NOAA Technical Memorandum NMFS-AFSC-472

Report of the Cook Inlet Beluga Whale Abundance Estimation Workshop

April 6-7 2023, Seattle, Washington

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This document should be cited as follows:

Wade, P. R., and Shelden, K. E. W. 2023. Report of the Cook Inlet beluga whale abundance estimation workshop. U.S. Department of Commerce., NOAA Technical Memorandum NMFS-AFSC-472, 48 p.

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Document available: https://repository.library.noaa.gov

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EXECUTIVE SUMMARY

The Marine Mammal Laboratory (MML) at the Alaska Fisheries Science Center has conducted aerial surveys for monitoring the abundance and trends of Cook Inlet beluga whales (*Delphinapterus leucas*) since 1994. Traditional survey methods include a coastal transect of all nearshore waters and offshore tracklines that typically follow a sawtooth pattern from the upper inlet to the entrance of Cook Inlet. When a beluga group is encountered, multiple observer counts and video data are used to estimate group sizes. The surveys were designed to take advantage of the clumped distribution of these whales in early June, when they are often found in a small number (2-8) of large groups. However, in recent years, whales have not been as aggregated in areas where they are known to occur (i.e., Susitna Delta). Therefore, in 2021 and 2022, the MML conducted standard line transect aerial surveys in passing mode within the Susitna Delta, Chickaloon Bay, and Trading Bay, in addition to the coastal and offshore surveys. Analyses of the line-transect survey data show that the number of sightings collected is sufficient for producing a relatively precise abundance estimate. Note that in the context of this report, for clarity, we refer to the survey conducted since 1994 as the Cook Inlet beluga traditional aerial survey in order to distinguish it from the recent line-transect aerial surveys.

In addition to the two types of aerial surveys, in 2017, the MML initiated a Cook Inlet beluga photo-identification project using overhead photos taken from an Uncrewed Aerial System (UAS). Preliminary analyses indicate these data are also sufficient to support relatively precise abundance estimates using closed population mark-recapture models. With multiple methods now available for estimating the abundance and trends of this population, a workshop was held to review all three methods. The main focus of the workshop was to review the potential biases of each method, and whether the biases can be corrected by further studies, with a view to understanding which method(s) may be best for estimating absolute abundance and/or relative trends in the population.

A number of presentations on all three methods were given by workshop participants. They are summarized here as follows:

- **Cook Inlet beluga traditional aerial survey**
    - History of Cook Inlet beluga aerial surveys (K. Shelden)
    - Cook Inlet beluga traditional aerial survey -- current analysis methodology and results (K. Goetz)
- **Cook Inlet beluga line-transect surveys**
    - Cook Inlet beluga line-transect survey field methods and analysis (P. Wade)
    - Review of correction factors for beluga whale line-transect surveys (M. Ferguson)
    - Calculating a correction factor for beluga line transect surveys in the St. Lawrence Estuary (V. Lesage)
- **Cook Inlet photo-identification mark-recapture**
    - Photo-identification of beluga whales (M. Moisan)
    - Cook Inlet beluga whale photo-ID project (T. McGuire, presented by P. Wade)
    - Cook Inlet beluga photo-ID methods using overhead photographs from UAS (P. Wade)
    - Cook Inlet beluga mark-recapture abundance estimation (P. Wade)
    - Potential extensions to mark-recapture methods for Cook Inlet beluga (P. Wade)

Substantial discussion was held after each presentation. Based on those discussions during the course of the workshop, the participants drafted a summary of strengths, weaknesses, and other issues to consider for the three abundance methods (summarized in this report). Suggestions and recommendations by workshop participants for making improvements to each method were also documented. Finally, each participant gave their individual conclusions and takeaways regarding the usefulness of each method for estimating abundance and trends of the Cook Inlet beluga whale population, and for providing additional information about the population. Many of the workshop participants expressed confidence in all three methods for providing information on abundance and trends of the Cook Inlet beluga whale population. The summary of strengths, weaknesses, and other issues to consider, along with the individual conclusions, provide a basis for future discussions about the best way to monitor abundance and trends of this population.

Contents

Introduction

The Marine Mammal Laboratory (MML) at the Alaska Fisheries Science Center has conducted aerial surveys for monitoring the abundance and trends of Cook Inlet beluga whales since 1994. Traditional survey methods include a coastal transect of all nearshore waters and offshore tracklines typically following a sawtooth pattern from the upper inlet to the entrance of Cook Inlet. When a beluga group is encountered, multiple observer counts and video data are used to estimate group sizes. The surveys were designed to take advantage of the clumped distribution of these whales in early June, when they are often found in a small number (2-8) of large groups. However, in recent years, whales have not been as aggregated in areas where they previously have been frequently seen at high densities (i.e., the Susitna Delta). Therefore, in 2021 and 2022, the MML conducted line transect aerial surveys in passing mode within the Susitna Delta, Chickaloon Bay, and Trading Bay, in addition to the coastal and offshore surveys. Note that in the context of this report, we refer to the survey conducted since 1994 as the Cook Inlet beluga traditional aerial survey in order to distinguish it from the recent line-transect aerial surveys.

The line-transect surveys have shown that enough sightings can be collected to support a relatively precise abundance estimate. Additionally, in 2017, the MML initiated a Cook Inlet beluga photo-identification project, using overhead photos taken from an Uncrewed Aerial System. Preliminary analyses indicate these data are also sufficient to support relatively precise abundance estimates using closed population mark-recapture models. With multiple methods now available for estimating the abundance and trends of this population, a workshop was held to review all three methods. The main focus of the workshop was to review the potential biases of each method, and whether the biases can be corrected by further studies, with a view to understanding which method(s) may be best for estimating absolute abundance and/or relative trends in the population.

Presentations

Traditional Aerial Survey

<u>Presentation 1</u>: History of Cook Inlet beluga aerial surveys (K. Shelden)

The Alaska Department of Fish and Game flew the first aerial surveys to enumerate the Cook Inlet beluga population in the 1960s. In the 1970s, increasing interest in petroleum development throughout Alaska waters led to NOAA funding large-scale, systematic surveys to determine seasonal distribution of seabirds and marine mammals. Surveys occurred one to two days monthly as weather allowed from November 1977 to August 1979 with a single observer and pilot. The lone abundance estimate calculated from this time period of 1,293 whales used a correction factor based on tagged Bristol Bay belugas and has been used as a benchmark for historic abundance. Distribution studies did not resume until the 1990s when the National Marine Fisheries Service conducted a distribution and abundance survey in June 1991. Observers were positioned at bubble windows on each side of the aircraft, there was a data recorder, and counts occurred in passing mode. Similar to the ADF&G survey, the correction factor for Bristol Bay belugas was applied to the highest count from a single survey day resulting in an estimate of 1,018 belugas.

In 1993, NMFS surveys were flown in June, July, and September to help establish optimal survey conditions and timing, as well as to refine survey methods. Of primary consideration was to take advantage of the predictable concentrations of belugas in a few river mouths during low tide. The June–July period was selected as the preferred time to survey (especially the first half of June) when anadromous fish have begun to return to the inlet to spawn. Subsequent aerial surveys conducted annually from 1994 to 2003 were completed in one week. Survey altitude is 800 feet and speed about 100 knots. The team consists of three observers and a data recorder. Two observers are positioned at windows on the shoreward side where most sightings occur and the third at a window looking offshore. Sightings were reported independently using an isolation system for the observer headsets to obtain a missed group correction. After reporting, the beluga group was circled in a racetrack pattern to obtain multiple independent counts by two observers while the third observer collected video. The abundance was calculated by breaking the inlet into sectors and summing high counts from the three regions.

Groups are circled for counting and video recording until at least four good passes have been completed. Passes are scored by the observer and only passes given an A or B score are used. Video data are used to correct for perception bias and proximity bias. Both video and tag data from a suction cup radio tagging project that took place in Cook Inlet are used to correct for availability bias. Video data are the preferred source of group size estimates. For groups without usable video records, observer counts were calibrated based on comparisons between video and observer counts from other groups. Paired observer records were also analyzed to estimate the fraction of the population in missed groups. A number of updates and modifications to the survey have occurred over the 30 years of this project (Table 1).

For a typical survey year, we try to survey the lower inlet, using a sawtooth pattern that is shifted each year, before beginning upper inlet surveys to ensure most if not all belugas are in the upper inlet (Fig. 1). In some years, the lower inlet surveys used tracklines running straight down the middle of the inlet, offset from one another. A typical lower inlet survey takes two days; a sawtooth flown south then a coastal survey of the west side north to West Foreland, and a coastal survey south from East Foreland with a sawtooth flown north. The focused upper inlet survey is timed to coincide with negative low tides in the Susitna region. We usually fly clockwise beginning in Turnagain Arm early in the day before winds increase which can occur later in the day. We continue the survey into Chickaloon Bay then southwest from Point Possession to East Foreland where we cross the inlet to West Foreland. At this point, the survey is resumed to the northeast where we aim to arrive in the Susitna Delta at low tide. Knik Arm and any remaining coastline are surveyed last. Depending on the number of beluga groups encountered, sometimes we can complete the survey without needing to refuel -- other times may require a two-flight survey (i.e., we arrive before the low tide and whales are scattered).

