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Abundance and Trend of Belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2021 and June 2022

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Abundance and Trend of Belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2021 and June 2022

K. T. Goetz[1], K. E. W. Shelden[1], C. L. Sims[1,2],
J. M. Waite[1], and P. R. Wade[1]

[1] National Oceanic and
Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
Marine Mammal Laboratory
7600 Sand Point Way N.E.
Seattle, WA 98115-6349

[2] Cooperative Institute for Climate,
Ocean, & Ecosystem Studies
University of Washington
3737 Brooklyn Ave N.E.
Seattle, WA, 98195-4550

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EXECUTIVE SUMMARY

The National Marine Fisheries Service (NMFS) has conducted aerial surveys to estimate the abundance of the beluga population in Cook Inlet, Alaska, between late May and early July from 1993 to 2012, after which biennial surveys during the even years began in 2014. However, the survey scheduled for 2020 was postponed until 2021 due to Covid-19, leading to consecutive surveys in 2021 and 2022. The current document presents abundance estimates and the population trend based on video and counting passes collected during late June 2021 and early June 2022 using analytical methods developed by Boyd et al. (2019).

Surveys occurred from 19 June to 1 July 2021 (~59 flight hours) and 6 – 18 June 2022 (~52 flight hours). All surveys were flown in a twin-engine, high-wing aircraft (i.e., an Aero Commander 690) at a target altitude of 244 m (800 ft) and speed of 220 km/hr (119 kts). The coastal survey track was positioned approximately 1 km offshore and included the entire Cook Inlet coast north of Ursus Cove and English Bay. Kamishak Bay, Augustine Island, and Elizabeth Island were not surveyed as in previous years to allow additional time for sampling offshore in the upper inlet.

In 2021, daily overall median observer counts on two days with complete coverage of the upper inlet were 100 and 124 whales. Unfortunately, bad weather coincided with many of the lowest low tide days. Minus tides (-3 ft. or more) that expose the tidal mudflats for extended periods are preferable for collecting video group size data because the whales aggregate along the edge of the mudflats until the rising tide allows them to access the channels and rivers. To estimate abundance using this survey method, it is preferable to obtain data on 3-5 days during the low tide period.

In 2022, daily overall median observer counts on three days with complete coverage of the upper inlet ranged from 152 to 224 whales. Unlike 2021, we were able to survey during three of the lowest negative low tide days (e.g., -4 ft.).

Median group size estimates in 2021 and 2022 were 34 and 15, respectively. Overall, the number of groups and size of groups has varied across surveys with just a few

large groups in some years and many smaller groups in others (Boyd et al. 2019). With the exception of one or two larger groups per day, most beluga groups during the 2021 and 2022 surveys were small and tended to be more scattered than in previous years.

A fully Bayesian method to estimate group size in the analysis of abundance and trends for Cook Inlet belugas was implemented in 2018 (Boyd et al. 2019) and was applied here to the time series from 2004 to 2022. In this analysis, we controlled for possible strong positive and negative outliers on single days by calculating the annual abundance as the median of all the daily abundance estimates. The annual point estimate of abundance was 361 (CV = 0.547, 95% probability interval 176 to 919) for 2021 and 381 (CV = 0.110, 95% probability interval 317 to 473) for 2022. Based on a 5-year moving average, the smoothed abundance estimate (considered the 'best' estimate) was 334 (95% probability interval 248 to 586) in 2021 and 364 (95% probability interval 292 to 532) in 2022. Given the numerous issues that occurred during the 2021 survey which is reflected in the high probability intervals, the 'best' estimate of abundance for 2022 was also calculated without the inclusion of the 2021 survey data and resulted in a best estimate of abundance of 331 (95% probability interval 290 to 386). As a precautionary approach, we recommend that 331 be considered the official best estimate of abundance, particularly for management purposes.

Previous to the 2021 and 2022 aerial surveys, a declining trend of 2.3% per year was found to occur from 2008 to 2018. However, the addition of data from two survey years resulted in a 65.1% probability that the population is now increasing at 0.9% per year (95% PI -3.0% to 5.7%) from 2012 to 2022. This increase drops slightly (0.2% per year) when excluding the 2021 data (95% PI -1.8% to 2.6%). The trend in the updated time-series suggests the population is stable and may be slightly increasing. This could indicate that the previous decline from 2008 to 2018 was part of a natural oscillation in the population or possibly due to an environmental impact, such as the unprecedented heat wave in the Gulf of Alaska within the same time period.

CONTENTS

INTRODUCTION

Five stocks of beluga whales (*Delphinapterus leucas*) inhabit waters surrounding Alaska from Yakutat Bay to the Alaska/Yukon Territory boundary (Hazard 1988): Cook Inlet, Bristol Bay, Eastern Bering Sea, Eastern Chukchi Sea, and Beaufort Sea (Muto et al. 2021). The Cook Inlet stock (hereafter CIBs) is geographically and genetically isolated from the other stocks (O'Corry-Crowe et al. 1997; Laidre et al. 2000). Their small population size (Wade et al. 2019) in combination with their strong site fidelity (Rugh et al. 2000, 2010; Shelden et al. 2015a, 2018; McGuire et al. 2020a) makes this stock vulnerable to natural and anthropogenic impacts in a highly populated region (Norman et al. 2015; Castellote et al. 2018; McGuire et al. 2020a, b, 2021). CIBs were designated as a Distinct Population Segment (DPS) and listed as endangered under the U.S. Endangered Species Act in October 2008 (NOAA 2008) followed by the designation of Critical Habitat in 2011 (NOAA 2011). In 2015, NOAA Fisheries selected the Cook Inlet DPS as one of its eight Species in the Spotlight.

Aerial surveys to estimate the abundance of the beluga population in Cook Inlet, Alaska, have occurred annually between late May and early July from 1993 to 2012 (Rugh et al. 2000, 2005; Shelden et al. 2013), after which biennial surveys began in 2014 (Shelden et al. 2015b, 2017, 2019). However, the survey scheduled for 2020 was postponed until 2021 due to Covid-19, leading to consecutive surveys in 2021 and 2022. The methods used to estimate abundance for the CIB population have evolved since 1993, many of which were introduced during the 2004 survey. The timing of the survey expanded from 1 week to 2 weeks (Hobbs et al. 2015) and the upper inlet was no longer divided into multiple sectors that were sometimes surveyed on different days and summed for an abundance estimate (e.g., Hobbs et al. 2000). Instead, since 2004, areas in upper Cook Inlet (north of East and West Foreland) were surveyed in a single day, so that an independent estimate of abundance could be obtained each day (Hobbs et al. 2015; Shelden et al. 2015b, 2017, 2019, 2022).

In 2016, a new method to estimate group size for calculating CIB abundance was developed by Boyd et al. (2019) and was subsequently applied to the 2004-2018 time-series (Boyd et al. 2019, Wade et al. 2019). This methodology replaced the estimation process developed by Hobbs et al. (2000, 2015), with key differences described in detail in both Boyd et al. (2019) and Wade et al. (2019). Briefly, the newly implemented method is fully Bayesian so that uncertainty in correction factors (availability, proximity, perception, and observer biases) is fully incorporated.

The current document presents abundance estimates for 2021 and 2022 and updates population trends, using the Boyd et al. (2019) approach for estimating group size.

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 Susitna River Delta, a known hotspot for CIBs, is located 315 km north of Cape Douglas. 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 intersected 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, 2012). Anchorage, the largest city in Alaska, served as the base of operations for all aerial surveys.

Figure 1. -- Cook Inlet with place names.

METHODS

Aerial Survey Protocol

In June of 2021 and 2022, aerial surveys were conducted using a twin-engine, high wing Aero Commander 690 (tail number: *N222ME*) with 6-hour flying capability. Bubble windows were installed at the forward observer positions to maximize the field of view (Fig. 2). The left-rear observer window was flat and an opening window located behind the seat of the left-forward observer allowed for video recording and photography. Two observers were positioned on the left side of the aircraft, which was flown along the coast to provide independent search effort on the shoreward side where belugas are more commonly seen. Because there are typically fewer belugas sighted >3 km from the coast, a single observer searched the right (non-coastal side) side of the aircraft. A data recorder sat at a computer desk in the right 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 CIB aerial surveys, June 2021 and June 2022 (photo courtesy of Clearwater Air, Inc.).

Headsets were used for communication among the observers, data recorder, and pilots. Seating positions were noted each time the survey team changed positions and/or tasks (i.e., video recording, data recording, observing/counting). Location data were collected from a handheld global positioning system (GPS) interfaced with the laptop computer. A custom-built software program was used to record 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, on the coastal side of the plane), glare (on the coastal and offshore sides of the plane), and visibility (on the coastal and offshore sides of the plane).

Visibility was documented in five subjective categories from excellent to useless. Best counting conditions (excellent visibility) occurred 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 fatigue, back pain, air sickness, etc., which can reduce search effort). Areas where visibility was poor or useless (as determined by the left-forward observer) were considered off-effort and treated as unsampled in the analysis.

Tracklines

Coastal surveys were conducted approximately 1 km from the coast or exposed mudflat edge. The objective was to search all nearshore, shallow waters where CIBs are typically seen in late May/early June (Rugh et al. 2000, 2005 and Shelden et al. 2013; 2015a, b; 2017; 2019). 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 220 km/ hr (119 kts). 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 beluga hunters who have flown on previous surveys.

In addition to the coastal surveys, systematic transects were flown across the inlet to document offshore distribution of belugas and other marine mammals in the study area. Mid-inlet tracklines were designed as a sawtooth pattern or as a straight line stretching the length of Cook Inlet. On occasion, when belugas were scattered rather than clumped within the study area (e.g., from Beluga River to the Little Susitna River, hereafter referred to as the Susitna Delta), strip transects along the mudflat/shoreline and positioned at roughly 2-km intervals parallel to shore were conducted to obtain counts for groups too dispersed to video. While informative, days when this occurred were not used to estimate abundance.

The broad geographical range of these surveys in conjunction with large and rapidly changing tidal heights -- as much as 9.5 m (30 ft) -- made it impractical to survey at specific tidal conditions (such as at low tide) throughout all of Cook Inlet. However, there was an attempt to synchronize flights with low tides in the Susitna Delta. Since water has receded off the mud banks, lower tides reduce the overall survey area and typically result in beluga groups being more compacted and confined along the mudflat edge as opposed to dispersed across the flats. 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. With the exception of areas south of Point Possession and North Foreland that are not impacted by tides, the flight schedule for every survey day was designed to take advantage of tidal patterns, relative to workable daylight hours which are typically between 07:30 and 20:30 AKDT.

In addition to the standard survey protocol, the 2021 and 2022 aerial surveys 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.

Counting Protocol

Immediately upon seeing a beluga group, an observer 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 and notable behaviors when possible, but not group size. The pilots, data recorder, and the left-rear observer did not cue the two forward observers to the presence of a whale group until it was behind the plane and it was clear that the group had been missed.

After a beluga sighting was reported, the trackline was maintained until the group was well behind the wing before returning to the group to mark its location and to commence circling passes for counting and video recording. A racetrack flight pattern was flown counterclockwise around the longitudinal axis of the group to count each whale group (Fig. 3). During each pass, CIBs were counted down the long axes of the racetrack unless poor visibility (usually due to glare) limited counts to only one side. There were typically four or more passes per whale group with two observers counting independently.

