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Marine Mammal Laboratory
Cetacean Assessment and Ecology Program

Aerial Surveys, Distribution, Abundance, and Trend of Belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2018

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Aerial Surveys, Distribution, Abundance, and Trend of Belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2018

K. E. W. Shelden and P. R. Wade (editors)

December 2019

EXTENDED ABSTRACT

The National Marine Fisheries Service (NMFS) has conducted aerial surveys to estimate abundance of the beluga population in Cook Inlet, Alaska, each June, July, or both from 1993 to 2012, after which biennial surveys began in 2014. The current document presents survey results and subsequent analyses yielding an abundance estimate and population trend based on data collected during June 2018.

Chapter 1: Field Report Summary

Surveys occurred 5 – 15 June 2018 (42.9 flight hours). For the 2018 season, Distance Sampling and Strip Transect experiments were conducted in addition to the abundance surveys. All surveys were flown in twin-engine, high-wing aircraft (i.e., an Aero Commander 690) at a target altitude of 244 m (800 ft) and speed of 185 km/hour (100 knots), consistent with NMFS' surveys of Cook Inlet conducted in previous years. A reconnaissance aircraft (Cessna 180) surveyed Knik Arm and Turnagain Arm during the Distance Sampling experiment to document beluga groups not within the experiment zones (Chickaloon Bay and Susitna Delta) (6.5 flight hours).

The coastal survey track was positioned approximately 1 km offshore and included the entire Cook Inlet coast north of Ursus Cove and English Bay. We did not survey Kamishak Bay, Augustine Island, Kalgin Island, and Elizabeth Island as in previous years to allow additional time for sampling experiments in the upper inlet. Additionally, tracklines were flown across the middle of the inlet, and in the Susitna and Chickaloon regions during distance sampling experiments. These aerial surveys effectively covered 50% of the total surface area of Cook Inlet. In particular, most of the upper inlet north of Moose Point and the McArthur River in Trading Bay, where belugas are consistently found, was surveyed on 7 of 11 days. Paired, independent observers searched on the coastal side of the plane, where most beluga sightings occur, while a single observer searched on the inlet side. A computer operator/data recorder periodically monitored distance from the shoreline

(1 km) with a clinometer (angle 14°). After finding beluga groups, a series of aerial passes allowed all observers to each make independent counts of every group. In addition, whale groups were video recorded for later analysis and more precise counts in the laboratory.

Belugas were not seen in lower Cook Inlet (south of East and West Foreland) nor in the upper inlet south of Moose Point and the McArthur River. Half of the survey period occurred during negative low tides, which expose vast expanses of mudflats and typically line up whales within the deeper channels. Beluga groups were found between the McArthur River and North Foreland in Trading Bay, from the Native Village of Tyonek to the Little Susitna River in the Susitna Delta, from Moose Point to Point Possession, from Burnt Island to the bluffs approaching Point Possession in Chickaloon Bay, and in Turnagain Arm. The annual sums of medians from aerial counts provide an index of relative abundance, not corrected for estimates of whales missed. Daily overall observer count medians on days with complete coverage of the upper inlet ranged from 113 to 194 whales. The annual median index count of 194 whales fell within the range of median counts collected to date for this project.

The summer contraction in range first documented in Rugh et al. (2010) has persisted. Since 2008, on average 81% of the total population occupied the Susitna Delta in early June during the aerial survey period, compared to roughly 50% in the past (1978-79, 1993-97, 1998-2008). The 2009-18 range was estimated to be only 29% of the range observed in 1978-79, similar to the 2009-16 range (Shelden et al. 2017) and a slight increase from the 2009-14 range of 25% presented in Shelden et al. (2015).

Chapter 2: Abundance and Trend Summary

A new method to estimate group size in the analysis of abundance and trends for Cook Inlet belugas was developed by Boyd et al. (2019) and replaces the method developed by Hobbs et al. (2000, 2015), with several important differences. It is now a fully Bayesian analysis so that the uncertainty in correction factors is fully incorporated. The visibility bias correction parameters (availability, perception, proximity) are now estimated for each video pass of a group assuming the true group size is the same for each pass (previously this important assumption was not included). The mean dive time for a group, used in calculating availability bias (probability of being at the surface) is now specified as a broad distribution, rather than a single fixed value. The perception bias correction is now a two-step approach incorporating a full estimation of two distributions: detection probability as a function of image size, and the distribution of image sizes for all individuals in a group. The revised methodology has been applied to the time-series from 2004 to 2018, with 2004 being the year that the computer-aided system, "Beluga Dots", was introduced, along with some survey changes. It is not possible to revise the time-series prior to 2004 as the earlier analyses relied on splitting the upper inlet into sectors and usually only one day included a complete survey of the upper inlet coastline north of East and West Foreland.

The new method makes some estimates of group size smaller and some larger compared to the Hobbs et al. (2000, 2015) method when applied to all groups recorded during the period 2004-2016. In particular, there are large changes in group-size estimates for the largest groups, and these changes also go in both directions (i.e., greater numbers using the older method versus the new method, and vice versa). To isolate the effect of just the change in group-size estimation, we compared the trend for the period 2004-2018 using the old method to the new, but using the exact same selection of days and method for calculating an annual abundance estimate. The trend in both cases is similar, with an initial increase, and then a decline. Using the older method, the decline is not as great primarily because the 2016 estimate is higher, and there is no 2018 estimate using this older method.

In addition to the new group-size estimation method, we control for possible strong positive and negative outliers on single days. Strong negative outliers (days with very low abundance) can potentially happen when some groups are not seen. Strong positive outliers (days with very high abundance) can potentially happen when the whales occur in one or more very large groups, and the video group size estimation process becomes difficult. Previously, the annual estimate of abundance was calculated as the average of three or more days with the highest estimate of abundance excluding a day's estimate if it was less than ~60% of the highest day. Now, we calculate the annual abundance as the median of all the daily abundance estimates, using all days with an acceptable survey. Using the median lessens the influence of strong positive and negative outliers. What represents an acceptable survey is defined objectively by weather/sighting conditions and spatial coverage. Nonetheless, the declining trend from 2008 to 2018 is not sensitive to the method used to convert the daily estimates from a survey into an estimate for the year, the message of a declining trend since 2010 is the same. Over the last 10 years (2008-2018), the estimated trend in the population is a decline of -2.3%/year (95% PI -4.0% to -0.1%). This is a substantially different result than reported previously. The revised time-series now shows a clear pattern in the trend in abundance; the data indicate the population was initially increasing but then started declining after 2010. Reasons for this change in the pattern of the trend, and potential analytical concerns, are discussed in detail within Chapter 2.

NOAA's Guidelines for Marine Mammal Stock Assessments (GAMMS) specifies that abundance estimates within the last 8 years can be used for estimating abundance. Using more than a single estimate of abundance has the advantages that the number will be more stable from year to year, and will be more precise. Model-based abundance procedures using multiple abundance estimates over years are already being used in several stock assessment reports (e.g., California fin whales and beaked whales). We now recommend using a weighted moving average, with a window size of 5 (2 steps back, 2 steps forward), and exponential weights (where the weight decreases by 0.5 each time step). Note that for the most recent estimate (currently 2018), the smoothed estimate is therefore a weighted average of the last three estimates, with weights of 1.0 (2018), 0.5 (2016), and 0.25 (2014). That provides a good compromise of having the most recent data have the most influence, but providing some stability and smoothing from the previous two estimates. We present that as the "Best estimate" of abundance, to distinguish it from the "Point estimate" of abundance calculated just from the survey data from that year. The annual point estimate of abundance for 2018, based on the median of all acceptable daily estimates in 2018, is 269 (95% probability interval 227 to 333). The best estimate of 2018 abundance for the

Cook Inlet beluga population from the aerial survey data is 279 (95% probability interval 250 to 317). This is based on the estimate of smoothed abundance for 2018.

CONTENTS

CHAPTER 1

Field Report for the June 2018 Cook Inlet Beluga Aerial Abundance and Distribution Survey

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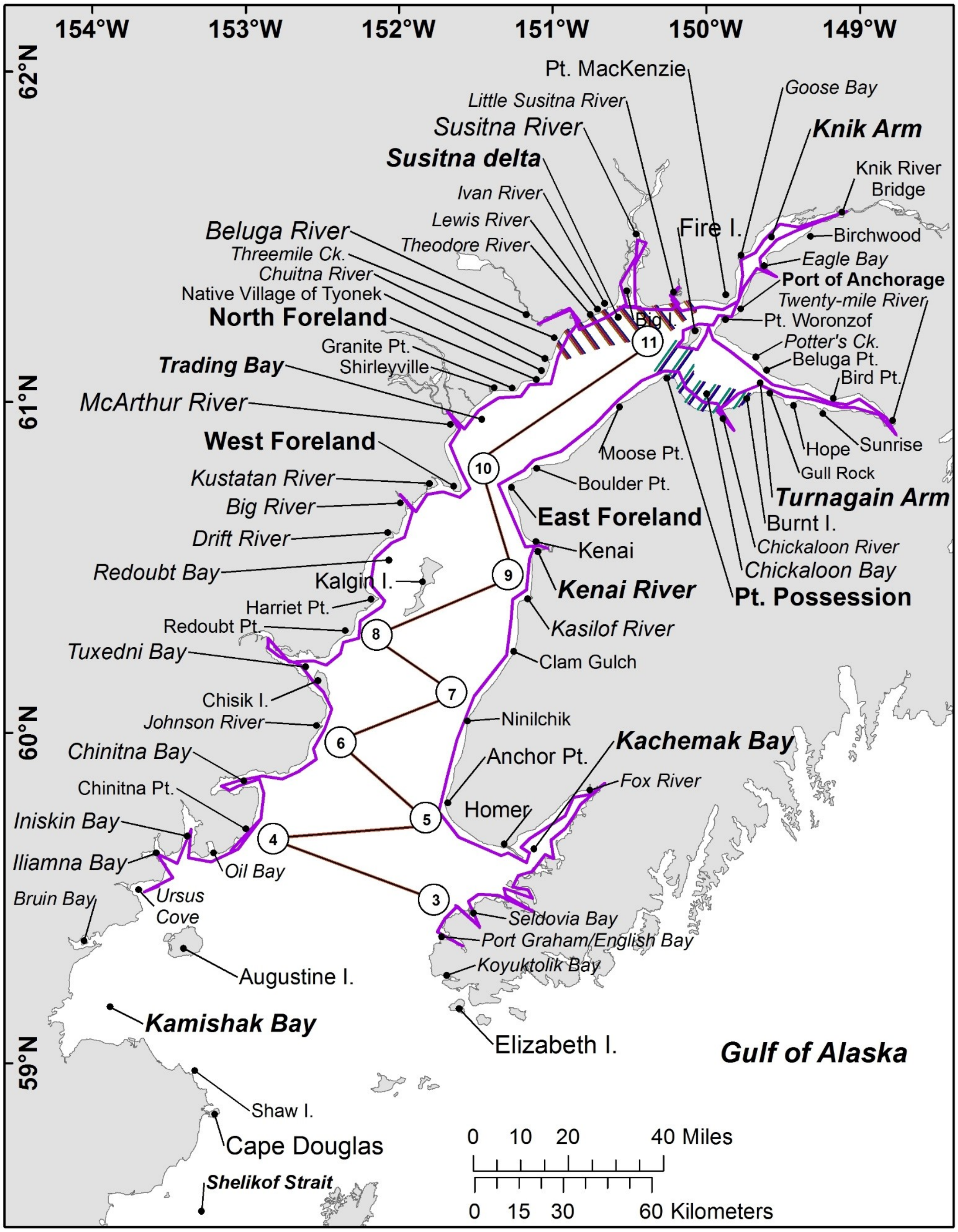
INTRODUCTION

Belugas (*Delphinapterus leucas*) inhabit waters surrounding Alaska from Yakutat Bay to the Alaska/Yukon Territory boundary (Hazard 1988). Five stocks are recognized in this region: Cook Inlet, Bristol Bay, Eastern Bering Sea, Eastern Chukchi Sea, and Beaufort Sea (O'Corry-Crowe et al. 1997, Allen and Angliss 2013). The most isolated of these is the Cook Inlet stock, separated from the others by the Alaska Peninsula (Laidre et al. 2000). Belugas in Cook Inlet (hereafter CIBs) gather in river mouths and bays during the summer months (Rugh et al. 2000a, 2005a, 2010). The small population size (fewer than 400 whales; Hobbs et al. 2000a, 2015) and geographic and genetic isolation of the whales in Cook Inlet (O'Corry-Crowe et al. 1997, Laidre et al. 2000, Rugh et al. 2000a), in combination with their strong site fidelity, has made this stock vulnerable to anthropogenic impacts. Until 1999, these whales were subject to an unregulated Native subsistence hunt (Mahoney and Shelden 2000), but on 31 May 2000, the stock of CIBs was designated as depleted under the U.S. Marine Mammal Protection Act (65 Fed. Reg. 34590) and is now managed with a small, regulated, subsistence hunt by Alaska Natives (65 Fed. Reg. 59164). The current co-management harvest plan establishes a 5-year harvest level based on the average abundance during the previous 5-year period and the population growth rate during the previous 10-year period. A harvest is not allowed if the previous 5-year average abundance is less than 350 beluga whales which has been the case since the first review period (2003-2007), and the harvest has been zero since 2005. The CIB population was designated a Distinct Population Segment and listed as endangered under the U.S. Endangered Species Act (73 Fed. Reg. 62919) in October 2008.

Each June, July, or both from 1993 to 2012, the National Marine Fisheries Service (NMFS) conducted annual aerial surveys to study the distribution and abundance of CIBs (Withrow et al. 1994, Rugh et al. 1995, 1996, 1997a, 1997b, 1999, 2000a, 2001, 2002, 2003, 2004; 2005a, 2006, 2007, Shelden et al. 2008, 2009, 2010, 2011, 2012). Results from 1993 to 2000, 2001 to 2004, and 2005 to 2012 were published in Rugh et al. (2000b, 2005b) and Shelden et al. (2013), respectively. After 2012, NMFS adopted a biennial survey schedule (Hobbs 2013) resuming abundance estimates with the June 2014 survey (Shelden et al. 2015a). Surveys were conducted in cooperation with the Cook Inlet Marine Mammal Council (CIMMC) and the Alaska Beluga Whale Commission (ABWC). Aerial surveys have proven to be an efficient method for collecting distribution and abundance data for CIBs and were used sporadically (e.g., Klinkhart 1966, Murray and Fay 1979, Calkins 1984, Shelden and Mahoney 2016) prior to the start of the annual NMFS surveys, though no complete systematic census had been conducted until 1993. The NMFS studies have been the most thorough and intensive in terms of coverage and effort (Shelden et al. 2015b). The primary objectives for the current study were to document sighting locations and count CIBs while maintaining continuity with preceding studies to allow for inter-year trend analyses. This document presents data collected in June 2018, the third year of surveys after adopting a biennial survey schedule for this project (Hobbs 2013).

Study Area

Cook Inlet is a major inland sea in south-central Alaska covering approximately 20,000 km^2 (Fig. 1). The southern boundary, which opens to the Gulf of Alaska, is approximately 85 km across from Cape Douglas to Elizabeth Island. The northern limit, at the Susitna River, is 315 km north of Cape Douglas. From there two substantial tidal estuaries extend to the northeast (Knik Arm, roughly 55 km long) and southeast (Turnagain Arm, 75 km long). The shoreline of Cook Inlet (1,810 km) is highly irregular and interrupted by many rivers and creeks, which contribute considerable freshwater input and glacial melt into the inlet. Detritus from glacial erosion and strong tidal fluxes keep the waters of upper Cook Inlet (north of East Foreland and West Foreland) extremely turbid and nearly opaque with silt. A description of beluga habitat in Cook Inlet can be found in Moore et al. (2000) and Goetz et al. (2007, 2012a). Anchorage, the largest city in Alaska, served as the base of operations for these aerial surveys.


154°W
153°W
152°W
151°W
150°W
149°W
62°N
61°N
60°N
59°N
Pt. MacKenzie
Goose Bay
Little Susitna River
Susitna River
Knik Arm
Susitna delta
Knik River Bridge
Ivan River
Lewis River
Theodore River
Fire I.
Birchwood
Beluga River
Threemile Ck.
Eagle Bay
Chuitna River
Port of Anchorage
Native Village of Tyonek
Twenty-mile River
North Foreland
Big
Pt. Woronzof
Granite Pt.
Potter's Ck.
Shirleyville
Beluga Pt.
Trading Bay
Bird Pt.
McArthur River
West Foreland
Moose Pt.
Hope
Sunrise
Kustatan River
Boulder Pt.
Gull Rock
Big River
Turnagain Arm
East Foreland
Burnt I.
Drift River
Kenai
Chickaloon River
Redoubt Bay
Kalgin I.
Chickaloon Bay
Kenai River
Pt. Possession
Harriet Pt.
Kasilof River
Redoubt Pt.
Tuxedni Bay
Clam Gulch
Chisik I.
Ninilchik
Johnson River
Kachemak Bay
Chinitna Bay
Anchor Pt.
Fox River
Chinitna Pt.
Homer
Iniskin Bay
Iliamna Bay
Oil Bay
Bruin Bay
Ursus Cove
Seldovia Bay
Port Graham/English Bay
Koyuktolik Bay
Augustine I.
Kamishak Bay
Elizabeth I.
Gulf of Alaska
Shaw I.
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0 10 20 40 Miles
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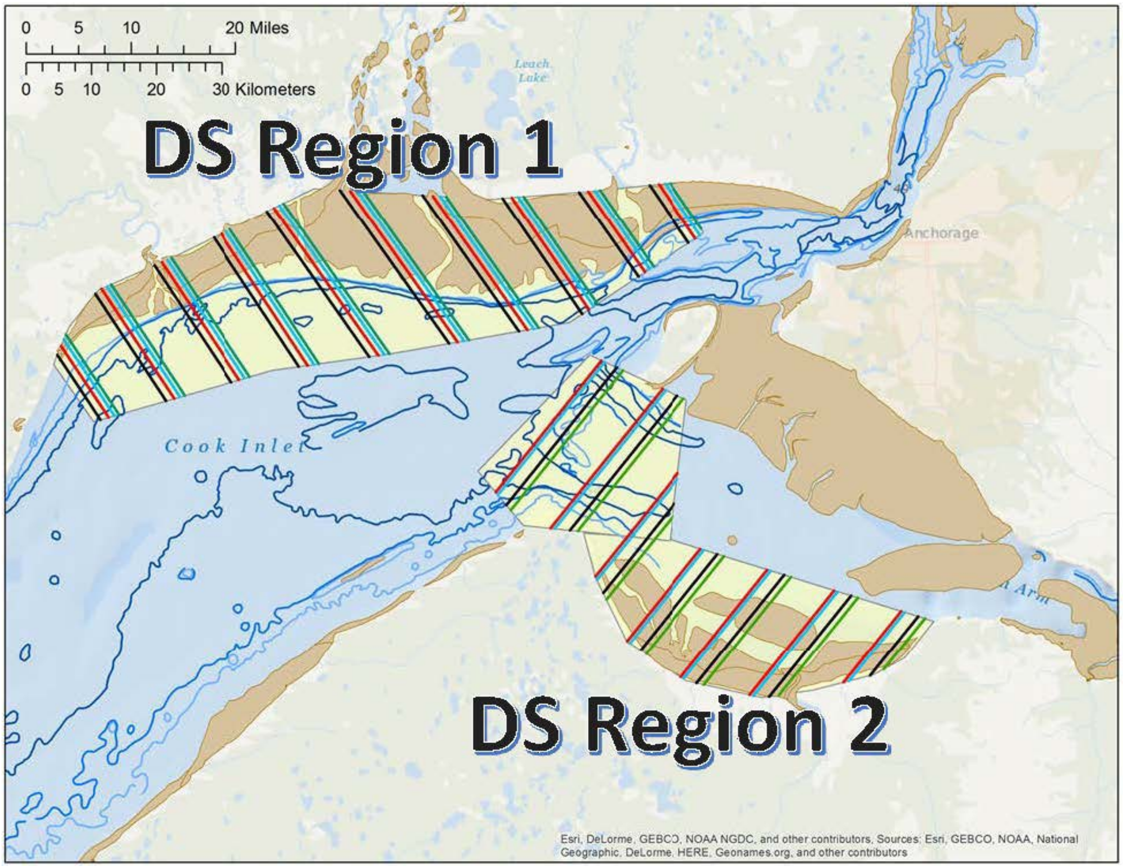

Figure 1. -- Cook Inlet, Alaska, with place names mentioned in text, and mid-inlet sawtooth tracklines with waypoints (numbers) proposed during beluga surveys in June 2018 (upper panel). Lower panel shows enlargement of distance sampling experiment (with four schemes) conducted in the Susitna Delta (DS Region 1) and Point Possession/Chickaloon Bay (DS Region 2).

METHODS

Aircraft and Data Entry

In June 2018, the survey aircraft was a twin engine, high wing Aero Commander 690 (tail numbers: *N840TW* and *N690AX*) with 6-hour flying capability. Bubble windows were inserted at the forward observer positions to maximize the search area. The left-rear observer window was flat (Fig. 2). An opening window allowed for video recording and photography. Two observers were positioned on the coastal side of the aircraft providing independent search effort on the side where most belugas were seen. A single observer searched on the mid-inlet side of the aircraft because of the paucity of beluga sightings more than 3 km from the coast. A data recorder sat at a computer desk in the rear portion of the aircraft. The data recorder and pilots also searched for belugas but were instructed not to alert observers until a sighting was beyond view.

Figure 2. -- Twin engine, high wing Aero Commander 690 survey platform used during Cook Inlet beluga aerial surveys, June 2018 (photo courtesy of Clearwater Air, Inc.).

An intercom system provided communication among the observers, data recorder, and pilots. Seating positions were noted each time the survey team changed positions and tasks (i.e., video recording, data recording, observing/counting). Location data were collected from a portable global positioning system (GPS) interfaced with the laptop computer used to enter sighting data. Data entries included routine updates of time, location (latitude/longitude), beginning and end of search effort, percent cloud cover, sea state (Beaufort sea state scale as a function of the wind on the water surface), glare (on the coastal and offshore sides of the plane), and visibility (on the coastal and mid-inlet sides of the plane).