<u>Presentation 2</u>: Cook Inlet beluga traditional aerial survey -- current analysis methodology and results (K. Goetz)

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. 2015a, 2017, 2019). The survey is a census of groups, with video data collected in order to estimate group size. 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. Of the two most recent surveys, the survey in 2021 was conducted late in June to comply with COVID-19 pandemic protocols. However, due to bad weather, only two successful survey days were conducted.

The survey in 2022 was conducted at the usual time period in early June and four survey days were successfully completed. During both the 2021 and 2022 surveys, the distribution of whales was seen to have changed from previous surveys. Specifically, that whales were less aggregated around river mouths, and were more dispersed, such that they occurred in a larger number of groups that had a smaller number of whales on average. Additionally, the data show that the whales occurred at lower density in groups in 2021-22 compared to previous surveys. The fact that the whales were more dispersed, occurred in more groups, the groups were of a smaller average size, and the groups themselves had a lower density of whales (meaning they were more spread out) meant that it was more difficult to collect good video data to use for group size estimation. This was particularly true in 2021, where these factors led to estimates of abundance with very high CVs, meaning that they had very low precision.

Line-Transect Surveys

<u>Presentation 3</u>: Cook Inlet beluga line-transect survey field methods and analysis (P. Wade)

The abundance and trends of the Cook Inlet beluga population have been monitored with an aerial survey in June that is not a typical line-transect survey; instead, it is a census of beluga groups in all nearshore habitat in Cook Inlet, with video data collected to estimate group sizes (Hobbs et al. 2000). The survey was designed to take advantage of large aggregations of the whales feeding on returning spawning eulachon or salmon at river mouths (Castellote et al. 2021, Rugh et al. 2000), which made line-transect surveys problematic. Two issues have led researchers to re-consider the use of line transect surveys for the Cook Inlet beluga population. The traditional coastal survey was successful because the whales have been aggregated into a small number of medium to large-sized groups along the coast. However, the whales have been less aggregated in recent years, which has made it harder to collect the video data used to estimate absolute group size during these surveys. With the whales more dispersed, line-transect methods are more practical. In particular, if the survey is not flown at low tide, the whales tend to be dispersed in the Susitna Delta into smaller, scattered groups. Second, it has always been recognized that some groups may be missed during the traditional survey, and researchers established *ad hoc* rules to discard survey days which were too low by various criteria (Hobbs et al. 2015). Therefore, the traditional survey is subject to criticism that groups may be missed, particularly if whales move offshore away from the coast, and no quantitative method has been established to fully correct for that.

Therefore, the MML began conducting line-transect surveys as an experiment, with surveys flown in June 2018, 2021, and 2022 during the same period that the traditional survey was flown. The survey in 2018 was flown as a closing-mode survey (i.e., the plane would break off the trackline to close for group size estimation), but it was difficult to define a group when there were many loosely associated small groups, and it was difficult to determine which group was initially seen on the transect-line. The survey team concluded that these difficulties made the use of a closing-mode survey problematic, and no further attempts were made to conduct closing-mode surveys. Therefore, the 2018 survey is not considered further here.

To correct for these issues, in 2021 and 2022 line-transect surveys were flown in upper Cook Inlet as a passing-mode survey (the plane did not break from the track-line, and the group was defined to be what was seen by the observer while passing by the group), which were more successful. The upper Cook Inlet was divided into three strata that covered the areas known to have the highest density of beluga whales: Susitna Delta, Chickaloon Bay, and Trading Bay. Given the surveys were conducted in passing mode, the only data collected were the estimated group size and clinometer angle for each observation. A single observer was positioned at a bubble window on each side of the aircraft. Observers scanned the field of view from beneath the aircraft (90°) to the horizon (0°) and ahead of the aircraft to abeam.

Successful line-transect surveys were flown on 30 June and 1 July in 2021 (Fig. 2) and on 6 June and 9 June in 2022. In each year, the two surveys were flown such that on the first day Trading Bay and the Susitna Delta were covered at low tide and Chickaloon Bay was covered at high tide, and on the second day Trading Bay and the Susitna Delta were covered at high tide and Chickaloon Bay was covered at low tide. A total of 241 sightings occurred across both years (2021-2022). The R package 'mrds' was used to analyze the data. After inspection of the distribution of perpendicular distances, a right truncation limit was specified at 2.3 km, as sightings were sparse beyond that limit. The distribution also indicated there is some evidence of a lower sighting probability at less than < 50 m perpendicular distance, which can happen if the observers are not looking straight down the entire time. Therefore, a left truncation of 50 m was specified, leaving a total of 221 sightings for fitting the detection function.

Model selection using AIC selected a Hazard rate key function, with the top two models being one with covariates of Beaufort state and group size, and a second model with just a covariate of group size. Estimates of total population size for each day (using the detection model that included covariates of group size and Beaufort state) were, for 2021, 144 (CV = 0.32) and 121 (CV = 0.29), and for 2022, 152 (CV = 0.26), and 229 (CV = 0.26) showing the estimates were relatively consistent from day to day. The mean of the two surveys days in each year were 132 (CV = 0.24) in 2021 and 190 (CV = 0.14) in 2022 (Fig. 4, filled circles). It is known that aerial line-transect surveys will be subject to negative bias because of several factors, including submerged whales (availability bias), g(0), or probability of detection on the trackline, and the probability of missing small, dark calves in a group (perception bias). A review of the literature suggests these three factors could lead to a correction factor of approximately 2.0 (or more) for Cook Inlet belugas, which would lead to corrected abundance estimates ranging from 241 to 457, which covers the range of recent estimates from the traditional survey used to survey Cook Inlet belugas.

<u>Presentation 4:</u> Review of correction factors for beluga whale line-transect surveys (M. Ferguson)

Ferguson discussed the data and methods used to derive correction factors and estimate abundance of Eastern Bering Sea (EBS) belugas from the ABWC-NMFS 2017 aerial line-transect survey in the Norton Sound/Yukon Delta region. The conventional geographically stratified analysis used multiple-covariates distance sampling (mcds) to estimate effective strip width from the 2017 survey data. The correction factor for availability bias was estimated to be 2.0 based on historical beluga surface and dive interval data and an estimate of the viewing time for a marine mammal observer during the 2017 aerial survey. The best available information on beluga respiration patterns was from behavioral observations made on three adult female belugas tagged with VHF radio tags: one beluga tagged in Bristol Bay, Alaska, in June 1983, and two belugas tagged in Cunningham Inlet, Somerset Island, Canada, in July 1988 (Frost et al. 1985, Frost and Lowry 1995). Because both the port and starboard observers had a clear view in a 180^{o} arc fore to aft, from the transect to the horizon, viewing time (15.9 sec) was estimated by dividing the right-truncation distance used in the mcds analysis (944 m) by the survey speed (213 km/h).

Data were not collected during the 2017 aerial survey to estimate a transect detection correction factor specific to the survey. Therefore, transect detection probability was estimated from belly port camera imagery and observer data collected during similar aerial line-transect surveys for marine mammals in the eastern Chukchi and western Beaufort seas conducted in 2018 and 2019. To accommodate uncertainty in matching belugas detected in the imagery with belugas detected by the aerial marine mammal observers, a sensitivity analysis was conducted that considered three different assumptions critical to the matching process. Expert judgment was used to select a single best estimate of transect detection probability, which was 0.752, resulting in a transect detection correction factor of 1.33.

<u>Presentation 5:</u> Calculating a correction factor for beluga line transect surveys in the St. Lawrence Estuary (V. Lesage)

Abundance estimation of wildlife populations can be effectively derived from systematic aerial surveys. Accuracy and precision of estimates, however, depend on the number of replicate surveys, and on adjustments made for animals unavailable to survey platforms (availability bias) or available but missed by observers (perception bias). This study offers a comprehensive analysis of the relative influence of methodological, environmental and behavioral factors on availability bias estimates from photographic and visual surveys of a small cetacean having typically a clumped distribution: the beluga (*Delphinapterus leucas*). It also provides, through 14 visual surveys repeated over a 21-day period, an estimate of the minimum number of surveys required to stabilize the variance and point estimate of abundance.

Availability was estimated using high-resolution (0.25 m and 1 s) dive data from 27 belugas from the St. Lawrence Estuary, Canada, and applied to repeated visual and photographic surveys of this population conducted using various survey platforms. Dive and surface interval durations varied among individuals, with a mean of 176.6 seconds (weighted S.E. = 12.6 seconds) and 51.6 seconds (weighted S.E. = 4.5 seconds), respectively. Generalized additive mixed models indicated that dive time and availability globally, but not surface time, were affected by local turbidity, seafloor depth, the whale behavior (i.e., whether beluga were likely in transit or not), and latent processes that were habitat specific. Overall, adjustments of availability for these effects remained minor compared to the influence exerted by survey design (photographic or visual) and type of platform, and by observer search patterns (i.e., time in view). For instance, mean availability estimates varied from 0.33 to 0.38 among photographic surveys depending on sightings distribution across the study area, but all exceeded 0.40 for visual surveys. Availability also varied considerably depending on whether observers searched forward within 0-90 degrees (0.42-0.60) or the full field-of-view (170 degrees) available to them (0.70-0.80). The cumulative abundance estimates and associated variance from the 14 replicate surveys indicate that a minimum of 4 surveys, ideally 6-8, are required to minimize variance and stabilize abundance estimates for a species with a clumped distribution like beluga.

