of the population and could be a highly sustainable level if it occurred in all years. The 7-yr (2006–12) average was 3.3% (SD = 3.8%). However, rates from 2007 to 2012 were between 0.5% and 3.5%, with a 6-yr average of 1.9%. With the inclusion of the large number of calves from the 2006 season, the probability of occurrence of Index 1–5 does not decline as quickly as Index 1 (Fig. 7b). Instead the decline occurred over 4 yr suggesting that Index 1–5 included calves up to 3 years of age.

Comparing June and August, we would expect both Index 1 and 1–5 for June 2007 to reflect the large number of young-of-the-year calves in August 2006. While Index 1–5 in June 2007 is the largest for the time series at about 6% of the population (Fig. 7a), no large increases or declines occurred

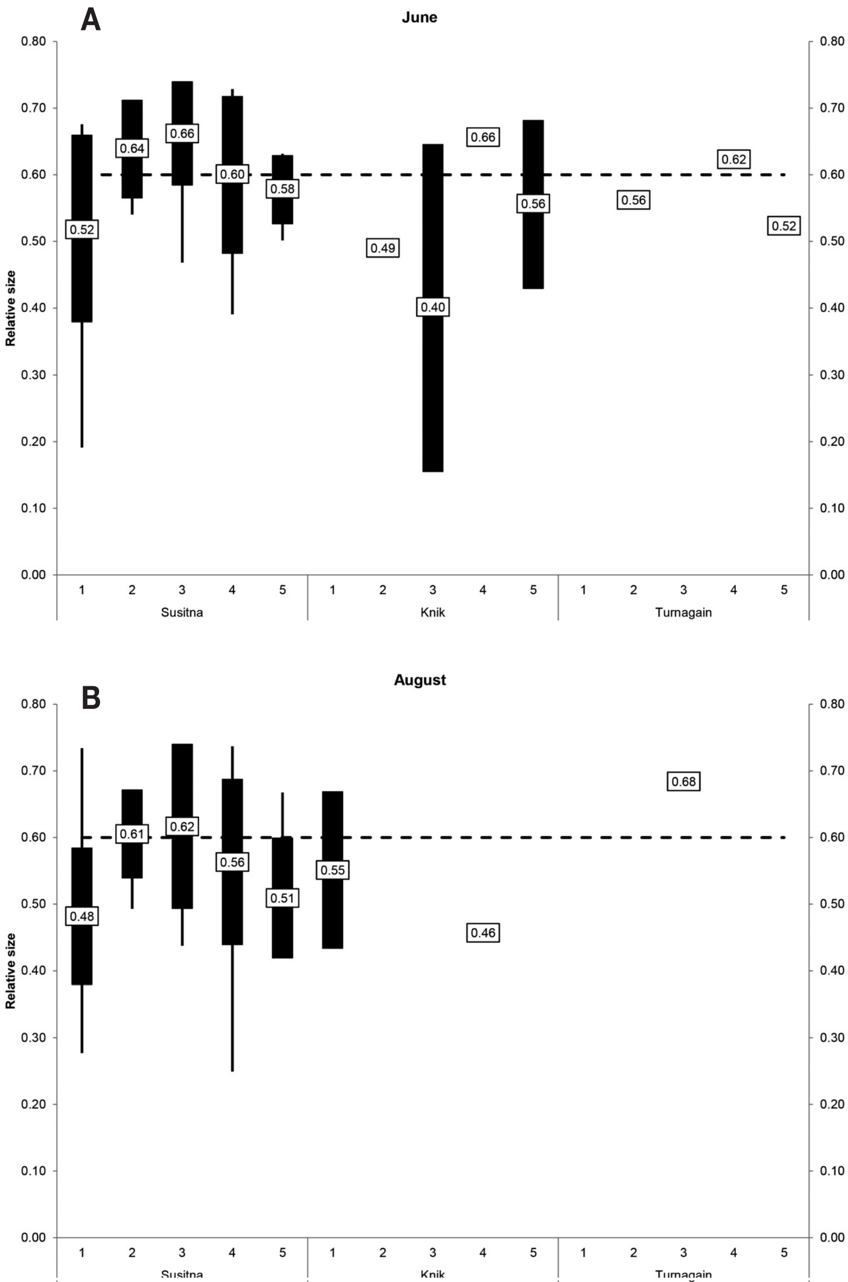


Figure 6.—Relative size for each calf proximity code per area (Susitna, Knik, and Turnagain) based on beluga whale video data collected during aerial surveys of Cook Inlet, Alaska, in June and August (2006–12). Bars indicate minimum and maximum ratio of calf to average adult size for the average ratio (in white box) with larger box representing +/- 1 standard deviation. Proximity codes are defined as 1) Calf touching an adult whale; 2) Calf within one body length of an adult whale; 3) Calf 2 or 3 body lengths from an adult whale; 4) Calf >3 body lengths from an adult whale; and 5) Calf alone in field of view. Estimated calf size was calculated by dividing calf pixel size by the average pixel size for all adult whales in the same counting pass. The 60% guideline (dashed line) represents maximum size of an unweaned calf. Note: belugas were not found in the Knik area in June after 2007, but were found there in August in all years but 2007. Belugas were not found in the Turnagain area in August in 2009 and 2011. Not shown: belugas in Trading Bay in June of 2012 (the sample of 5 whale images did not include calves or subadults).

in subsequent years as occurred in August. Also, the low percentage in August 2010 was not reflected in either of the June 2011 indices. Therefore, a retrospective analysis of video data from earlier June surveys (1995–2005) would not be useful for estimating a calf index given this lack of correspondence between August and the following June.

With its 95% confidence interval, Index 1 demonstrates that the sampling effort has been sufficient to show a difference between a good calving year (2006) and poor years (2007–12) (Fig. 7b). Although Index 1–5 shows significant differences between years, it is less certain what fraction of young animals this index represents. For example, when whale groups are very dense, calves and young juveniles are more likely to appear in the same video frame with an unassociated adult by chance.