To record the duration of each counting pass, counts began and ended with a start/end count cue from the left-forward observer. Counts started when the first whale(s) of the group were close enough to be counted and ended when the last whale(s) went behind the wing of the aircraft. The position of each counter was noted (i.e., left-forward (LF), left-rear (LR)) as visibility varies by window type (bubble vs. flat) and proximity to the engine cowling and wing, which obstructed the left-rear observer's view at times. After each pass ended, the two observers recorded their count on a form along with the date, time, group, pass number, and quality of the count. These counts were entered into an Access database at the end of each survey day.

The quality of a count (A through F) was based on conditions which could affect the ability to see a whale, such as glare, whitecaps, or distance to the group/individual. Quality ranged from no adverse conditions to those which caused poor or obstructed visibility. These ratings were 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).

Only quality A and B counts were used in the median count calculations and subsequent abundance estimation. Only whales that were at the surface during a pass were counted; mud plumes or ripples indicating subsurface whales were ignored.

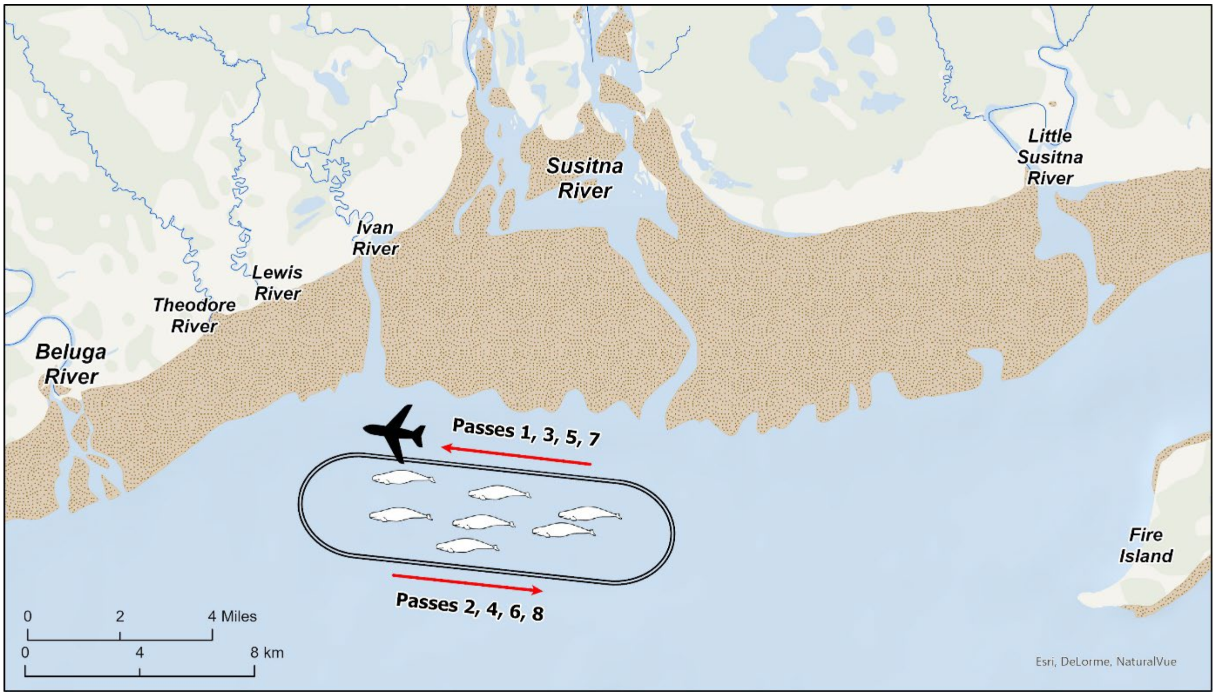

Figure 3. -- Illustration of a racetrack pattern flown during counting/video passes of Cook Inlet belugas. Each pass consists of one side of the oblong circle. Due to glare, counting/video passes are sometimes flown in a single direction.

Most whale groups were counted on four different aerial passes, not including counts made later from video recordings. The daily aerial counts were medians of each of observers' median counts on multiple passes over a group. 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. When a median for a group of whales included decimals, the median was rounded up to the next whole number.

After median counts were calculated for each group on each day, the highest daily sum was used as the annual index count for the entire survey, assuming some whales were missed on lower count days (Shelden et al. 2022). However, it should be noted that the median counts and annual index count do not include corrections to observer counts, which are obtained during the video analysis (see below). Because of the evident movement of whales between areas in upper Cook Inlet (e.g., Chickaloon Bay to/from Susitna Delta) on some days, over-counting was avoided by not summing counts across days. To date, movements have not been observed between the lower and upper inlet during the counting period.

Video Cameras and Data Summary

During both years, one full view digital video camera (termed 'standard') and one narrow view digital video camera (termed 'zoomed'), mounted side by side, were operated together during most counting passes. The 'standard' camera was generally set at maximum wide angle to keep the entire group of CIBs in view, while the 'zoomed' camera was kept at maximum optical zoom (10×). The standard video was used to count the total number of whales surfacing during the video pass and the zoomed video was used to estimate a correction factor for missed whales (Hobbs et al. 2015). Once recording is started, the setting for each camera was held constant throughout the pass so that magnification of each video camera was consistent.

In 2021, we used a Sony HXR-NX5U HD with 1920 × 1080 pixel resolution for the 'standard' camera paired with a Panasonic HC-X1 with 3840 × 2160 (4K) pixel resolution for the 'zoomed' camera (Fig. 4). A tripod mounting system was created that allowed both cameras to be positioned side by side while supporting their weight (Fig. 4).

In 2022, smaller 4K resolution video cameras were introduced to improve the quality of video data collection. Two Sony FDR-AX700 video Handycams (3840 × 2160 pixel resolution) replaced the larger video cameras allowing for easier handling and positioning during video recording (Fig. 4). An aluminum-based camera mounting system was created with adjustable brackets which allowed the video cameras to be positioned side by side or stacked for video alignment purposes.

Figure 4. -- Video cameras and setup used during the 2021 (left) and 2022 (right) Cook Inlet beluga aerial survey. In 2021, a Sony HXR-NX5U HD video camera (1920 × 1080 pixel resolution) was paired with a "zoomed" Panasonic HC-X1 (3840 × 2160 pixel resolution) (left) while in 2022, two 4K Sony FDR-AX700 video Handycams (3840 × 2160 pixel resolution) replaced the larger video cameras (right).

After the field season, each video counting pass was reviewed for the ability to identify beluga whales and rated as excellent, good, fair, poor, or unacceptable. These quality ratings considered features such as white caps, glare, and whether the whole group was captured in the video. Video passes rated excellent and good were analyzed using a computer-aided system called "Beluga Dots" (introduced in 2004, Fig. 5). This system allowed analysts to count and catalog individual whales in the survey video, track whales from frame to frame across the computer screen, and to record size (in pixels) and color of each whales at the midpoint of a surfacing (Hobbs et al. 2015).

Scan time was used to calculate availability bias and was calculated as the time a beluga stays on the screen (seconds) divided by the distance moved (pixels) and then multiplied by the resolution of the cameras (1,920 in 2021 and 3,840 in 2022). Because the video analysis program had been developed for video cameras with lower resolution and smaller file sizes, it was unable to import the high-resolution video collected by the new cameras (4K) in 2022. Therefore, videos recorded in 2022 were exported at the same resolution as the 2021 cameras (1,920 pixel) and scan times were calculated accordingly.

After primary and secondary counts and zoomed analysis were completed, the data were exported as a text file for use in calculating the annual abundance estimate. Images from the zoomed camera were examined for whale surfacings that could not be seen in the standard video, either due to a partial surfacing, small size, or cryptic body coloration within the respective groups.

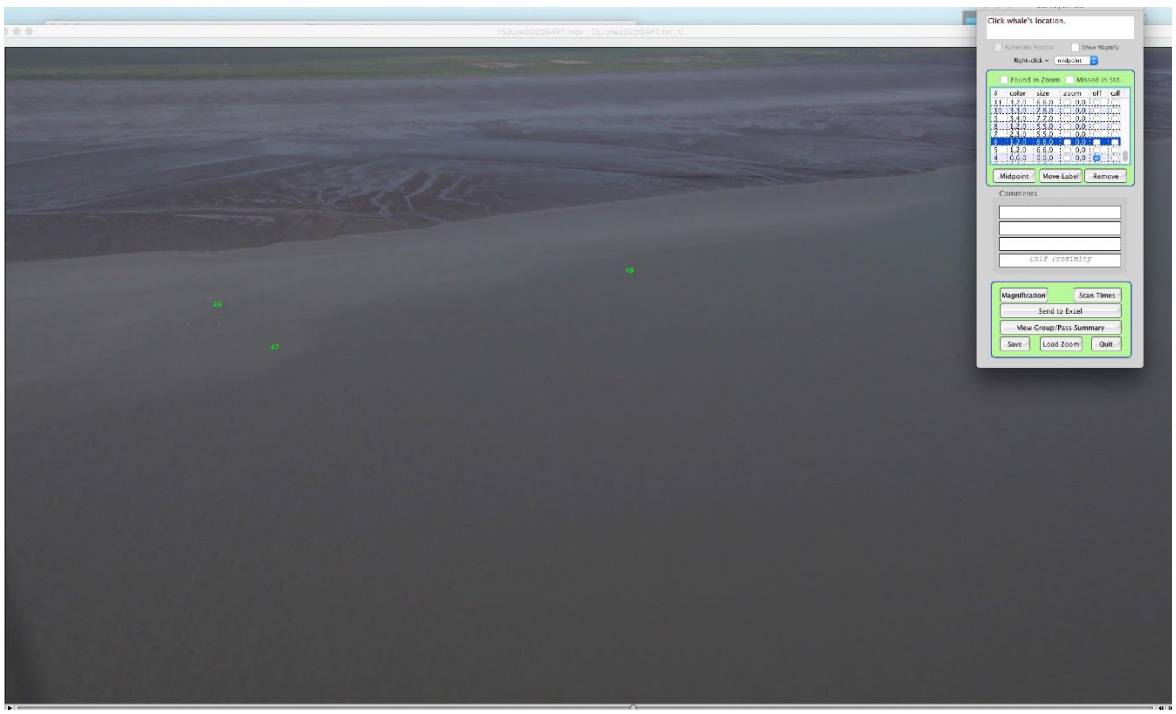

Figure 5. -- Computer screen shot of “Beluga Dots” program used to catalog individual beluga images found in the Cook Inlet survey video. Small green numbers are used to mark individual beluga whales.

Acceptable Survey Days

Following the 2018 abundance survey and the revised analyses of group size estimates from the 2004 to 2016 surveys (Boyd et al. 2019), Wade et al. (2019) reviewed and defined criteria for "acceptable days" to be used when calculating abundance estimates. These include the following:

1. Good to excellent sighting conditions throughout the survey area, including little to no fog, little glare, and sufficiently low wind speeds with few to no whitecaps on the water.
2. Whales seen in medium to large size groups were sufficiently compact or linear to allow for video pass recording of the group during a "standard" survey day.
3. The survey represented "complete" coverage of the upper Cook Inlet survey area north of East and West Foreland.