Photo-Identification Mark-Recapture

Presentation 6: Photo-identification of beluga whales (M. Moisan)

Moisan described their experiences of photo identification of beluga whales in the St. Lawrence Estuary, including types of marks used for identification, and the coloration stages of belugas as they get older. They use seven color categories that represent stages of development from neonatal calf to fully physically mature adult. The categories are (a) neonate (calf, year 0), (b) Yearling (bluevet, year 1), (c) dark (small) gray (year 2-3), (d) medium gray (year 4 and older), (e) large gray, (f) white-dirty, and (g) white. Neonatal calves are very small and short, a brownish-gray color, with a stubby neck. Fetal folds are often visible. They are clean-looking (no or few scratches) and sometimes have a dark circle around their eyes. Their head comes completely out of the water when surfacing, and they are often very close to the presumed mother.

Marks on calves do not seem to carry over to the next year, but last long enough to be recognized in their first few months. Yearlings are bluish-gray or dark-grayish in color, or even sometimes brownish. They often have a mottled appearance, with lighter gray patches. They are still quite small, with a no-neck look, and sometimes the area posterior to the blowhole is darker. They are still often very close to the presumed mother. The dark (small) gray calves are dark greyish in color, and are distinctly smaller and shorter than a medium or light gray beluga. They still have a no-neck look but are less spotted or mottled than yearlings, so the coloration is more uniform. They can still have dark coloration on the head and posterior to the blowhole.

Scratches mostly show as dark (darker than background). They are generally 2 or 3-year's old, and are less closely associated with the presumed mother. Medium gray whales have a pale gray coloration that is not as dark as small grays, but is not light gray. The head is often darker. There can be a mix of dark and white scratches. They are not as long as an adult whale. There can be an indentation behind the blowhole, and the dark area posterior to the blowhole may appear more diffuse. Large gray whales have a light gray coloration, and they are similar in shape to completely white adults but are smaller. Scratches appear generally white against a darker gray background. The dark area posterior to the blowhole has usually faded. Some whales have started to develop pontoons (a flaring out of the body along the flank of the animal). The white-dirty category are whales that are mostly white but not pure white; they are easier to determine when swimming near fully white whales. They look like white whales but are a bit splotchy or slightly dirty looking. The dark area posterior to the blowhole is usually gone or is thin. Scratches show as distinctly lighter white against the background, but just barely. They often have developed pontoons and a "shoulder" where the body flares out at the base of the neck. Finally, white whales are fully white, with white scratches against a bright white background. They usually have fully developed pontoons. The dark area posterior to the blowhole is completely gone.

The development through these stages was shown for one whale that suffered a wound when it was a neonatal calf that allowed it to be recognized through its life. It was categorized as a small gray at year 3, medium gray at year 7, large gray at year 11, white-dirty at age 12, and white at year 16 as one example of the progression through the color categories.

They use four primary types of markings for identification, which are spots, scars, dorsal ridge nicks, and scratches. Spots can be white, gray, or black and can come in a variety of shapes and sizes. Spots are almost always permanent, though one exception is that white spots on gray whales can disappear. Some markings that appear light against a dark background on dark gray whales can eventually appear dark against a white background as the whale ages, so there is an inversion of the color. Scars are caused by wounds from sources such as collisions with boats or from a severe skin disease, and they can leave permanent marks that can be used for identification. Older whales often acquire nicks along the dorsal ridge, and these are generally permanent and are therefore useful for identification.

The last category routinely used for identification are scratches, which are superficial marks that may fade or disappear over a few months. They are useful to help confirm identification in the short term, but they may not last across seasons. Deeper scratches (where a furrow can be seen, meaning there is a visible indentation into the skin) may stay visible for a few years and turn into a white line that becomes a long-term mark. Moisan showed an example of deep scratches that have remained visible for 13 years on one whale. They also occasionally see deformities, such as curvature of the spine laterally, curvature of the spine dorsal-ventrally (hunchback), or swelling in a single location on the body. In summary, one difficulty is that for identification, the white adult whales often have relatively few permanent markings, so it is important to use as many marks as possible. However, most marks last at least a few months, so can be useful for identification within a summer season.

Presentation 7: Cook Inlet beluga whale photo-ID project (T. McGuire, presented by P. Wade)

Tamara McGuire summarized their experiences with Cook Inlet beluga whale photo-identification from 2005 to 2023, using photographs of whales from shore and vessels; they have received funding from a variety of sources, including NOAA Fisheries. The types of marks they use for multi-year identification include lines, crosshatches, pigment, dents, notches, holes, and lesions. The marks come from a variety of sources, including possibly teeth (beluga, killer whales, sharks), claws (harbor seals), ice, debris, disease, vessel strikes (bow, propeller), entanglements (nets, line), and research (e.g., satellite tagging). The criteria they use for assigning an ID and including it in their catalog is that the whale has healed marks on their body, such that the whale has healed white scratches (or other marks like dark pigment areas) that they know are likely not to change over time. That seems to happen when the whales are about 5 years old. Their subset of whales with known age has allowed them to know what the age is where this change occurs.

Regarding mark acquisition and retention, the impression of their team is that overlapping mark accumulation is unlikely to obscure an active (unhealed) marking seen in an initial sighting for intra-annual re-sightings. It is possible that a whale might receive a new marking within a field season that obscured an old mark, but it is likely relatively infrequent. The use of multiple markings will help confirm identifications. They have lots of examples of whales obtaining scratches and rake marks within a season and they see the marks persist for the remainder of the season, even if they are not permanent marks that persist for years. From tracking calves through association with their presumed mothers, they have found that the marks on yearlings and 2-year-old whales do not turn into permanent marks, but these temporary marks last for a couple of months, at least, and so could be used to identify individuals within a season.

Tamara's team has looked at habitat use by males versus females, and by neonates and calves present versus not present, and they have not seen any evidence of age or sex-segregation of habitat use in summer (McGuire et al. 2020). They also do not see any changes in the proportion of gray or white animals within groups. The sex ratio has been consistently 50:50 in all datasets examined, including strandings, historical tagged whales, and recent biopsied whales, so there is no obvious sex-segregation in summer. Similar to the MML aerial survey data, they have seen maximum group size become smaller in recent years, and they have seen lots of dispersed smaller groups as opposed to the big groups (e.g., 200+ whales) that usually aggregate on the Susitna Delta (McGuire et al. 2023).

Presentation 8: Cook Inlet beluga photo-ID methods using overhead photographs from UAS (P. Wade)

In 2017 the MML initiated surveys of Cook Inlet beluga whales using an Uncrewed Aircraft System (UAS) to take overhead photographs of the whales. The project was initiated as a photogrammetry study, designed to measure relative lengths of whales to help identify neonatal calves and estimate calf production annually. However, it was immediately realized that the study resulted in a large number of high-resolution photographs of beluga whales that can also be used for photo-identification. The whales are relatively well-marked from scratches and other wounds or markings, and previous work by the Cook Inlet beluga whale photo-ID project (led by T. McGuire) has shown that nearly all whales that are not calves carry long-lasting marks. The number of photographs and resulting identifications collected from the UAS surveys appears to provide a large enough sample size to be used to estimate abundance of the population using photo-ID mark-recapture methods.

Field work was conducted from a 7 m Safeboat, with the UAS (an APH-28 hexacopter) operated by a 2-person flight crew consisting of a pilot and a visual observer.

Photographs were taken at 0.5 second intervals in order to capture the full rolling sequence of each whale, which is generally around 1.5-2.5 seconds. In 2017-19, two, 6-8 day surveys were conducted during a period of negative tides; in 2019 this was expanded to three, 6-8 day surveys, resulting in a total of ~22 potential survey days, though poor weather prevented surveys on about one-third of the days. Surveys were conducted at low tide in Knik Arm, Chickaloon Bay, and along the Susitna Delta (from the Little Susitna River at the eastern end to the Beluga River at the western end), covering nearly all of the summer habitat of the whales in upper Cook Inlet. Although the boat did not survey the upper Knik Arm (past Eagle Bay) or Turnagain Arm, few or no whales were expected in those areas because the water depth was too shallow during minus low-tides.

Photographs were processed manually and were scored for three types of quality: angle, exposure/lighting, and sharpness. If the photo was acceptable, the whale was then categorized by four characteristics: initial color (dark gray, medium gray, light gray, and white), lesions (yes/no), notch in the dorsal fin (yes/no), and injury (yes/no). Whales were then scored for which zones of the body were visible, where 4 zones were defined on each side of the whale, 1-4, running from the blowhole to the peduncle, for a total of 8 zones, where, for example, L3 would refer to zone 3 on the left side of the whale (Fig. 3). For each zone that was visible in a photograph, a score was given based on the number of marks; 0 (no visible marks), 1 (1-2 visible marks), 2 (3-5 visible marks), or 3 (6+ visible marks). For zones that were not visible in a photograph, the number of marks was coded as NA.