Visibility was documented in five subjective categories from excellent to useless. Best counting conditions (excellent visibility) were when Beaufort sea state was less than 3 (no white caps), there was a light overcast (reduced glare), the sun was well above the horizon (good lighting), windows were clean (no dust particles or smears to distract from sighting effort), and the observer was comfortable (no back pain, air sickness, etc., which can reduce search effort). Areas where visibility was considered poor or useless (as determined by the left-forward observer) were treated in the analysis as unsampled. Only the typical search area (e.g., > 10° below the horizon and 10° to 60° horizontally) was considered when selecting a visibility category.

A reconnaissance aircraft (Cessna 180: tail number *N64337*) surveyed Knik Arm and Turnagain Arm during the Distance Sampling experiment (details below) to document beluga groups not within the experiment zones (Chickaloon Bay and Susitna Delta). A single observer and pilot collected GPS locations for the trackline and any beluga whale groups encountered during the flight.

Tracklines

Coastal surveys were conducted approximately 1 km from the shoreline or exposed mudflat edge. The objective was to search all nearshore, shallow waters where belugas are typically seen in late spring/early summer (Rugh et al. 2000b, 2005b; Shelden et al. 2013, 2015b). The trackline distance from shore was monitored with a clinometer to keep the shoreline 14° below horizontal while the aircraft was at the standard altitude of 244 m (800 ft). Ground speed was approximately 185 km/hour (100 knots). This coastal survey included searches up rivers until the water appeared to be less than 1 m deep, based on the appearance of rapids or riffles or as recommended by Alaska Native hunters who have flown with us in the past.

In addition to the coastal surveys, systematic transects were flown across the inlet (Fig. 1). During past surveys, mid-inlet tracklines were designed to run the length of Cook Inlet or in a sawtooth pattern across it, minimizing overlap from year to year. A distance sampling experiment was conducted along tracklines angled across the mudflats in the Susitna Delta and Chickaloon Bay (Fig. 1). Each scheme (one for each experiment day) was created using a random starting point east of the Susitna Delta (DS Region 1) and west of Point Possession (DS Region 2) with 2 km strip width moving east to west in DS Region 1 and west to east in DS Region 2. Lines began or terminated at the shoreline or exposed mudflat edge, which varied depending on tide height. A strip transect along the mudflat/shoreline of both of these regions was also conducted one day during which each region was sampled two times.

Tides and Light

The broad geographical range of these surveys in conjunction with rapidly changing tide heights -- as much as 9.5 m (30 ft) -- made it impractical to survey at specific tidal conditions (such as at low tide) throughout Cook Inlet. However, there was an attempt to synchronize flights with low tides in the Susitna Delta. Lower tides kept beluga groups confined along the mudflat edge in more compact groups, rather than dispersing across the flats, and reduced the area that would need to be searched, as a large proportion of upper Cook Inlet has exposed mudflats only at low tide that would otherwise have to be surveyed. Increased emphasis on surveying during preferred tidal conditions is thought to improve the efficiency of the aerial surveys but probably does not significantly affect the visibility of whales, as long as the whales are still over shallow waters. When beluga groups are in deeper water, they tend to be more scattered making counting and video recording more difficult.

Whales seen near Anchorage usually could not be circled (see Counting Protocol) due to aircraft traffic in the vicinity of the Ted Stevens Anchorage International Airport. Turnagain Arm was usually surveyed in the morning when wind speeds were often slower allowing for better survey conditions and smoother flights. The timing of aerial surveys in areas south of Point Possession and North Foreland was a function of weather, not tides.

Daylight hours in the Cook Inlet area during early June (just prior to the summer solstice) cover about 19 hours between sunrise and sunset, though light levels become low enough to limit our survey to hours between 07:30 and 20:30 AKDT. The flight schedule for every survey day was designed to take advantage of tidal patterns, as described above, relative to workable daylight hours.

Counting Protocol

Immediately upon seeing a beluga group, an observer independently reported the sighting to the data recorder. As the aircraft passed abeam of the whales, the observer informed the data recorder of the clinometer angle, whale travel direction, and notable behaviors when possible, but not group size. With each sighting, the observer's position (left-forward, left-rear, or right-forward) was also recorded. An important component of the survey protocol was the independence of the paired observers (i.e., observers do not cue each other to their sightings). After a group of whales was reported, the trackline was maintained until the group was well behind the wing; then the aircraft returned to the group to mark its location and begin a circling routine. This allowed each observer an opportunity to independently sight and report whale groups. The pilots and data recorder did not cue the observers to the presence of a whale group until the whale group was behind the plane and it was clear as to whether an observer had seen the group.

The location of each whale group was established at the onset of the aerial counting passes by flying directly over the group, then recording (i.e., marking) the group perimeters. The flight pattern used to count a whale group involved an extended oval around the longitudinal axis of the group with turns made well beyond the ends of the group (Fig. 3). Counts of whales were usually made on each pass down the long axis of the oval unless poor visibility (usually due to glare) limited counts to only one side of the long axis of the oval. There were typically eight or more separate counting opportunities per whale group, with two observers counting during each pass then rotating positions after four good counts to allow another pair of observers to count. During the 2018 survey, observers did not rotate positions when counting a group. This was to remove a possible source of variability in the data. Counts began and ended on a cue from the front observer, starting when the leading edge of the group was close enough to be counted and ending when the trailing edge went behind the wing of the aircraft. This provided a precise record of the duration of each counting pass. The paired observers each made independent counts and wrote down their results along with date, time, pass number, and quality of the count.

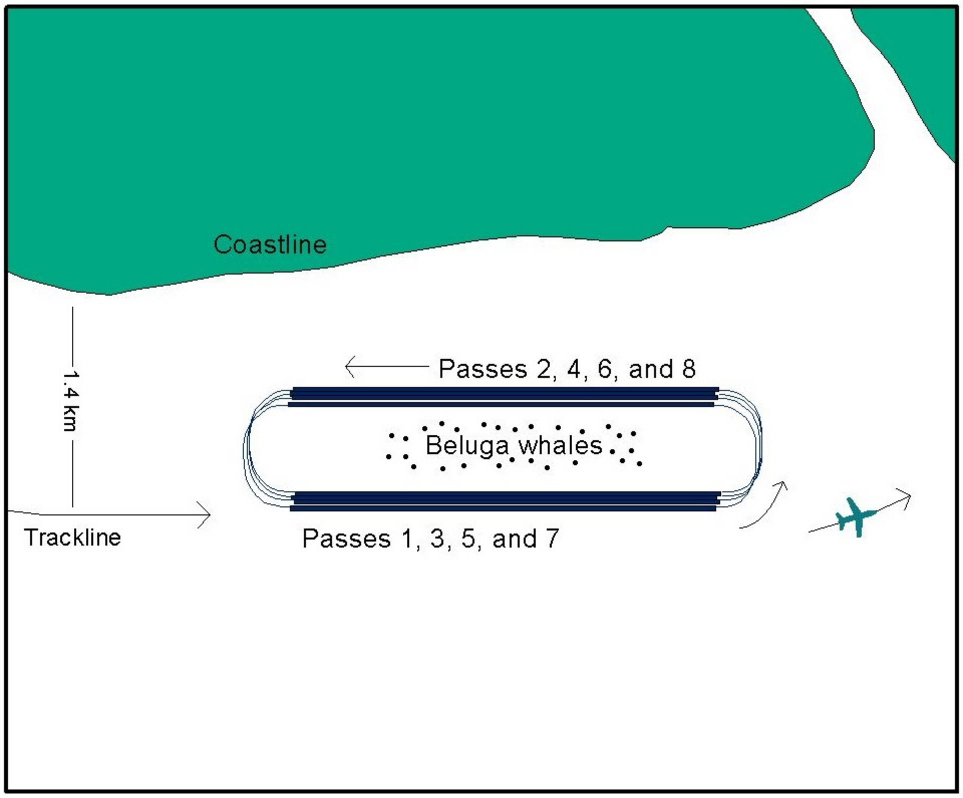

Figure 3. -- Racetrack pattern flown during counting passes of Cook Inlet belugas.

The quality of a count was not dependent on whales being present at the surface during a pass (i.e., a count could be zero and still used if other factors did not compromise visibility). Ratings were A (if glare, whitecaps, or distance did not compromise the counting effort) through F (if it was not practical to count whales on the respective pass). Only quality A and B estimates were used in the median count calculations and abundance estimate analysis. Only whales that were at the surface during a pass were counted; mud plumes or ripples from subsurface whales were not counted. Count records were not shared among aerial team members until each season's surveys were complete in order to maintain the independence of each observer's counts.

Most whale groups were counted on four different aerial passes, some larger groups up to eight passes, and because two observers were counting during each pass, there were at times 16 counts made per group per day, not including counts made later from video recordings (Hobbs et al. 2000b, 2015). The daily aerial counts were represented by medians of each of the four observers' median counts on multiple passes over a group. The process of using medians instead of maximums or means reduces the effect of outliers (extremes in high or low counts) and makes the results more comparable to other surveys which lack multiple passes over whale groups. Medians were also more appropriate than maximums when counts were corrected for missed whales (see Chapter 2).

After median counts were calculated for each location (e.g., Chickaloon Bay, Susitna Delta) on each day, the annual index count for the survey was taken from the highest daily sum. This procedure of using the highest daily median sum for the index ameliorates problems with partially or totally missing whale groups in certain areas on some days (Rugh et al. 2005b). Previously, the highest median count for each area (e.g., Susitna Delta, Knik Arm, Turnagain Arm, Chickaloon Bay, Trading Bay, lower inlet) was used as the annual index count irrespective of survey day (Rugh et al. 2000b). However, because of the evident movement of whales between these areas in upper Cook Inlet on some days, over-counting was avoided by not adding counts from different days (with the exception of sightings made in the lower inlet since it takes two days to complete a lower inlet survey). To date, movements have not been observed between the lower and upper inlet during the counting period.

Cameras

Two digital video cameras mounted on a board were operated together on most counting passes (Fig. 4). The "standard" camera was adjusted to keep the entire group of belugas in view (generally at maximum wide angle). Magnification was kept constant throughout a pass. The second "zoomed" camera was kept at maximum optical zoom (12×). The zoomed video was used to determine correction factors for missed animals (Hobbs et al. 2000b, 2015) and to examine color ratios of white adults relative to dark juveniles (Litzky 2001, Sims et al. 2003). Paired Sony HXR-NX5U HD digital video cameras with 1920 × 1080 pixel resolution were used during the June 2016 survey. We also tested two GoPro cameras mounted to the top of the HD cameras. The GoPros were also set to a wide-angle and zoomed setting.

A.

B.

Figure 4. -- Video and counting passes of Cook Inlet belugas. Observers counted from the left-forward position (A. hidden behind the camera operator) and left-rear position (B. opposite the computer display) while pass number and flight path were recorded by the computer operator.

Each video counting pass was reviewed for quality and rated on a scale (excellent, good, fair, poor, and unacceptable). Video passes rated excellent and good were analyzed using a computer-aided system (introduced in 2004). With this program (called "Beluga Dots"), analysts were able to count and catalog the individual whale images found in the survey video, track the images across the computer screen, and measure image size and color. All of these data were stored in a text file used by the program (Fig. 5). Video counts were then used to calculate abundance estimates[1] (Hobbs et al. 2015). Images from the camera kept at maximal zoom were examined for whale surfacings that did not show up in the standard video, and for color ratios (white adults vs. dark juveniles) within the respective groups (as described in Litzky 2001).

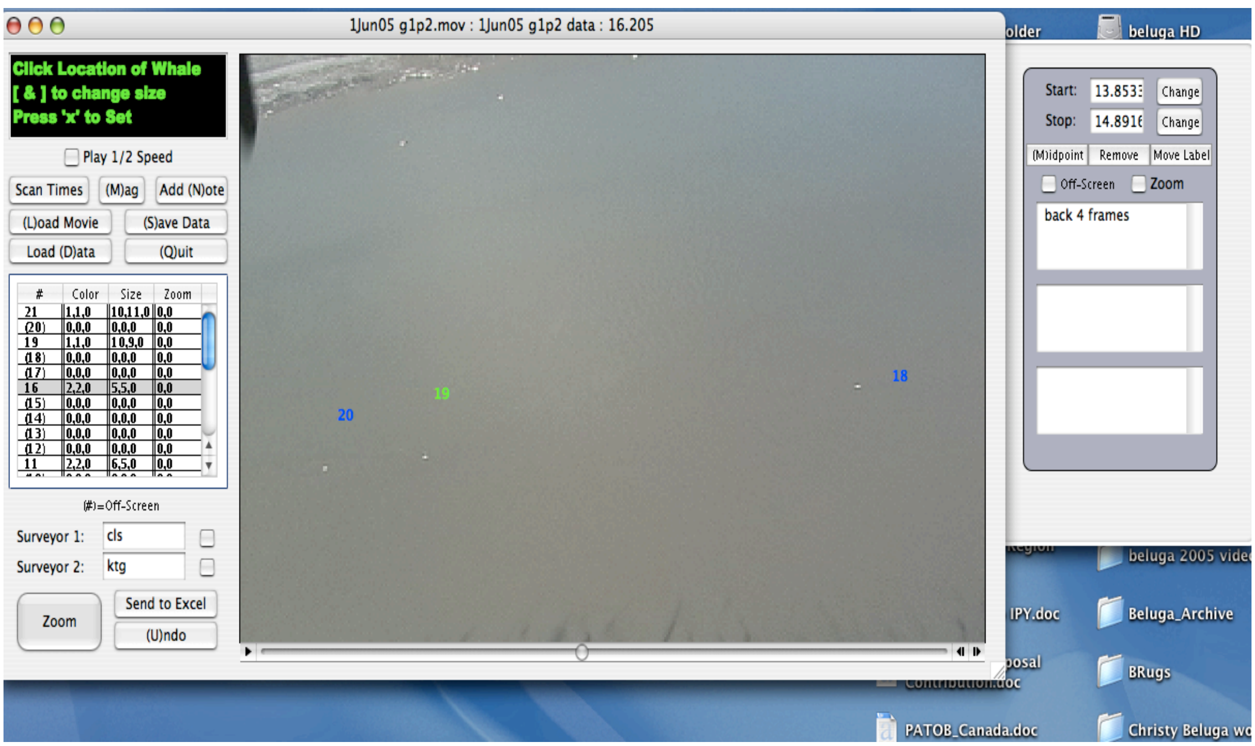

Figure 5. -- Computer screen shot of "Beluga Dots" program used to catalog individual beluga images found in the Cook Inlet survey video.

[1]Although whale counts made from video were used in abundance estimates, the median counts made by observers in the aircraft provided a quick, efficient approximation of relative abundance. Aerial counts could also be used as a proxy (with appropriate corrections relative to each observer and group density) for video counts when video was inadequate for a particular group.

RESULTS AND DISCUSSION

Survey Effort

The June 2018 survey included 12 flights in the Aero Commander, which ranged from 1.5 to 5.4 hours in duration from takeoff to landing. Flight time, the sum of time spent in the air, whether or not a search effort was underway, totaled 42.9 hours for the season. Systematic search effort, not including time spent circling whale groups, deadheading without search effort, or periods with poor visibility was 18.2 hours. Poor visibility interfered with search effort during 2.7 hours. This is the sum of time spent in the air when glare, fog, white caps, or similar problems interfered with the survey effort, as determined by the left-forward observer. The reconnaissance aircraft (Cessna) surveyed Knik Arm and Turnagain Arm during the Distance Sampling experiment to document beluga groups not within the experiment zones (Chickaloon Bay and Susitna Delta) for a total of 6.5 flight hours.

The 2018 aerial survey provided a thorough coverage of the coast of Cook Inlet north of Augustine Island for most of the area within approximately 3 km of shore. Including mid-inlet tracklines, survey coverage totaled 50% of the 20,943 km^2 of Cook Inlet surface area (assuming a 2.0 km transect swath: 1.4 km on the left plus 1.4 km on the right, less the 0.8 km blind zone beneath the aircraft). Most of upper Cook Inlet was surveyed seven times, especially areas where belugas have consistently been found in the past – such as the Susitna Delta, Knik Arm, and Chickaloon Bay.

One of the primary observers (authors of this report) has flown with this project on almost all of these surveys since 1993 (KWS). The other observers have flown on 9 to 12 of the abundance surveys (CLS, BAM), with one new participant in the Aero Commander (CB) and one observer in the Cessna (VG). Differences between observers' sighting performances (whether or not an observer found whale groups seen by others and how high or low that observer's counts were relative to the other observers) are incorporated into correction factors for the abundance estimates (see Chapter 2).

Summary Counts and Daily Reports

Median counts of beluga groups for each area are presented in Table 1. Typically, there were four good counts made by each observer for each group. The use of medians (instead of means or maximum counts) and the consistency of the observation team have meant that changes in index counts between years are probably not a function of observer performance. The median index count for all observers for 2018 was 194, which falls within index counts generated to date for this project. These summary counts do not reflect any correction for missed whales or groups (see Chapter 2).

Day-by-day survey effort and marine mammal sighting locations are summarized below. Lower inlet surveys and Distance Sampling experiments were planned for the beginning of the project because tides were more favorable (negative low tides later in the day) for upper inlet surveys starting 11 June.

Table 1. -- Beluga counts made during aerial surveys of Cook Inlet in June 2018. Counts are medians from multiple counts of each whale group. Dashes (---) indicate no survey effort and zeroes (0) indicate that the area was surveyed but no whales were seen. Locations are listed in a clockwise order around Cook Inlet starting with Turnagain Arm. If more than one group was found within a location, the median for each group was added together (see Daily Reports for specific group locations). Note: median group counts were rounded up when the final median included a "partial" whale (e.g., Group 6 on 6/12 was 74.75 whales), depending when rounding occurred (by group, by region, or by day) resulted in overall daily index counts that may vary by a few whales (+/- 1 to 4) (see Chapter 2 tables).

Location	6/5	6/6	6/7	6/8	6/9	6/10	6/11	6/12	6/13	6/14	6/15
Turnagain Arm	---	0	0	0	---	---	0	1	0	0	---
Chickaloon Bay/ Point Possession	1*	b	16[b]	24[b]	---	---	39, 56[d]	8	21	9	9
Point Possession to Moose Point/ East Foreland	0	0	0	0	---	---	2	7	3	0	0
Mid-inlet transect	---	0	0	0	c	0	---	0	0	0	---
East Foreland to Homer	0	---	---	---	---	---	---	---	---	---	---
Kachemak Bay to English Bay	0	---	---	---	---	---	---	---	---	---	---
Ursus Cove to Harriet Point	0	---	---	---	---	---	---	---	---	---	---
Redoubt Bay	0	---	---	---	---	---	---	---	---	---	---
Trading Bay	0	---	---	---	---	---	0	4	52	21	11
Susitna Delta [a]	---	b	47[b]	19[b]	91[c]	---	56, 152[d]	92	118 [e]	105	58
Knik Arm	---	0	0	0	---	---	0	0	0	0	---
Fire Island	---	0	0	0	---	---	0	0	0	0	0
Index counts	0	b	b	b	c	0	d	112	194	135	78[f]

[a] The coast between North Foreland and Point MacKenzie is defined as the Susitna Delta.
[b] Distance sampling experiment days. See section in text.
[c] Attempted sawtooth trackline of offshore upper and lower Cook Inlet but low clouds obscured water. Ran an experimental strip transect of the Susitna Delta.
[d] Ran experimental strip transect of upper inlet with two counting passes each in the Chickaloon and Susitna distance sampling areas.
[e] Includes 35 whales (Group 9 = 32 whales, Group 11 = 3) seen by the offshore observer as groups between Threemile and Little Susitna were widely dispersed.
[f] Unable to complete the upper inlet survey due to rain and gale force winds.

5 June 2018

The Aero Commander 690 (*N690AX*) departed Merrill Field at 10:37 h and flew the eastern coastline from Point Possession to English Bay before returning to Homer in Kachemak Bay for a refueling stop. The survey continued from Homer to Ursus Cove in Kamishak Bay where the coastal survey resumed heading north. The coastal track terminated at North Foreland and the team flew off-effort back to Anchorage.

Marine mammal sightings (Fig. 6) included a single beluga near the Chickaloon bluffs prior to going on-effort at Point Possession. Harbor seals (*Phoca vitulina*) were sighted in Kachemak Bay (7 sightings, 253 animals) and between Big River in Redoubt Bay and McArthur River in Trading Bay (6 sightings, 357 animals). Unidentified pinnipeds were sighted in Kachemak Bay (1 sighting, 4 animals). Sea otters (*Enhydra lutris*) were found in large numbers in Kachemak Bay (33 sightings, 1,991 animals [biased downward as sightings and group sizes were lumped together and estimated at times at great distances from the plane]) with only a few encountered in Ursus Cove on the western coastal survey (2 sightings, 2 animals). One Steller sea lion (*Eumetopias jubatus*) was observed north of English Bay (Fig. 6). Sea states ranged from Beaufort sea state 0 to 4, with brief periods (0.3 hours) of poor visibility during the 5.7-hour survey.