Group Size Estimation and Spatial Distribution

Since aerial surveys began in 1993, a number of changes were introduced, most of which occurred during the 2004 survey. Two of the main changes were extending the timing of the survey from 1 week to 2 weeks (Hobbs et al. 2015) and no longer breaking the upper inlet into multiple sectors that were sometimes surveyed on different days and summed for an abundance estimate (e.g., Hobbs et al. 2000). Instead, since 2004, areas in 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. 2015b, 2017, 2019, 2022).

In 2016, a major revision was made to the methods used to estimate group sizes from the survey; a Bayesian approach was applied to the 2004-2016 (Boyd et al. 2019) and the 2004-2018 time-series data (Wade et al. 2019). This approach allowed us to estimate CIB group sizes for both the June 2021 and 2022 survey while accounting 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). Posterior distributions for the model parameters and the size of each group were estimated using Markov Chain Monte Carlo (MCMC) methods, using a run of 1,000,000 samples, a burn-in of 500,000, and a thinning rate set to 1,000 in order to retain a posterior sample of 1,000. Two separate chains were run to check on convergence.

Finally, we calculated the median group size estimate by taking the median of the 1,000 samples from the posterior distribution of group sizes for each group and produced violin plots using the '*ggplot2*' package (version 3.4.1, Wickham 2016) within R statistical software version 4.2.3 (R Core Team 2020). Similarly, we also calculated the daily median group size by taking the median of the median group sizes for each day as calculated above and similarly plotted the data.

The distribution of estimated group sizes in 2021 and 2022 were compared to the last 10 years 2009–2018 (Shelden et al. 2019, also see methods in Rugh et al. 2010). Briefly, distributional changes were calculated (using the 'Directional Distribution' (Standard Deviational Ellipse) tool in ArcMap 10.7.1 Spatial Statistics Tools for Measuring Geographic Distributions) by determining the proximity of whales relative to a central location computed for all whale sightings observed within the two time periods: 2009-2018 and 2021-2022. These statistics were weighted by the number of animals in each group and set at 1 SD (encompassing ~68% of whales) and 2 SD (~95% of whales). The central location of the beluga groups was calculated for each time period using the 'Central Feature' tool.

Annual Abundance Estimates and Trends

In addition to using the new group-size estimation method, we controlled 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 model overestimates group size; this could happen from random sampling error, but it is also suspected that the model sometimes performs poorly in estimating the size of very large groups, so that on days when the whales occur in one or more very large groups the estimation of group size may be difficult.

Prior to 2018, 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 a posterior distribution for the median of the daily abundance estimates for all acceptable survey days (defined objectively by weather/sighting conditions and spatial coverage) 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. Using the median lessens the influence of strong positive and negative outliers. This was repeated 1,000 times, calculating a median each time, to create a posterior distribution for the median abundance in that year.

To estimate the overall trend, and calculate the 'best' estimate of current abundance, we 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). For example, for the 2022 estimate, the smoothed estimate is therefore a weighted average of the last three estimates, with weights of 1.0 (2022), 0.5 (2021), and 0.25 (2018) (weights were rescaled to sum to one to create an exponential decay of weights: 0.57 (2022), 0.29 (2021), and 0.14 (2018), respectively). Due to the high level of uncertainly in the 2021 estimates, we also examined the trend with the 2021 survey data removed. In this case, the three estimates used in the trend analysis were 2022, 2018, and 2016. 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 than just the annual ‘point’ estimate from the survey data from only that year. Therefore, this method provides a good compromise with the most recent data having the most influence, but provides some stability and smoothing from the previous two estimates. This makes the ‘best’ estimate more precise than the annual point estimate, and reduces the small up and down ‘bumps’ that occur from year to year, bringing us closer to the true abundance of the population.

To estimate the trend for the most recent 10-year time period, we 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. The 10-year trend was calculated with and without the inclusion of the 2021 survey data for reasons mentioned previously.

RESULTS

Acceptable Survey Days and Median Index Counts

In 2021, only two of the four standard survey days (June 26-27) were acceptable for calculating abundance (see Shelden et al. 2022 for details on all survey days). However, in 2022, all three standard survey days were deemed suitable (June 15-17). Figure 6 shows all on-effort tracklines and beluga groups for all acceptable survey days in 2021 and 2022.

During the 2021 survey, a total of 25 groups were visually detected, 15 on June 26th and 10 on June 27th (Table 1). In 2022, a total of 26 beluga groups were detected over three standard survey days, 6 on June 15th, 8 on June 16th, and 12 on June 17th (Table 1). In 2021, observers were able to make one or more excellent/good counts on 17 of the 25 groups (Table 1). However, excellent/good video data were only obtained for 14 of the groups which was within, but on the lower end of, the range of video per groups collected since 2004 (Table 2). In 2022, excellent/good observer counts and video recordings were made for all but one group (count) and three groups (video), respectively.

Daily sums of median observer counts for 2021 were 100 (June 26th) and 124 (June 27th), and for 2022 were 152 (June 15th), 224 (June 16th), and 186 (June 17th) (Table 3). The highest daily sum of median observer counts (referred to as the ‘index’ count for each survey year) was 124 and 224 for 2021 and 2022, respectively. The annual index count of 124 CIBs in 2021 falls below the range of annual index counts collected in June aerial surveys from 2004 to 2018 (Tables 3 and 4). However, the highest daily index count of 224 CIBs in 2022 falls within the range of index counts from previous years (Table 4).

Table 1. -- Beluga whale groups in Cook Inlet, Alaska, June 2021 and June 2022, included in the index of median counts and mean and median Bayesian group size estimates on all "acceptable" survey days. The "CV" is the standard deviation of group size estimates divided by the mean. "O/V" is the number of passes with observer (O) and video (V) counting passes used to determine corrected group size estimates (Boyd et al. 2019). Groups without counting passes were not included in the Bayesian abundance estimation analysis. Note: Due to rounding, median group counts and size estimates may vary by a few whales in subsequent tables in this report.

Date	Flight	Group	Passes	Location	Effort	Num O/V	Med. O count	Med. V count	Bayesian group size estimate Median	Mean	CV
6/26/2021	6	1	7	Turnagain Arm	On	7/2	2	1	5	6	0.555
6/26/2021	6	2	1	Chickaloon Bay	On	0/0	1*	--	--	--	--
6/26/2021	6	3	5	Chickaloon Bay	On	5/2	11	9	34	39	0.509
6/26/2021	6	4	5	Trading Bay	On	4/3	16	11	63	72	0.514
6/26/2021	6	5	4	Trading Bay	On	4/2	5	4	16	18	0.535
6/26/2021	6	6	1	North Foreland	On	0/0	2*	--	--	--	--
6/26/2021	7	7	1	Chuitna Creek	On	0/0	1*	--	--	--	--
6/26/2021	7	8	5	Beluga River	On	5/3	30	18	98	110	0.501
6/26/2021	7	9	3**	Susitna River	Off	2/0	2	--	4	6	1.112
6/26/2021	7	10	1	Susitna River	Off	0/0	5*	--	--	--	--
6/26/2021	7	11	1	Susitna River	On	0/0	2*	--	--	--	--
6/26/2021	7	12	7	Little Susitna River	On	6/2	15	11	56	65	0.502
6/26/2021	7	13	2**	Little Susitna River	On	1/0	3	--	7	13	2.190
6/26/2021	7	14	1	Cairn Point	On	0/0	3*	--	--	--	--
6/26/2021	7	15	1	Ship Creek	On	0/0	2*	--	--	--	--
6/27/2021	8	1	4	McHugh Creek	On	4/1	6	6	23	26	0.526
6/27/2021	8	2	5	Chickaloon Bay	On	5/2	7	8	30	35	0.536
6/27/2021	8	3	5	Indian Creek	Off	2/0	3	--	9	10	0.637
6/27/2021	8	4	4	McArthur River	On	4/4	12	5	35	40	0.517
6/27/2021	8	5	4	Shirleyville	On	4/3	17	9	58	66	0.514
6/27/2021	8	6	4	North Foreland	On	4/4	40	22	142	161	0.484
6/27/2021	8	7	5	Beluga River	On	5/2	13	7	45	51	0.511
6/27/2021	9	8	5	Lewis to Susitna R.	On	5/3	10	4	30	35	0.521
6/27/2021	9	9	4	Susitna River	On	4/4	13	8	50	56	0.510
6/27/2021	9	10	1	Goose Bay	On	0/0	3*	--	--	--	--
6/15/2022	9	1	5	Turnagain Arm	On	5/3	3	3	8	8	0.114
6/15/2022	9	2	4	Chickaloon Bay	On	4/2	4	7	10	11	0.167
6/15/2022	9	3	6	Trading Bay	On	6/5	42	33	77	78	0.151
6/15/2022	10	4	4	Beluga to Ivan R.	On	4/3	67	91	168	170	0.117
6/15/2022	10	5	4	Susitna River	On	4/4	30	24	42	43	0.173
6/15/2022	10	6	5	E. of Little Susitna	On	5/3	6	3	8	8	0.202
6/16/2022	11	1	6	Chickaloon Bay	On	6/3	5	6	9	9	0.195
6/16/2022	11	2	6	Chickaloon Bay	On	6/6	5	3	10	10	0.165
6/16/2022	11	3	4	Trading Bay	On	4/4	44	22	62	63	0.171
6/16/2022	11	4	5	Trading Bay	On	5/0	1	--	1	1	0.413
6/16/2022	12	5	4	Beluga to Ivan R.	On	4/4	76	91	174	177	0.109
6/16/2022	12	6	4	Susitna River	On	4/4	53	43	107	108	0.145
6/16/2022	12	7	4	Susitna River	On	4/3	23	16	43	44	0.166
6/16/2022	12	8	4	Susitna River	On	4/4	17	11	31	32	0.167
6/17/2022	13	1	5	Fire Island	On	4/2	2	1	5	5	0.243
6/17/2022	13	2	5	Fire Island	Off	5/2	2	2	3	3	0.281
6/17/2022	13	3	7	Chickaloon Bay	On	5/4	3	2	7	7	0.200
6/17/2022	14	4	5	Trading Bay	On	5/5	4	4	15	15	0.073
6/17/2022	14	5	4	Beshta Bay	On	4/4	23	13	49	50	0.163

6/17/2022	14	6	4	North Foreland	On	4/2	2	2	4	5	0.267
6/17/2022	14	7	1	Chuitna Creek	On	0/0	1*	--	--	--	--
6/17/2022	14	8	4	Beluga-Theodore R.	On	4/4	80	63	142	143	0.147
6/17/2022	14	9	5	Susitna River	On	4/1	55	60	121	124	0.164
6/17/2022	14	10	4	Susitna River	On	1/0	2	--	1	1	0.497
6/17/2022	14	11	6	Little Susitna River	On	5/2	7	9	20	20	0.186
6/17/2022	14	12	4	Little Susitna River	On	4/3	5	3	10	10	0.213

*= No counting passes
**= One pass aborted

Table 2. -- Percentage of Cook Inlet beluga groups for which video counts were obtained on acceptable survey days, 2004-2022. Note that data in this table are limited to survey days used to calculate the annual abundance estimate (i.e. beluga groups with video counts for survey days not used to calculate the abundance estimate are not reflected in the table).