Each identification (ID) photograph of suitable quality was then matched to an ID catalogue to determine if each ID photograph was a match to an existing ID, or represented a new ID. An Access database was used to increase efficiency of the matching by first displaying candidate IDs of similar coloration and number of marks in each zone. Because some photographs only have a small number of zones in view, it is understood that there are likely individual whales with multiple IDs in the catalogue (e.g., a photograph of a whale with zones R1, R2, L1, and L2 visible, and a photograph of the same whale with zones R3, R4, L3, and L4 visible would be initially catalogued under two ID numbers, until a photograph linking those photographs was obtained). Although retained in the database, photographs and identifications were filtered before analyses to prevent inclusion of the same individual as two different IDs (see mark-recapture methods). After an ID has been confirmed and added to the Catalogue, any new photographs were then re-scored for a more detailed color/appearance category, receiving a score from 1 to 7 (Appendix 4).

Examples of ID marking for Cook Inlet beluga whales were shown, demonstrating that in good to excellent quality photographs, most of the whales have a sufficient number of marks to make ID possible. Examples of mark longevity and acquisition were also shown. Marks can be acquired rapidly, and do not always persist from one year to the next. However, many marks have been seen to persist across the first three field seasons (2017-2019). Most marks on yearling and small dark gray calves (2-3 year-old whales) do not appear to persist into adulthood, but do usually persist for several months, making them sufficient (at least) for matching within year. Some marks on yearlings were seen to persist for at least one-year, allowing them to be re-identified as a 2-year-old small dark gray calf. However, the number of permanent marks on some physically mature white whales appears to be small, suggesting further work is needed on whether all white whales are identifiable.

Presentation 9: Cook Inlet beluga mark-recapture abundance estimation (P. Wade)

A preliminary mark-recapture estimate was calculated from the 2019 UAS dataset of overhead photographs, which represents the largest dataset of the first three years of data collected, the only years that have been fully matched to date. The survey was able to fly the UAS over 18 groups of beluga whales on 11 separate days, collecting >27,000 photographs. 11,649 photographs were processed for IDs, with 9,884 photos were assigned an ID. After filtering on a Good or Excellent quality score for angle, exposure, and focus, 4,194 ID photographs remained. It has been noted that some of the large adult whales, especially white whales, do not necessarily have a large number of marks. Therefore, the ID photographs were further filtered, by sighting, to ensure that all eight zones of the body (Fig. 3) were visible in at least one photograph in the sighting in order to maximize the number of marks that could be used to uniquely identify each whale. In other words, an ID within a sighting was not always based on just one photograph, as is typical for other species like humpback or killer whales but was often based on multiple photographs of the same individual.

These photographs were linked as the same individual either by overlap of some zones allowing matching within the sighting, from photographs of the same individual from other sightings that allowed matching across the zones, or because the photographs came from a single sequence of photographs. In the latter case, it often occurred that the multiple photographs used were from the same rolling sequence of an individual whale, where the time stamp of the photographs helped make it certain that it was the same individual in a sequence of photographs (where the photographs were taken 0.5 or 1 second apart). Using all eight zones provides more area on the body for identifying marks to be seen. Although some whales have many identifying marks in just one or two zones, some whales have relatively few identifying marks, and using all eight zones provides greater assurance that false positives do not occur (i.e., two different individuals being incorrectly matched as the same whale due to a similarity in their marks).

After some preliminary calculations, it was recognized that for color categories 2 and 3 (yearlings and small dark calves), there were few cases where all 8 zones were seen. Therefore, for whales in those two color categories, the criteria was changed to require that only zones R2 and L2 were visible (these were the zones most frequently visible in those two color categories). Neonatal calves were not included in the analysis. For 2019, a total of 373 IDs were made across the 16 separate sightings that had at least one ID. For mark-recapture analysis, the 16 sightings were grouped into four bins (sampling periods), aggregating across sequential sightings until each bin had at least 45 IDs. The first bin contained IDs from Sightings 1, 2, 3, 5, 7, and 8, the second bin contained IDs from Sightings 9, 12, and 13, the third bin contained IDs from Sightings 14 and 18, and the fourth bin contained IDs from Sightings 19, 20, 21, 23, and 24. Once collapsed into bins, the total number of IDs was 285 (due to multiple IDs of the same whales across different sightings within a bin), representing 214 unique individual whales. 156 whales were seen in one bin, 46 whales were seen in two bins, 11 whales were seen in three bins, and one whale was seen in all four bins, for a total of 58 recaptures.

A closed mark-recapture model was used, which assumes that the population was closed during the study, meaning there was no immigration, emigration, births, or deaths. There is thought to be no or very little immigration or emigration in this population. The assumption of no deaths was likely not strictly met, as some whales might have died during the 58 days of the study, but this would likely be a very small bias. The assumption of no births was met because neonates were not included in the analysis. Analyses were run in Multimark (McClintock 2015), using the single mark option, which provides a Bayesian estimator for the standard closed population mark-recapture abundance models. A Markov chain Monte Carlo (MCMC) algorithm was used to estimate the posterior distribution for the model parameters.

A total of 110,000 values were sampled from the posterior distribution, using a burn-in of 10,000 and a thinning value of 10 (only every 10th sample is retained). Two independent chains were run, using different initial values. Four standard models were run, including p(.) (with constant capture probability), p(t) (with time-varying capture probability), p(h) (with individual heterogeneity in capture probability), and p(t,h) (with both time-varying and individual heterogeneity in capture probability). The best model, as selected by the log posterior probability, was model p(t), with time-varying capture probability. Capture probabilities were 0.13, 0.14, 0.23, and 0.30 for each of the four defined sampling periods. The estimated abundance from the p(t) model was 364 (CV = 0.08, 0.95 probability interval of 313-430). As a check, analyses were run with program Capture (run from program Mark), with similar results, where the Chao model M(t) provided an estimate of 380 (CV = 0.10) and the Darroch M(t) model provided an estimate of 363 (CV = 0.08). These should be considered very preliminary estimates of abundance for this population using mark-recapture methods; further analyses need to be undertaken to ensure that all assumptions of the model are met, and to understand potential biases.

Although heterogeneity models were estimated, they did not provide a better fit to the data, although this is often the case for cetacean data. This may be due to the apparent lack of sex- or age-segregation in the population in summer (McGuire et al. 2020), so whales from all sex and age classes were available to be photographed in single encounters. Another reason may be that taking photographs from the drone may represent a fairly random sample from all the individuals available in a group. Although there may be small clusters of gray whales or white whales, because the water is opaque it is impossible to track subgroups over time. As a result, the drone usually ends up moving from subgroup to subgroup while taking photographs. Finally, some simulation work has shown that more than four sampling periods may be necessary to provide enough information to inform the heterogeneity models.

Presentation 10: Potential extensions to mark-recapture methods for Cook Inlet beluga (P. Wade)

The photo-identification data, along with the color categories and the photogrammetry measurements of relative body lengths, may allow for extensions of the mark-recapture methods to provide further information about the population. With the ability to categorize whales by color and appearance into categories (Appendix 4), this would allow for the possibility of a grouped mark-recapture analysis. This would be approximately the same as using age classes as a grouping factor in the mark-recapture analysis, although it is clear that in older color categories, there is likely overlap of ages between categories. The younger categories are more clearly non-overlapping age classes, whereas with light gray to white whales, there is likely a lot more overlap in ages. A grouped analysis would allow for estimation of the number of whales in each color category, allowing for annual estimation of the number of neonates and yearling calves, in order to monitor calf production and survival. This would provide an additional metric for monitoring the population. Capture probability could be modeled in a couple of ways. For example, a p(t*g) model could be used, where the capture probability of each group was independently estimated each time period. But perhaps a better model would be a p(t+g) model, where capture probability would vary by time period and by group, but the values for each group would be scaled the same relative to one another, where just the overall capture probability varied with time. For example, it may be the case that small dark gray whales are not identified as often because of their small size, where a higher quality photograph would be needed to meet the same criteria of sharpness than would be the case for a larger whale.

Summary of Strengths and Weaknesses of Each Survey Method

There was substantial discussion after each presentation. Rather than documenting all of the discussion for this workshop report, instead, a Google Doc was created during the workshop to summarize the strengths and weaknesses of each method, and to document other relevant issues for each of the three abundance methods. Not every workshop participant necessarily agreed completely with every single listed point, but all workshop participants reviewed the Google Doc near the end of the workshop, and agreed it represented a fair summary of the discussions about each abundance method. The final summary is presented in Appendix V. Similarly, suggestions and recommendations for improving each of the three methods were collected during the workshop and are summarized in Appendix VI.

Individual Conclusions

In the last section of the workshop, each workshop participant was asked to provide their own conclusions regarding how good each method was at providing abundance and trends for the Cook Inlet beluga population, using any considerations or criteria that they considered important. These individual conclusions were documented by a rapporteur, turned into draft text summarizing each person's conclusion, then sent back to each participant for review. Any edits provided by each participant were included in the final summaries below.