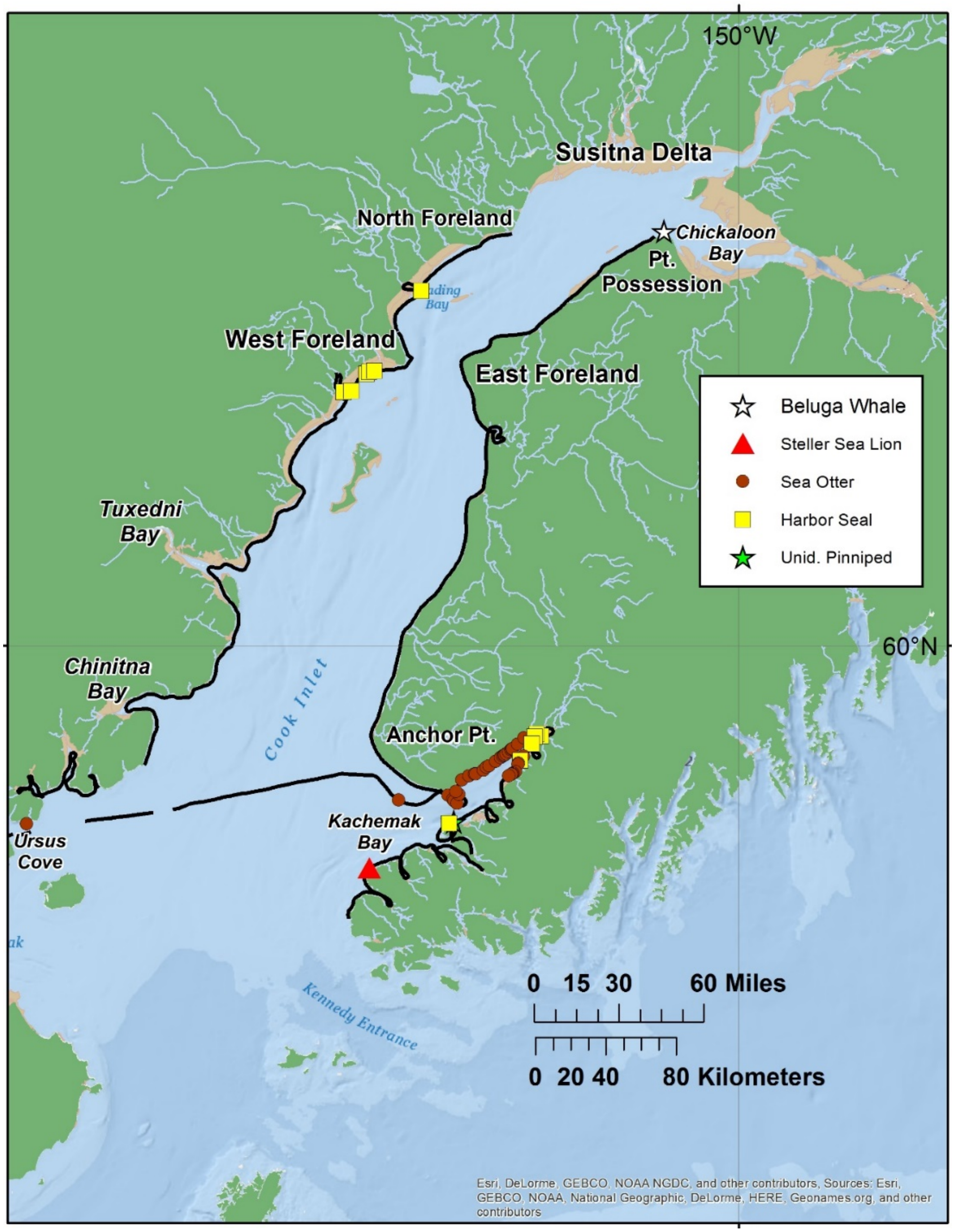

Figure 6. -- On-effort trackline and marine mammal sightings on 5 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska.

6 June 2018

We began Distance Sampling surveys on 6 June, departing Merrill Field at 11:30 h in an Aero Commander 690 (*N690AX*). Viewing conditions were excellent to fair during the 2.2-hour survey. Winds were mostly calm (Beaufort sea states ranged from 1 to 2) throughout much of the survey area, with brief periods of Beaufort sea state 3. The tide was rising from a +7 ft. low tide at 07:48 h (at Fire Island) to a 21 ft. high tide at 13:04 h and mudflats were completely submerged during the entire survey. Tracklines crossed the submerged mudflats in the Susitna Delta beginning east of Little Susitna River (offshore at Waypoint 1) and ending east of Threemile Creek (offshore at Waypoint 20) (Fig. 7), at which point we flew across the inlet toward Moose Point to begin the Chickaloon Bay survey lines. We continued the shore to offshore pattern, starting at Moose Point shoals (Waypoint 21) and ending near the entrance to Turnagain Arm (Waypoint 35). Simultaneously, a reconnaissance plane (Cessna 180 *N64337*) surveyed the coastal areas of Knik Arm, Turnagain Arm, and the northern shoreline of Chickaloon Bay from 11:40 to 14:00 h.

Belugas were observed in the Little Susitna River during an off-effort transit between Waypoints 2 and 3 (Fig. 7). While on-effort, belugas were seen off the east and west forks of the Susitna River, at the Ivan, Theodore, and Beluga rivers, the Chickaloon Bay bluffs, Chickaloon River, and Burnt Island. Other marine mammal sightings included hauled-out harbor seals in both study areas (not shown on Fig. 7). The reconnaissance airplane encountered only one harbor seal (near Hope in Turnagain Arm) and the same beluga group that was observed on the final Distance Sampling trackline (Waypoints 34-35) at Burnt Island near the entrance to Turnagain Arm (Fig. 7). Video and counting passes were attempted near the Theodore and Lewis rivers but whales were too dispersed. Five counting passes were completed on the Chickaloon River beluga group.

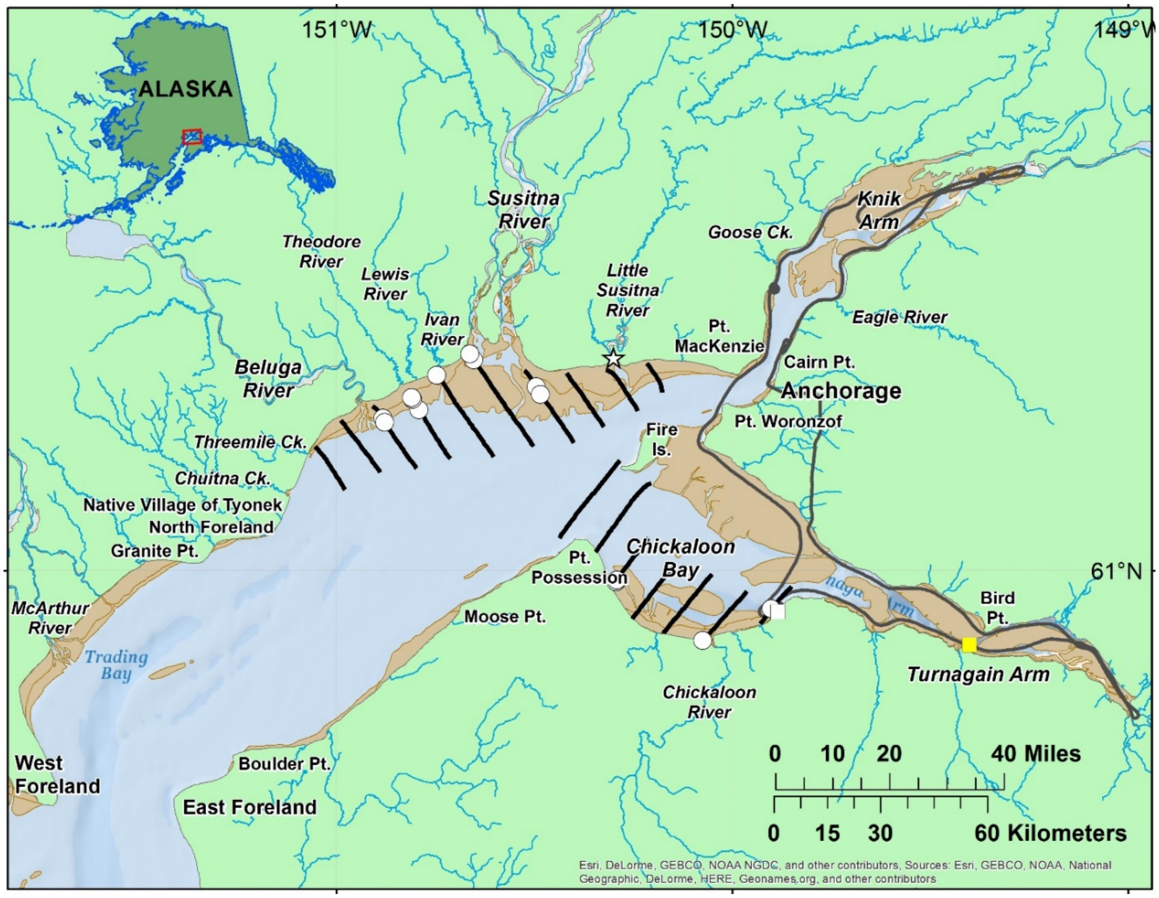

Figure 7. -- On-effort trackline and marine mammal sightings on 6 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Shown: Distance Sampling tracklines (straight lines), reconnaissance survey (coastal track in Knik and Turnagain arms), Distance Sampling beluga sighting (white circle = on effort, white star = off effort), reconnaissance beluga sighting (white square), and harbor seal sighting (yellow square).

7 June 2018

We followed a similar pattern as the previous survey day, departing Merrill Field in an Aero Commander 690 (*N840TW*) at 11:07 h. Viewing conditions were excellent to fair during much of the 3.2-hour survey. Winds were mostly calm (Beaufort sea states ranged from 0 to 2 with brief periods of 3). Scheme 2 began near the Little Susitna River at Waypoint 36 (Fig. 8). Mudflats were submerged during the entire survey (+6.7 ft. low tide at 08:46 h, rising to almost 21 ft. by 14:10 h). Belugas were encountered in the Little

Susitna River (off effort), between the east fork of the Susitna River and the Little Susitna River, off both the east and west forks of the Susitna River, off the Ivan River, in Beluga River (off effort), off Point Possession, off Chickaloon Bay bluffs, in Chickaloon River, and near Burnt Island (Fig. 8). Other marine mammals included 6 harbor seals in the water off the unexposed mudflats at Susitna River (Fig. 8). Video and counting passes were attempted on the groups found between the Susitna and Little Susitna rivers, between Beluga and Ivan rivers, off Chickaloon Bay bluffs, and in the mouth of the Chickaloon River. The reconnaissance aircraft (Cessna 180 *N64337*) did not encounter any marine mammals during the coastal survey conducted from 11:08 to 13:20 h.

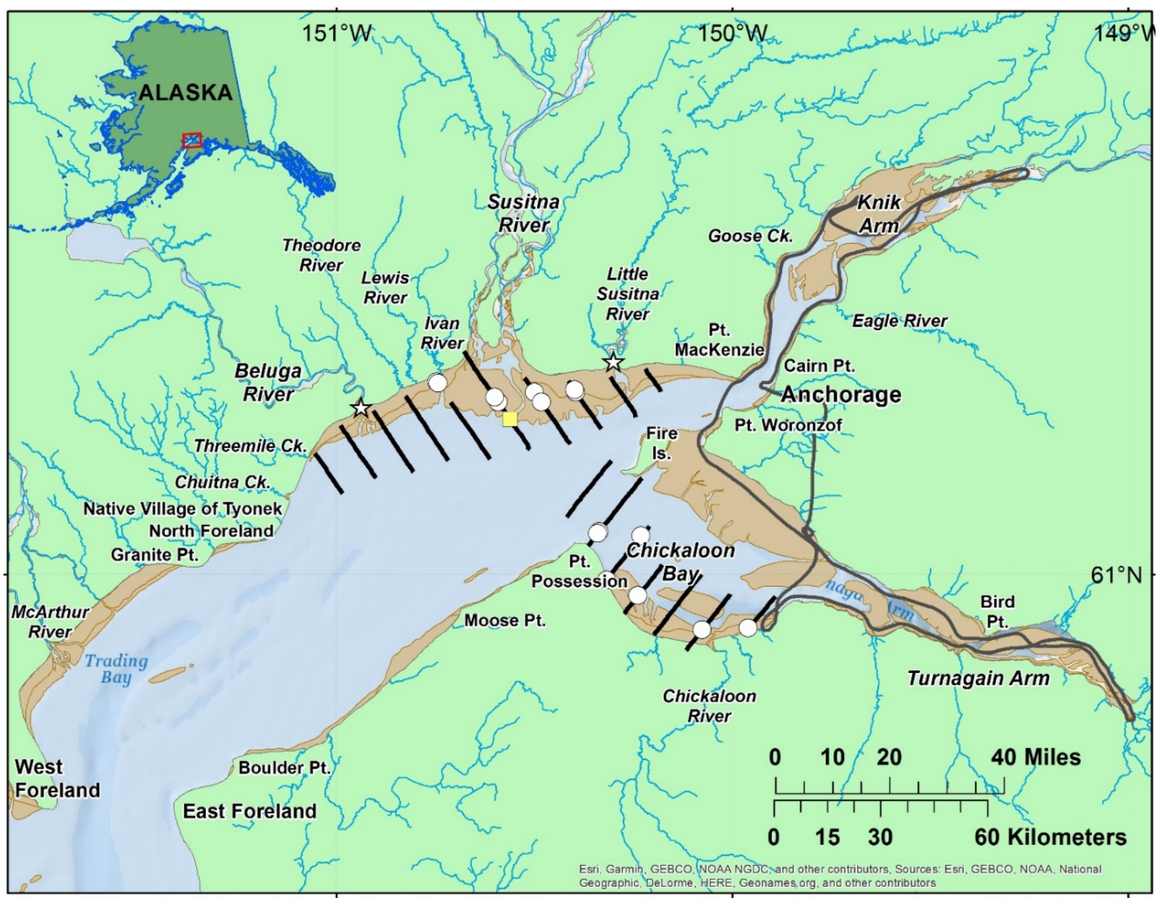

Figure 8. -- On-effort trackline and marine mammal sightings on 7 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Shown: Distance Sampling tracklines (straight lines), reconnaissance survey (coastal track), Distance Sampling beluga sighting (white circle = on effort, white star = off effort), and harbor seal sighting (yellow square).

8 June 2018

We continued the Distance Sampling experiment for a third day. Viewing conditions were excellent to fair during much of the 2.4-hour survey. Winds were mostly calm (Beaufort sea states ranged from 0 to 2). We departed Merrill Field in the Aero Commander 690 (*N840TW*) at 09:51 h. Scheme 3 began near the Little Susitna River at Waypoint 71 (Fig. 9). The earlier departure time caused us to encounter partially exposed mudflats (+5.3 ft. low tide at 09:40 h, rising to over 21 ft. by 15:17 h) in both sampling regions. Belugas were seen in the Little Susitna River (off effort), between the Theodore and Ivan rivers, off Point Possession, off the Chickaloon Bay bluffs, and at the mouth of Chickaloon River (Fig. 9). Video and counting passes were attempted on the groups found between the Theodore and Ivan rivers, off Point Possession, and along the Chickaloon Bay bluffs. The reconnaissance aircraft (Cessna 180 *N64337*) did not encounter any marine mammals during the coastal survey conducted from 09:40 to 11:45 h.

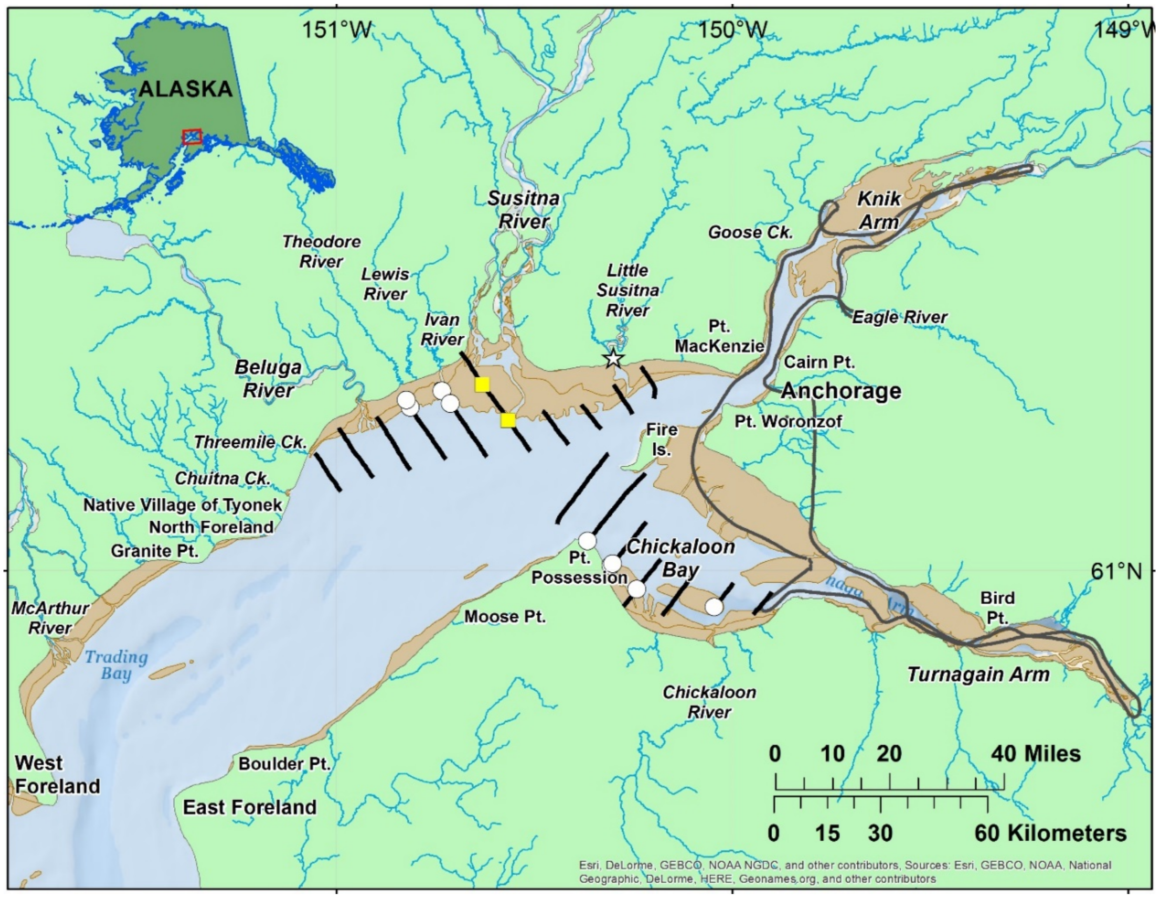

Figure 9. -- On-effort trackline and marine mammal sightings on 8 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Shown: Distance Sampling tracklines (straight lines), reconnaissance survey (coastal track), Distance Sampling beluga sighting (white circle = on effort, white star = off effort), and harbor seal sightings (yellow squares).

9 June 2018

With the low tide predicted at +3 ft. at 11:00 h, we planned an offshore sawtooth survey beginning offshore of the Susitna River (Waypoint 11) and ending off Kachemak Bay (Waypoint 3; see Fig. 1), then returning on a straight line back to East and West Foreland (Waypoint 10; see Fig. 1). We departed Merrill Field at 09:39 h and were on effort until approximately midway to Waypoint 10 before encountering low ceilings (300 ft. to 800 ft.). It was not possible to survey below the clouds, so we climbed to 2,000 ft. and continued south to Kalgin Island to determine the extent of the cloud cover. At Kalgin Island, low clouds continued south to the visible horizon and the lower inlet survey was aborted. We returned to the upper inlet to conduct a coastal transect in passing mode in the Susitna Delta. Six beluga groups were encountered between Beluga River and the east fork of the Susitna River (Fig. 10). Viewing conditions were excellent to fair during the passing mode survey. Winds were mostly calm (Beaufort sea states ranged from 1 to 2) during the 1.5 h survey.

Figure 10. -- On-effort trackline and marine mammal sightings on 9 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Beluga sighting = white circle.

10 June 2018

We made a second attempt at the offshore sawtooth survey from Waypoint 11 (offshore of the Susitna River) to Waypoint 3 (off Kachemak Bay) then returning on a straight line back to Waypoint 10 (between East and West Foreland) (Fig. 11). We departed Merrill Field at 10:55 h. Marine mammals were not seen though seabirds, flotsam, and small boats were visible during the 3.1-hr survey. Beaufort sea states ranged from 1 to 5 and visibility ranged from excellent to poor with percent overcast ranging from 0 to 80%.

Figure 11. -- On-effort trackline on 10 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska.

11 June 2018

The first survey of upper Cook Inlet included all coastal areas north of Moose Point and the McArthur River. Low tide was predicted at -1.3 ft. at the Fire Island station at 12:09 AKDT. We departed Merrill Field at 09:56 h and began the on-effort coastal survey in Turnagain Arm (Fire Island to the entrance of Turnagain Arm was off-effort due to poor visibility). We surveyed the entire Arm and continued the survey into Chickaloon Bay where we observed the first group of belugas swimming west of Chickaloon River. As the whales swam toward the Chickaloon Bay bluffs, we flew counting passes. After resuming the coastal survey, we observed Group 2 along the bluffs. Group 3 was encountered along the bluffs while counting Group 2. During the counting passes, Group 4 was observed offshore by the right front observer. Group 5 was encountered west of Point Possession as the whales swam into Chickaloon Bay (Fig. 12). We rotated observer positions and returned to Burnt Island to conduct a second circuit of the Chickaloon Bay region. Groups had moved during the aircraft transit (Fig. 12). Counting passes were conducted until each observer had a best, high, and low count for each group. We resumed the coastal survey from Point Possession to Moose Point, observing a beluga group beyond the survey strip width near Moose Point shoals (Fig. 12). We crossed the inlet to the shoreline south of the McArthur River.

Whales were not found in Trading Bay. In the Susitna Delta, a lone beluga was observed near the Theodore River and a lone beluga near the west fork of the Susitna River. An eastbound group was encountered at the mudflat edge of the east fork of the Susitna River. We conducted counting and video passes before resuming the coastal survey. The final group of the first circuit of the Susitna Delta was observed beyond the strip width in the Little Susitna River. We returned to Threemile Creek to conduct a second circuit of the Susitna Delta region. A westbound group was observed offshore as we approached the eastbound group encountered on the first circuit. Both beluga groups began to merge and weather conditions deteriorated and only one counting pass was obtained. We continued the coastal survey into Knik Arm where weather conditions improved. The survey terminated at Pt. Woronzof (Fig. 12). Other marine mammal sightings included harbor seals hauled out on the Susitna River mudflats (Fig. 12). Sea states ranged from Beaufort sea state 0 to 3. Sighting conditions were fair to excellent, with the exception of the segment from Fire Island to Turnagain Arm during the 5-hour survey.

Figure 12. -- On-effort trackline and marine mammal sightings on 11 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Beluga groups on the first circuit of the Chickaloon Bay and Susitna Delta regions are shown as open circles, second circuit as circles with black dots, and beyond strip width as stars. Harbor seals were hauled out at multiple sites along the Susitna mudflats (yellow square).