Examining the indices as a function of area within Cook Inlet, it appears that Knik Arm is the preferred location for young-of-the-year calves in both June and August, with more than twice the likelihood that an animal is a young-of-the-year calf in Knik area than in the Susitna area, and an even lower probability of finding a calf in the Turnagain area (Fig. 8).

The probability of finding older calves was far greater in Knik Arm in June than in the other areas (Fig. 8a) despite the lack of beluga groups in this area since 2007. The high value of Index 1–5 in Knik Arm (0.247) was likely the result of the large number of calves in August 2006. In August, Index 1–5 indicates that older calves were found in both the Susitna and Knik areas, with percentages being similar in the two areas (Fig. 8b). The Turnagain area had a very low probability of Index 1–5 sightings in both months, but the sample size was sufficient to show that the probability of calves being sampled in a group was significantly less than either of the other two areas (Fig. 8).

The 7-yr average per capita calving rate in August, assuming that Index 1 is unbiased, was 3.5% (SD = 4.3%).

With this average per capita birth rate, the average annual mortality would have to be less than 3.5% for the population to increase (Fig. 9). We do not have a good measure of mortality rate for CIBWs, a minimum value of 2% (SD = 1.2%) for the period 2006–12 can be estimated from the number of carcasses discovered each year (which was likely an underreporting of total mortalities given the difficulty of detecting carcasses in Cook Inlet). When the 6-yr period following 2006 (2007–12) was considered, the average per capita birth rate was 1.9% (SD = 1.1%, 2007–12)) compared to a minimum mortality rate of 1.9% (SD = 1.2%, 2007–12). This suggests that the birth rate was probably at or below the replacement level in those years.

Although the biases in the indices have not been estimated, the range indicates that birth rates per adult female were probably low in most years and the average of the estimated per capita birth rates for the years 2007–12 was about 15% of the level in 2006. If we assume that adult females make up about 30% of the population and that the index was unbiased, then 44% of adult females gave birth in 2006, and in an average year (2006–12), 12% gave birth which was one-third the maximum rate estimated for other Alaska beluga populations (Burns and Seaman[19]). In Cook Inlet, it was likely that the birth rate per adult female was lower than the maximum rate but this cannot be confirmed until we have an estimate of percent mature females within this population.