<u>Paul Conn</u>:

Overall, I was impressed with all three methods presented for estimating beluga abundance, and think all of them could legitimately be used for management. Each of them is likely subject to a small amount of negative bias, but that is much preferable to positive bias when managing a population of conservation concern. The primary considerations, then, seem to be operational ones (e.g., cost, safety) and perception (which method stakeholders will 'trust' more). With regards to the mark-recapture modeling, some simulation work I've done with Pledger heterogeneity models indicates you really need at least 5 occasions (preferably more like 10) to select heterogeneity models (with AIC or another criteria), even when that is the model used to simulate data. The Chao or other models might require fewer, but I guess my point is that I wouldn't conclude heterogeneity doesn't exist just because you haven't detected it with 4 occasions. However, for belugas using non-heterogeneity models is probably preferable because you will tend to estimate smaller (and therefore more conservative) abundances if heterogeneity exists. Ideally, we'd have a covariate to explain detection heterogeneity, so I like the idea of using something like age/color class as a proxy. To do this, I'd go straight to a Huggins (Horvitz-Thompson-like) estimator, which would provide both total estimates and estimates for the number of individuals in different age classes.

Brett McClintock:

In general, I agree with what Paul Conn said. I think it is important to consider how stakeholders perceive any new methods, to make sure that they will be they can trust the results. It will be good to review the pros and cons of each method, and see if you can get broad agreement on those, and broad agreement on whether you can satisfy the important assumptions for each method. The traditional census survey has a lot of assumptions, and it is also difficult to test some of the assumptions necessary for calculating correction factors for line transect estimates. Given that, perhaps the mark recapture estimate has fewer assumptions (or at least has assumptions where it may be easier to demonstrate the assumptions are being met). These include the effect of binning (how sightings or days are aggregated into sampling periods), whether there are an important number of unmarked individuals in the population, and documenting how quickly mark loss can occur. But, finally, it should be emphasized that individual based data, such as photo ID, brings a lot of additional useful information that is not usually gained from other methods like aerial surveys, and, as was seen in the preliminary estimates, mark recapture often can result in more precise estimates.

Eric Patterson:

I am impressed with how much data we have to look at. Practically, from a national level perspective of a priority species, what is least expensive and most sustainable is an important consideration, when we are trying to balance competition for limited resources. Everything presented about all 3 survey types sounds good, so maybe what is least expensive is best, but in the long term, I agree that the mark recapture provides a lot more information about the population than do the two aerial survey methods.

Megan Ferguson:

I think it is important to consider more than just estimation of abundance. I strongly advocate for continuing an aerial survey to continue to document current distribution/density and changes in distribution/density through time. It could be either the traditional coastal survey or a line-transect survey. I think the idea of supplementing the mark-recapture surveys by doing an inexpensive simple scouting survey would be a bad idea as the data are not as useful as a systematic survey using reliable, repeatable methods. Therefore, I strongly advocate for continuing a scientifically designed aerial survey. It is difficult to decide between the two different aerial survey types in this situation. I also want to point out that it is important to not focus only on the precision of the estimate, as it is important to consider bias as well. Additionally, the estimation of trackline detection from availability and perception bias is a shared issue with study of the Norton Sound beluga population, so there could be a benefit from joint studies that help with estimating correction factors for both populations.

Robert Suydam:

I want to start by pointing out that monitoring the Cook Inlet population while it declines until they go extinct is not the ultimate goal; instead, the ultimate goal is to try to figure out what is going on in the population. I feel it is relatively easy to come to a conclusion to what is best in one sense. I agree with Paul Conn that all the methods are good for abundance estimation. Mark-recapture seems to give us a good estimate that is relatively unbiased, but importantly it also gives a lot more information, and it is also good that it seems to be less expensive. If less money is spent on the population estimate, that money can then be available to investigate threats, or to implement recovery actions. In our experience with bowhead whales, having multiple methods for abundance available in one year has been helpful to deal with changing ice conditions. If stakeholders will accept the mark-recapture estimates, it seems like that is the way to go. I do appreciate the importance of being able to continue to monitor distribution to catch possible changes in the future. I think that listing the additional benefits of the mark-recapture analysis would help in future decision making about which method to use.

Sarah Converse:

It is important to note that a lot of data on potential threats to the Cook Inlet beluga population are not available, so that makes it hard to test hypotheses about what is causing the decline or lack of recovery of the population. I agree with Robert Suydam on the importance of doing more than monitoring the population, as the ultimate goal is to figure out what is going on. Mark-recapture may be the best tool for that because it allows us to ask those deeper questions about demographic parameters and their drivers as the data become available. It would be hard for me to imagine not collecting the kind of data (photo ID) that can provide the power to estimate life history parameters, because that information is so important. That said, mark-recapture may not always be best for trends or abundance. Aerial survey may be better for trends. Finally, it is valuable to stress that if we don't have to choose one or another, an integrated model provides the ability to combine data from multiple sources, providing lots of benefits simultaneously.

Lori Quakenbush:

I think that mark-recapture abundance estimation will work well, and adds a lot of value in providing further information for other studies, particularly for estimation of age classes. If there is a large drop in abundance, we might want to check on whether a distribution change has happened in the population, so aerial surveys may be useful for that. However, aerial surveys seem problematic for abundance estimation.

Erin Oleson:

I like the idea of using mark-recapture as the primary abundance estimation method and pairing it with occasional line-transect surveys seems sensible and a valuable way of at looking at possible changes in distribution and abundance through time. I do feel envious of your 3 streams of data on abundance coming in at the same time, as we struggle to collect even a single data stream to inform assessments of the Main Hawaiian Islands Insular stock of false killer whales, also a small endangered population undergoing decline. This influences my sense that maintaining all of these approaches moving forward isn't the best use of resources, nor necessary to monitor beluga abundance. Of course, false killer whales are different from belugas, and the optimal survey approach won't be the same, but I think our lessons about group structure may be relevant as you consider the design of aerial line-transect surveys going forward.

Thomas Doniol-Valcroze:

I agree with most of what others have said. I arrived thinking that aerial surveys were the best way to monitor belugas, as that method is used in many other beluga populations. That being said, there are challenges in doing aerial surveys for beluga so they are not always ideal. The traditional Cook Inlet beluga aerial survey was designed to try to deal with how aggregated the population was around river mouths. The current behavior of the animals (where they are not as aggregated) is possibly forcing the move away from that type of survey, but as Paul Conn said, they may change back in the future. Line-transect is a standard method, but the line-transect estimates in the St. Lawrence have jumped around a lot, showing a lot of variability. The CI beluga line-transect visual surveys seem to be more stable, so maybe they work better. There are good simulation packages for investigating how best to do line-transect surveys and allocate the effort (e.g., spacing of lines). Initially I would support more line transect surveys, but there is still the issue of availability and perception bias. Estimation of the perception bias part of g(0) can be difficult and can be a substantial correction. Although I was initially skeptical of using photo ID, I was mostly convinced that the use of temporary marks for short-term studies has a lot of promise. Mark-recapture also has the advantage of providing other information on life history and individual-level demographic parameters. I also think there is great promise in the use of integrated models to combine data sources. Like others have said, I do agree that it would be important to continue aerial studies to monitor potential changes in distribution.

Jordan Bernard:

I agree with many others, that it makes a lot of sense to monitor abundance primarily through mark-recapture estimates, supplemented by line-transect surveys on some schedule. For trend estimation, traditional aerial surveys are likely biased low. The paired design of line-transect with mark-recapture could be good, as the mark-recapture could help scale the line transect estimates. I do agree that individual data is very powerful in providing more information than solely abundance, and allows for good science. One of the notable advantages of employing a photo-ID based monitoring approach is the potential utilization of the data it generates in an age-structured integrated population dynamics model. Looking forward, it may be useful to conduct a feasibility study to get a better understanding of the data requirements needed to estimate vital rates with a reasonable level of precision using an integrated population dynamics model. This would enhance our comprehension of the benefits associated with employing a photo-ID based monitoring approach.

Veronique Lesage:

I do prefer line-transect surveys because they are systematic. It is a big effort to do photo-ID in the St. Lawrence because it takes a lot to get enough IDs and to process so many photographs. It is impressive that you are able to identify as many as 212 individuals in a year in the Cook Inlet population, and suggests the population may be larger than previously thought. However, there are other issues to consider in ensuring the mark-recapture estimates are unbiased and robust, such as the issue of whether white adults have enough marks to be reliably identified. Given the method is new, it may make sense to consider some kind of aerial survey as well for the near future. The mark-recapture looks very promising, but there likely will be a lot of tweaking of the analysis that will take some time and lead to some uncertainty going forward with the reliability of the method.

John Citta:

I wonder if the annual costs are a little off in what you have roughly estimated, so I wonder if you will really reduce costs doing mark-recapture versus doing line-transect analysis. He points out that even though the Boyd et al. (2019) method for group size estimation is really good work, it is likely that there could probably be a lot more work done on just those analytical methods to improve them. I think that using the photo-ID data for other research besides just abundance estimation will involve a lot of analytical issues. I would suggest that transitioning to line-transect from the traditional survey in the near term makes sense, while continuing to develop the mark-recapture methods. I agree that it absolutely makes sense to continue developing the mark-recapture methods, as the amount of information to be gained is substantial and can help us understand more about what is happening in the population. It is impressive that you are able to collect so many photographs of so many individuals in the Cook Inlet population, so that shows how promising the work is. So, I suggest continuing line-transect in the short- to medium-term, while continuing the mark-recapture as it is likely the future for monitoring the population. We need information on abundance, but just abundance is not enough to understand the issues facing this population. I suggest it might be good to continue annual line-transect surveys if there was funding for that, but I do appreciate the added value of mark-recapture data. Mark-recapture is clearly the way forward to learn more about the population. But it may be the case that line-transect is the least expensive way to monitor trends overall. It would be good to summarize all the ancillary additional data that could come out of the photo ID data, as this will help in future decision making about how to proceed.