Year	Days	Groups	Video	Percentage
2004	4	17	15	88
2005	4	21	14	67
2006	4	31	16	52
2007	5	45	31	69
2008	4	9	7	78
2009	5	23	14	61
2010	4	26	15	58
2012	5	22	15	68
2014	3	16	12	75
2016	5	32	11	34
2018	2	21	14	67
2021	2	25	14	56
2022	3	26	23	88

Table 3. -- Daily sums for acceptable survey days during 2021 and 2022 Cook Inlet beluga aerial surveys. The median and mean daily Bayesian estimates were calculated by taking the median/mean of the summed median/mean estimated group sizes across 1,000 simulations for each day. The “CV” of the Bayesian estimate is the standard deviation of group size estimates across 1,000 simulations divided by the mean.

Date	Sum of median observer counts	Sum of Bayesian group size estimates				
		median	mean	5th percentile	95th percentile	CV
6/26/21	100	291	330	144	739	0.497
6/27/21	124	426	478	206	1121	0.491
6/15/22	152	313	317	265	394	0.104
6/16/22	224	440	444	375	545	0.099
6/17/22	186	381	384	315	475	0.111

Table 4. -- Annual index counts, Bayesian 'point' estimate, and 'best' estimates of abundance for acceptable survey days from 2004 to 2022. Index counts are the highest summation of median observer counts across survey days for each year. The 'point' estimate of abundance (N) is the median of the summed daily median group size estimates (see summed daily median values on Table 3). The 'best' estimate of abundance (N) uses a weighted moving average to smooth the 'point' estimates (see Fig. 11). The "CV" of the Bayesian 'point' estimate is the standard deviation of the posterior distribution of total group size 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. Years below the double line show changes that result from excluding the 2021 survey.

		Point Estimate					Best Estimate				
Year	Index count	N	L95	U95	*CV*(N)	20^{th} %ile	N	L95	U95	*CV*(N)	20^{th} %ile
2004	187	238	208	280	0.079	224	257	235	284	0.049	247
2005	192	285	249	329	0.072	269	280	260	305	0.041	271
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	301	273	357	0.073	287
2018	190	269	227	333	0.103	250	308	263	421	0.133	284
2021	124	361	176	919	0.547	253	334	248	586	0.263	286
2022	224	381	317	473	0.110	349	364	292	532	0.169	325
2016	298	247	217	287	0.077	232	302	282	325	0.037	293
2018	190	269	227	333	0.103	250	303	276	339	0.052	290
2022	224	381	317	473	0.110	349	331	290	386	0.076	311

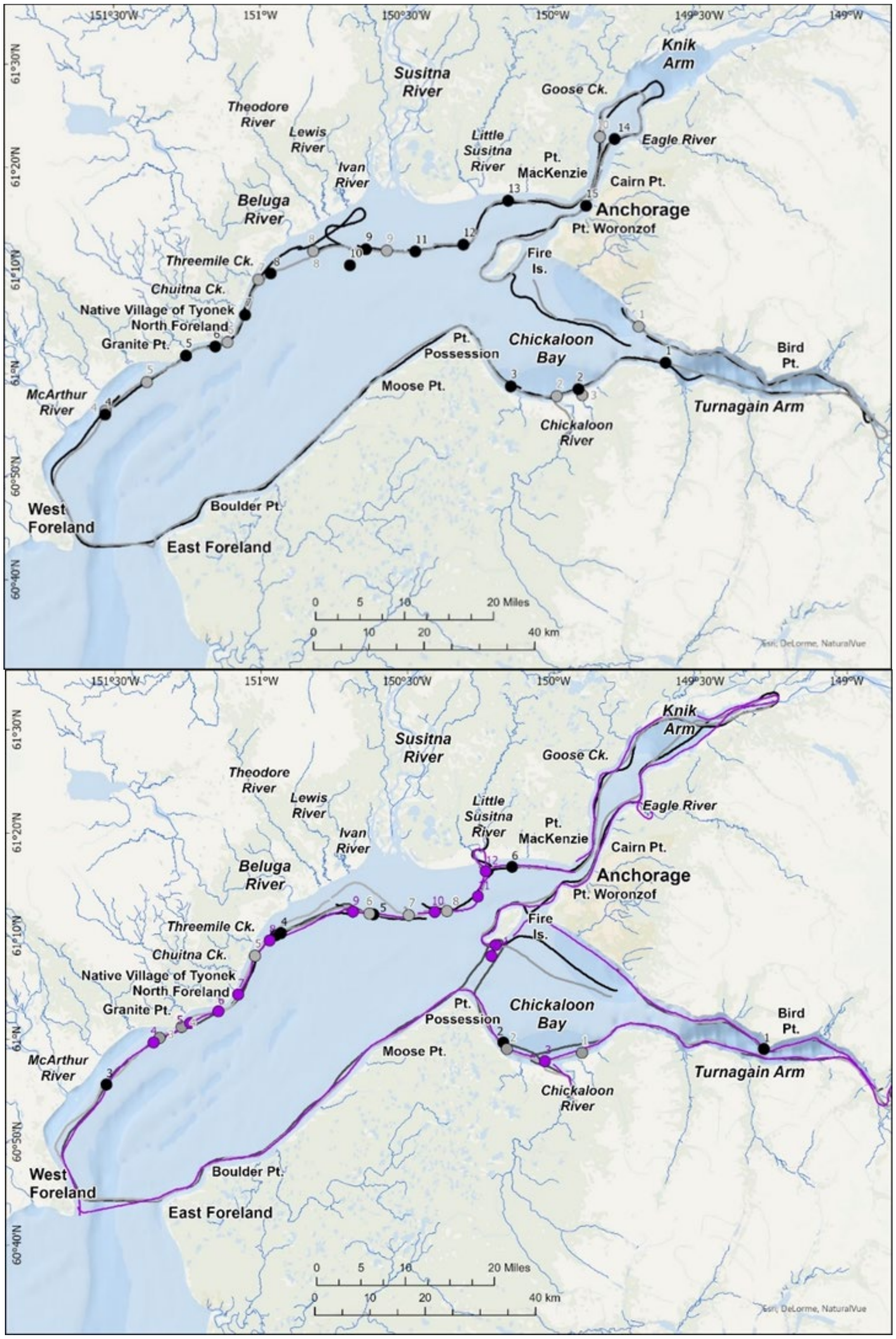

Figure 6. -- On-effort tracklines and beluga groups used to estimate the 2021 and 2022 abundance. Top panel shows tracklines and beluga groups for the two survey days in 2021 as black (June 26th) and gray (June 27th) lines and circles. Bottom panel shows tracklines and beluga groups for the three survey days in 2022 as black, gray, and purple lines and circles on June 15th, 16th, and 17th, respectively.

Modeled Group Size Estimates and Daily Abundance

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 = 11.4), however the opposite was true for 2022 in which the lognormal model indicated greater support (ΔDIC = 19.8). Even though the left-rear observer had a flat window in both 2021 and 2022, DIC indicated greater support for the model that included an estimated correction factor for a flat window only for 2022. Besides 2021, 2014 was the only other year with the two window-type configuration that the DIC did not support the inclusion of a correction factor for a flat window.

Median correction factors for availability bias ($1/pa$), perception bias ($1/pd$), and individual observer bias ($1/\delta$) for 2022 were within the range of median correction factors estimated for previous survey years (2004-2018; Fig. 7). However, for 2021, the correction factor for availability bias was slightly lower than previous years while the correction factors for perception bias and observer bias were higher than other years (Fig. 7). The median estimate of the percentage of individuals available at the surface during video clips (availability) was 72.2% in 2021 and 65.5% in 2022, which translates into correction factors of 1.38 and 1.53, respectively. The estimate of proximity bias, calculated from matched video clips, was 0.0% in 2021 and 0.9% in 2022, which was consistent with fairly minor values across all years since 2004 (<4%) except 2014 which was 10.9%.

The median estimate of the percentage of individuals that were detected in video clips in 2021 and 2022 was 22.7% and 60.3%, respectively. Therefore, the median correction factors for perception bias were 4.40 (2021) and 1.66 (2022), respectively (Fig. 7). For all groups used to estimate abundance from 2004 to 2022 (excluding 2011), the number of CIBs counted in the video was less than the number of CIBs estimated by the model (Fig. 8).

The median ratio of belugas counted by observers to those counted in video clips (observer count : video count) was 1.83:1 in 2021 and 1.42:1 in 2022 which was consistent with values since 2011 when video cameras were upgraded (1.20-2.24) (Fig. 9). However, with the exception of 2004, median observer: video counts in 2021 and 2022 were higher than years prior to the upgrades (2005-2010: 0.71-1.38) (Fig. 9).

The median estimated correction factor for observer bias was 3.93 in 2021 and 1.94 in 2022, both of which were higher than the correction factor of 1.64 for the 2018 survey (i.e., observer counts were 25.4% and 51.5% of the estimated group size in 2021 and 2022, respectively, which was lower than the 60.9% in 2018) (Fig. 7). For all groups from 2004 to 2022 (excluding 2011), the number of CIBs counted by observers was less than the number of CIBs estimated by the model (Fig. 10).

Median group size estimates in 2021 and 2022 were 34 and 15, respectively, though estimated group sizes were highly variable (range: 4 to 142 whales in 2021 and 1 to 174 in 2022) as in previous survey years (Table 1, Fig. 11) (Boyd et al. 2019, Wade et al. 2019). Overall, the number and estimated size of groups has varied across surveys with just a few large groups in some years and many smaller groups in others (Boyd et al. 2019) (Table 1, Fig. 11). With the exception of one or two larger groups per day, most beluga groups during the 2021 and 2022 surveys were small and tended to be more scattered than in previous years (Table 1).

The range distribution of the estimated group sizes in 2021-2022 has expanded slightly from the previous 10-year period (2008-2018). The 2021-2022 period was estimated to be 38% of the range observed in 1978-1979, a 9% increase from the 2009-2018 period and similar in size to the range occupied in 1998-2008 (39%), though shifted southwest (Fig. 12). The central location also shifted farther south, notably south of Beluga River, compared to the three previous time periods (Fig. 12). Including 2018 with 2021-2022 did not change the distribution patterns or central location calculated for the 2021-2022 period; however, the 2009-2018 central location shifted slightly west in the Susitna Delta when compared to the 2009-2016 time period (Shelden et al. 2017), primarily due to more whales occupying Trading Bay.

When standardizing the number of belugas per group-pass that were counted in each video by the length of the video clip, results showed that there was at least one large condensed group per survey year from 2004 to 2016 (>2 belugas per second of video) (Fig. 13). However, since 2018, the maximum number of belugas per second of video has been < 1 for all group-pass combinations (Fig. 13). In 2021, the number of beluga groups seen per survey day (12.5 groups/ day) was higher than any other survey year since 2004 (2.3 to 10.5 groups/ day) (Fig. 13). With the exception of 2007, the last three surveys (2018, 2021, and 2022) had the highest number of beluga groups/ day and the lowest median number of belugas counted in the video clips (Fig. 13). In 2007, the median number of belugas counted per second of video was higher (0.33) than the last three surveys (0.09-0.21), indicating that while there were more groups, belugas were more aggregated in 2007 than in recent years.

Summed group size estimates for each acceptable survey day varied considerably across years (2004-2022) (Table 3, Fig. 14). This could be attributable to (1) uncertainty in group size estimates or (2) imperfect group detection. For the two complete survey days in 2021 (June 26 and 27), the daily total group size estimates were, on average, 3.17 times greater than the daily sums of group medians (range: 2.91-3.44). In 2022, the daily total group size estimates were on average 2.02 times greater than the daily total group size estimates for the three survey days (range: 1.96-2.06).