Conclusions

It is well documented that beluga calves remain in close proximity to their mothers and in the first few months in direct contact with their mothers at least 90% of the time (Krasnova et al., 2006; Suydam, 2009). After the first year, older calves break

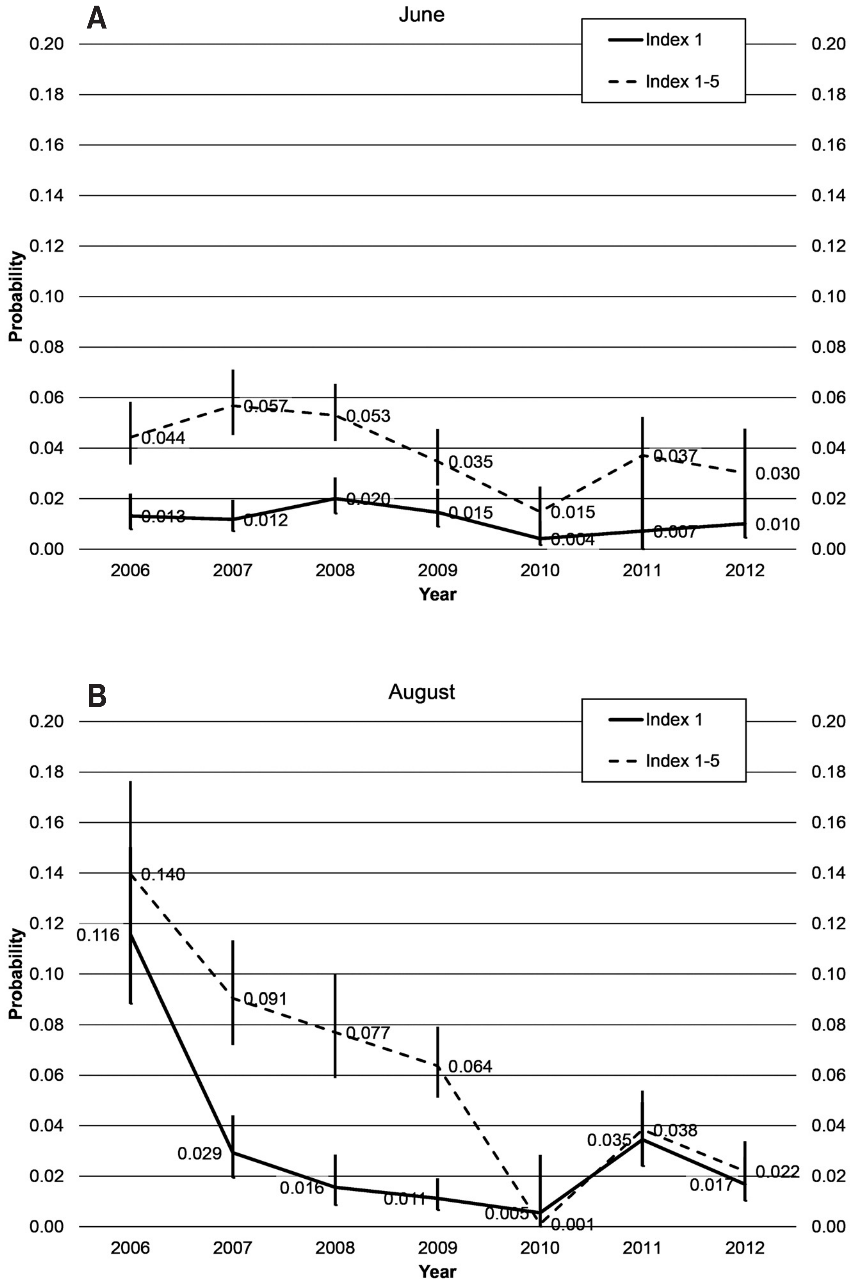


Figure 7.—Probability that a beluga whale drawn at random from the Cook Inlet population would be a calf in June and August for each study year (2006–12). Index 1 includes proximity 1 calves only and represents primarily young-of-the-year. Index 1–5 includes all proximity codes representing juvenile recruitment. Note: Proximity 1 calves were not detected in the August 2010 or June 2011 video sample.