Kim Goetz:

I agree that it makes sense to continue some overlap of two methods, mark-recapture and an aerial survey (preferably line-transect). There are ways to make a line-transect survey less expensive, such as not doing as much survey effort in Trading Bay, as there are not many whales there usually. There is the issue of not knowing as much about the distribution of the population in other months, which is hard to address. As was said, we still don't know what is causing the lack of recovery of the population, and for the issue of investigating prey and possible food limitation, either through the PCOD model or other ways, it is important to get the distribution of the population in other months.

Erin LaBrecque:

I agree with the points that Robert Suydam made. I want to emphasize that we need to get good absolute abundance estimates for management under the MMPA. The idea of moving to mark-recapture for abundance estimation, but also to get more demographic information, is important. But I also agree that it is important to continue line-transect aerial surveys for looking at distribution and possible changes in the future.

Michel Moisan:

I initially had some doubts about whether photo-ID mark-recapture would work to estimate abundance of beluga whales, given how we do things in the St Lawrence, using only photographs flanks of whales taken from boats. We have worried that we cannot do mark-recapture in the St. Lawrence, given issues of matching left and right sides. But the overhead view to get the whole view of the animal, and being able to look at the subtle scratches, shows a lot of promise. I agree that there is some concern about the identification of adult white animals, given the possible lack of distinctive marks on those whales. However, I do recognize that adjusting the levels of the photographs (contrast, highlights, etc.) of white whales can help to resolves some scratches, and that can help with identification.

Kim Shelden:

Aerial surveys have been the go-to for trends, abundance, and distribution, but only a snap shot for the most part in early June. I agree with Kim Goetz, and that we need to know more to understand what is happening with the population. Mark-recapture can provide demographic data as well as abundance. Of course, there are a lot of things to consider going forward, such as funding, safety during surveys, before a decision can be made about what is best for the future.

Jill Seymour:

I agree with many of the points that were raised, especially those of Robert, Eric, and others talking about the value of the mark-recapture, but also the continued need of information on distribution for management purposes. It is important that stakeholders understand the implications of changing methods, and we will need to have a good plan for explaining to stakeholders why we are making a change, as otherwise we might end up having to spend a lot of time working on that explanation rather than doing other important work. Funding and safety are other important considerations. If we can do a less expensive survey, that frees up money for other things.

Janice Waite:

I have a lot of experience with photo-ID and mark-recapture in other species, so I have seen the value of mark-recapture studies, and I see the value of doing that for Cook Inlet beluga. There are uncertainties about how much time it will take to process and match photos using our new Artificial Intelligence/Machine Learning system on Flukebook, but it should be more efficient that the manual processing and matching we have been doing until now.

Paul Wade:

After the discussions, it is good to hear that many people felt that all three abundance methods have merit. And it has been very good to hear that many people think that the photo-ID mark-recapture method has merit. In particular, the concept that the mark-recapture may have less potential bias, and the biases that are potentially there can be investigated, is important, as it means we may have some clear ways to show whether or not each source of bias is a concern. And it was great to hear the confirmation of what I already thought, that the other benefits of mark-recapture, such as estimating life history parameters such as calf production, mean that mark-recapture adds a lot of value for studying the Cook Inlet beluga population in more detail, with a chance to provide more understanding of the lack of recovery that we have seen. One thing that the workshop discussions helped me appreciate is the benefit of continued aerial surveys to help monitor possible changes in distribution of the population. I was so focused on estimating abundance and trends that I was not considering some of the other benefits of aerial surveys such as that.

Acknowledgments

We would like to thank Tamara McGuire for providing a presentation of the Cook Inlet beluga photo-ID project to use prior to the workshop, and allowing us to present it at the workshop. Reviews of this document were provided by MML staff. We particularly thank Kim Goetz for a thorough review of the document. Technical edits were provided by James Lee of the Alaska Fisheries Science Center's Communications Program. The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and workshop participants and do not necessarily reflect those of NOAA, or the U.S. Department of Commerce.

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Tables and Figures

Table 1. -- Summary of changes in methodology of the Cook Inlet beluga traditional aerial survey through time.

<table>
<tr><th>Changes over Time</th><th>1994-2003</th><th>2004-2006</th><th>2007</th><th>2008-2010</th><th>2011</th><th>2012-2016</th><th>2018</th><th>2021</th><th>2022</th></tr>
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<tr><td>Survey Platform</td><td colspan="2">AC 680</td><td>NOAA TO</td><td colspan="6">AC 690</td></tr>
<tr><td>Isolation Unit</td><td colspan="2">Yes</td><td colspan="7">No</td></tr>
<tr><td>Opening Window</td><td colspan="4">Yes</td><td>No</td><td colspan="4">Yes</td></tr>
<tr><td>Camera Upgrades</td><td>Hi-8 to Digital 8 (2001-02) to DSR (2003)</td><td colspan="3">DSR to HD (2006)</td><td colspan="4">VHD</td><td>VHD</td></tr>
<tr><td>LR Observer Window</td><td colspan="2">Bubble</td><td colspan="7">Flat</td></tr>
<tr><td>LCI Survey</td><td colspan="6">Forelands to Entrance</td><td colspan="3">To Augustine</td></tr>
<tr><td>UCI Survey</td><td>Sectors/ modified</td><td colspan="5">Entire/ modified</td><td colspan="3">Entire (no mod) + DS</td></tr>
<tr><td>Video analysis</td><td>Plastic sheets</td><td colspan="8">Beluga Dots</td></tr>
</table>

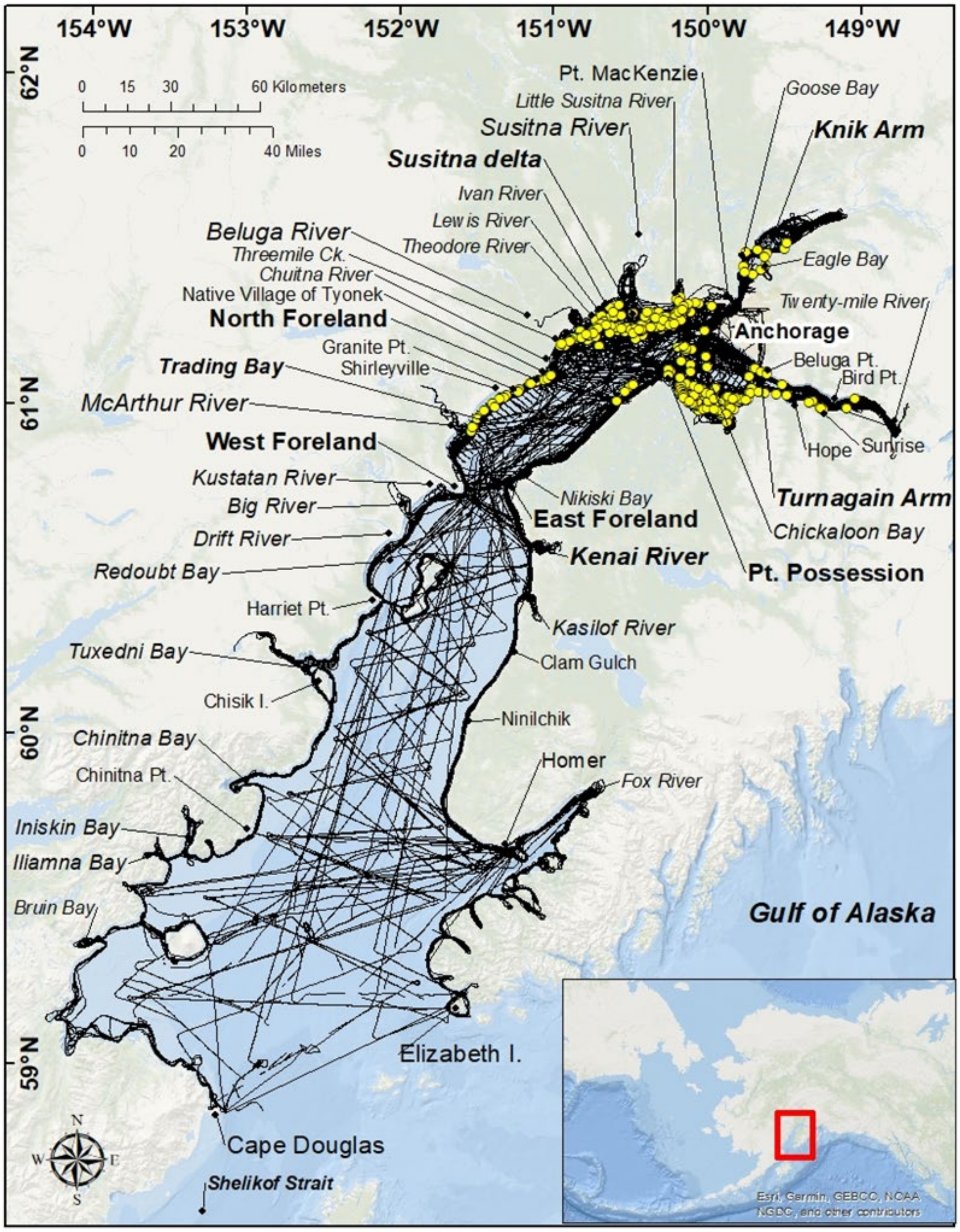

Figure 1. -- Survey effort (black lines) for the Cook Inlet beluga traditional aerial survey, 2004 to 2022. Yellow circles = beluga groups.