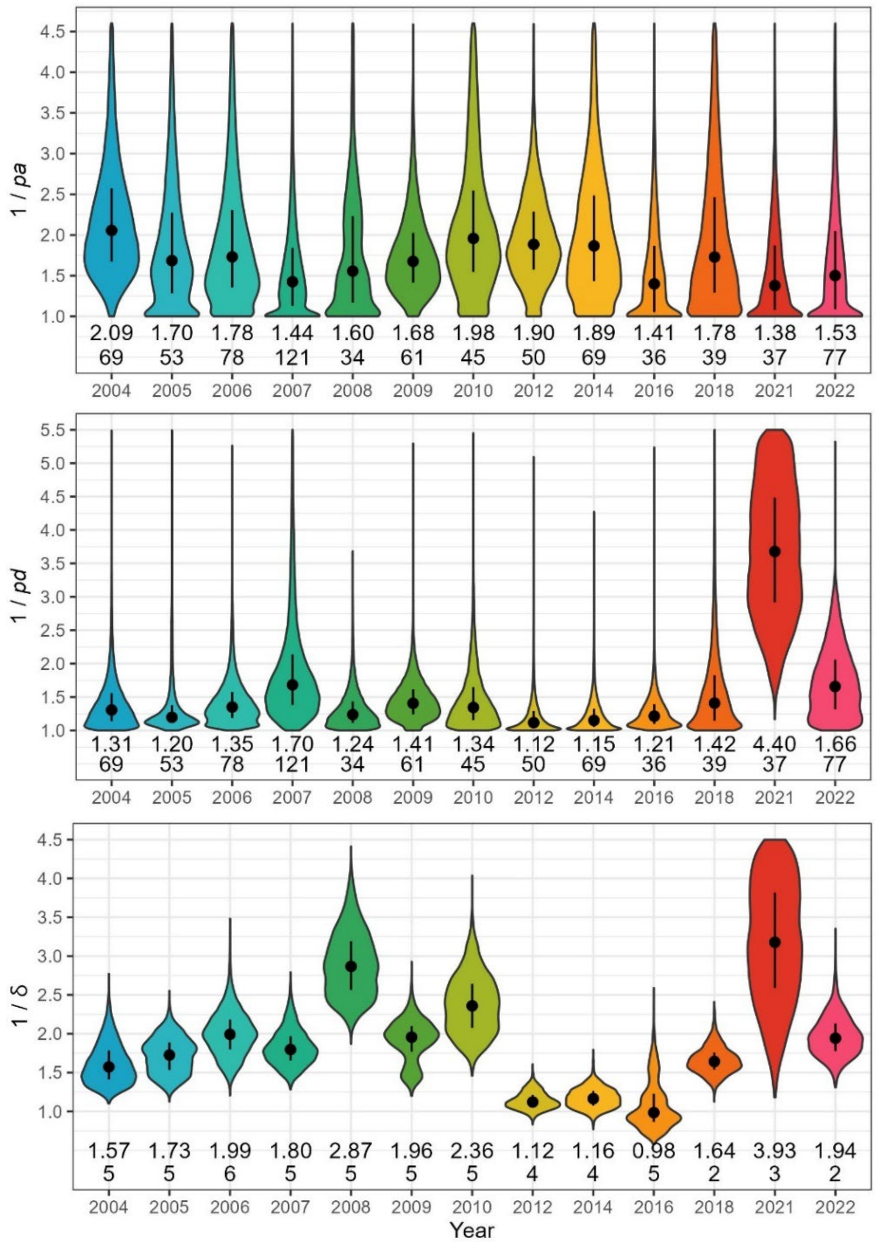

Figure 7. -- Violin plots of correction factors for Cook Inlet beluga video counts by survey year: $1/pa$ = availability bias (top panel), $1/pd$ = perception bias (middle panel), $1/\delta$ = observer bias (bottom panel). Large black points and lines show median and interquartile range, respectively. Data distribution is indicated by shape, representing kernel densities of individual corrections for 1,000 samples from the posterior distribution of each unique day, group, and pass combination (top and middle) and each observer (bottom). Numbers below each plot show the median for each correction factor (first line) and total number of sample for each correction factor estimated, which is the total number of passes made across all groups and days for the upper two plots, and the total number of observers for the lower plot.

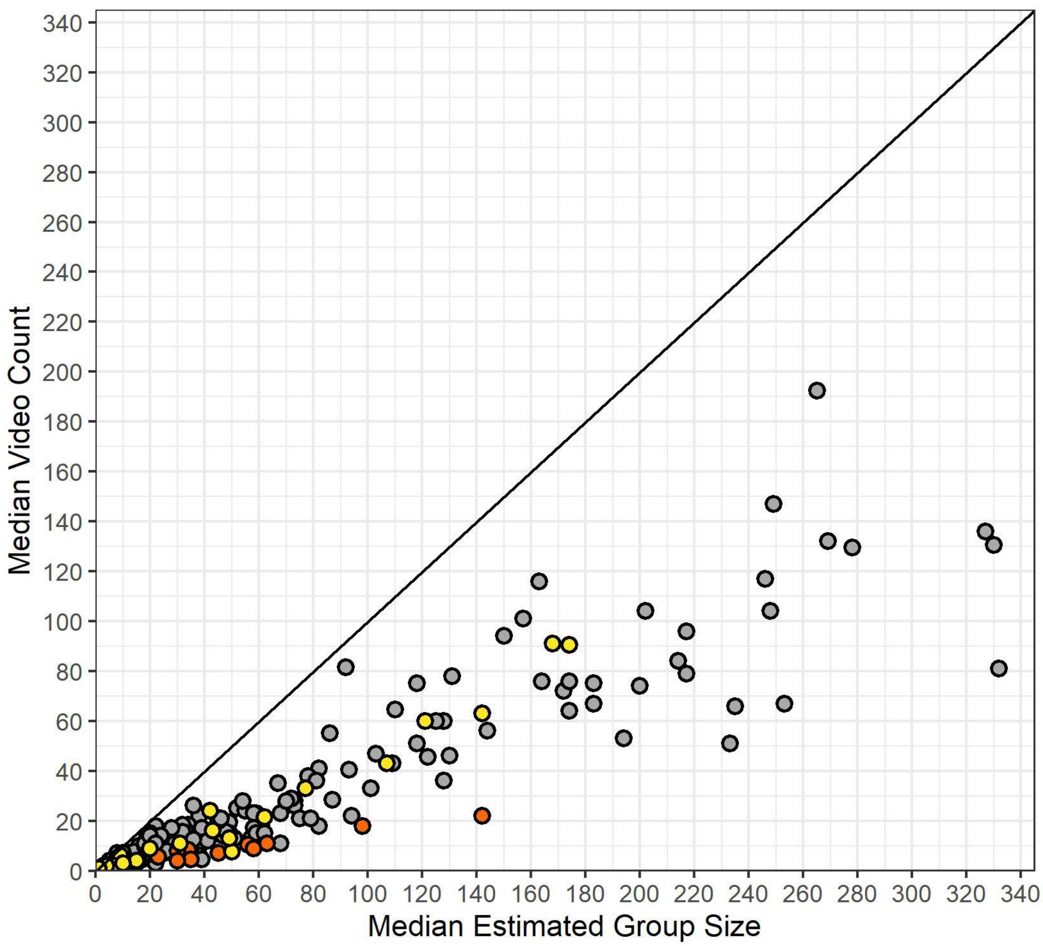

Figure 8. -- Scatterplot comparing the median number of Cook Inlet belugas counted per group in the video to the number of belugas estimated by the model for survey years since 2004, with the exception of 2011. Orange and yellow points indicate the most recent surveys in 2021 and 2022, respectively. The black diagonal line (slope=1, y-intercept =0) indicates where values on both axes are equal.

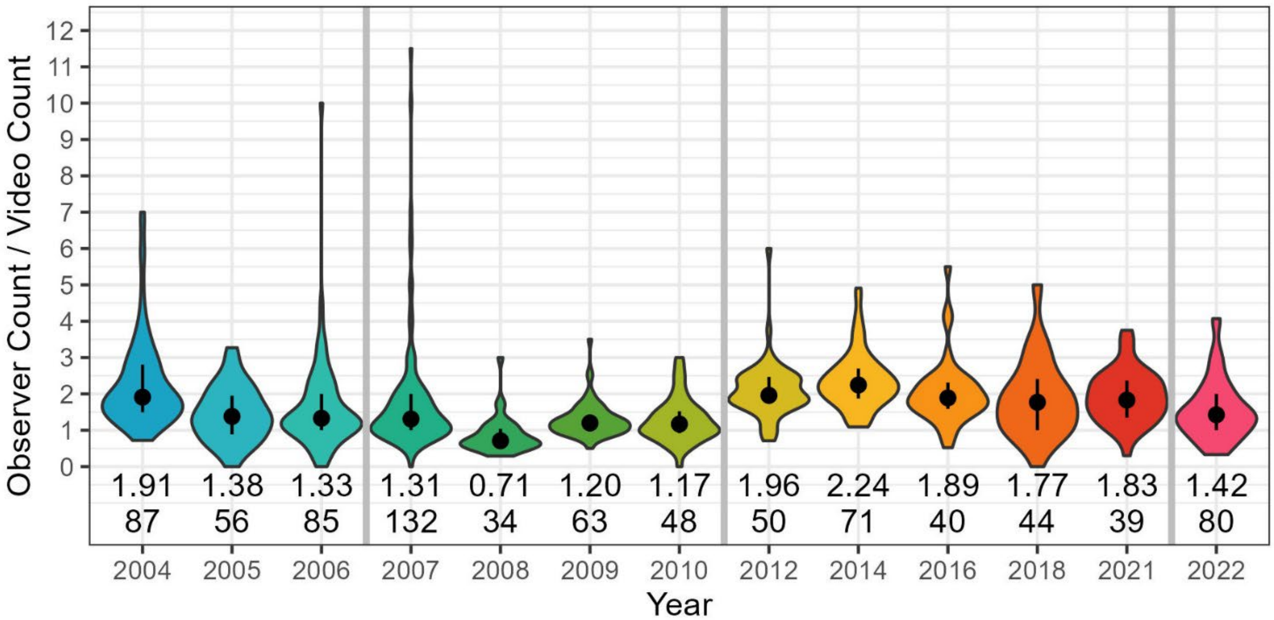

Figure 9. -- Violin plots of observer to video counts of Cook Inlet belugas for each group-pass combination by year. Large black points and lines show median and interquartile range, respectively. Data distribution for each year is indicated by the shape, representing kernel density plots. Numbers below each plot represent the median observer to video count ratio (first line) and total number of group-pass (second line) for each survey year. Solid gray lines indicate video camera upgrades.