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

from this close contact but remain near their mothers. This change in behavior after one year of age, allowed us to conclude that Index 1 (calves touching an adult) corresponded closely to the number of calves that were born in the respective year, while Index 1–5 was less well defined and probably represented young-of-the-year, yearlings, and unweaned older calves.

Calves found in our data were consistent with the assumption of a summer birthing period in Cook Inlet. Treating Index 1 as a reliable indication of calving rates, we concluded that more calves were produced in 2006 than in subsequent years. The high calving rate in 2006 may be reflected in lower rates in 2007 and 2008, if we assume many mature females had dependent calves and were not ready to begin a new pregnancy (Brodie, 1971; Sergeant, 1973; Seaman and Burns, 1981). However, 2006's higher calving year does not explain continued low calving rates in subsequent years (i.e., 2009–12) when it could be assumed the same mature female cohort would calve again.

Comparing the two indices, they were very close in 2006 suggesting that the previous years (2004 and 2005) may have been poor, so that the 2006 cohort represented the majority of the young age classes. The indices were again close in 2010 and remained so in 2011 and 2012, after poor reproduction years following 2006. This provided further support to the idea that poor reproductive years occurred prior to 2006.

The poor correspondence between June and the previous August indicated that the June video results from earlier years (1995–2005) would not be useful for estimating calving rates. The high Index 1–5 value for Knik Arm (i.e., almost one-quarter of belugas were calves), resulting from the high calving rate in August 2006, suggests that the Knik area may be an important rearing ground in June, and that the presence of belugas in June may be indicative of high calving rates in the previous years. However, the lack of belugas after 2007 in the Knik