12 June 2018

The negative low tide (-3.3 ft.) was predicted for 12:56 AKDT at Fire Island. Due to potential heavy air traffic in Knik Arm during the afternoon, we began the survey in Knik

Arm after departing Merrill Field at 09:37 h, before surveying to Fire Island, Turnagain Arm, and Chickaloon Bay. We encountered the first beluga group on the south shore of Turnagain Arm (Fig. 13). The whales were swimming toward Chickaloon Bay. Group 2 was between the Chickaloon Bay bluffs and mudflats east of Point Possession. We continued the coastal survey to Moose Point where Groups 3 and 4 were observed offshore near the Moose Point shoals. After transiting across the inlet to North Foreland, Group 5 was sighted near the T-dock as we resumed the coastal survey. Group 6 included belugas dispersed in the mud plume from Threemile Creek to Ivan River. We continued along the Susitna Delta, encountering Group 7 along the mudflats at the east fork of the Susitna River. Group 8 was just outside the mouth of the Little Susitna River. Counting and video passes were completed on each group. The coastal survey terminated at Point MacKenzie (Fig. 13). Other marine mammal sightings included harbor seals hauled out in Chickaloon Bay and the Susitna Delta (Fig. 13). Sightings conditions were generally excellent to fair with Beaufort sea states ranging from 1 to 3, and only brief periods of poor visibility near Fire Island and northern Chickaloon Bay due to glare and high sea states. Total survey time was 4.9 hours.

Figure 13. -- On-effort trackline and marine mammal sightings on 12 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Beluga groups are shown as open circles. Harbor seals were hauled out at multiple sites along the Chickaloon River mudflats and Susitna mudflats (yellow squares).

13 June 2018

We started the survey in Knik Arm at Port MacKenzie to take advantage of the low tide in the Susitna Delta (-4.8 ft. at 13:43 AKDT), following the shoreline clockwise to Fire Island, Turnagain Arm, Chickaloon Bay, Pt. Possession, and Moose Point before crossing the inlet to McArthur River and concluding the survey at Point MacKenzie. The first beluga group was in the Chickaloon River (Fig. 14). The second group was along the Chickaloon River mudflats. Group 3 was dispersed along the Chickaloon Bay bluffs. Group 4 was at Pt. Possession. Group 5 was observed at Moose Point prior to crossing the inlet on-effort to the

McArthur River. Group 6 was travelling north toward Granite Point in Trading Bay. Group 7 was just north of the T-dock at North Foreland. Group 8 was offshore of the Native Village of Tyonek. Multiple counting and video passes were conducted on all groups.

With 30 minutes of fuel remaining, we encountered beluga Group 9, spread from Threemile Creek to the middle of the Susitna Delta. We returned to Threemile Creek to conduct a continuous counting pass from Threemile Creek to the Little Susitna River with observers tallying whales on the left and right sides of the plane. Group 9 included whales from Threemile Creek to the west fork of the Susitna River. Group 10 included a few whales seen near the east fork, while Group 11 was observed offshore from Group 10. Group 12 was west of the Little Susitna River (Fig. 14).

Beaufort sea states ranged from 0 to 5. Sighting conditions were excellent to fair during the 5.4-hr survey, with brief periods of poor visibility in Turnagain Arm due to high winds and glare. Other marine mammal sightings included harbor seals hauled out near Chickaloon River (Fig. 14) and on the Susitna River mudflats (not mapped due to focus on continuous counting pass).

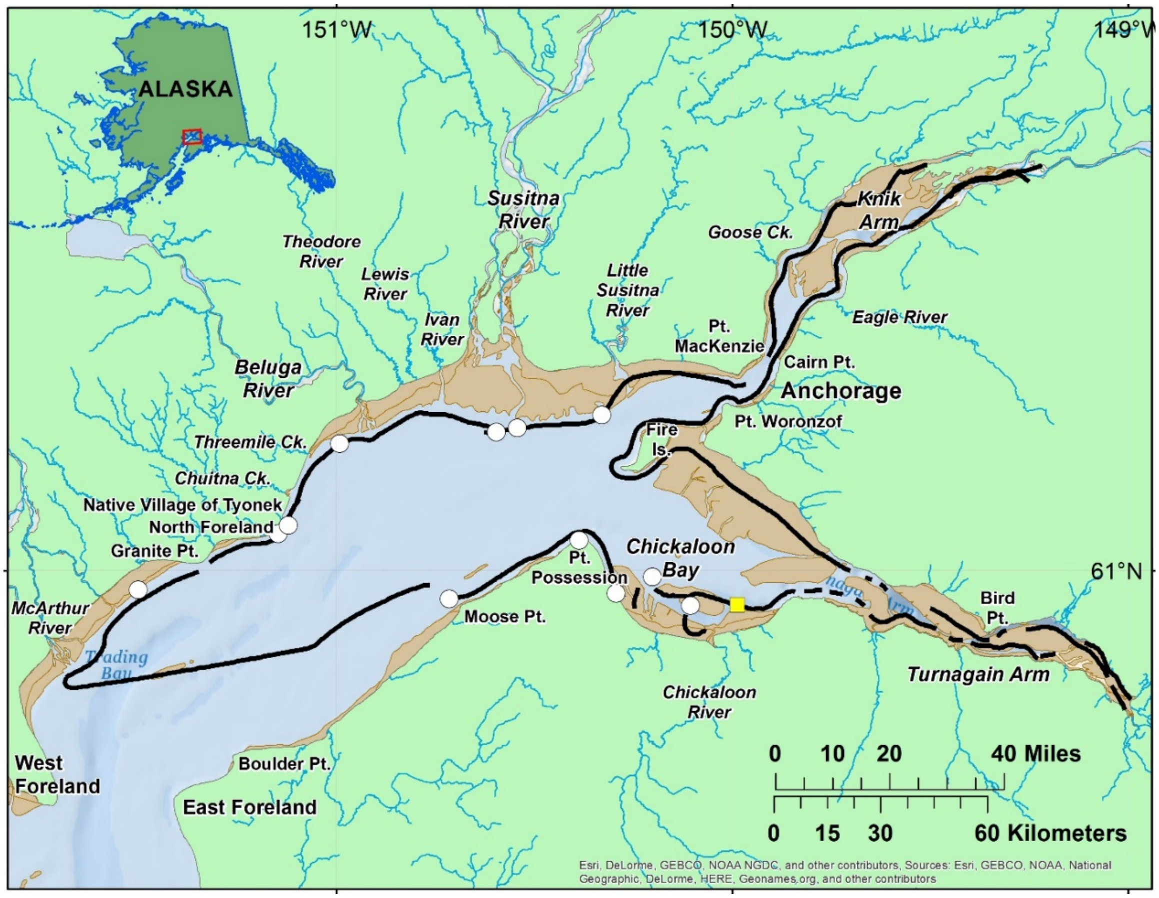

Figure 14. -- On-effort trackline and marine mammal sightings on 13 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Beluga groups are shown as open circles. Harbor seals were hauled out near Chickaloon River (yellow square) and Susitna River mudflats (not shown).

14 June 2018

We started the survey at Fire Island to take advantage of the low tide in the Susitna Delta (-5.6 ft. at 14:31 AKDT), following the shoreline clockwise to Turnagain Arm, Chickaloon Bay, Pt. Possession, Moose Point, and Boulder Point before crossing the inlet to West Foreland and concluding the survey after flying Knik Arm during the low tide. We encountered the first beluga group at Chickaloon River (Fig. 15). Group 2 was along the

Chickaloon Bay bluffs. Group 3 was swimming toward the McArthur River from Granite Point (Fig. 15). Group 4 was south of the T-dock at North Foreland.

Group 5 was dispersed from the Threemile Creek area to Beluga River where we also encountered Group 6 while off-effort on counting passes. Group 6 extended from Beluga River to Ivan River. Group 7 was located along the mudflats (at the -5 ft. tide) off the east fork of the Susitna River. Group 8 was located west of the mouth of the Little Susitna River. Four counting and video passes were conducted on all groups. Group 9 was seen west of Pt. MacKenzie, directly in the flight path to Anchorage International Airport, so only one counting pass was completed. The coastal survey terminated after surveying Knik Arm on the low tide. Other marine mammal sightings included harbor seals (1 sighting of 300 animals) hauled out on the Susitna River mudflats (Fig. 15, Appendix). Sightings conditions were excellent to fair, with brief periods of poor visibility due to glare with Beaufort sea states ranging from 0 to 3 during the 5-hour survey.

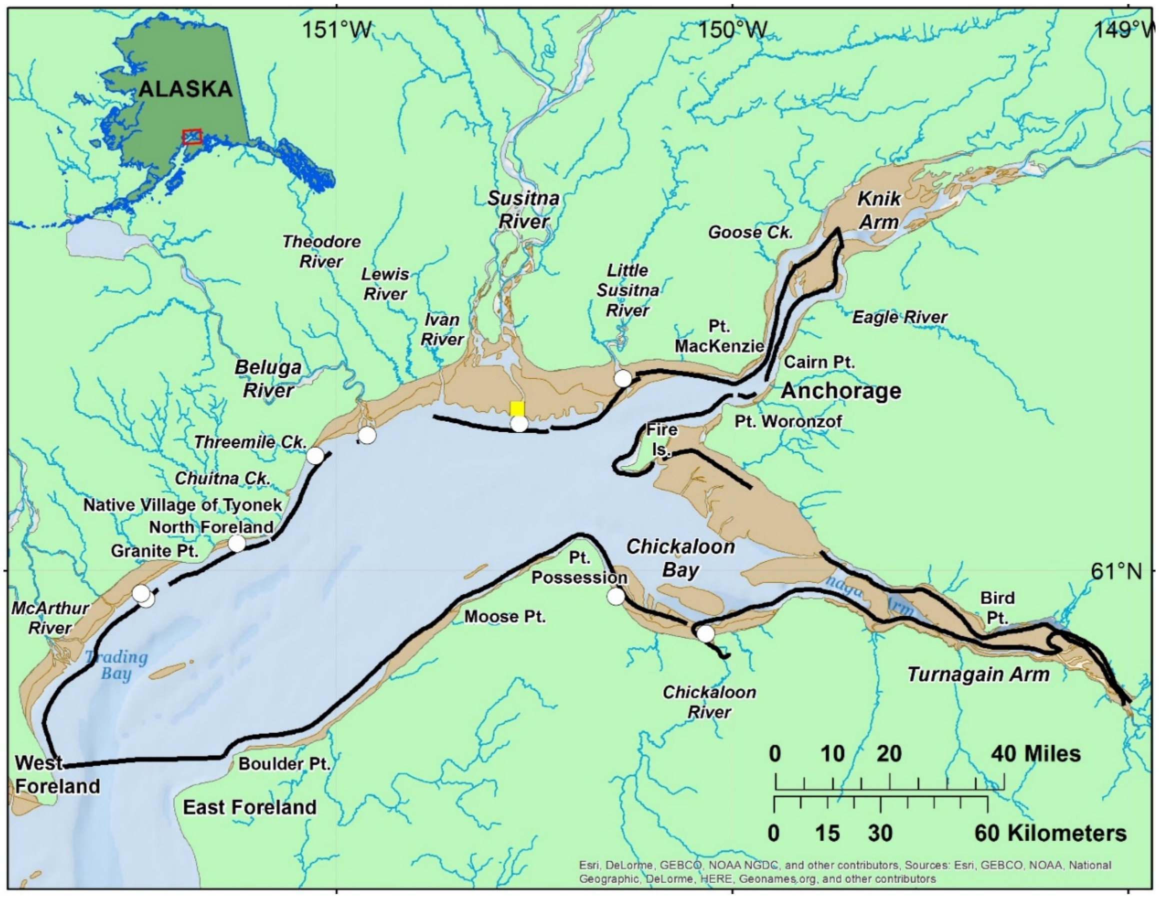

Figure 15. -- On-effort trackline and marine mammal sightings on 14 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Beluga groups are shown as open circles. Harbor seals were hauled out at the east fork of Susitna River (yellow square).

15 June 2018

Winds were predicted to increase throughout the day. We started the survey at Fire Island but high winds out of Turnagain Arm created poor sighting conditions. We transited across the entrance of Turnagain Arm off-effort to Burnt Island and began surveying the Chickaloon Bay shoreline. Group 1 was at the mouth of Chickaloon River. Group 2 was along the survey track off the mudflats while Group 3 was by the Chickaloon Bay bluffs (Fig. 16). We conducted a second circuit of Chickaloon Bay before continuing to Pt. Possession then Moose Point. We continued the survey to midway between Moose Point and Boulder Point then crossed the inlet off-effort in heavy rain to Trading Bay. We resumed the coastal survey south of the McArthur River. We encountered the next beluga group north of McArthur River. Two groups were located near Beluga River, one dispersed from the Chuitna River to Threemile Creek and the other across the mouth of the Beluga River. High sea states (Beaufort 5-6) in the Susitna Delta reduced visibility to poor, although a small group of belugas was detected in the surf near the east fork of the Susitna River. No belugas were found at the Little Susitna River, which we surveyed up to the first bend. We did not survey upriver at the McArthur, Beluga, or Susitna rivers as mudflats exposed during the low tide (-5.6 ft. at 15:19 h) prevented belugas from accessing the rivers. Low clouds, high winds, and heavy rain in Knik Arm meant terminating the coastal survey at Point MacKenzie. Total survey time was 4.7 hours.

Figure 16. -- On-effort trackline and marine mammal sightings on 15 June during the 2018 beluga aerial abundance survey, Cook Inlet, Alaska. Beluga groups are shown as open circles.

Summary

In 2018, the daily medians ranged from 113 to 194 (Table 1) for days where coverage included the entire upper inlet. The 2018 index count (the median count from the best survey day) of 194 belugas, falls within the range of index counts (see Chapter 2). Similar to past years, belugas were found in the Susitna Delta, Turnagain Arm, and Chickaloon Bay. Belugas were also found in Trading Bay, from the Native Village of Tyonek to the Little Susitna River, in Turnagain Arm, from Burnt Island to the bluffs along Chickaloon Bay, and from Point Possession to Moose Point and near the Moose Point shoals. None were seen in Knik Arm. See Appendix for all other marine mammal sightings.

While counts in the Susitna Delta have remained fairly constant during the 20+-year span of these surveys, whales have not been observed in Knik Arm the last eight survey years (2008-2012, 2014, 2016, 2018; Fig. 17). Belugas found in Chickaloon Bay were typically near the south shore, most often in an area 3 km southeast of Point Possession between the bluffs and Chickaloon River. Annual counts in Chickaloon Bay have been in the range of 20-60 belugas (Fig. 17). However, in 2004, counts were as high as 176, and for the first time there appeared to be exchanges of belugas between the Susitna Delta and Chickaloon Bay/Turnagain Arm within the timeframe of the survey; that is, when counts were low in the Susitna area, they were high in Chickaloon Bay and vice versa (Rugh et al. 2005a). Similar apparent exchanges were seen in 2010 and 2011, and possibly in 2016 and 2018 when we observed small groups between the Susitna Delta and Point Possession (Fig. 18).

Throughout each abundance survey, CIBs were seen near the coast and within river mouths in all years, and after 2000, nearly all of the sightings occurred in the northernmost portions of the inlet (Hobbs et al. 2015, Shelden et al. 2015a). Belugas were found in the Susitna Delta region (defined as the area between Point MacKenzie and North Foreland) throughout the survey time series. Whales were also seen in large numbers in Knik Arm from 1997 to 2003, with a few observations continuing until 2007, after which none were found in this region during the June surveys (Fig. 17). From 2004 to 2007, more whales were observed in the Chickaloon Bay–Turnagain Arm region, coincident with the lower numbers seen in Knik Arm. Belugas (group sizes ranging from 1 to 27 whales) have been observed in areas south of North Foreland and Point Possession, but not consistently. In 2018, groups were once again observed near Moose Point and the tidal shoals offshore and, similar to the 2012 survey, in Trading Bay. We also observed belugas north and south of North Foreland and near the Native Village of Tyonek.

The contraction in range first documented in Rugh et al. (2010) has persisted. Since 2008, on average 81% of the total population occupied the Susitna Delta in early June during the aerial survey period, compared to roughly 50% in the past (1978-79, 1993-97, 1998-2008) (Fig. 18). The 2009-18 range was estimated to be only 29% of the range observed in 1978-79 (Fig. 19), similar to the 2009-16 range (Shelden et al. 2017) and a slight increase from the 2009-14 range of 25% presented in Shelden et al. (2015).

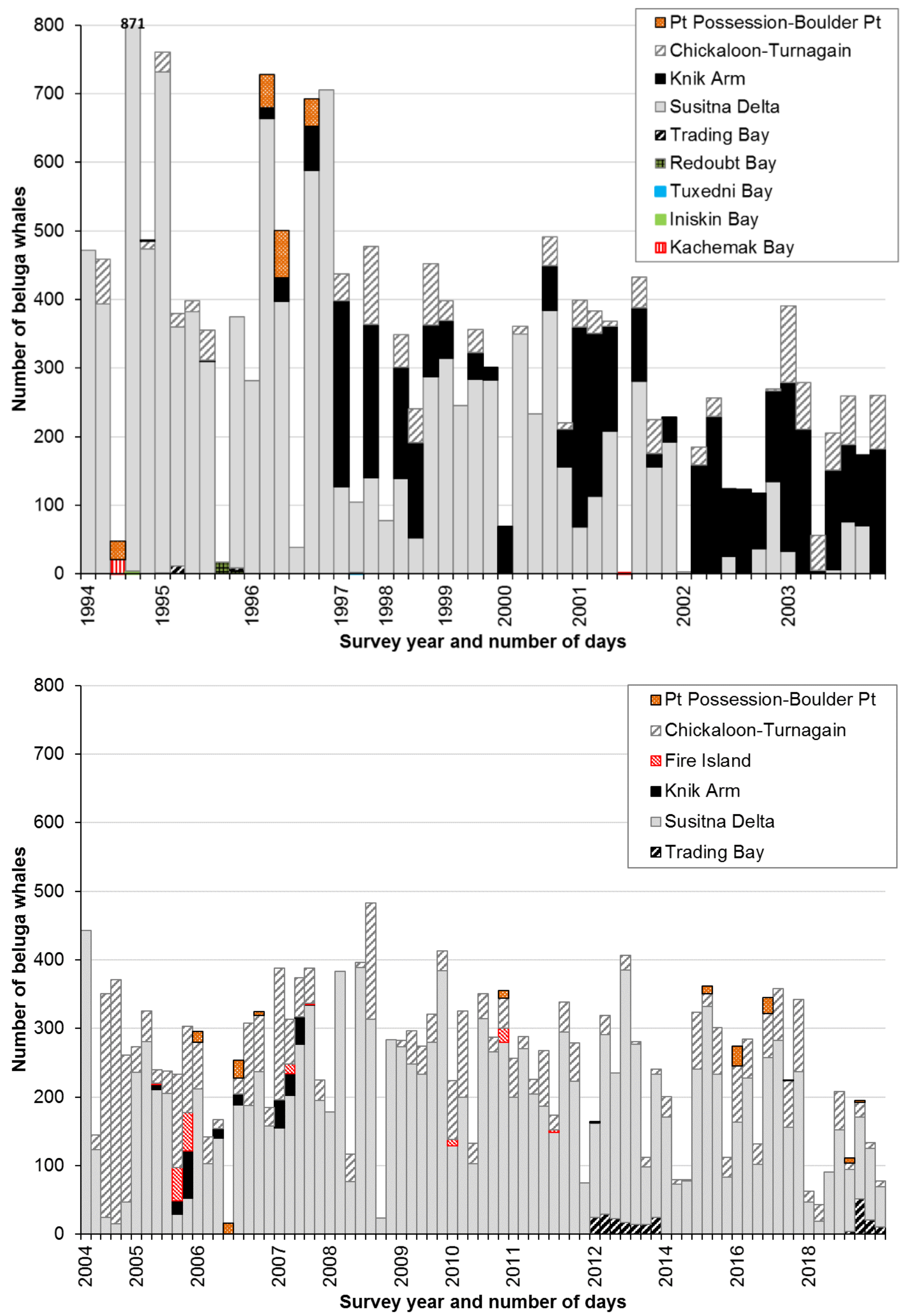

Figure 17. -- Regions occupied by belugas in upper Cook Inlet, Alaska, from 1994 to 2018. Each survey day is represented as a single bar above and following the year indicated on the x-axis. (Originally published in Hobbs et al. (2015) for the period 1994-2012).

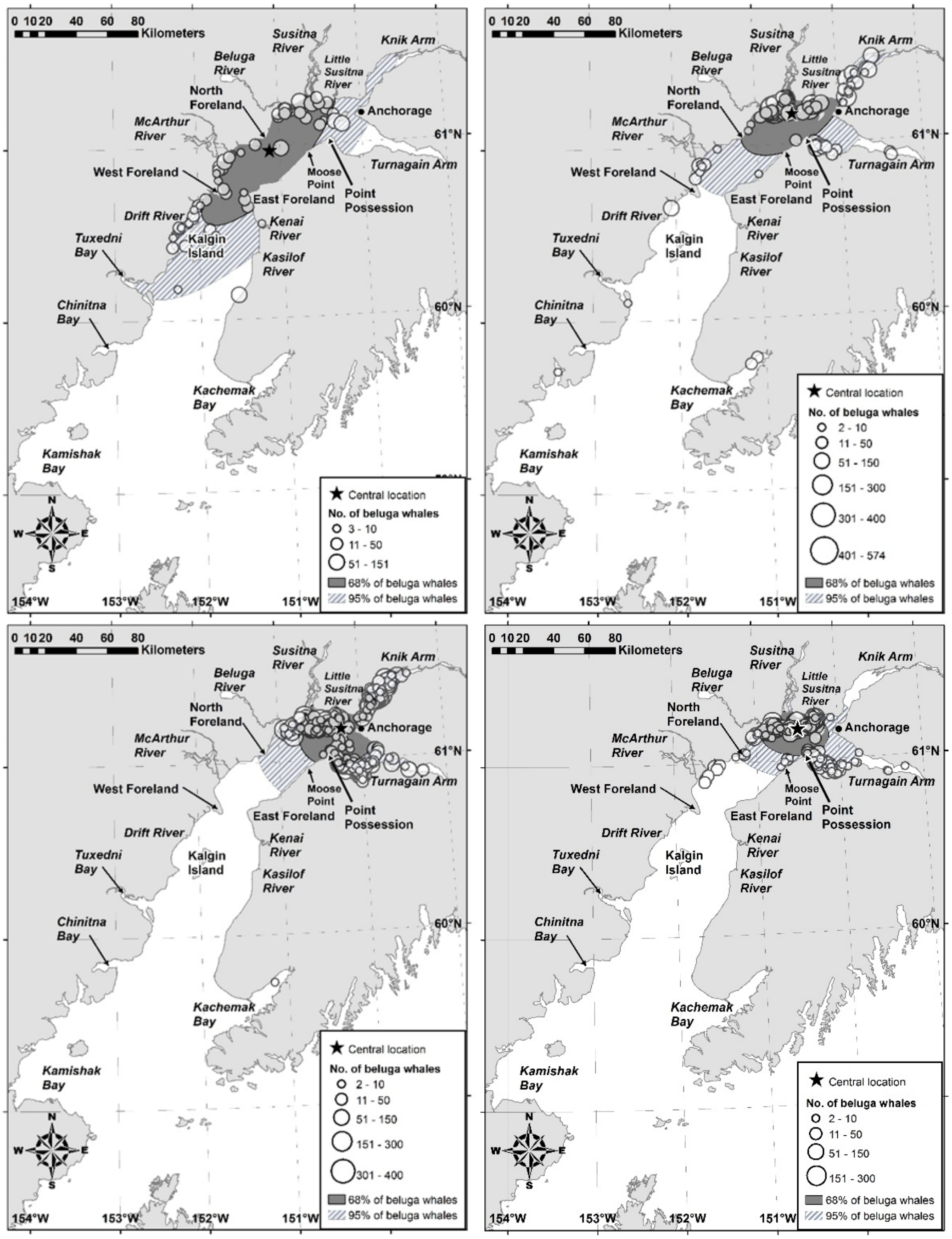

Figure 18. -- Areas occupied by belugas in Cook Inlet, Alaska, during systematic aerial surveys in 1978–79 (upper left panel), 1993–97 (upper right panel), 1998–2008 (lower left panel), and 2009–18 (lower right panel). The distribution of belugas around each central location for each period was calculated at 1 and 2 SD (capturing ca. 68% and 95% of the whales; shaded regions). (Originally published in Shelden et al. 2015b for the period 1978-2014).