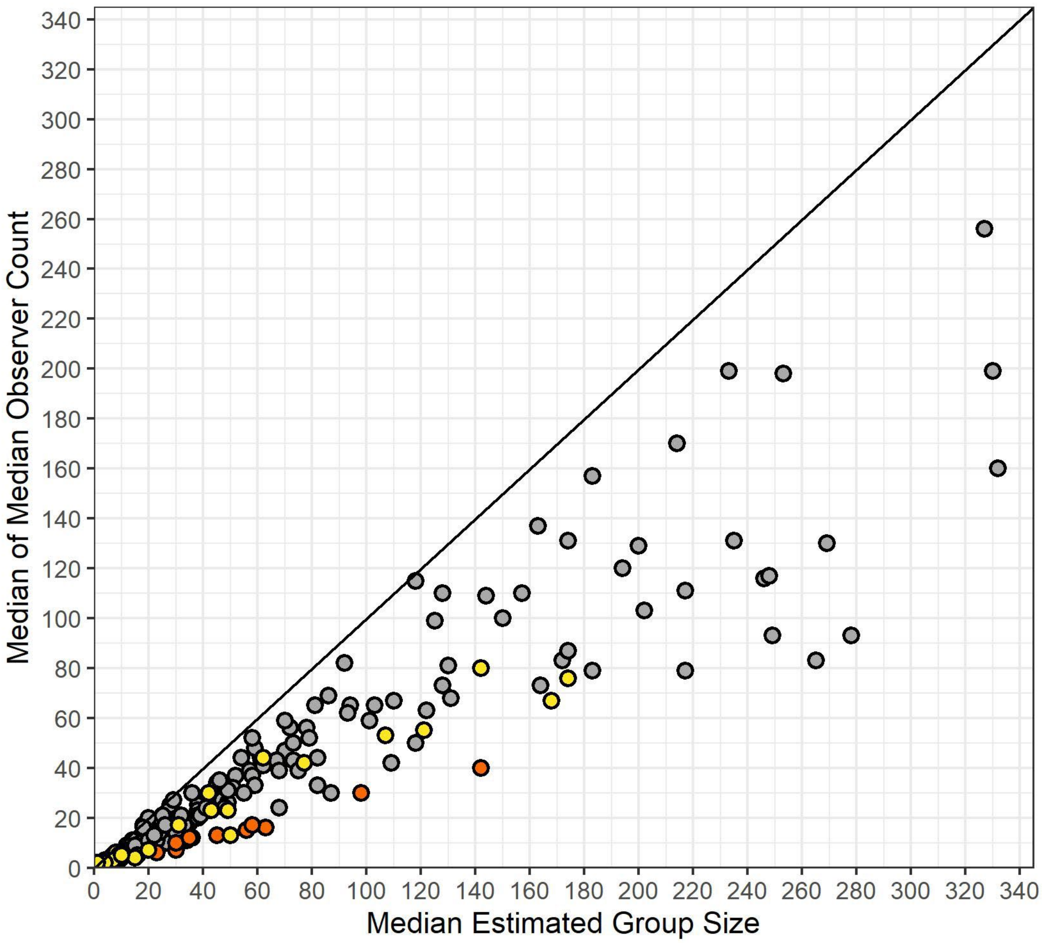

Figure 10. -- Scatterplot comparing the median number of Cook Inlet belugas counted per group by observers to the number of belugas estimated by the model for survey years since 2004, with the exception of 2011. Orange and yellow points indicate the most recent surveys in 2021 and 2022, respectively. The black diagonal line (slope=1, y-intercept =0) indicates where values on both axes are equal.

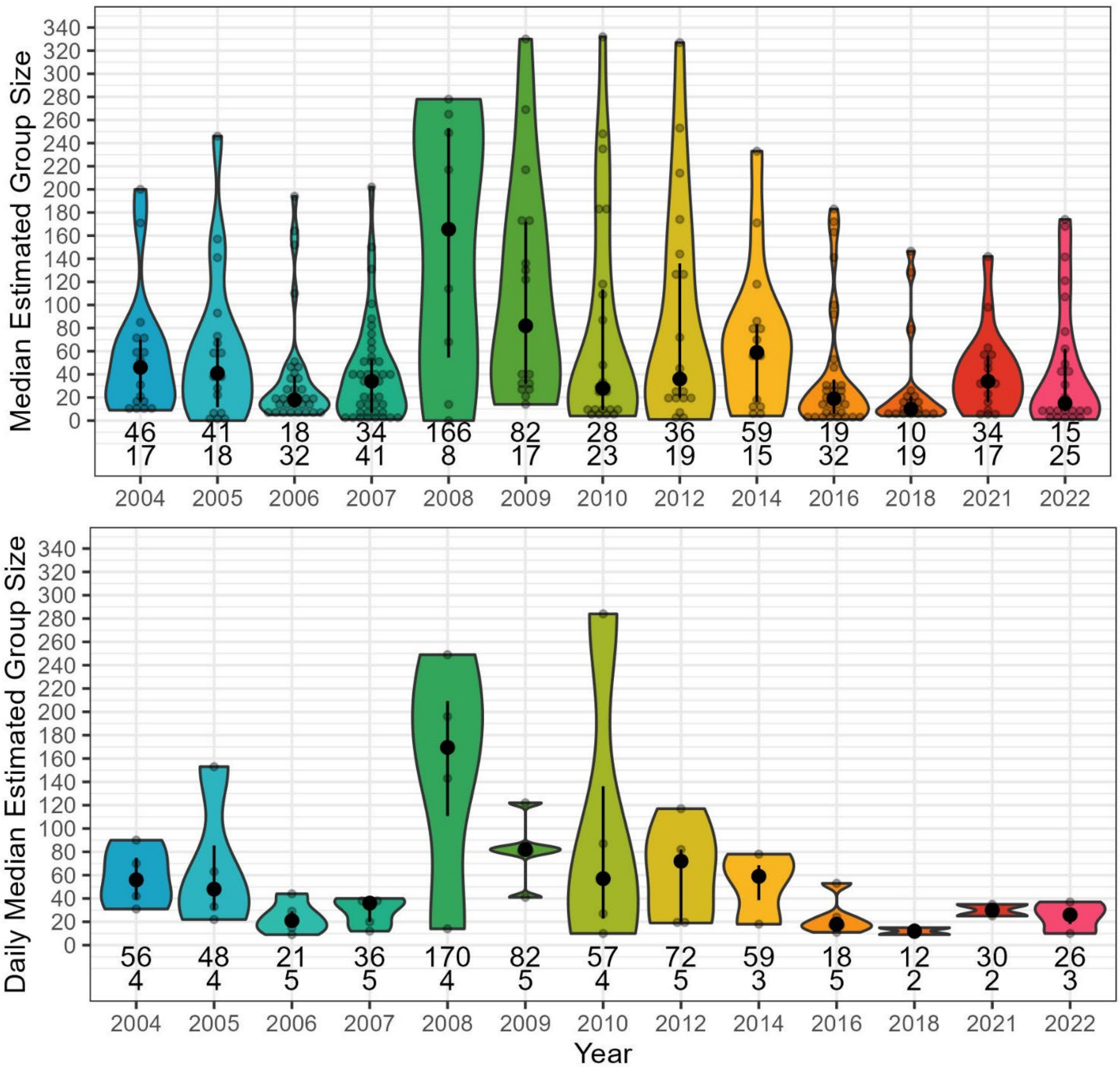

Figure 11. -- Violin plots of median of 1,000 samples from the posterior distribution of group sizes per Cook Inlet beluga group (top panel) and daily median estimated group sizes (bottom panel) by survey year. Large black points and lines show median and interquartile range, respectively. Data distribution for each year is indicated by the shape, representing kernel density plots. Smaller transparent points show the underlying binned data. Numbers at the bottom of the top panel represent the medians of estimated group sizes (first line) and the total number of estimated groups (second line) per survey year. Numbers at the bottom of the bottom panel represent the median of the daily median estimated group sizes (first line) and the number of daily median group size estimates (second line) per survey year.

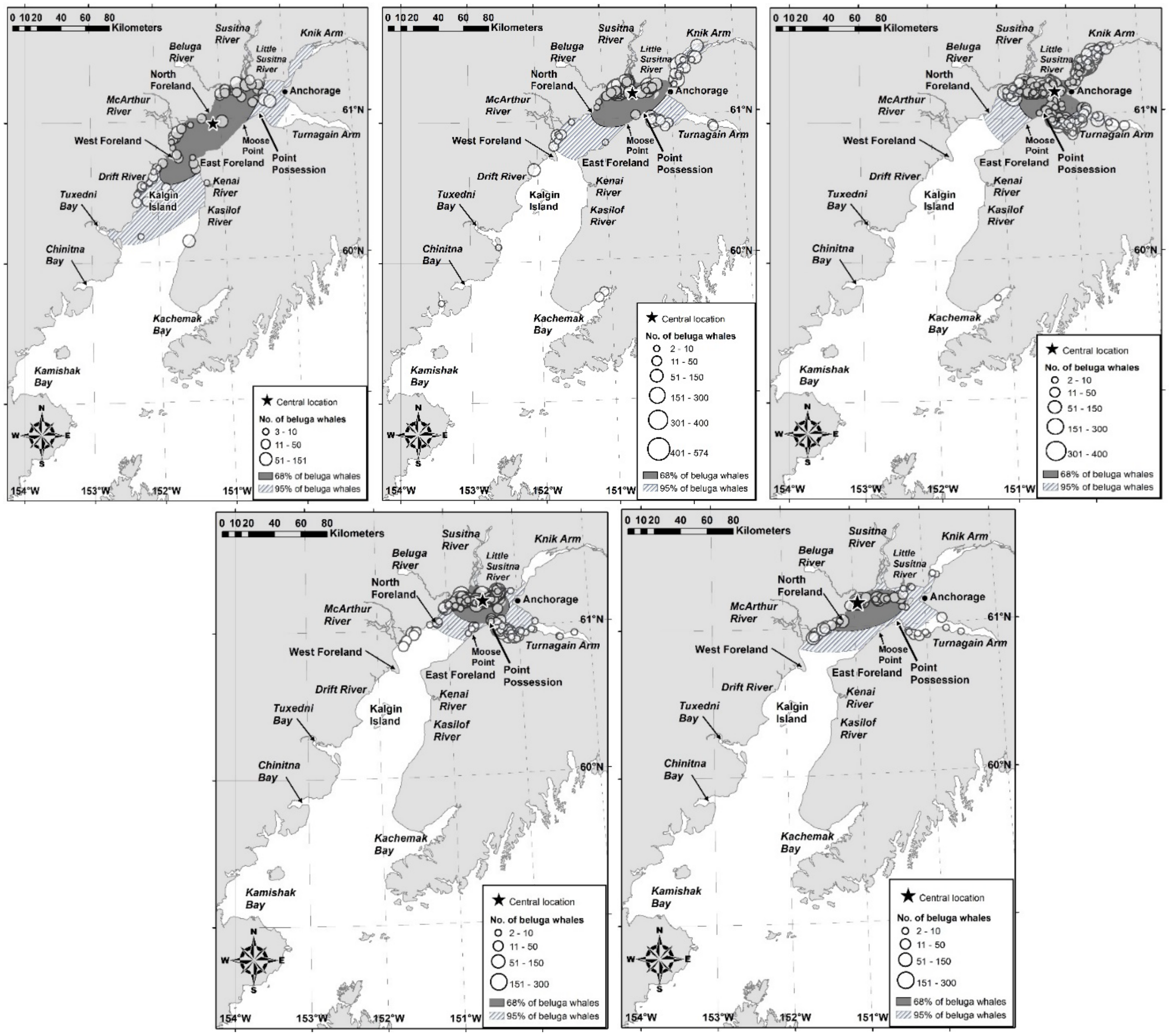

Figure 12. --Areas occupied by belugas in Cook Inlet, Alaska, during systematic aerial surveys in 1978-79 (top left), 1993-97 (top middle), 1998-2008 (top right), 2009–18 (bottom left) and 2021-22 (bottom right). Distribution of belugas around each central location (star symbol) for each period was calculated at 1 and 2 SD (capturing ca. 68% and 95% of the whales; shaded regions).