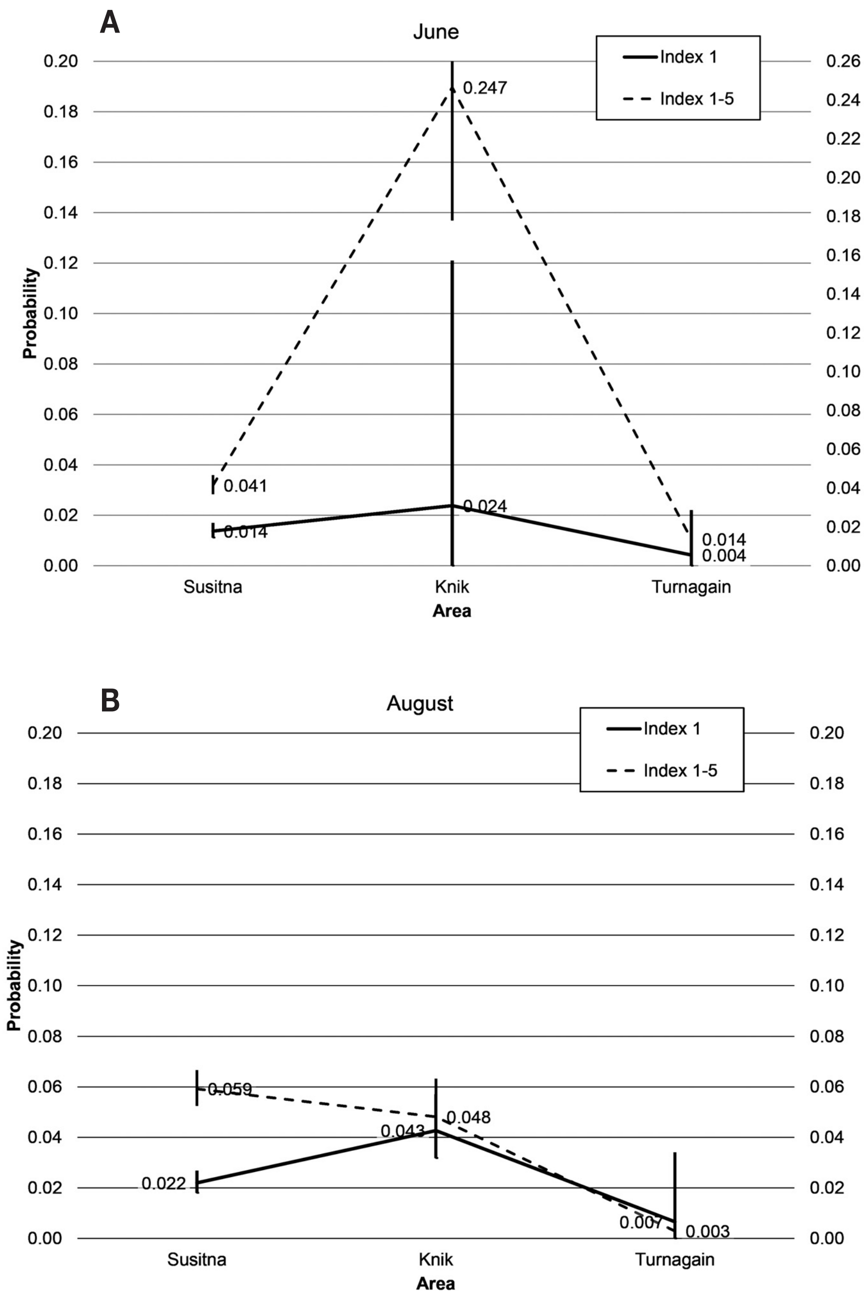


Figure 8.—Probability that a beluga whale drawn at random from the Cook Inlet population would be a calf in June and August for each area (Susitna, Knik, and Turnagain) during the study period (2006–12). Index 1 includes proximity 1 calves only and represents primarily young-of-the-year. Index 1–5 includes all proximity codes representing juvenile recruitment (this index is represented by the secondary axis, which in June is slightly larger than August to accommodate the Knik results). Note: Proximity 1 calves were not detected in Turnagain in August and June, and Knik in June.

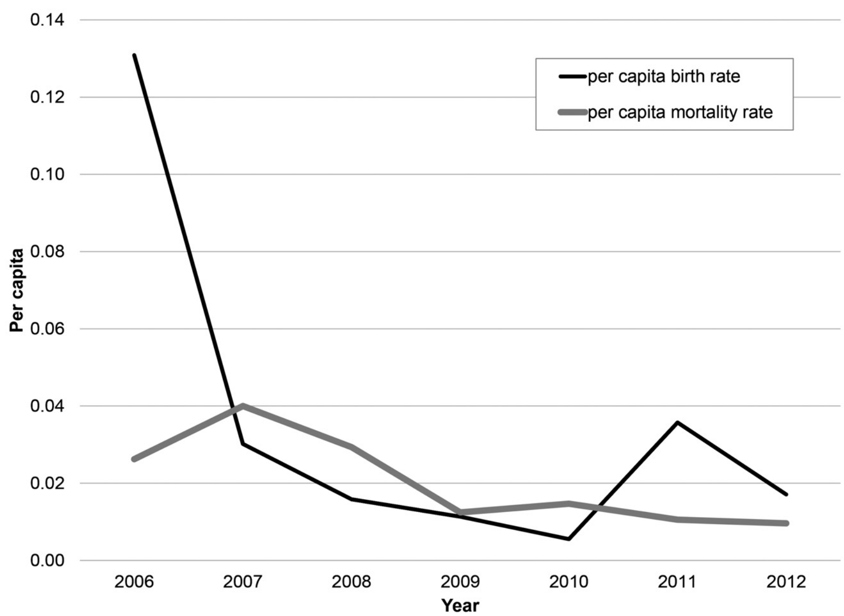


Figure 9.—Per capita birth rate in August compared to the estimated annual per capita mortality rate for the Cook Inlet beluga whale population (2006–12).

area in June may also reflect a change in habitat features in those years unrelated to the number of calves.

While these two indices can be used to monitor the trend in relative number of calves, several key issues remain to be resolved before an estimate of the calving rate of mature females in the population can occur:

1) Surfacing frequency of calves. Young calves are inefficient swimmers compared to adults and will surface much more frequently than an adult. Young-of-the-year calves are nearly always accompanied by an adult (Suydam, 2009). A calf in echelon position with an adult will surface and breathe when the adult surfaces. However, adults accompanying a calf have been observed to bring the calf to the surface without surfacing themselves (Krasnova et al., 2006). Both the increased frequency of surfacing and the appearance of calves surfacing on their own confounds the possibility of an unbiased estimate of calves in the population.
2) Verification of relative image size assumption. We have assumed that the measure of size of the visible portion of the beluga is a constant fraction of the total length and the relative image sizes represent proportional sizes of belugas. The high particulate loads in the waters of Cook Inlet preclude the collection of images of the entire length of each animal, and the current practice of collecting video at an oblique angle further increases the variability in relative size.
3) Unknown fraction of the population that represents mature females. These indices are proportional to the entire population. As the population changes in size, and the age structure recovers from effects of high levels of removals, we expect that the fraction of mature females will change.