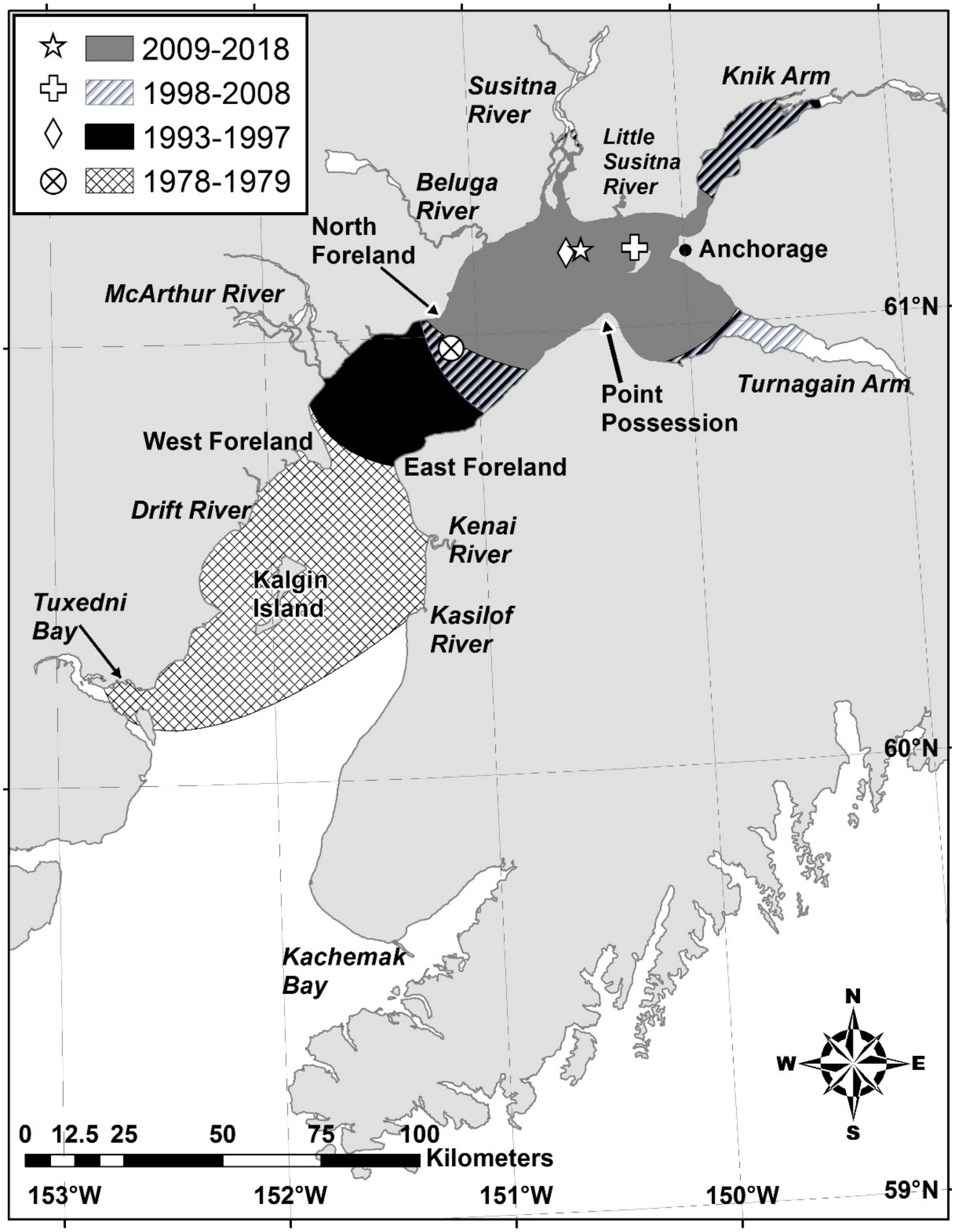

Figure 19. -- Areas occupied by belugas in Cook Inlet, Alaska, during systematic aerial surveys in 1978–79, 1993–97, 1998–2008, and 2009–18. The distribution of belugas around each central location (shaded regions next to symbols) for each period was calculated at 2 SD (capturing ca. 95% of the whales). The 95% core summer distribution contracted from 7,226 sq. km in 1978–79 to 2,110 sq. km in 2009–18 (29% of the 1978–79 range).

CONCLUSIONS

In Cook Inlet, belugas concentrate in large groups near river mouths or shallow bays during late spring and early summer in the northernmost reaches of the inlet, especially in the Susitna Delta, Knik Arm, and Chickaloon Bay (Rugh et al. 2000b, 2005b; Shelden et al. 2013, 2015a, 2017). These concentrations usually last from mid-May to July or later and are very likely associated with the migration of anadromous fish, particularly eulachon (*Thaleichthys pacificus*) and several species of Pacific salmon (*Oncorhynchus* spp.; Moore et al. 2000). Research protocol and coverage area for the June aerial surveys of Cook Inlet have been kept consistent to minimize variables in inter-year analyses. The type of aircraft, window configuration, altitude, air speed, and coastal search patterns were constant, and most of the observers have been on many or all of the surveys, maintaining continuity in effort. On all but one of these 22 surveys, flights were in the first half of June. Each year there have been at least 4-6 replicate flights around upper Cook Inlet with the difference that in 2004 and subsequent years additional survey days were included. The large number of flights per year across many years and the consistency of effort have helped us detect patterns of whale distribution and identify changes that have occurred.

Historically many belugas were seen in both upper and lower Cook Inlet in June and July (Rugh et al. 2000b, Shelden et al. 2015b). However, between 1993 and 1995, during the first 3 years of the NMFS surveys, very few belugas (less than 3% of all of the annual sightings) were in the lower inlet, south of East Foreland and West Foreland (Rugh et al. 2000), and in subsequent years, 1996-2011, hardly any (one whale in Tuxedni Bay in 1997 and two in Kachemak Bay in 2001) were seen in the lower inlet during these surveys. Many other marine mammal species were seen in the lower inlet throughout the study period: sea otters, harbor seals, harbor porpoise, fin whales, humpback whales, and Steller sea lions (Appendix), which indicates the lack of beluga sightings was not due to poor visibility.

Furthermore, in the southern half of the upper inlet, south of North Foreland and Point Possession, sighting rates dropped from an annual average of 1.5% during the period 1993-1995, to zero for all subsequent years until June 2012. Sighting conditions have generally been ideal during these aerial surveys, but with the exception of June 2012 and June 2018 (when a group was repeatedly found in Trading Bay) the only places where belugas were consistently found were waters north of North Foreland and Moose Point. A steep decline in the number of June sightings in both Knik Arm and Turnagain Arm also occurred after 2007 (Figs. 17 and 18).

Although these aerial surveys provide a broad-scale picture of the whale distribution each June, satellite-tagging provides much more detail over longer time periods, albeit of only a few whales (e.g., 14 belugas: see Hobbs et al. 2005, Goetz et al. 2012b, Shelden et al. 2015b). Results from tagged whales (from 1999 to 2003) show that the beluga distribution seen during the June aerial surveys is representative of most of the summer through late autumn, with whales remaining in waters north of East and West Foreland (Shelden et al. 2015b). In winter, some of the tagged whales dispersed into deeper waters and a few explored waters farther south (Chinitna Bay) before returning to the upper inlet, but they never left Cook Inlet (Hobbs et al. 2005, Goetz et al. 2012b, Shelden et al. 2015b).

Median estimates presented in Table 1 are a rough index of relative abundance; however, calculated abundances with their respective *CV*s (Hobbs et al. 2015, Shelden et al. 2015a; Chapter 2) include corrections for whales missed within the viewing range of observers, whales missed because they were beneath the surface throughout an aerial counting pass, as well as density corrections. The abundance estimates, with their associated *CV*s, are the appropriate values to use in inter-year trend analyses. The next biennial survey is scheduled for June 2020.

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CHAPTER 1 APPENDIX

Sighting data for other marine mammals observed during the 2018 beluga abundance survey.

Common name	Group size	Date	Latitude	Longitude	Time	Flight No.	General location
Steller sea lion	1	6/5/2018	59.427	-151.888	13:03:36	1	N. of English Bay
Sea otter	35	6/5/2018	59.616	-151.485	11:59:06	1	Kachemak Bay
Sea otter	40	6/5/2018	59.606	-151.461	11:59:36	1	Kachemak Bay
Sea otter	15	6/5/2018	59.602	-151.454	11:59:46	1	Kachemak Bay
Sea otter	1	6/5/2018	59.595	-151.439	12:00:06	1	Kachemak Bay
Sea otter	2	6/5/2018	59.618	-151.43	12:01:56	1	Kachemak Bay
Sea otter	75	6/5/2018	59.626	-151.444	12:02:16	1	Kachemak Bay
Sea otter	2	6/5/2018	59.656	-151.414	12:03:26	1	Kachemak Bay
Sea otter	8	6/5/2018	59.666	-151.379	12:04:06	1	Kachemak Bay
Sea otter	100	6/5/2018	59.671	-151.35	12:04:36	1	Kachemak Bay
Sea otter	150	6/5/2018	59.671	-151.345	12:04:40	1	Kachemak Bay
Sea otter	40	6/5/2018	59.681	-151.304	12:05:26	1	Kachemak Bay
Sea otter	40	6/5/2018	59.688	-151.289	12:05:46	1	Kachemak Bay
Sea otter	25	6/5/2018	59.692	-151.276	12:06:01	1	Kachemak Bay
Sea otter	20	6/5/2018	59.704	-151.242	12:06:40	1	Kachemak Bay
Sea otter	12	6/5/2018	59.713	-151.217	12:07:10	1	Kachemak Bay
Sea otter	30	6/5/2018	59.717	-151.205	12:07:26	1	Kachemak Bay
Sea otter	15	6/5/2018	59.719	-151.2	12:07:31	1	Kachemak Bay
Sea otter	42	6/5/2018	59.72	-151.196	12:07:36	1	Kachemak Bay
Sea otter	35	6/5/2018	59.723	-151.188	12:07:46	1	Kachemak Bay
Sea otter	100	6/5/2018	59.728	-151.175	12:08:01	1	Kachemak Bay
Sea otter	4	6/5/2018	59.733	-151.164	12:08:16	1	Kachemak Bay
Sea otter	250	6/5/2018	59.735	-151.16	12:08:21	1	Kachemak Bay
Sea otter	600	6/5/2018	59.736	-151.156	12:08:26	1	Kachemak Bay
Sea otter	4	6/5/2018	59.748	-151.129	12:09:01	1	Kachemak Bay
Sea otter	12	6/5/2018	59.764	-151.096	12:09:46	1	Kachemak Bay
Sea otter	1	6/5/2018	59.717	-151.098	12:20:36	1	Kachemak Bay
Sea otter	2	6/5/2018	59.699	-151.126	12:21:21	1	Kachemak Bay
Sea otter	1	6/5/2018	59.696	-151.128	12:21:26	1	Kachemak Bay
Sea otter	250	6/5/2018	59.677	-151.141	12:22:06	1	Kachemak Bay
Sea otter	1	6/5/2018	59.673	-151.153	12:22:21	1	Kachemak Bay
Sea otter	4	6/5/2018	59.671	-151.158	12:22:26	1	Kachemak Bay
Sea otter	50	6/5/2018	59.67	-151.162	12:22:30	1	Kachemak Bay
Sea otter	25	6/5/2018	59.666	-151.175	12:22:46	1	Kachemak Bay
Sea otter	1	6/5/2018	59.604	-151.737	15:09:30	2	mouth of Kachemak Bay
Sea otter	1	6/5/2018	59.542	-153.64	15:49:40	2	Ursus Cove

Common name	Group size	Date	Latitude	Longitude	Time	Flight No.	General location
Harbor seal	20	6/5/2018	59.772	-151.03	12:10:56	1	Fox R., Kachemak Bay
Harbor seal	50	6/5/2018	59.77	-151.01	12:11:16	1	Fox R., Kachemak Bay
Harbor seal	100	6/5/2018	59.775	-151.032	12:16:16	1	Fox R., Kachemak Bay
Harbor seal	50	6/5/2018	59.768	-151.041	12:16:31	1	Bradley R., Kachemak Bay
Harbor seal	20	6/5/2018	59.75	-151.057	12:17:10	1	Bradley R., Kachemak Bay
Harbor seal	12	6/5/2018	59.707	-151.115	12:21:01	1	Kachemak Bay
Harbor seal	1	6/5/2018	59.544	-151.479	12:35:45	1	Kachemak Bay
Harbor seal	20	6/5/2018	60.644	-152.019	17:06:31	2	Big R., Redoubt Bay
Harbor seal	225	6/5/2018	60.646	-151.98	17:11:22	2	Big R., Redoubt Bay
Harbor seal	12	6/5/2018	60.689	-151.902	17:12:52	2	Kustatan R., Redoubt Bay
Harbor seal	10	6/5/2018	60.694	-151.887	17:13:07	2	Kustatan R., Redoubt Bay
Harbor seal	80	6/5/2018	60.697	-151.862	17:13:27	2	Kustatan R., Redoubt Bay
Harbor seal	10	6/5/2018	60.896	-151.621	17:22:12	2	McArthur R., Trading Bay
Harbor seal	6	6/7/2018	61.19	-150.561	11:56:46	4	Susitna R.
Harbor seal	75	6/8/2018	61.184	-150.565	10:13:06	5	Susitna R.
Harbor seal	6	6/8/2018	61.227	-150.631	10:14:51	5	Susitna R.
Harbor seal	50	6/11/2018	61.175	-150.518	13:10:00	8	Susitna R.
Harbor seal	10	6/12/2018	60.957	-149.979	11:20:10	9	Chickaloon Bay
Harbor seal	45	6/12/2018	60.959	-149.999	11:20:30	9	Chickaloon Bay
Harbor seal	25	6/12/2018	60.965	-150.052	11:21:21	9	Chickaloon Bay
Harbor seal	8	6/12/2018	60.969	-150.095	11:22:01	9	Chickaloon Bay
Harbor seal	45	6/12/2018	60.958	-150.115	11:22:31	9	Chickaloon Bay
Harbor seal	40	6/12/2018	61.175	-150.537	13:02:11	9	Susitna R.
Harbor seal	60	6/12/2018	61.176	-150.526	13:02:21	9	Susitna R.
Harbor seal	65	6/12/2018	61.174	-150.518	13:59:57	9	Susitna R.
Harbor seal	35	6/13/2018	60.958	-149.987	11:08:03	10	Chickaloon Bay
Harbor seal	300	6/14/2018	61.198	-150.542	13:53:51	11	Susitna R.

CHAPTER 2

Group Size Estimates and Revised Abundance Estimates and Trend for the Cook Inlet Beluga Population

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INTRODUCTION

Aerial surveys for the endangered Cook Inlet beluga population have been used since 1993 to estimate the abundance of the population and to monitor trends. A statistically significant decline in the population, thought to be due to over-hunting, was detected over the 1994-1998 time period (Hobbs et al. 2000). Since the reduction of hunting starting in 2000, the steep decline in the population stopped, and the population has been described as roughly stable or slightly declining since then. The most recent assessment of abundance and trend prior to this study, following the 2016 aerial survey, concluded there had been an initial steep decline until 1998, followed by a gradual decline from 1999 to 2016. The trend from 2006 to 2016 was estimated to be a decline of -0.5%/year (SE of 1.0%), not significant at the 0.05 alpha level, but it was estimated the probability the population was declining was 70%. The new aerial survey provides an additional estimate of abundance for 2018, and allows for a revision of the recent trend of the population, that we present here.

The methods used to estimate abundance and trends for the endangered Cook Inlet population have evolved since the aerial surveys began in 1993. In particular, a number of changes were introduced during the 2004 survey. The first was extending the timing of the survey from 1 week to 2 weeks (Hobbs et al. 2015). The second was to no longer break the upper inlet into multiple sectors that were sometimes surveyed on different days, with estimates from these sectors summed for an abundance estimate (e.g., Hobbs et al. 2000). Instead, from 2004 on, areas in the upper Cook Inlet (north of East and West Foreland) were surveyed in a single day, so each day, if logistics and conditions allowed, could provide an independent estimate of abundance (Hobbs et al. 2015, Shelden et al. 2015, 2017). This addressed the concern that groups of whales might move from one sector to another in the upper inlet between days during the 2-week period of the surveys.

Following the June 2016 abundance survey (Shelden et al. 2017), a major revision was made to the methods used to estimate group sizes from the survey. We developed a Bayesian approach to group size estimation that was applied to the 2004-2016 time series (Boyd et al.

2019) and is presented here along with results from the 2018 survey. This methodology replaces the estimation process used in the past. Group sizes for Cook Inlet belugas had previously been estimated using point estimation methods to obtain a series of correction factors to correct video and observer count data for various types of visibility bias. Correction factors were then applied sequentially to calculate an average estimated group size for each group (Hobbs et al. 2000, 2015). Bayesian methods are better suited for multistep analyses, in which estimates from one step are used as inputs in a subsequent step, because uncertainty is automatically propagated from one step to another. The approach developed by Boyd et al. (2019) was designed to address the same four types of bias as previous methods (Hobbs et al. 2000, 2015):

1) availability bias due to diving behavior (individuals unavailable in video data because submerged, hereafter "availability bias");
2) availability bias due to proximity in video data (individuals unavailable because concealed by another animal, hereafter "proximity bias");
3) perception bias (individuals not detected because of small image size) in video data; and
4) individual observer bias (i.e., the tendency for individual observers to under- or over-count whales) in visual observer data.

The main advantages to the change in group size estimation methods are as follows:

1) the Bayesian methods allow the variance in the parameter estimates to be fully propagated through the analysis, rather than just using point estimates to estimate correction factors, with a delta method then applied to approximate the variance. Use of Bayesian methods also allows for specification of distributions for some parameters, rather than just single values, to more completely consider uncertainty in the analyses;
2) for estimating the visibility bias correction factors (perception, availability, and proximity bias), the important assumption was added that the true group size was the same for all video passes of the same group (this assumption was not previously used in the analysis);

3) for availability bias, a prior distribution is specified for mean dive time for a beluga group; previously this was fixed at the single value of 24.1 seconds;
4) for perception bias, the analysis now simultaneously estimates two distributions as part of the integrated analysis – detection probability as a function of image size, and the distribution of image sizes for all individuals; previously, this was done as a separate *ad hoc* analysis.

The revised group size estimates for the 2004-2016 time period are available in Boyd et al. (2019: table S1: http://onlinelibrary.wiley.com/doi/10.1111/mms.12592/suppinfo).

We also undertook a detailed review of the completeness of each daily survey conducted since 2004, reviewed the viewing conditions for each day, and, as a result revised the criteria used to determine whether a day's survey was considered acceptable. It should be noted that small errors in calculation or designation of groups for 2004-2012 presented in Hobbs et al. (2015: table 1) and 2014 and 2016 in Shelden et al. (2015: table 3; 2017: table 3) were also corrected during this process and during the revision of the group size estimation methods.

Using the methods presented in Boyd et al. (2019), we estimated beluga group sizes for the June 2018 survey and calculated daily abundance estimates. Daily abundance estimates from acceptable days in each year were used to calculate an estimate of annual abundance for each year, and we calculate a smoothed trend line for the entire time-period for 2004 to 2018. We also present the exponential trend for the most recent 10-year period (2008-2018). In addition to the standard survey protocol, the 2018 aerial survey also included experimental days using Distance Sampling and Strip Transect survey designs, analyses of which are underway and will be presented in a future document.

METHODS

The 2018 index count and abundance estimate are based on data collected on four survey days (12, 13, 14, 15 June) following the "standard" sampling strategy used in Cook Inlet beluga abundance surveys since 2004 (see Chapter 1). The annual index of median counts by visual observers provides an indicator of relative abundance. The index is calculated directly from the observer counts for each survey year, without any calibration of individual observer bias. For each group, the median count by each observer is calculated based on counts rated excellent or good followed by the median of observer medians. As described in Chapter 1, these ratings are typically given a grade of A (excellent) or B (good) and are based on how confident the observer felt they would see whales in the field of view and on the accuracy of their counts. The resulting group medians are then summed for each survey day. For each year, the annual index value is the highest daily sum of median counts.

The annual abundance estimate is based on estimates of the size of detected groups, using Bayesian methods to account for various forms of visibility bias: 1) availability bias due to diving behavior; 2) proximity bias due to individuals concealed by another individual in the video data; 3) perception bias due to individuals not detected because of small image size in the video data; and 4) individual observer bias in visual observer data (see Boyd et al. (2019) for a complete description of methods). One slight modification to methods in Boyd et al. (2019) was to examine the effect of expanding the prior for the dive interval to attempt to capture more of the uncertainty around this parameter given it is based on behavior of a single whale.