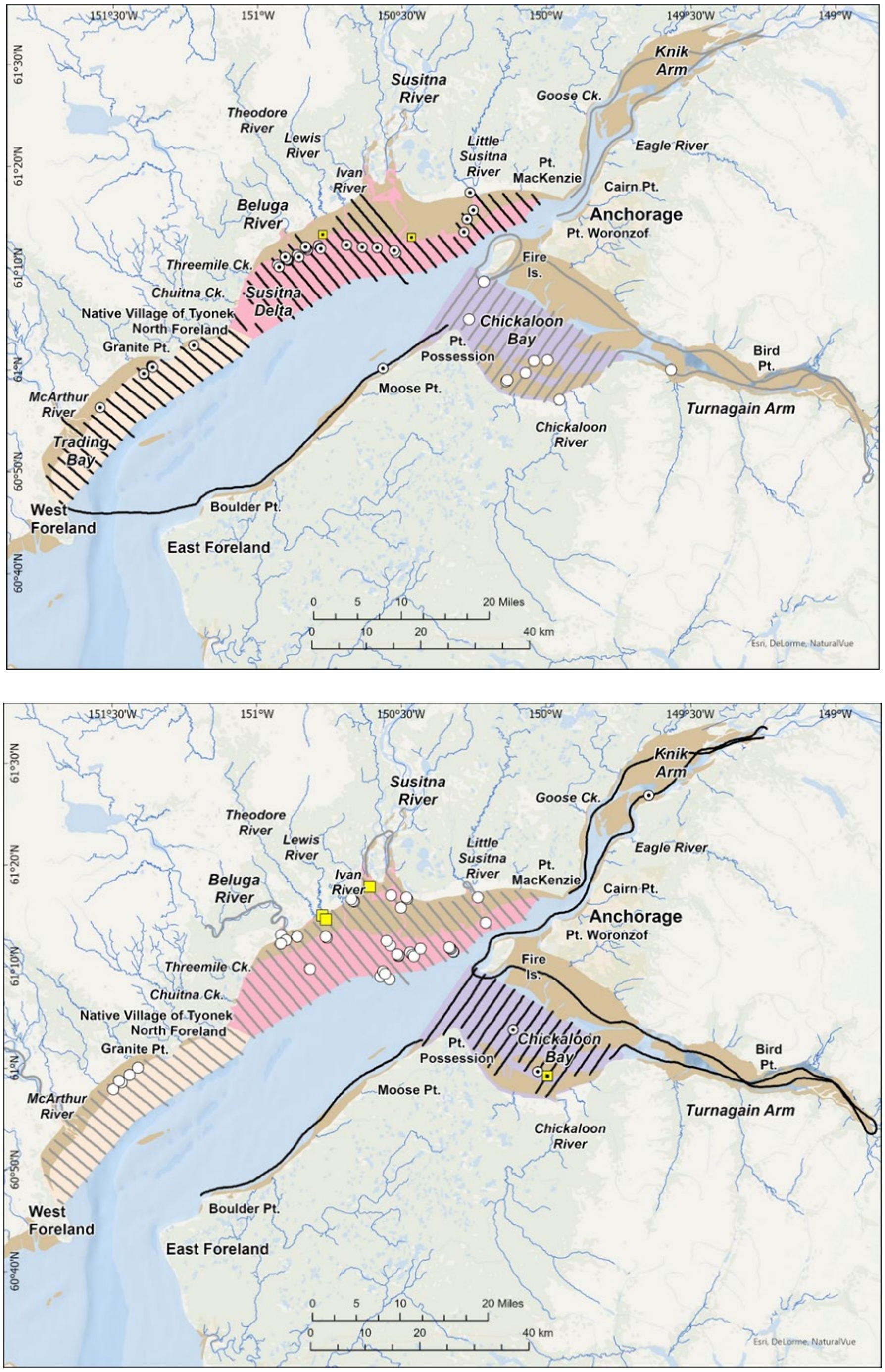

Figure 2. -- Line-transect surveys flown in 2021. a) Survey on 30 June 2021, flown at low tide in Trading Bay and Susitna Delta, and high tide in Chickaloon Bay, with beluga sightings as white circles. Note that the beluga sightings are lined up along the mud flat edge in the Susitna Delta. b) Survey on 1 July 2021, flown at high tide in Trading Bay and Susitna Delta, and low tide in Chickaloon Bay. Note that the beluga groups are spread out across the survey area in the Susitna Delta, both up on the mud flat but also offshore.

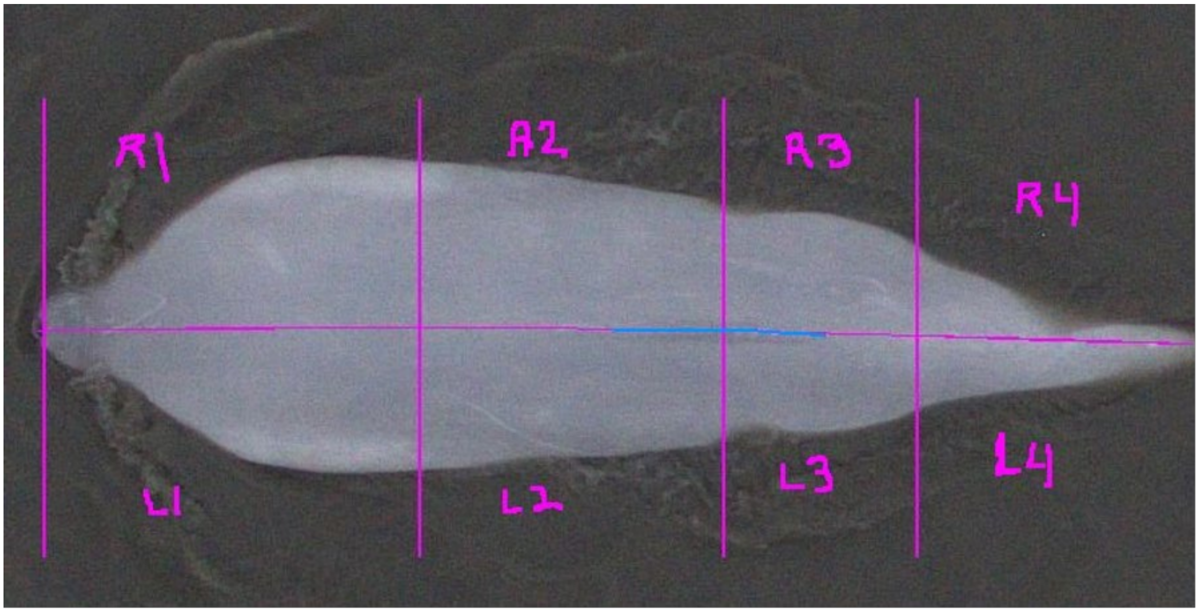

Figure 3. -- Zones used for scoring identification photographs. Each ID photo was scored for whether each of the 8 zones was visible in the photo, and for how many identification marks occurred in each zone.

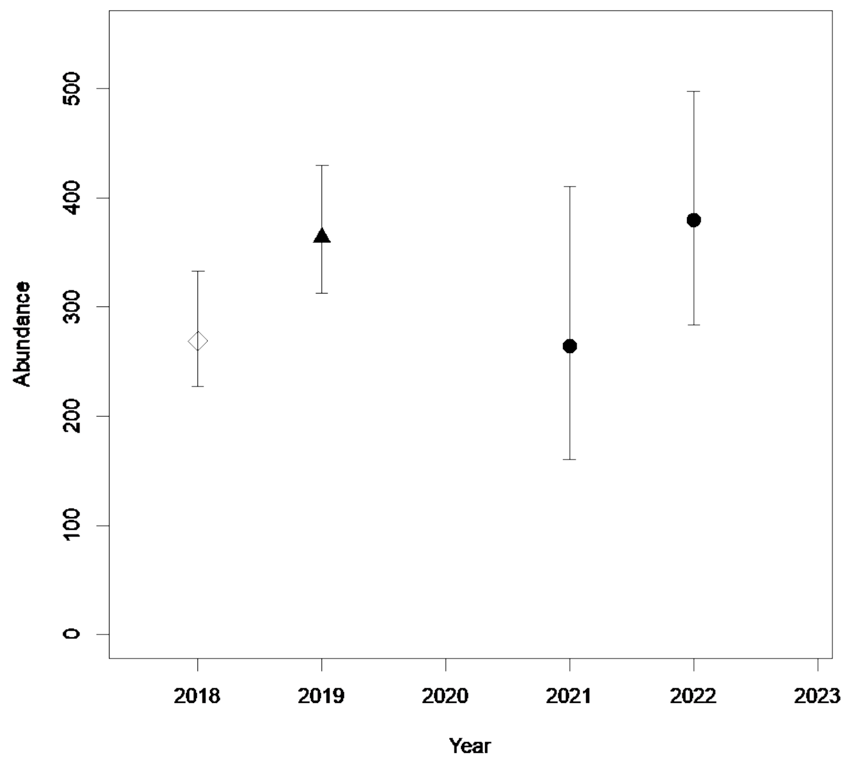

Figure 4. -- Preliminary estimates of abundance from line-transect surveys and from photo-identification mark-recapture methods. Photo-identification mark-recapture methods in 2019 (closed triangle) and from two line-transect surveys in 2021 and 2022 (closed circles).