Until these issues are resolved, the results presented here represent an index proportional to the per capita calving rate that is suitable for trend analysis only. The current trend from 2007–12, suggests that the birth rate was probably at or below the replacement level.

While the survey effort presented here was sufficient to determine the relative success of calving from year to year, we propose that further work be done to resolve the uncertainties listed above. To address issue 1, we propose attaching time-depth recorders to mothers and their calves for short periods of a few hours to collect surfacing data. For issue 2, we propose surveying a similar population of beluga whales, such as those in Bristol Bay, that occupy waters somewhat less turbid than Cook Inlet, in order to measure full body lengths. To address issue 3, we propose annual biopsy surveys in conjunction with photo-identification surveys to determine the fraction of pregnant females. Finally, with the poor correspondence between August and the following June, we are not constrained by the need to collect comparable data. Therefore, we plan to change the August protocol to collect video beneath the aircraft (vertical rather than oblique) to improve the relative image size measurements.

Understanding calving rates is an important piece of information for the future recovery of this population. Changes in abundance result from the difference between mortality and reproduction from year to year; however, the difference between a good year for calves and a poor year was only a small percent change in the population estimate and less than the statistical error in the estimate. Our ability to estimate the reproductive rate directly gives us a measure that can be compared to environmental data to identify the conditions that promote calving. Calving rates varied more than 10 times between the highest year (2006) and the lowest (2010) and understanding the mechanisms driving this wide variation will be key to developing a successful recovery plan for this population.

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Literature Cited

Béland, P., A. Vézina and D. Martineau. 1988. Potential for growth of the St. Lawrence (Québec, Canada) beluga whale (*Delphinapterus leucas*) population based on modelling. J. Cons. Int. Explor. Mer. 45:22–32.

__________, A. Faucher, and P. Corbeil. 1990. Observation on the birth of a beluga whale (*Delphinapterus leucas*) in the St. Lawrence estuary, Québec, Canada. Can. J. Zool. 68:1327-1329. (doi: 10.1139/z90-198).

__________, S. D. Guise, and R. Plante. 1992. Toxicologie et pathologie des mammifères marins du Saint-Laurent. Fonds pour la toxicologie faunique du Fonds mondial pour la nature, Toronto, 99 p.

Brodie, P. F. 1971. A reconsideration of aspects of growth, reproduction, and behavior of the white whale (*Delphinapterus leucas*), with reference to the Cumberland Sound, Baffin Island, population. J. Fish. Res. Board Can. 28:1309– 1318. (doi: 10.1139/f71-198).

Cox, D. R., and E. J. Snell. 1989. *Analysis of binary data.* Chapman and Hall, Lond., 236 p.

DFO. 2012. Recovery strategy for the beluga whale (*Delphinapterus leucas*) St. Lawrence Estuary population in Canada. Species at Risk Act, Recov. Strat. Ser. Fish. Oceans Canada, Ottawa, 88 p.

_______. 2014. Status of beluga (*Delphinapterus leucas*) in the St. Lawrence River Estuary. Can. Sci. Advis. Sec., Sci. Advis. Rep. 2013/076, 17 p.

Hobbs, R. C., J. M. Waite, and D. J. Rugh. 2000. Beluga, *Delphinapterus leucas*, group sizes in Cook Inlet, Alaska, based on observer counts and aerial video. Mar. Fish. Rev. 62(3):46–59.

___________, K. E. W. Shelden, D. J. Rugh, C. L. Sims, and J. M. Waite. 2015. Estimated abundance and trend in aerial counts of beluga whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994–2012. Mar. Fish. Rev. 77(1):11–31. (doi: 10.7755/MFR.77.1.2).