Criteria were used in the past to determine if a daily survey was compromised. For example, if poor sighting conditions (gale force winds, glare, fog, etc.) affected counts and video in primary beluga habitats such as Chickaloon Bay, the Susitna Delta, and Knik Arm, usually the day was considered to be unacceptable. Additionally, logistics or other issues sometimes resulted in some areas in the lower part of the upper inlet (between the Forelands and Point Possession) not being surveyed. The area surveyed in the upper inlet has also been adaptively modified, with areas in the lower part of the upper inlet not surveyed every day if whales were not seen in those locations the day(s) before. Finally, in the past an *ad hoc* rule has also been used to discard survey days with a point estimate $\lesssim$60% of the highest daily point estimate that year, to attempt to minimize negative bias from days where it was thought possible that substantial groups of whales were missed during the survey day for some reason. We undertook a review of these criteria used to consider a survey day acceptable, and applied them retrospectively to all the survey days from 2004-2018. Combined with the new Bayesian group size estimation methods, this results in a new time-series of abundance estimates for Cook Inlet beluga whales from 2004 to 2018, which is different from the estimates previously reported (e.g., Hobbs et al. 2015; Shelden et al. 2015, 2017).

Determination of Acceptable Survey Days

Every survey day was reviewed to determine if it was considered an acceptable day. Several criteria were used to define an acceptable day. These include the following:

1. Good to excellent viewing and sighting conditions throughout the survey area, including little to no fog, little glare, and sufficiently low wind speeds that there were little to no whitecaps on the water.
2. Whales seen in medium to large size groups were sufficiently compact or linear (not widely scattered in many small subgroups) to allow for video pass recording of the group. In large groups the whales are sometimes widely scattered in many small subgroups, and because this prevents proper estimation of group size from the video data, this was deemed unacceptable. This was most often an issue when the Susitna Delta region was surveyed on a rising or high tide, and the whales had dispersed onto the mudflats.
3. The survey represented "complete" coverage of the upper Cook Inlet survey area. What represents complete coverage varies slightly from year to year, because the survey design was adaptive (see below).

No upper inlet survey day was considered complete, and therefore acceptable, unless the entire Susitna Delta (defined here as from North Foreland in the west to Point MacKenzie to the east), Chickaloon Bay, and Knik Arm were surveyed. The great majority of whales seen on the surveys were always found in these broad areas (but note that few whales have been seen in Knik

Arm at this time of year since 2007, although the whales still use Knik Arm in August and September (Castellote et al. 2016)). Fire Island was surveyed on nearly every survey day, as well. Turnagain Arm is more prone to high wind speeds than other areas, which makes surveying it difficult on some days. Because Turnagain Arm is not typically surveyed during high tide when tidal mudflats are submerged, there are generally few whales observed there. Since 2008, there have been 43 surveys of Turnagain Arm, and the largest number of whales seen there during a daily survey was five. Therefore, on a few days the survey was considered complete (and therefore acceptable) even if winds prevented Turnagain Arm from being surveyed, as long as Turnagain Arm had been surveyed on an adjacent day and few (<5) whales were seen. The same criteria applied to the few days Fire Island was not surveyed.

The areas in the upper inlet that were adaptively dropped from the surveys were essentially Trading Bay (North Foreland to West Foreland) on the west side of the inlet, and the area on the east side of the inlet from Moose Point (about 20 km southwest of Possession Point) to East Foreland. These areas were sometimes surveyed during the lower and middle inlet survey days. If no whales were seen on those surveys, or no whales were seen in those areas on the first upper inlet survey day, those areas were sometimes dropped from subsequent survey days. This was done primarily to allow for additional time for video passes of large groups in other areas. From 2004 to 2018, the area from Moose Point to East Foreland (and at times farther south to the Kenai River) was surveyed on 26 days without detecting any beluga whales, so the decision to adaptively drop this area seems sound. For Trading Bay, from 2004 to 2011 this area was surveyed on 16 days with no whales seen. However, in 2012, whales were detected in Trading Bay 7 out of 7 days it was surveyed. In 2014 and 2016, no whales were seen in Trading Bay on the 5 days it was surveyed. In 2018, as in 2012, beluga whales were seen in Trading Bay on 4 out of 6 days it was surveyed. The criteria for adaptively dropping this area has been more stringent in recent years given belugas appear to be using this area once again. Since 2012, Trading Bay has been surveyed on at least 4 days in each year (with the exception of 2014 when only one survey was conducted in Trading Bay).

In 2011, an unexpected change in aircraft for the survey resulted in having to film all video through a non-opening Plexiglas® window, in contrast to every other year where the video was obtained through an open window. The 2011 data were excluded from the trend analysis due to complications arising from these compromised video data.

Combining Daily Estimates to Calculate an Annual Abundance Estimate

In principle, every daily survey can serve as an estimate of abundance for the population. However, because the survey is an attempt to be a census of all the groups in the upper inlet, for accuracy it relies on the assumption that all substantial-sized groups in the upper inlet were detected. Therefore, in the past, each day's resulting abundance estimate has been reviewed to see if this assumption had been met. An *ad hoc* rule was used to judge whether a single day's estimate was so low that it indicated substantial groups were missed. If the point estimate for a day was less than ~60% of the highest daily point estimate that year, that day's estimate was discarded and not used (e.g., Hobbs et al. 2015). The annual estimate was then calculated as the mean of the remaining acceptable daily estimates (or sometimes the mean of the highest three remaining acceptable daily estimates).

There is some justification for this in that it is possible to miss one or more medium to large groups during a daily survey, and it is clear that this can happen on the survey. For example, if a group near the Susitna River moved offshore rather than remaining along the edge of the mudflats at low tide, as is typically observed, it could be missed. Similarly, if a group of whales happened to be transiting between the known high-use habitat areas (e.g., Chickaloon Bay and the Susitna Delta) in the upper inlet while the survey was conducted, it could also be missed. Therefore, there is an obvious mechanism that could result in an estimate on one particular day being too low because of a missed group or groups, such that the survey represents an incomplete census of groups. The variance between daily estimates within a year suggest this is possible. Assuming the precision of the daily abundance estimates is accurately estimated by the group size estimation methodology, there is more variance between the daily estimates than expected. For example, in 2012, the coefficient of variation (*CV*) of the daily estimates ranged from 0.055 to 0.064, whereas the *CV* calculated between the daily point estimates is higher at 0.113. Days with low estimates due to missed groups could be causing this additional variation between days from what are essentially low outliers.

On the other hand, review of the daily estimates shows that there are also several years with a single day that looks like a high outlier (e.g., 2010). Although it is not as obvious why there could be substantial positive bias in a daily estimate, the estimation process is complicated and it is difficult to be completely certain that there are no days with positive bias. For example, one possibility would be if whales were surfacing at very short time intervals in a relatively synchronized manner, as might happen if the whales were in very shallow water. Also, the logistics of estimating group size for some very large groups becomes difficult. For example, the highest daily estimate in 2010 was 568 on June 2nd, which was the sum of just two very large groups, one compact group in the Susitna Delta estimated to include 332 whales, and one group in Chickaloon Bay that was spread over five miles and estimated to include 235 whales. It is possible that the assumption of a binomial distribution for visibility correction factors may not always perform well if there is over-dispersion in the group size counts, and this could affect the magnitude of the correction, given that the mean and variance of the binomial are the same parameter. This potentially adds model uncertainty to the estimated group sizes that would not necessarily be captured by the probability intervals calculated from the assumed model. Therefore, the possibility of days that are high outliers cannot be completely discounted.

In light of this, the *ad hoc* 60% rule that has been used for rejecting days that appear too low is problematic. First, it does not take into account the precision of the estimates. If low estimates are discarded but are simply due to sampling error (i.e., the *CV* or precision of a group size estimate determines a distribution about the true group size, and our estimate is just a single value 'sampled' from that distribution), this would introduce positive bias into the annual abundance estimates. One could devise a different test for low outliers that took account of the precision of the estimates. However, comparing to the highest daily estimate, if it was itself biased high, would also be problematic.

Additionally, the use of a rank-order statistic, such as the single highest daily estimate in a year, under the logic that this addresses the negative bias of low outliers from missed groups, is problematic because it is a function of sample size (i.e., the number of acceptable survey days available in a year). If we had the same number of acceptable days available each year, this would not be an issue, but that is not the case. Some years have only two acceptable days, whereas several other years have as many as five acceptable days. The expectation of a rank-order statistic, such as the highest day, will be correlated with sample size, and therefore be higher for years with more acceptable days. This is also problematic for the previous rule of taking the mean of the highest three or more days, which will also have a positive correlation with sample size.

Therefore, we decided to stop using the *ad hoc* 60% rule to drop days with a low abundance estimate, and we no longer discard days just because the abundance estimate is low. Instead, we have chosen to calculate the median of the acceptable daily abundance estimates, and consider this the point estimate of abundance for that year. In general, the median has the property in that it is a more robust estimate of central tendency than the mean. Therefore, it was used to limit the potential effect of outliers in the daily abundance estimate, which may have substantial negative or positive biases.

We calculated a posterior distribution for the median of the daily abundance estimates as follows. Abundance for each day in a year was randomly sampled from the posterior distribution of abundance estimates for that day, and the median of that sample was calculated across all days in that year. This was repeated 1,000 times, calculating a median each time, to create a posterior distribution for the median abundance in that year.

We recognize and acknowledge that, given the above, our abundance estimates may have an unknown degree of negative bias if medium- to large-sized groups are missed on many survey days. On the other hand, if groups are not missed, as is possible, the median across days may not have a lot of negative bias. Hobbs et al. (2000) estimated the fraction of groups that were missed during the surveys from paired, independent records of the primary observers on the shoreward side of the aircraft, under the assumption that detection was a function of group size. The correction for whales in missed groups was 1.015 (CV = 3%) for the years 1994–98 and 1.021

(CV = 1%) for the years 1999 and 2000 (Hobbs et al. 2000), indicating very few groups were missed. However, as pointed out in Boyd et al. (2019), such a small correction factor is inconsistent with some of the large interdiel variation in total group size seen during the surveys in some years. This correction is a correction for groups close enough to the plane to be seen, but does not correct for groups in locations that are not surveyed. The potential effect of missed groups will be revisited in the discussion.

Estimating Trend and Calculating the Best Estimate of Current Abundance

To estimate the overall trend, and calculate the best estimate of current abundance, we have smoothed the estimates using a weighted moving average, with a window size of 5 (2 steps back, 2 steps forward), and exponential weights (where the weight decreases by 0.5 each time step). Note that for the last, most recent, estimate in 2018, the smoothed estimate is therefore a weighted average of the last three estimates, with weights of 1.0 (2018), 0.5 (2016), and 0.25 (2014) (scaled weights of 0.571, 0.286, and 0.143, respectively). A Bayesian posterior distribution for smoothed population size in each year was calculated by sampling from the posterior distribution for the median abundance in each year, calculating the smoothed trend for each year, and then storing the smoothed abundance from each sampling iteration.

We consider the smoothed estimate of abundance to be the best estimate of abundance in each year, because it uses more data to estimate abundance in each year than just the annual estimate from the survey data from only that year. This makes the smoothed estimate more precise than the annual estimate, and reduced the small up and down ‘bumps’ that occur from year to year, and should be closer to the true abundance of the population.

Estimating the trend for the most recent 10-year time period (2008-2018)

To estimate the trend for the most recent 10-year time period, we have calculated a Bayesian linear regression of the natural logarithm of abundance in each year. This represents an exponential model for the rate of change of the population, with the estimated slope of the regression representing the rate. The Bayesian regression was done by sampling from the posterior distribution for median annual abundance in each year, fitting a simple linear regression of natural log of abundance, and then storing the estimated slope parameter from each iteration. This estimates a posterior distribution for the slope, or rate of change in the population. Model-predicted abundance in each year was also stored to calculate a posterior distribution for the predicted regression model. This is analogous to a weighted regression, as the precision of the abundance estimate in each year is implicitly accounted for in the estimated parameters by sampling from their posterior distributions.

RESULTS

In 2018, 36 beluga whale groups were detected over the four standard survey days. Only two of the four survey days were considered acceptable. On June 12th, Trading Bay was not surveyed due to logistical reasons (i.e., reserving sufficient fuel for the plane to complete the upper inlet survey and arrive during the low tide in the Susitna Delta). However, on the subsequent day (June 13th), Trading Bay was surveyed and two groups were seen, estimated to be 79 and 15 whales, respectively, for a total of 94 whales. Assuming those same groups were present in Trading Bay the previous day essentially accounts for the discrepancy between the total abundance estimate for the two days. Therefore, given the presence of whales in Trading Bay on June 13th, the survey on June 12th was considered incomplete, and therefore not acceptable. On June 15th, high winds in the Susitna Delta compromised video and counting passes, making that survey day unacceptable.

On the two acceptable survey days (i.e., 13 and 14 June), 9 and 12 groups were detected per day, compared to a median of 4 per day (range: 1 to 12) on 'complete' survey days from 2004 to 2016 (Boyd et al. 2019). Including incomplete survey days, observers were able to make one or more excellent/good counts on 33 groups (Table 1). Excellent/good video data were also obtained for 26 of these groups. The survey team was unable to collect excellent/good video or excellent/good observer counts for one small group each on 13, 14, 15 June (Group 11, Group 9, Group 2, respectively). These three groups were not included in the index of median counts or abundance estimates, but are presented in Table 1 (note: these groups are included in observer count medians presented in Table 1 in Chapter 1). Due to limited fuel, it was only possible to implement a single counting pass for Groups 9, 10, 11, and 12 on June 13th. The median observer count for Group 9 was 58 whales for the left-side of the aircraft, and 32 whales were also counted on the right-side of the aircraft. Left-side and right-side counts were combined for the purposes of abundance estimation, but additional whales were possibly missed if they were directly below the aircraft. Because using a single survey day is not considered optimal, and we had good counts for most groups on June 13th and 14th, both days were considered acceptable noting that Group 9 on June 13th did not meet criteria 2.

Daily sums of median counts for the four standard survey days were 111, 190, 131, and 76 for 12, 13, 14, 15 June, respectively, excluding a few small groups (as mentioned above). The 2018 annual index of median counts (i.e., the highest daily sum of median counts) was 190 whales (Table 2). This falls within the range of annual index counts collected in June aerial surveys from 2004 to 2016 (Table 3).

Table 1. -- Beluga whale groups in Cook Inlet, Alaska, June 2018, included in the index of median counts and abundance estimates. The "CV" of the Bayesian group size estimate is the standard deviation of group size estimates divided by the mean. Groups without counting passes were not included in the Bayesian abundance estimation analysis (see Table 2). Note: median group counts were rounded up when the final median included a "partial" whale (e.g., group 6 on 6/12 was 74.75 whales), depending when rounding occurred (by group, by region, or by day) resulted in overall daily counts that may vary by a few whales (+/- 1 to 4; see Chapter 1 (Table 1) and subsequent tables in this chapter).

						Bayesian group size estimate		
Date	Flight	Group	Location	Effort	Median count	Median	Mean	CV
6/12/2018	9	1	Turnagain Arm	On	1	2	3	0.308
6/12/2018	9	2	Chickaloon Bay bluffs	On	8	17	17	0.154
6/12/2018	9	3	Moose Point shoals	On	5	8	8	0.152
6/12/2018	9	4	Moose Point shoals	On	2	2	2	0.395
6/12/2018	9	5	North Foreland-T dock	On	4	6	6	0.210
6/12/2018	9	6	Beluga to Ivan River	On	75	126	127	0.121
6/12/2018	9	7	Susitna River	On	11	17	17	0.151
6/12/2018	9	8	Little Susitna River	On	6	8	9	0.175
6/13/2018	10	1	Chickaloon River mudflats	On	10	17	17	0.157
6/13/2018	10	2	Chickaloon River mudflats	On	4	7	7	0.196
6/13/2018	10	3	Chickaloon Bay bluffs	On	5	9	9	0.171
6/13/2018	10	4	Point Possession	On	3	4	4	0.279
6/13/2018	10	5	Moose Point shoals	On	2	4	4	0.222
6/13/2018	10	6	Trading Bay	On	52	79	79	0.110
6/13/2018	10	7	North Foreland-T dock	On	9	15	15	0.166
6/13/2018	10	8	Tyonek	On	3	6	6	0.236
6/13/2018	10	9	Beluga to Ivan River	On	90	147	149	0.173
6/13/2018	10	10	E tributary Susitna River	On	3	5	5	0.662
6/13/2018	10	11	E tributary Susitna River	On	3*	-	-	-
6/13/2018	10	12	W of Little Susitna River	On	10	16	17	0.278
6/14/2018	11	1	Chickaloon River mouth	On	3	4	4	0.245
6/14/2018	11	2	Chickaloon Bay bluffs	On	6	9	10	0.186
6/14/2018	11	3	Trading Bay-Middle River	On	17	26	26	0.143
6/14/2018	11	4	Trading Bay-Nikolai Creek	On	4	8	9	0.104
6/14/2018	11	5	Tyonek to Three Mile Cr	On	11	20	20	0.154
6/14/2018	11	6	Beluga to Ivan River	Off	73	128	129	0.113
6/14/2018	11	7	Susitna River	On	13	22	22	0.125
6/14/2018	11	8	Little Susitna River	On	6	10	11	0.168
6/14/2018	11	9	W of Pt MacKenzie	On	2*	-	-	-
6/15/2018	12	1	Chickaloon River mouth	On	2	3	3	0.282
6/15/2018	12	2	Chickaloon Bay mudflats	On	2*	-	-	-
6/15/2018	12	3	Chickaloon Bay bluffs	On	6	8	8	0.163
6/15/2018	12	4-6	Repeat count: groups 1-3	On	-	-	-	-
6/15/2018	12	7	Trading Bay-Middle River	On	11	17	17	0.148
6/15/2018	12	8	Chuitna to Beluga River	On	7	10	11	0.176
6/15/2018	12	9	Beluga River	On	36	57	57	0.128
6/15/2018	12	10	Susitna River	On	16	28	29	0.160

*= no counting passes

Table 2. -- Daily sums for standard surveys of the upper Cook Inlet during the June 2018 beluga whale aerial survey. The "CV" of the Bayesian group size estimate is the standard deviation of group size estimates divided by the mean.

		Sum of Bayesian group size estimates				
Date	Sum of median counts	median	mean	5h percentile	95th percentile	*CV*
6/12/18	111	188	189	155	237	0.109
6/13/18	190	310	313	244	399	0.120
6/14/18	131	228	231	195	281	0.097
6/15/18	76	124	125	102	154	0.105

Table 3. -- Annual estimates of the sum of detected group sizes from aerial surveys of beluga whales in upper Cook Inlet in June, calculated as the median across all acceptable days within a year. The Best estimate of abundance (N) uses a weighted moving average to smooth the Point estimates (see Figure 2). The "CV" of the Bayesian group size estimate is the standard deviation of total group size estimates divided by the mean. Note: 2011 was excluded from the trend analysis due to complications arising from having to shoot all video through a non-opening Plexiglas® window.

	Index	Point estimate					Best estimate				
Year	count	N	L95	U95	*CV*(N)	20th %ile	N	L95	U95	*CV*(N)	20th %ile
2004	187	238	208	280	0.079	224	257	235	284	0.049	270
2005	192	285	249	329	0.072	269	280	260	305	0.041	279
2006	151	268	229	318	0.085	250	289	269	314	0.040	279
2007	225	358	315	416	0.073	338	318	295	343	0.038	308
2008	132	283	261	318	0.051	273	323	304	344	0.031	314
2009	301	342	301	389	0.067	324	346	323	373	0.036	337
2010	290	415	353	489	0.085	388	369	339	400	0.042	356
2012	318	336	306	373	0.051	323	353	333	376	0.031	344
2014	334	379	337	426	0.059	363	338	317	360	0.033	329
2016	298	247	217	287	0.077	232	293	271	318	0.040	284
2018	190	269	227	333	0.103	250	279	250	317	0.061	267

For the estimates of group size, all models converged, as indicated by visual inspection of trace plots, posterior predictive checks, and the Gelman-Rubin statistic. The Deviance Information Criterion (DIC, Spiegelhalter et al. 2002, Gelman et al. 2003) indicated substantially greater support for a zero-truncated normal model for image size distributions versus a lognormal model (ΔDIC = 28.7).

Median correction factors for availability bias, perception bias, and individual observer bias were within the range of median correction factors estimated for previous survey years (2004-2016). The median estimate of the percentage of individuals available at the surface during video clips was 55.1%, consistent with the median percentage calculated from the data (53.5%) assuming a constant surface-dive interval of 23.0 seconds (based on data collected by Lerczak et al. 2000). Expanding the prior for the dive interval only slightly decreased the median abundance estimate by a few whales (Appendix Table A1). The estimate of proximity bias, calculated from matched video clips, was 2.9%. The median estimate of the percentage of available individuals that were detected in video clips was 71.5%. This is lower than in previous years with similar video technology and aircraft setup (i.e., 2012-2016; see Fig. 1), but is consistent with the size distribution of measured individuals in video clips. The median ratio of observer counts to video counts was 1.63:1. The median estimated correction factor for observer bias was 1.64 (i.e., on average, observer counts were 60.9% of the estimated group size).

Median group size estimates indicated smaller groups than in previous years (median = 11 whales), but estimated group sizes were highly variable (range: 2 to 147 whales) as in previous survey years (Boyd et al. 2019). Total group sizes (i.e., the sum of detected group sizes) for the four standard survey days are shown in Table 2. For the two complete survey days (i.e., June 13, 14), the daily total group size estimates are, on average, 1.69 times greater than the daily sums of group medians (range: 1.63-1.74). The highest median Point estimate for 2018 falls slightly below the range of highest median estimates for surveys from 2008 to 2016 (median: 314-568 whales) if 2011 is excluded (Table 3).