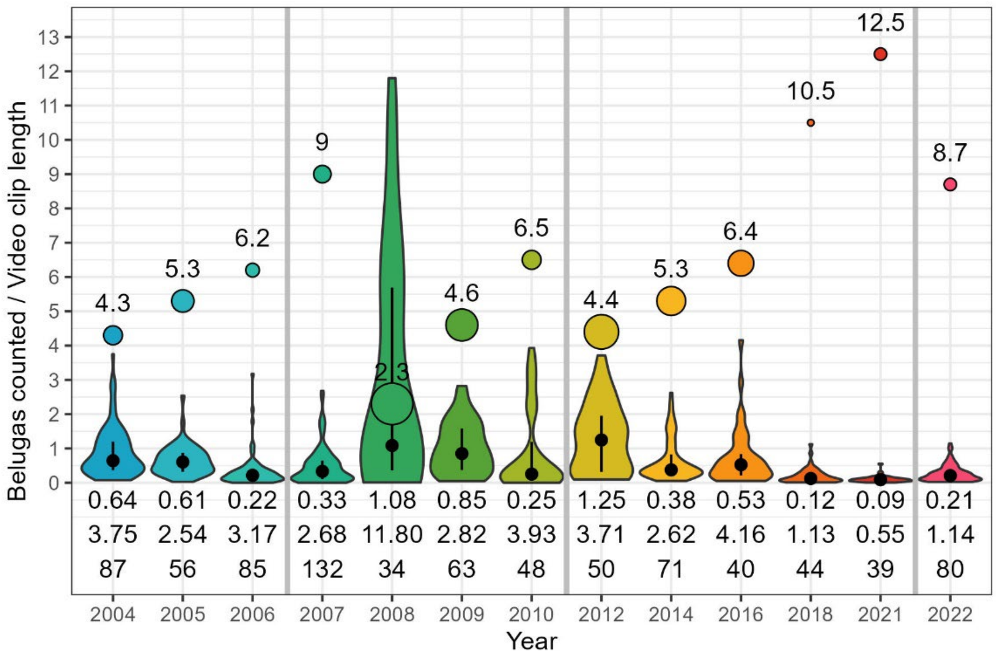

Figure 13. -- Violin plot of number of Cook Inlet belugas counted in each video group-pass divided by the length of each video clip by survey year. Large black points and lines show median and interquartile range, respectively. The distribution of the data for each year is indicated by the shape, representing kernel density plots. Numbers at the bottom of plot represent the medians of belugas counted in each group-pass divided by the length of the video pass (first line), maximum values of belugas counted in each group-pass divided by the length of the video pass (second line), and the total number group-pass combinations with video recordings (third line) for all acceptable survey days per survey year. Colored points and labels indicate the number of groups per acceptable survey day by year. The size of the point represents the median number of animals counted per length of video clip with larger dots indicating more densely packed groups. Solid gray lines indicate video camera upgrades.

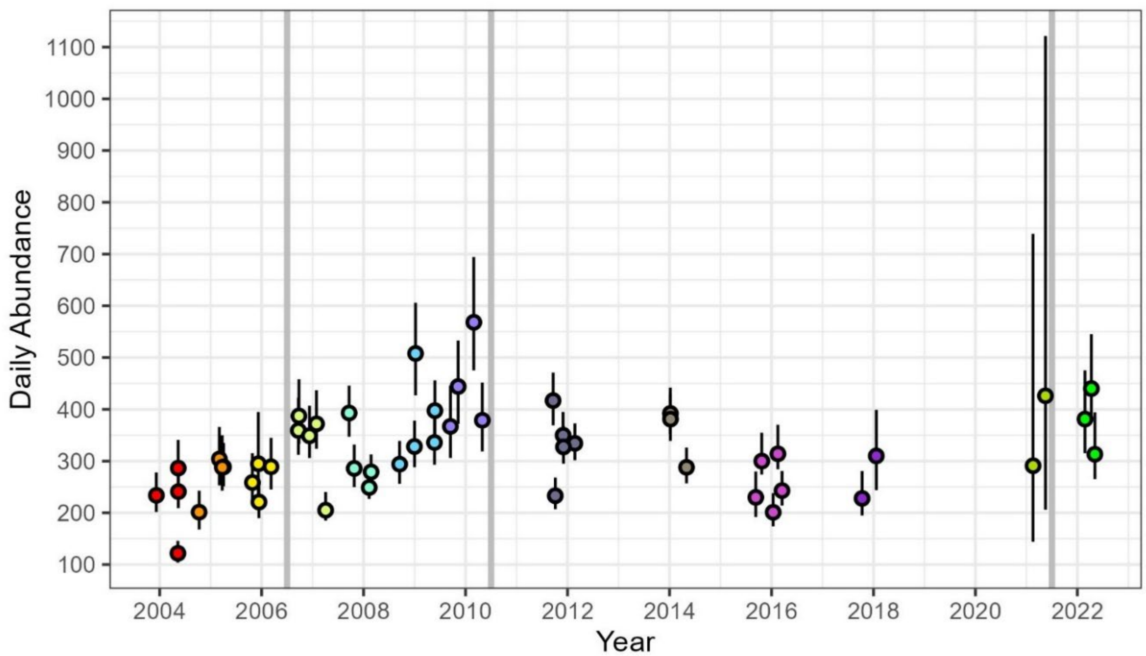

Figure 14. -- Interdiel variation in total Cook Inlet beluga group size estimates. Variation in color serves to differentiate between survey years. Points indicate the median of the posterior distribution and lines represent error bars indicate the 20th and 80th percentiles. Solid gray lines indicate video camera upgrades.

Annual Abundance Estimates and Trends

The annual 'point' estimate of abundance for 2021 and 2022, based on the median abundance estimate of all acceptable days is 361 (CV = 0.547, 95% probability interval 176 to 919) and 381 (CV = 0.110, 95% probability interval 317 to 473), respectively (Table 4). These point estimates fall within the range of median estimates for surveys conducted since 2004 (238 to 415 whales) (Table 4). The 'best' estimate of abundance for the CIB population from the aerial survey data is 334 (CV = 0.263, 95% probability interval 248 to 586) for 2021 and 364 (CV = 0.169, 95% probability interval 292 to 532) for 2022. These best estimates are based on the estimate of smoothed abundance across years. If the 2021 survey year is excluded, the best estimate of abundance for 2022 is 331 (CV = 0.076, 95% probability interval 290 to 386).

The revised time-series shows a clear pattern in the trend in abundance; the data indicate the population was initially increasing but then started declining from 2010 to ~2016 or 2018, after which it appears to be on a slight upwards trajectory (Fig. 15). This pattern is also evident when excluding data from the 2021 survey (Fig. 15). Over the most recent 10-year time period (2012-2022), the estimated trend in the abundance estimates shows a slight increase of 0.9% per year (95% PI -3.0% to 5.7%) (Fig. 16). There is a 65.1% probability that the CIB population is increasing but only a 47.4% probability that the increase is more than 1% per year. When excluding the 2021 survey, the estimated trend in abundance is reduced to an increase of 0.2% per year (95% PI -1.8% to 2.6%) with a 60.0% probability that the CIB population is increasing more than 1% per year (Fig. 16). With or without the inclusion of the 2021 survey data, a slightly increasing trend in abundance is more encouraging than the 2.3% per year decline reported from 2008-2018 (Wade et al. 2019). Reasons for this change in trend, and potential analytical concerns, are discussed below.

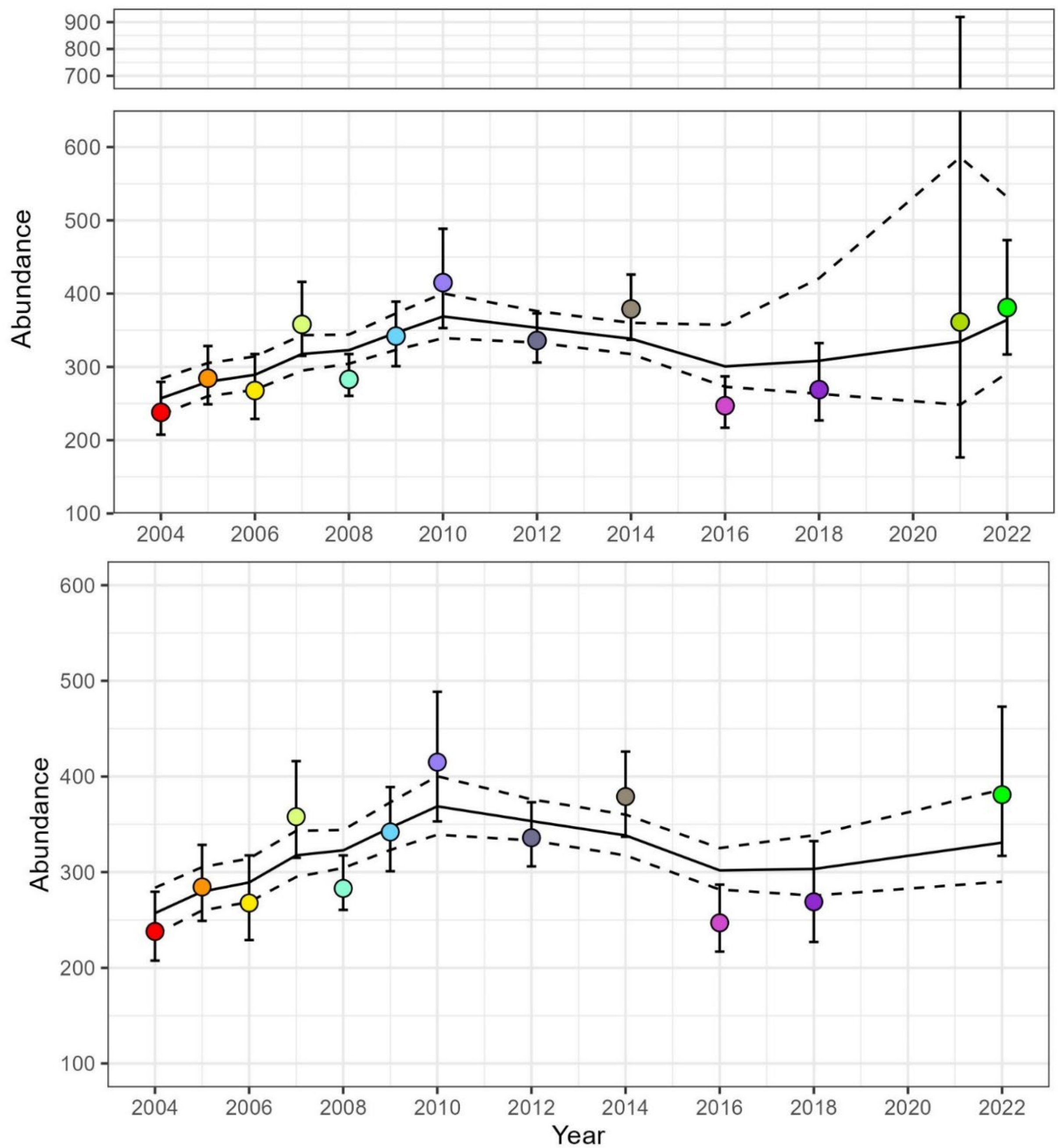

Figure 15. --Annual Cook Inlet beluga abundance estimates (circles) and 95% probability intervals (error bars) for the survey period 2004-2022. The moving average is also plotted (solid line), with 95% probability intervals (dashed lines). The top panel shows abundance estimates including data from the 2021 survey and bottom panel excludes 2021 survey data.