Huntington, H. P. 2000. Traditional knowledge of the ecology of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):134–140.

Krasnova, V. V., V. M. Bel'kovich, and A. D. Chernetsky. 2006. Mother-infant spatial relations in wild beluga (*Delphinapterus leucas*) during postnatal development under natural conditions. Biol. Bull. 33(1):53–58. (doi: 10.1134/S1062359006010079).

Laidre, K. L., K. E. W. Shelden, D. J. Rugh, and B. A. Mahoney. 2000. Beluga, *Delphinapterus leucas*, distribution and survey effort in the Gulf of Alaska. Mar. Fish. Rev. 62(3): 27–36.

Litzky, L. K. 2001. Monitoring recovery status and age structure of Cook Inlet, Alaska belugas by skin color determination. M.S. thesis, Univ. Wash., Seattle, 76 p.

Matthews, C. J. D., and S. H. Ferguson. 2015. Weaning age variation in beluga whales (*Delphinapterus leucas*). J. Mammal. 96(2):425–437. (doi: 10.1093/jmammal/gyv046).

McCullagh P., and J. A. Nelder. 1989. *Generalized linear models.* Chapman and Hall, Lond., 532 p.

NOAA. 2000. Designating the Cook Inlet, Alaska, stock of beluga whale as depleted under the Marine Mammal Protection Act (MMPA). 65 Fed. Regist. 34590 (31 May 2000), p. 34,590–34,597 (avail. online at https://federalregister.gov/a/00-13371).

__________. 2008. Endangered and threatened species; endangered status for the Cook Inlet beluga whale. 73 Fed. Regist. 62919 (22 Oct. 2008), p. 62,919–62,930 (avail. online at https://federalregister.gov/a/E8-25100).

O'Corry-Crowe, G. M., R. S. Suydam, A. Rosenberg, K. J. Frost, and A. E. Dizon. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. Mol. Ecol. 6:955–970. (doi: 10.1046/j.1365-294X.1997.00267.x).

Rugh, D. J., K. E. W. Shelden, and B. A. Mahoney. 2000. Distribution of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, during June/July, 1993–2000. Mar. Fish. Rev. 62(3):6–21.

Rugh, D. J., K. E. W. Shelden, C. L. Sims, B. A. Mahoney, B. K. Smith, L. K. Litzky, and R. C. Hobbs. 2005. Aerial surveys of belugas in Cook Inlet, Alaska, June 2001, 2002, 2003, and 2004. U. S. Dep. Commer., NOAA Tech Memo. NMFS-AFSC-149, 71 p.

__________, __________, and R. C. Hobbs. 2010. Range contraction in a beluga whale population. End. Species Res. 12:69–75. (doi: 10.3354/esr00293).

Seaman, G. A., and J. J. Burns. 1981. Preliminary results of recent studies of belukhas in Alaskan waters. Rep. Int. Whal. Comm. 31:567–574.

Sergeant, D. E. 1973. Biology of white whales (*Delphinapterus leucas*) in western Hudson Bay. J. Fish. Res. Board Can. 30:1065–1090. (doi: 10.1139/f73-178).

Shelden, K. E. W., D. J. Rugh, K. T. Goetz, C. L. Sims, L. Vate Brattström, J. A. Mocklin, B. A. Mahoney, B. K. Smith, and R. C. Hobbs. 2013. Aerial surveys of beluga whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, June 2005 to 2012. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-263, 122 p.

____________, K. T. Goetz, D. J. Rugh, D. G. Calkins, B. A. Mahoney, and R. C. Hobbs. 2015. Spatio-temporal changes in beluga whale, *Delphinapterus leucas*, distribution: Results from aerial surveys (1977–2014), opportunistic sightings (1975–2014), and satellite tagging (1999–2003) in Cook Inlet, Alaska. Mar. Fish. Rev. 77(2):1–31. (doi: 10.7755/MFR.77.2.1).

Suydam, R. S. 2009. Age, growth, reproduction, and movements of beluga whales (*Delphinapterus leucas*) from the eastern Chukchi Sea. Ph.D. dissert., Univ. Wash., Seattle, 169 p.