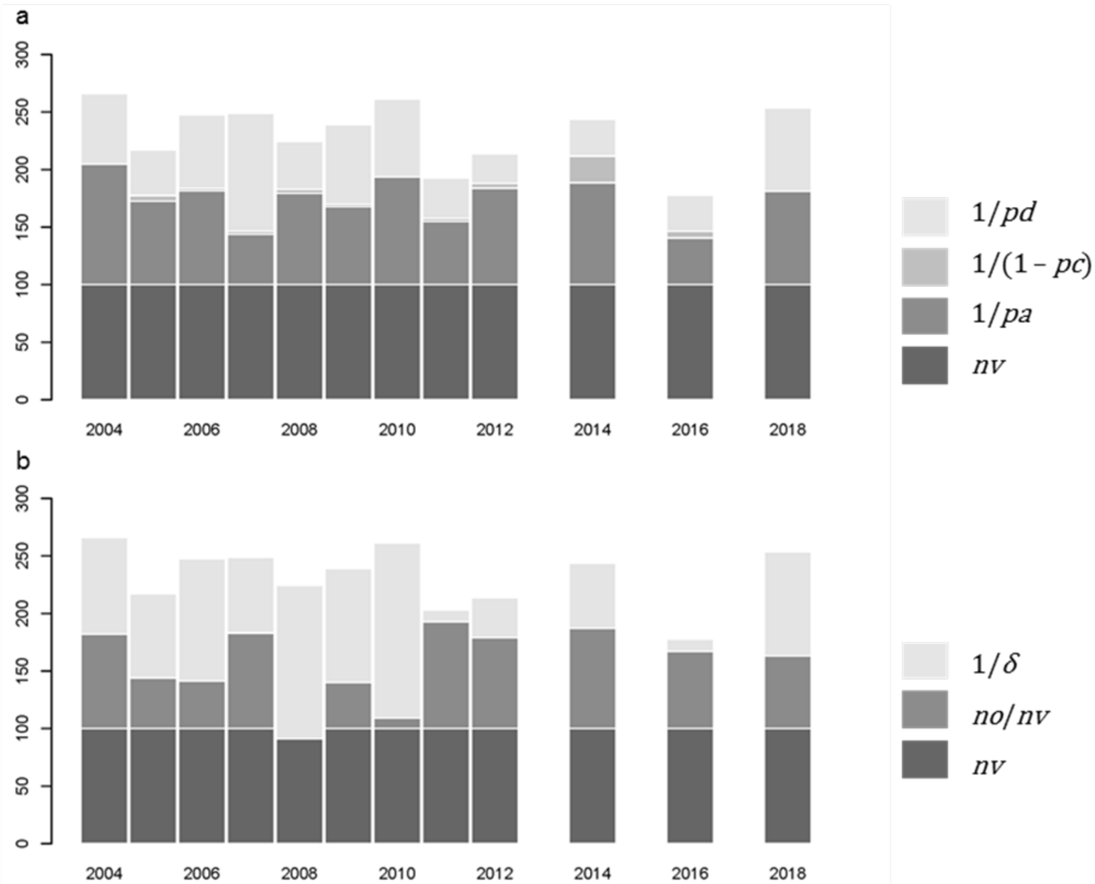

Figure 1. -- (a) Standardized representation of median correction factors for video counts by survey year (pa is availability bias; pc is proximity bias; and pd is detection bias), based on 100 hypothetical individuals detected in a wide-angle video clip (nv) in each survey year. (b) Standardized representation of the median correction factor for observer bias (δ) by survey year, based on 100 hypothetical individuals detected in a wide-angle video clip (nv) in each survey year. no/nv is the ratio of observer counts to video counts; and 1/δ is the median correction factor for observer bias.

Abundance in 2018

The annual point estimate of abundance for 2018, based on the median of all acceptable daily estimates in 2018, is 269 (CV = 0.103, 95% probability interval 227 to 333). The best estimate of 2018 abundance for the Cook Inlet beluga population from the aerial survey data is

279 (CV = 0.061, 95% probability interval 250 to 317). This best estimate is based on the estimate of smoothed abundance for 2018.

Trends in Abundance

The revised time-series now shows a clear pattern in the trend in abundance; the data indicate the population was initially increasing but then started declining after 2010 (Fig. 2). Over the most recent 10-year time period (2008-2018), the estimated trend in the abundance estimates (Fig. 3) is a decline of -2.3%/year (95% PI -4.1% to -0.6%). The abundance estimates indicate there is a 99.7% probability of a decline, and a 93.0% probability of a decline that is more than 1% per year.

Given the importance of the revision to the group size estimation method in Boyd et al. (2019), daily abundance estimates using both methods are plotted in Figure 4 for all acceptable survey days (see Appendix Table A2). To compare the influence of the revised group size estimation method on the trends in abundance, the annual estimate of abundance is plotted for both group size estimation methods, using the same selection of acceptable days, and in both cases using the median across the daily estimates as the annual estimate of abundance (Fig. 5).

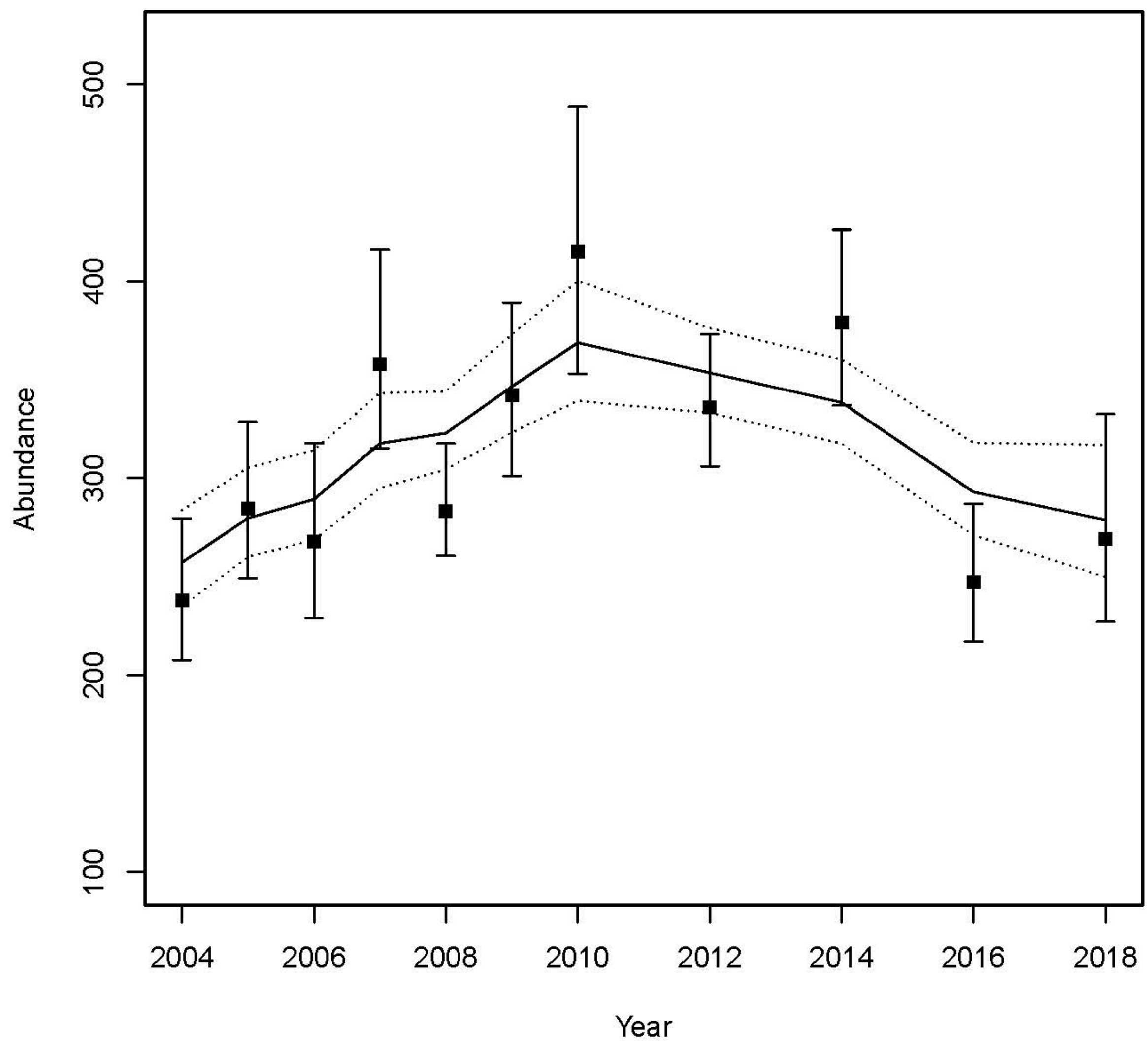

Figure 2. -- Annual abundance estimates (squares) and 95% probability intervals (error bars) for the reanalyzed survey period 2004-2016 with results from 2018. The moving average is also plotted (solid line), with 95% probability intervals (dotted lines).

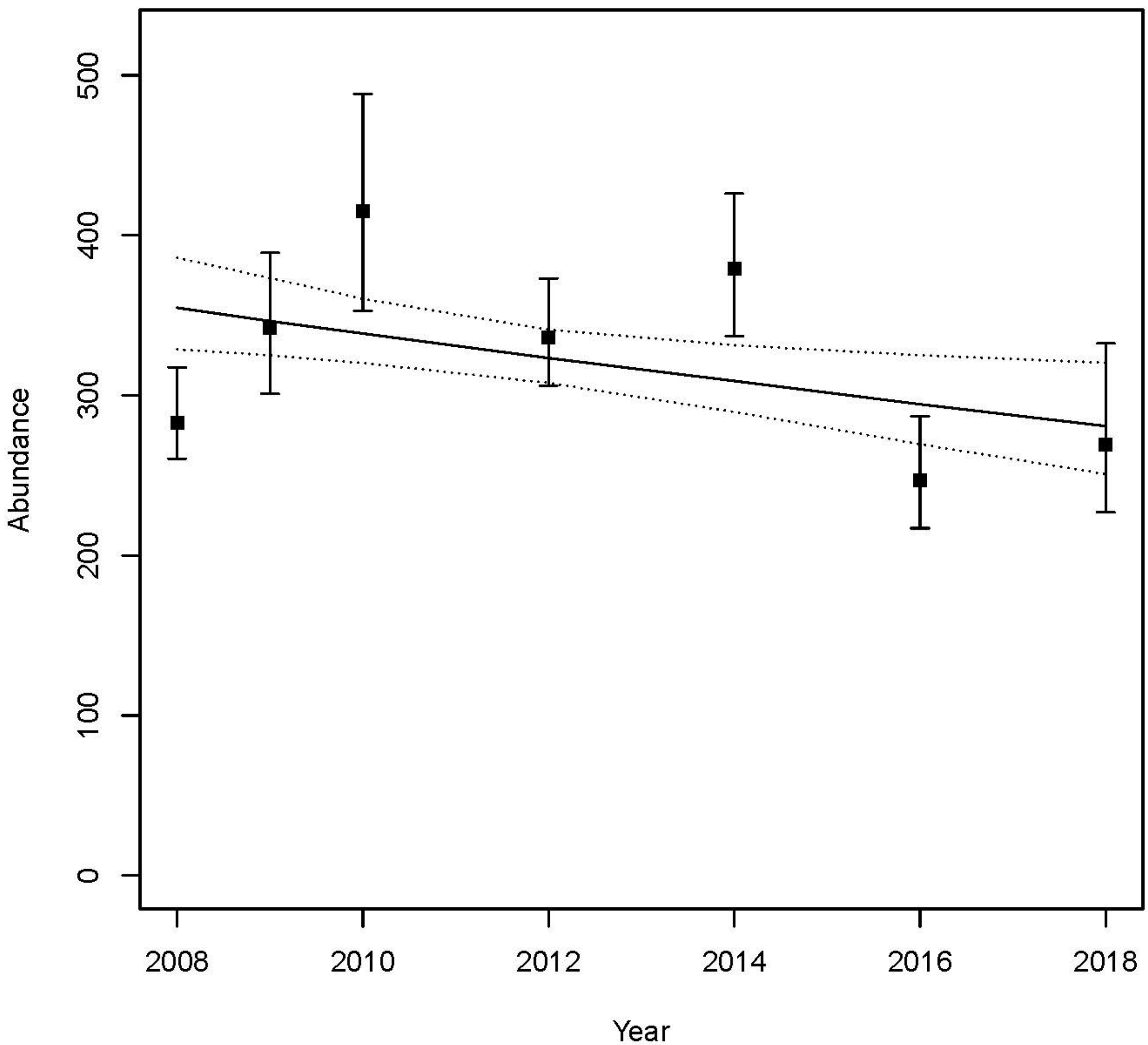

Figure 3. -- Estimated exponential trend of the population over the most recent ten-year time-period (2008 to 2018), estimated as a linear regression on the natural logarithm of abundance in each year. The solid line represents the Bayesian predicted model, with 95% probability intervals (dotted line).

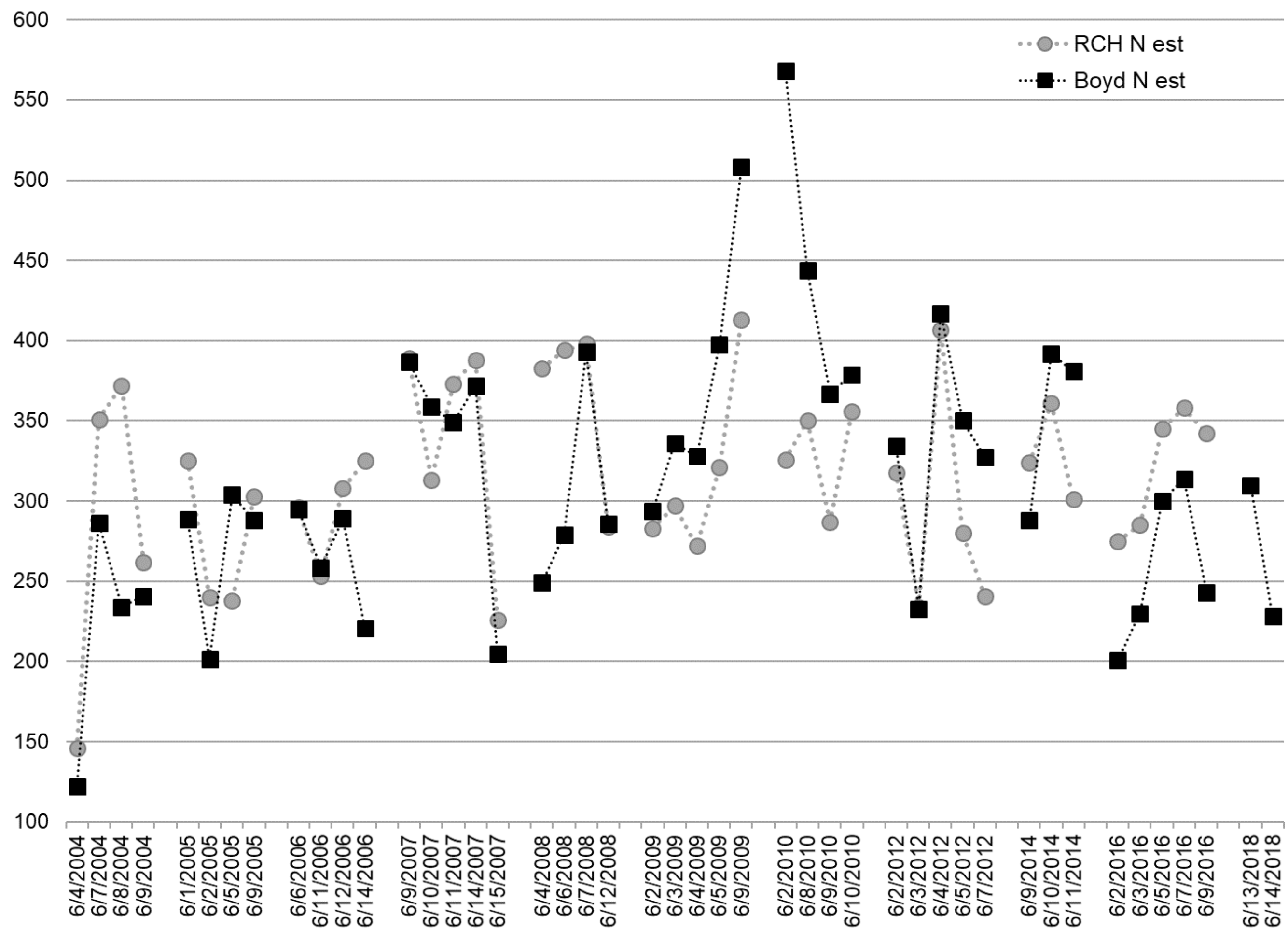

Figure 4. -- Daily estimates of abundance for both group size estimation methods. RCH N est = previous estimation method. Boyd N est = revised Bayesian estimation method.

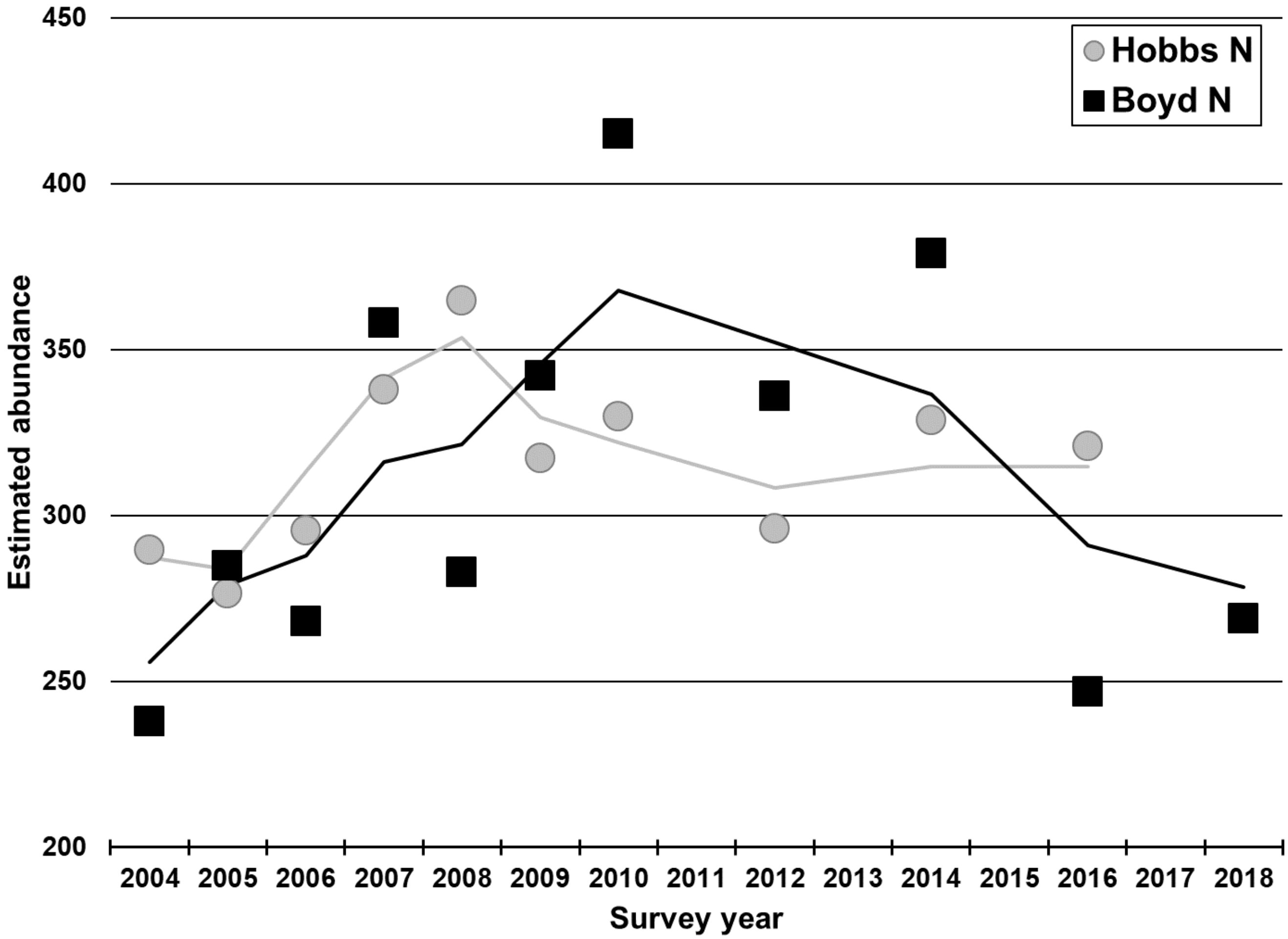

Figure 5. -- Annual estimates of abundance for both group size estimation methods. The moving average of each set of estimates is also plotted.

DISCUSSION

Trends in Abundance

The previous estimate of the trend in the population, after the 2016 survey estimate was calculated, resulted in a roughly stable trend with only a slight decline that was not significant (e.g., Shelden et al. 2017). Our results are quite different, showing an increase from 2004 to ~2010, and then a highly significant decline since then, so it is important to understand why that is the case. We examine the reasons for the change in estimated trend in detail. Four things have changed since the previous trend estimate that could have contributed to the different results:

1) An additional survey makes an estimate available for 2018,
2) a change was made to what constitutes an acceptable survey day (and the *ad hoc* 60% rule was dropped),
3) a change was made to use the median versus the mean of all acceptable days for an annual estimate, and
4) a substantial revision of the methods used for estimating group size was implemented (Boyd et al. 2019).

A comparison of daily estimates of abundance on acceptable days using the methods of Hobbs et al. (2015) versus those of Boyd et al. (2019) show a high level of concordance (Fig. 4). To examine the effect of just the revised group size estimation method on the overall trend, we compare annual estimates for each method (Fig. 5) when the same criteria has been used for selecting acceptable survey days, and with both sets of estimates using the median across days to estimate annual abundance. In this comparison, it can be seen that the general signal (from the moving average) is similar – an increase in the early years of the time period, followed by a decline in the latter half of the time period. Therefore, it can be seen that the change in trend over the time period is not solely due to the change in group size estimation methods; although the change in methods does shift the “peak” of the trend to 2010 (from 2008), and does, along with the new, relatively low, 2018 abundance estimate, cause the decline over the last 10 years to be more severe. Therefore, using the group size estimation method of Hobbs et al. (2015), the revision of what represents an acceptable day, along with the cessation of the *ad hoc* 60% rule, does lead to a similar trend through time. This is due to three more days being included in the annual abundance estimates, and excluding a day with a particularly high abundance estimate in 2004 (see below). The addition of a low estimate in 2018 contributes to the estimation of a decline in the most recent 10-year period.

The change in group-size estimation methodology also contributed to the declining trend result by lowering the estimate for 2016 substantially. The only change in the trend analysis that did not contribute to the new trend was the use of the median across days rather than the mean. Using the mean across days gives a nearly identical trend through time, and also leads to a high probability of decline over the last 10 years (results not shown).