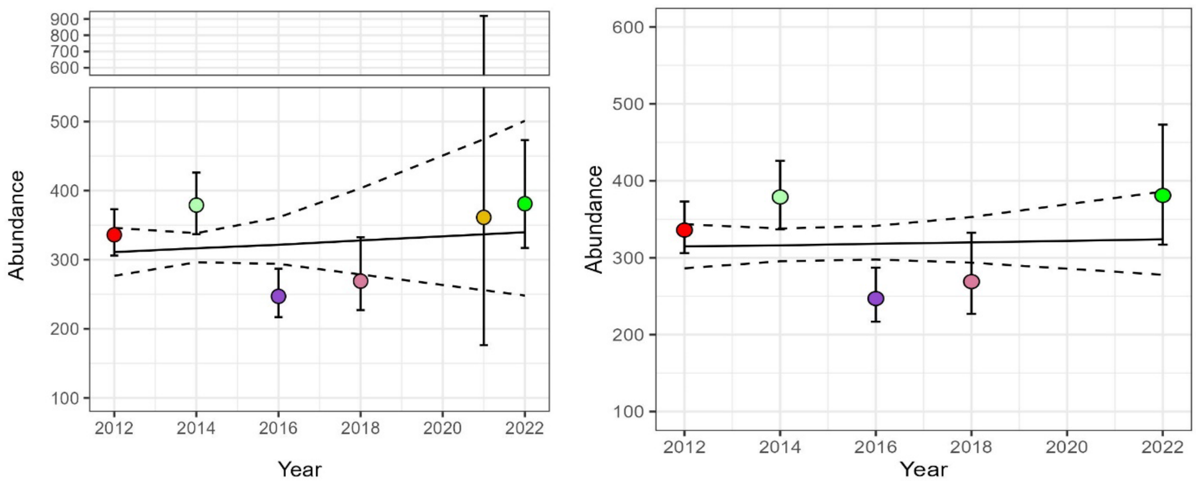

Figure 16. -- Estimated exponential trend of the Cook Inlet beluga population over the most recent ten-year time-period. The left panel shows abundance estimates including data from the 2021 survey and right panel excludes 2021 survey data. (2012-2022), estimated as a linear regression on the natural logarithm of abundance in each year. The solid line represents the Bayesian predicted model, with 95% probability intervals (dashed lines). The left panel shows abundance estimates including data from the 2021 survey and the right panel excludes 2021 survey data.

DISCUSSION

As in previous years, the correction factors used to correct group sizes resulted in groups size estimates that were much larger than observer counts. Similar to 2018, there were no video passes in 2021 that had animals surfacing close enough together that one was missed in the standard video and, therefore, no correction for proximity bias was needed in the analysis for that year. Because the median estimate of the percentages of available individuals detected in video clips during the 2021 and 2022 survey were lower (22.7% and 60.3%, respectively) than in previous years with similar video technology and aircraft setup (i.e., 2012-2018), larger correction factors were needed to correct for perception bias, particularly for 2021.

In 2021, the observer: video count ratio was also higher (1.83) which was consistent with values since 2011 after a change in aircraft and an upgrade in video cameras (1.77-2.24). The combination of larger cameras and a smaller window for the videographer required the aircraft to fly at a greater distance from groups during counting passes for surveys conducted from 2011-2021. The most plausible explanation for the increased observer: video count ratio in 2021 is the associated expansion in the left-forward observer's field-of-view relative to the wide-angle video frame and also the increased difficulty of seeing belugas in the standard video when animals are farther away.

In 2022, the video cameras were upgraded once again which resulted in a lower observer: video count ratio (1.42). Unlike the previous upgrade, the video cameras were much smaller and easily fit through the aircraft window. While the observer: video count ratio is still slightly higher than the surveys from 2007 to 2010 (0.71-1.31), we suspect that this may be due to the spread-out nature of the groups which required flying straight line passes that were several miles long. Thus, the race track pattern was located farther off-shore to ensure that whales could be seen without banking the aircraft and obscuring observer views. The only observer: video count ratio that was < 1 was in 2008 which also had the fewest groups per acceptable survey day and the most animals per video clip length. This finding suggests that when groups are large and concentrated within a small area, observers tend to underestimate the number of whales (likely due to the difficulty of counting individuals when large numbers of animals are surfacing at once). On the contrary, observers tend to overestimate the number of individuals when belugas are scattered, occurring in multiple small groups over a large area.

The median estimated correction factor for observer bias was higher (3.93) in 2021 than any other year since 2004 (0.98-2.87) and, on average, observer counts were 25.4% of the estimated group size. The high correction factor for observer bias in 2021 may have been due to turnover in the observer team in which two of the three observers were new to the survey and were less experienced with the protocols used to count belugas in the Cook Inlet environment. Another potential cause of differences in observer bias is the variation in beluga dispersion and behavior within groups which make it easier or harder for observers to count in some years. In 2022, both observers had previous experience with survey protocols and the correction factor for observer bias fell within the range of other years since 2004 (1.94). Belugas appeared more aggregated in 2022 than in 2021 but were still more spread out than in previous years.

Since 2004, three of the four highest number of groups per acceptable survey day have occurred during the most recent survey years (2018, 2021, and 2022). Additionally, the last three surveys have also had the lowest median and maximum number of belugas counted per second of video as well as the lowest median number of belugas counted per video clip. These findings show that since 2018, an increased number of beluga groups consisting of fewer animals that are less aggregated than in previous years, has added an increased level of difficulty in conducting annual abundance surveys using our current methodology.

Summed group size estimates for each acceptable survey day varied considerably across years (2004-2022) which could be attributable to (1) uncertainty in group size estimates or (2) imperfect group detection. In 2021 and 2022, the point estimate of abundance (median abundance for all acceptable survey days) was 361 (CV = 0.547, 95% probability interval 176 to 919) and 381 (CV = 0.110, 95% probability interval 317 to 473), respectively. While the point estimate of abundance for 2022 does not change whether the 2021 survey data are included or not, because the ‘best’ estimate of abundance is generated from a weighted average of the last three years, the 2022 best estimate of abundance is influenced by the inclusion or exclusion of the 2021 survey data.

In 2021, the best estimate of CIB abundance was 334 with a 95% probability interval of 248 to 586 and CV of 0.263. The high CV was the result of poor weather which limited the number of survey days and prevented flights from occurring during the lowest tide days when belugas are most likely to be aggregated. During the two acceptable survey days in 2021, belugas occurred in a large number of spread out groups with a small number of animals (17 groups over 2 days) which resulted in only 14 of the 25 groups having usable video. Note that the point estimate for 2021 had, by far, the worst CV (0.547) over the 2004-2022 time period, whereas the CV for the 2022 point estimate (0.110) was similar to other years.

Due to the high level of uncertainly in the 2021 survey data, the 2022 best estimate of abundance was calculated with and without the inclusion of the 2021 survey data. With the inclusion of the 2021 survey data, the best estimate of beluga abundance in 2022 was 364 belugas with a 95% probability interval of 292 to 532 which is substantially higher than all other survey years since 2004, except 2010. The CV of 0.169 was greatly improved from the previous year due to an additional survey day and a higher percentage of groups with video data (88% comparted to 56% in 2021). Additionally, the 2022 survey data were collected during early June and during the lowest tides when belugas tend to be aggregated at river mouths to forage on seasonally abundant fish runs which was not the case during the 2021 survey which occurred in late June. Excluding the 2021 data from the analysis results in a slightly lower best estimate of abundance: 331 belugas (95% probability interval: 290 to 386) and an even lower CV of 0.076. Despite the relatively high level of uncertainty associated with the 2021 survey data, the 2022 estimated abundance remains relatively the same (364 vs. 331). However, as a precautionary approach, we recommend 331 as the best estimate of abundance due to the challenges encountered during the 2021 survey and the resulting high CVs.

As reported in Wade et al. (2019), the trend in CIB abundance increased from 2004 to 2010, after which the abundance decreased until 2018. However, since 2018, it appears that the CIB population may be starting to increase, if only slightly. The trend in abundance has changed from a decline of 2.3% per year over a 10 year period from 2008 to 2018 (Wade et al. 2019) to a slight increase over the 10 year period stretching from 2012 to 2022 (0.9% increase per year including 2021 survey data or 0.2% increase per year excluding 2021 data). The analysis of the distribution of estimated group sizes also indicates that the range calculated from 2021-2022 may have expanded from the estimated range from the previous 10-year period (2009-2018). However, since the most recent range contraction analysis includes only two or three years of survey data, it is too early to draw any conclusions.

While the cause for the decreasing trend in CIB abundance from 2010 to 2018 is unknown, the timing of this decline overlaps with the 2014-2016 northeast Pacific marine heatwave (PMH) in the Gulf of Alaska which greatly impacted many facets of the ecosystem (Suryan et al. 2020). This unprecedented PMH caused marked decreases in forage fish abundance as well as piscivorous species such as marine mammals and seabirds during the 2014 to 2016 period (Suryan et al. 2020). At the onset of the PMH, Arimitsu et al. (2021) documented a synchronous collapse of the forage community from 2014-2015 in the northern Gulf of Alaska. During 2013-2015, capelin (*Mallotus villosus*), a common forage fish declined by at least 98% along with a mass mortality of humpback (*Megaptera novaeangliae*) and fin (*Balaenoptera physalus*) whales (Arimitsu et al. 2021).

The sustained warm water anomalies that occurred through the winter was hypothesized to cause increased mortality of Pacific cod (*Gadus macrocephalus*) in the Gulf of Alaska (Suryan et al. 2020). As Pacific cod is a known prey item for CIB, a reduction in Pacific cod in winter could have bioenergetic consequences for belugas foraging in winter when prey are less abundant. Declines in abundance of quality forage fish can lead to mass mortality, changes in distribution, reproductive failure, and malnutrition in piscivorous marine predators (Arimitsu et al. 2021).

The slight increase in CIB abundance since 2018 also matched the increasing trends for marine mammals documented in Suryan et al. (2020) as well as an increase in encounter rates of humpback whales after the PMH (Arimitsu et al. 2021). While it is impossible to know if the 2010-2018 decline in CIB abundance (Wade et al. 2019) was related to the 2014-2016 PMH, the timing and trend in abundance suggests it is likely a contributor to the decline. However, it is unknown to what extent anthropogenic activities in the area (Castellote et al. 2018) may have also contributed to the decline during these years. Regardless, the subsequent increase in CIB abundance since 2018 provides a glimmer of hope that the population is slowly growing or at least stable after the passing of the unprecedented PMH.

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