It is worth examining the most important years that have influenced the trend, and the most important days within those years, to see where the greatest changes have occurred. Figure 5 shows there were three years (2004, 2016, 2018) that contributed the most influence to the change in resulting trend, and another three years (2008, 2009, 2010) that contributed substantially to the shift in peak abundance. We examine those years, and influential days within those years, in detail here.

2004

In Hobbs et al. (2015), this estimate is much higher (366), and it effectively masked what is now seen as an increasing trend after this year. We now estimate this year to be the low point of the time series. The change in annual abundance for this year was primarily due to which days were considered acceptable, but also shows what might have been positive bias for one very large group size estimate using the methods of Hobbs et al. (2015).

6/3/2004: This day had been included, but on review, the day was found to be unacceptable because there were poor viewing conditions in Chickaloon Bay and Turnagain Arm. No groups were seen in Chickaloon Bay and Turnagain Arm, whereas groups were seen there on four subsequent days and two subsequent days, respectively. The estimated abundance of this day using the new methods is 180, so it is likely that missed groups led to this being a negatively biased abundance for the day.

Previously, this day was a high outlier when compared to the other days in this year, because the estimate in Hobbs et al. (2015) for this day was 443. When averaged across days, this had the effect of substantially raising the abundance at the beginning of the time-series, which removed most of what is now seen as an apparent increase in abundance between 2004 and 2018.

Examining the individual groups that were seen that day, the high estimate reported in Hobbs et al. (2015) was due to a single large group in the Susitna Delta, with 8 video passes with visual counts ranging from 80 to 137 whales. Although there were eight video passes, under analysis only one video pass was deemed suitable for counting because the others had too many waves and whitecaps. The video count for that one pass was 152. The group size was estimated to be 424 by Hobbs et al. (2015), which is the largest estimated group size for any group for the entire time period. The group size is estimated to be 171 in Boyd et al. (2019), a substantially smaller estimate. This suggests that the previous group size estimation method did not estimate the size of this group very well, and possibly contributed substantial positive bias into the estimate. The presence of lots of waves and whitecaps made the collection of video data poor, and contributed to why this day is now considered unacceptable.

Even if this survey day was still included (it is not), the estimate for this day is now 180, and so there would no longer be a high estimate overall for 2004. Use of the median across days, rather than the mean, would have also diminished the influence of this single group previously, as the use of the median will diminish the influence of both high and low outliers.

6/4/2004. This day was previously excluded by the *ad hoc* 60% rule, but is now included. This was a complete survey with excellent viewing conditions. The change is group size estimation method did not change the estimate for the day very much (Fig. 4). The day's estimate was low (122), and presumably the survey missed some groups this day, but we include it because it met the criteria for an acceptable day. The use of the median across days is intended to diminish the influence of outliers such as this day. The inclusion of this day had a minimal effect on the annual estimate (238 when included vs. 241 when excluded).

2008

Under the previous methods, this year is the peak in abundance of the time-series, whereas now 2010 is the peak (Fig. 5). The main reason for this being the peak for the previous method is because two days were substantially higher than they are now estimated to be as follows:

6/4/2008. The estimate under the previous method was 383 (the third highest group size estimate in the time-series), whereas now it is 249. Only one very large group was seen this day, and represented the abundance estimate for the day. Given how much larger it was, the previous group size methodology may have over-estimated the size of this group compared to the current method. There were seven successful video passes of this group, with video counts ranging from 122 to 205.

6/6/2008. Similar to 6/4, one very large group represented most of the estimate for the day. Under the previous method the estimate was 387 (the second highest group size estimate in the entire time-series), whereas now it is 265. Only one other group, estimated at 14 whales, contributed to the total for the day. Although there were fourteen passes of the large group, only four led to successful video data being collected, with video counts ranging from 146 to 236. Problems on other passes included glare on two passes, whales too close to the plane so not captured in the video on two passes, other camera alignment or timing issues, and issues with the whales being too spread out. This highlights difficulties that can occur when attempting to collect good video data from the very largest groups.

2009

Two days are substantially higher in 2009 using the Boyd et al. (2019) methodology, contributing to shifting the peak in abundance to 2009/2010 from 2008.

6/5/2009. Two large groups, one estimated to be 217 (previously 181) and another estimated to be 136 (previously 99).

6/9/2009. This day was dominated by one very large group with the group size estimated at 330 now, where previously it was estimated to be 252.

2010

Three days are substantially higher in 2010 using the methods of Boyd et al. (2019), which resulted in this year becoming the peak in abundance for the time-series.

6/2/2010. The estimate for this day is now 568 whereas it was 326. There were only two very large groups seen, estimated at 332 (previously 200) and 235 (previously 126). For the first group, there were nine video passes, but successful video was collected on only three of the passes as there were difficulties on the other passes in getting all the whales in the frame. For the second group, five of the eleven video passes were successful.

6/8/2010. The estimate for this day is now 443, whereas it was 351. The majority of the difference was due to one group now estimated at 118, whereas before it was estimated to be 69 whales.

6/9/2010. The estimate for this day is now 367, whereas previously it was 287. Most of this difference came from two large groups, estimated at 183 (previously 144) and 109 (previously 88).

2016

The estimate for this year, 243, is much lower than the previous estimate of 342. This now contributes a low estimate near the end of the time-series, the result being the decline now observed in the last ten years. The new estimates are lower on all five days, but are particularly low on three days with large groups.

6/2/2016. The estimate for this day is now 201, whereas previously it was 275. This is mainly due to one large group now estimated at 100 (previously 139).

6/3/2016. The estimate for this day is now 230, whereas previously it was 285. This is mainly due to one large group now estimated at 172 (previously 214).

6/9/2016. The estimate for this day is now 243, whereas previously it was 342. This is mainly due to one large group now estimated at 163 (previously 230).

2018

The new estimate available for 2018 calculated in this document adds a second very low value to the end of the time-series, contributing to the estimated decline, which was not part of the estimated trend in Shelden et al. (2017).

Other changes

Two other days that were previously excluded, but are now included (6/15/2007, 6/3/2012), had very little influence on the annual abundance estimate for those years (annual estimates of 359 when included vs. 366 if excluded in 2007, and 351 when included vs. 342 if excluded in 2012).

CONCLUSIONS

Overall, the two changes to the methods that had the most influence on the revised abundance trends presented here were: 1) developing more objective criteria for what represents an acceptable survey day, including dropping the *ad hoc* 60% rule to discard survey days with low value, and 2) revising the group size estimation methods. The change in group-size estimation methods helped clarify the trend by making the estimates more consistent from year to year, identified a previously undetected peak from 2004 to 2010, and lowered the estimate in 2016. The increase in abundance in the early part of the time series, followed by a decline over the last ten years, would have still been present if we had used the group-size estimation methods of Hobbs et al. (2015) (Fig. 5). The change in group-size estimation methodology did not result in group-size estimates uniformly becoming larger or smaller, as noted in examples above. The addition of the new estimate in 2018 that is relatively low, also contributes to the estimation of a decline over the last 10 years.

The close examination of influential days that changed substantially due to the revision to the group-size estimation methods showed that in nearly every case the substantial change was due to a revision to the group size estimate of a large or very large group or groups. This is not surprising, as the large and very large groups, when found, are always very influential to the day's abundance estimate. It is apparent that there is potentially high variability in the estimation of group size for large and very large groups, which could contribute to both positive and negative bias in the daily abundance estimates. As noted above, this could be partially due to model mis-specification from the assumption of a binomial distribution for the visibility correction factors, if there is over-dispersion in the group size video counts because of the large groups. The use of the median across days likely makes the estimation of annual abundance more robust to these potential biases that may cause outliers on some days.

As mentioned above, one caveat to consider is the issue that on some days it seems apparent that a substantially sized group or groups may be missed by the survey, such that the survey does not actually represent a census of all groups in the upper Cook Inlet. It is important to consider what affect this might have on the estimated trend in the data. As discussed, the use of a median across days should make the annual estimate more robust to low outlier days from this issue, as long as days with substantial-sized missed groups do not occur too often. As we have noted above, there are no data from which we can estimate the probability that groups were missed because some groups were not in the area which was surveyed.

An inspection of the inter-day variability of the daily estimates within a year can suggest what may be occurring, though it cannot lead to definitive conclusions. Over the 11 years with estimates from 2004 to 2018 (Fig. 4), it can be seen that in six years (2004, 2005, 2006, 2007, 2012, 2014) all the daily estimates except one are clustered at a higher value, with the one exception being a low outlier day (2018 may also fit this pattern, although it cannot be determined with only two acceptable survey days). One explanation for this outcome is that there was only one day each year where a substantially sized group or groups were missed, and the other days represent unbiased estimates of the true population size. An alternative explanation for this outcome is that similar sized groups were missed on all days during the survey except one day, on which even more groups were missed. The first explanation seems more likely, unless a commonality explains why the same size group(s) could be missed on nearly all the days. Groups seen away from foraging hot spots such as river mouths are often smaller groups, and may represent groups of whales that are moving between foraging locations; it seems unlikely that similar sized groups would be moving between foraging locations on every day and therefore be missed leading to the same negative bias on each of the days. This suggests that it may be that substantial sized groups are only missed on a minority of the days, although there is no way to make a definitive conclusion about this.

In three other years (2008, 2009, 2010), most of the daily estimates were clustered around a lower value, with a single high outlier day that was much higher than the other days. As discussed, the abundance estimates were driven predominantly by one or two very large groups on those high outlier days, with the possibility that these very large groups have positively biased group size estimates. If this is the case, it may be that there are no days with substantially sized group(s) missed. An alternative explanation is that the one high day in each of these three years is actually closest to the true population size, and similarly sized group(s) were missed on all the other days. Again, the first explanation seems more likely, but there are no data from which to make a definitive conclusion about missed groups. The one remaining year (2016) has two higher and three lower estimates, and so could represent a year where substantially sized groups were missed on three days, or large groups were over-estimated on two days.

This method is an improvement over the last iteration (Hobbs et al. 2000, 2015), with a substantially improved model structure, and represents the best available science applied to Cook Inlet beluga whale abundance and trend determinations. However, there are some model inadequacies that have been identified, and future analyses, simulations, and model development are planned. In particular, the potential for positive bias due to measurement error impedes our ability to make a definitive inference about the magnitude of the downward trend in abundance. In addition, there is the issue of missed groups. If the number of survey days with substantially-sized, missed group(s) is relatively low, this should represent a true decline in the Cook Inlet beluga population. Alternatively, if the proportion of the population in groups that are missed is relatively consistent on most days, the abundance estimates should still represent a true decline in the Cook Inlet beluga population. On the other hand, if the number of days with substantially-sized, missed groups is large, and the proportion of the population missed is highly variable, then the estimates of trend calculated here could be subject to unknown bias.

Currently, our results indicate there is a high probability that there has been a substantial decline in the estimates of abundance for the Cook Inlet beluga whale population over the last ten-year period. The decline is estimated to be -2.3% per year, with a high probability the abundance is declining by at least -1% per year (93.0%), and a moderate probability (64.8%) the abundance is declining by at least -2% per year. A survey is planned for June 2020, and this will allow for further examination of the trend in abundance of this population.

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CHAPTER 2 APPENDIX

Appendix Table A1. -- *Dive interval:* Results as per Boyd et al. (2019) for the June 2018 aerial survey (A), and results based on expanded prior for the dive interval for the June 2018 aerial survey (B).

A). Day	**Minimum**	**20th percentile**	**Median**	**80th percentile**	**Maximum**
June 12	138	172	188	206	262
June 13	220	282	310	342	465
June 14	172	212	228	249	323
June 15	92	114	124	135	175
B).					
June 12	139	170	186	204	273
June 13	227	279	306	341	447
June 14	180	211	227	247	329
June 15	87	112	123	135	167

Appendix Table A2. -- Determination of acceptability for inclusion in the annual Cook Inlet beluga whale abundance estimates calculated for the period 2004-2018.

Date	Decision	Comments
6/2/2004	Not acceptable	No survey in Chickaloon Bay or Turnagain Arm
6/3/2004	Not acceptable	Poor visibility in Chickaloon Bay and Turnagain Arm, no whales found. Whales were seen in these areas, however, on 4 and 2 subsequent days, respectively.
6/4/2004	Acceptable	Complete survey, conditions good, no issues
6/7/2004	Acceptable	Complete survey, conditions good, no issues
6/8/2004	Acceptable	Complete survey, conditions good, no issues
6/9/2004	Acceptable	Complete survey, conditions good. In Chickaloon Bay it was noted there were "65 whales in a wide scatter across most of the nearshore area", but good multiple visual counts were collected.
5/31/2005	Not acceptable	Nearly complete survey, conditions fair in lower Turnagain Arm, and poor in Chickaloon Bay. Whales were too scattered in Little Susitna River for adequate video, possibly due to presence of boats. Survey was terminated at that point.
6/1/2005	Acceptable	Complete survey, conditions good, no issues
6/2/2005	Acceptable	Complete survey, conditions good, no issues
6/5/2005	Acceptable	Complete survey, conditions good, no issues
6/8/2005	Not acceptable	Complete survey, but Chickaloon Bay, Turnagain Arm, and Fire Island had fair or poor conditions due to glare and high winds.
6/9/2005	Acceptable	Complete survey, visibility in some areas of Turnagain Arm and Chickaloon Bay compromised (wind, glare, rain) but most areas fair to good viewing.
6/6/2006	Acceptable	Complete survey except Turnagain Arm was not surveyed, but no whales found there the next 2 days
6/7/2006	Not acceptable	Complete survey, with viewing conditions mostly good. However, after refueling and a break in Kenai, Susitna Delta was surveyed 2-3 hours after the low tide, and whales had moved onto the mudflats and were scattered.
6/8/2006	Not acceptable	Complete survey, but Turnagain Arm was windy with high sea states from Fire Island to Beluga Point. Conditions were poor to fair in Chickaloon Bay. Index count in Chickaloon lower than on other days.
6/11/2006	Acceptable	Excellent viewing conditions everywhere except small area in western Turnagain Arm.
6/12/2006	Acceptable	Different flight pattern, started in Trading Bay to avoid Turnagain Arm weather. Elsewhere good conditions. Survey was complete other than Turnagain Arm, no whales seen in the area on previous and subsequent days.
6/14/2006	Acceptable	Complete survey, conditions excellent, no issues
6/15/2006	Not acceptable	Complete survey but it was conducted at high tide, and whales had likely dispersed in the Susitna Delta. Viewing conditions were good except insect densities were high enough to compromise visibility on the forward side of bubble windows.
6/9/2007	Acceptable	Complete survey, conditions good. Survey diverted to Kalgin Island to look for a dead beluga, surveyed Susitna on rising tide 3-4 hours after the low, but whales were not dispersed. Refueled before surveying Turnagain Arm and Chickaloon Bay.
6/10/2007	Acceptable	Complete survey, conditions excellent, no issues.
6/11/2007	Acceptable	Complete survey, conditions excellent, no issues
6/14/2007	Acceptable	Complete survey, conditions excellent, no issues

Date	Decision	Comments
6/15/2007	Acceptable	Complete survey except for abbreviated trackline in two areas, did not cover all of Knik or Turnagain Arm, but no whales seen in those areas on previous day. Viewing conditions were excellent.
6/3/2008	Not acceptable	On first pass at Susitna Delta, a large group at Beluga River, but it was scattered from the river mouth to well offshore, so not suitable for video. Refueled and returned to try to re-survey Susitna but encountered high winds and whitecaps.
6/4/2008	Acceptable	Complete survey, good conditions except glare and white caps in parts of Turnagain Arm. Surveyed Chickaloon Bay twice as no whales were found there, but whales were also not seen there the previous day.
6/5/2008	Not acceptable	Complete survey but rain and whitecaps in Chickaloon Bay and in Susitna Delta. Groups in Susitna seen by pilots were confirmed missed by observers due to poor viewing conditions.
6/6/2008	Acceptable	Complete survey, conditions good. Susitna was surveyed on falling tide 2-3 hours after high tide but whales were not dispersed, adequate video data obtained.
6/7/2008	Acceptable	Complete survey except for Turnagain Arm but no whales seen there the three previous days, or on two subsequent days. Chickaloon Bay was initially unacceptable but team returned and resurveyed under better conditions
6/11/2008	Not acceptable	Survey was conducted on flood tide and high tide, whales too scattered in both Susitna and Chickaloon to allow for adequate video.
6/12/2008	Acceptable	Complete survey, conditions excellent, no issues
6/2/2009	Acceptable	Complete survey, conditions good, no issues other than poor viewing for some small areas in Turnagain Arm. Did not survey Trading Bay but no whales seen there subsequent 2 days.
6/3/2009	Acceptable	Complete survey, conditions good, no issues
6/4/2009	Acceptable	Complete survey, conditions were good except only fair conditions in Chickaloon Bay. Had enough fuel to conduct a coastal track, an offshore track, and additional extensive effort in Chickaloon and found one medium sized group of whales with an index count similar to other days. Effort in Chickaloon was considered acceptable
6/5/2009	Acceptable	Complete survey, conditions good. Fog delayed survey of Susitna, but only by ~1 hour after low tide, so acceptable.
6/9/2009	Acceptable	Estimate based on second of two surveys that was conducted at low tide. No zoomed video just standard due to camera malfunction.
6/1/2010	Not acceptable	Complete survey, but viewing conditions were poor in the Susitna Delta and Turnagain Arm (Beaufort 4-5), precluding video. Some poor conditions in Chickaloon as well. Airspace restrictions prevented some survey effort near Point MacKenzie and Elmendorf Air Force Base.
6/2/2010	Acceptable	Complete survey with fair to excellent viewing conditions, with calm sea states.
6/4/2010	Not acceptable	Chickaloon Bay was surveyed on rising tide, and Susitna Delta was surveyed at high tide. Whales were scattered and too dispersed in both locations.
6/8/2010	Acceptable	Complete survey with fair to excellent viewing conditions, no issues.
6/9/2010	Acceptable	Complete survey with fair to excellent viewing conditions. Not able to survey all of Eagle Bay in Knik Arm due to airspace restrictions, but no whales seen in Knik on previous and subsequent days.
6/10/2010	Acceptable	Complete survey with good to excellent viewing conditions, no issues.
2011	Not acceptable	Unexpected change in aircraft occurred, so unlike all other years, had to shoot video through a non-opening Plexiglas window, which compromised video data.
6/1/2012	Not acceptable	Complete survey with fair to excellent viewing conditions. One group at Susitna River was too scattered for video, and index count for Susitna was much lower than 5 other days it was surveyed. Chickaloon Bay was surveyed twice, second survey was used.

Date	Decision	Comments
6/2/2012	Acceptable	Complete survey with good to excellent viewing conditions, no issues.
6/3/2012	Acceptable	Complete survey with good to excellent viewing conditions, except for poor conditions around Fire Island. Estimate may be low because of missed groups; no whales were seen in Chickaloon though they were seen on previous and subsequent day, and index count for Susitna lower than previous and subsequent days.
6/4/2012	Acceptable	Complete survey with fair to excellent viewing conditions, no issues.
6/5/2012	Acceptable	Complete survey with fair to excellent viewing conditions, no issues.
6/6/2012	Not acceptable	Poor sighting conditions in Susitna due to high winds, Fire Island to Turnagain Arm not surveyed.
6/7/2012	Acceptable	Complete survey with good to excellent viewing conditions except for some glare, no issues.
6/5/2014	Not acceptable	Complete survey (other than Trading Bay to Beluga River), with poor to excellent viewing conditions, but Susitna was surveyed at high tide and high sea states were encountered there.
6/6/2014	Not acceptable	Aborted survey day due to weather and illness of crew member.
6/7/2014	Not acceptable	Low tide was only +7'. Survey started at Beluga River (not West Foreland), survey was terminated early due to high winds.
6/8/2014	Not acceptable	Sighting conditions were fair to good. Large group off Susitna River was too scattered to allow for good video data to be collected.
6/9/2014	Acceptable	Complete survey (other than Trading Bay to Beluga River) with fair to excellent viewing conditions, no issues. No whales seen from Trading Bay to Beluga River on previous survey day.
6/10/2014	Acceptable	Complete survey (other than Trading Bay to Beluga River) with fair to excellent viewing conditions, no issues.
6/11/2014	Acceptable	Complete survey (other than Trading Bay to Beluga River) with fair to excellent viewing conditions, no issues.
6/12/2014	Not acceptable	Sighting conditions were fair to good. Very large group at Susitna was too scattered to allow for good video data to be collected, even though survey returned to the location 3 times.
6/2/2016	Acceptable	Complete survey with fair to excellent viewing conditions, no issues.
6/3/2016	Acceptable	Complete survey with fair to excellent viewing conditions, no issues.
6/4/2016	Not acceptable	Complete survey except for Little Susitna to Point MacKenzie, and Trading Bay, but whales were too scattered near Beluga River on first pass, and then sighting conditions were poor when survey returned to area.
6/5/2016	Acceptable	Complete survey with fair to excellent viewing conditions, no issues.
6/7/2016	Acceptable	Complete survey with mostly fair to excellent viewing conditions, only brief period of poor conditions, no issues.
6/8/2016	Not acceptable	Complete survey with fair to excellent viewing conditions. Large group from Theodore River to Susitna River was too scattered to allow for adequate video data to be collected. Returned to area a second time but whales were still too scattered.
6/9/2016	Acceptable	Complete survey (except for Trading Bay), with fair to excellent viewing conditions, no issues. No whales were seen in Trading Bay on 4 previous days.
6/12/2018	Not acceptable	Complete survey except for Trading Bay, with fair to excellent viewing conditions. Survey of west side started at North Foreland where a group was immediately seen. On subsequent day, a group was again seen there, but also two larger groups in Trading Bay, indicating this day's survey may have missed a large number of whales.

Date	Decision	Comments
6/13/2018	Acceptable	Complete survey with fair to excellent viewing conditions, with only brief periods of poor visibility near Fire Island and northern Chickaloon Bay due to glare and high sea states. Last group only counted once due to fuel constraints, possible a few whales under the plane, no other issues.
6/14/2018	Acceptable	Complete survey with fair to excellent viewing conditions, with only brief periods of poor visibility in Turnagain Arm due to high winds and glare, no other issues.
6/15/2018	Not acceptable	Incomplete survey because high winds were encountered at Susitna River and survey was terminated. Turnagain Arm also not surveyed due to high winds.

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