Note: These are preliminary estimates that should not be considered final estimates, as further analyses are needed to confirm that assumptions of the models are met, and that the best estimation process has been used. The line-transect estimates, for comparative purposes, have been multiplied by an assumed correct factor of 2.0 to account for availability, perception, and trackline detection bias, as similar studies have estimated correction factors similar to that value. However, the true overall correction factor for the Cook Inlet beluga survey could be a different value. Given the different methods, this figure should not be used to assume trends in abundance.

Appendices

Appendix I. Workshop Agenda

Cook Inlet Beluga Whale Abundance Estimation Workshop
6-7 April 2023 Seattle, WA

<u>Day 1. Thursday, 6 April 2023</u>

9:00am **Introduction & Logistics** (45 min)
- Opening remarks (Angliss, Wade)
- Introductions, venue logistics, schedule
- Agenda review – anything missing?

9:45am **Cook Inlet beluga aerial survey** (2 hr)
- History of Cook Inlet beluga aerial survey (Shelden, 30 min)

10:15 Break (15 min)

10:30 **Cook Inlet beluga aerial survey** (continued)
- Current analysis methodology and results (Goetz, 45 min)
- Discussion of strengths and weaknesses (45 min)

12:00pm Lunch (1:15 hrs)

1:15pm **CI beluga line-transect surveys**
- CI beluga field methods and analysis (Wade, Shelden, and Goetz, 30 min)
- Review of correction factors for beluga whale line-transect surveys (Ferguson, 30 min)
- Calculating a correction factor for beluga line transect surveys in the Gulf of St. Lawrence (Lesage, 30 min)
- Discussion of strengths and weaknesses (30 min)

3:15pm Break (15 min)

3:30pm **CI beluga photo-ID mark-recapture analysis**
- Photo-ID of beluga whales (Moisan, 30 min)
- CIB Photo-ID Methods (Wade, Waite, Sims, 30 min)
- CIB Mark-recapture analysis (Wade, 30 min)

5:00pm End of Thursday Workshop day

Day 2. Friday, 7 April 2023

9:00am **CI beluga photo-ID mark-recapture analysis (continued)**

- Discussion of issues to consider (30 min)
    - Heterogeneity of capture probability (distribution, segregation)
    - Mark longevity and acquisition
    - Other

- Potential extensions to mark-recapture methods (Wade, 30 min)
    - Color categories for grouped analysis and estimation of calf production
    - Photogrammetry for category assignment
    - AI/ML matching

10:00am **Background for comparison between methods**

- Brief summary of survey and analysis costs (Wade, 10 min)
- Are there alternative methods to also consider? (20 min)

10:30am Break (15 min)

10:45am **Discussion of best methods for estimating absolute abundance** (75 min)

- Aerial survey
- Line-transect survey
- Mark-recapture

12:00pm Lunch (1:15)

1:15pm **Discussion of best methods for estimating trends in abundance** (45 min)

- Aerial survey
- Line-transect survey
- Mark-recapture

2:00pm **Open/continued discussion of merits of each method** (30 min)

- Topics to be determined by group

2:30pm Break (15 min)

2:45pm **Conclusions and summary** (75 min)

- Best method(s) for estimating absolute abundance?
- Best method(s) for estimating trends?

4:00pm End of workshop

Appendix II. Workshop Documents

Primary Documents

CIB Aerial Survey

Shelden, K. E. W. and P. R. Wade (editors). 2019. Aerial surveys, distribution, abundance, and trend of belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2018. AFSC Processed Rep. 2019-09, 93 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Boyd, C., R. C. Hobbs, A. E. Punt, K. E. W. Shelden, C. L. Sims, and P. R. Wade. 2019. Bayesian estimation of group sizes for a coastal cetacean using aerial survey data. Marine Mammal Science 35(4):1322-1346. DOI: 10.1111/mms.12592

CIB Line-transect survey

Wade, P. R., K. E. W. Shelden, K. T. Goetz and A. Zerbini. Unpublished draft. Line-transect surveys for Cook Inlet belugas in 2021 and 2022. 20 p.

CIB Photo-ID and Mark-recapture

Wade, P. R, J. M. Waite, C. L. Sims and K. T. Goetz. Unpublished draft. Cook Inlet beluga photo-identification mark recapture abundance estimates. 13 p.-

Background Documents

Goetz K. T., R. A. Montgomery, J. M. Ver Hoef, R. C. Hobbs, and D. S. Johnson. 2012 Identifying essential summer habitat of the endangered beluga whale *Delphinapterus leucas* in Cook Inlet, Alaska. Endangered Species Research 16:135-147. https://doi.org/10.3354/esr00394

Hobbs, R. C., K. E. W. Shelden, D. J. Rugh, C. L. Sims, J. M. Waite. 2015. Estimated abundance and trend in aerial counts of beluga whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994-2012. Marine Fisheries Review 77(1):11-31. DOI: 10.7755/MFR.77.1.2

McGuire, T. L., G. K. Himes Boor, J. R. McClung, A. D. Stephens, C. Garner, K. E. W. Shelden, and B. A. Wright. 2020. Distribution and habitat use by endangered Cook Inlet beluga whales: Patterns observed during a photo-identification study 2005-2017. Aquatic Conservation: Marine and Freshwater Ecosystems 30(12):2402-2427. DOI: 10.1002/aqc.3378

McGuire, T. L., J. R. McClung, G. K. Himes Boor, C. Garner, A. Gilstad, and B. Wright. 2023. Oscillation or trend? Recent decline in annual maximum group size of Cook Inlet belugas observed during surveys 2005-2022. Poster presented at the Alaska Marine Science Symposium, Anchorage, Alaska, January 2023.

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

Shelden, K. E. W., K. T. Goetz, D. J. Rugh, D. G. Calkins, B. A. Mahoney, and R. C. Hobbs. 2015. Spatio-temporal changes in beluga whale, *Delphinapterus leucas*, distribution: Results from aerial surveys (1977-2014), opportunistic sightings (1975-2014), and satellite tagging (1999-2003) in Cook Inlet, Alaska. Marine Fisheries Review 77(2):1-31 [with supplemental data].

Warlick, A. 2022. Understanding the effects of environmental variability on demography in species with complex life histories through integrated population modeling. Ph.D. University of Washington. 200 p.

Appendix III: List of Workshop Participants

Invited participants

Jordan Bernard (ADF&G)
John Citta (NSB)
Sarah Converse (UW/SAFS)
Thomas Doniol-Valcruze (DFO)
Anne Marie Eich (AKR) (virtual)
Verena Gill (AKR) (virtual)
Erin LaBrecque (MMC)
Veronique Lesage (DFO)
Michel Moisan (GREMM)
Jeff Moore (SWFSC)(virtual)
Erin Oleson (PIFSC)
Eric Patterson (F/PR)
Lori Quakenbush (ADF&G)
Jill Seymour (AKR)
Robert Suydam (MMC)
Amanda Warlick (UW/CICOES)

Marine Mammal Laboratory participants

Robyn Angliss (CAEP/MML)
Manuel Castellote (CAEP/MML/CICOES)
Paul Conn (PEP/MML)(virtual)
Kim Goetz (CAEP/MML)
Megan Ferguson (CAEP/MML)
Brett McClintock (PEP/MML)
Kim Shelden (CAEP/MML)
Christy Sims (CAEP/MML)
Paul Wade (CAEP/MML)
Janice Waite (CAEP/MML)

Appendix IV. Beluga Color/Size Categories

Beluga whales are usually dark gray as calves and gradually lighten to become white as adults. Researchers in Quebec at the *Group for Research and Education on Marine Mammals* (GREMM), who have conducted a decades-long photo identification project on beluga whales in the St. Lawrence Estuary, have developed a system for evaluating photographs of beluga whales to place them in one of seven color/size categories, and have information on their relative ages. With their assistance, we have adapted their system and applied it to Cook Inlet beluga whales. It is recognized that the color/size category determination is affected by the exposure and lighting of the whale in the photograph, so this determination is more accurate the more photographs that are available and the better the exposure is. However, researchers at GREMM have found that individual whales rarely get categorized across more than two categories in a single field season.

Neonate (NC1 or NC2)

In neonatal calves, fetal folds are often visible, and the calves look very small and short, with a brownish-gray color, and they are clean-looking with no or relatively few scratches. The color and lack of scratches/skin molt is usually very distinctive from yearling calves (see below). Fetal folds are often present, indicating the calf has likely been born within 2-4 weeks. Within our system, we further divide this category into NC1 if fetal folds are visible and NC2 if no fetal folds are visible.

Yearling (Bleuvet, BL)

Bluish-gray or dark-greyish (usually not brownish or tan) with lighter gray patches and/or mottled appearance, scratches show as deep and darker colored, sometimes with skin molting off with darker tissue underneath. Still very small. There is sometimes a dark pigment area posterior to the blowhole.
Overhead view: Body shape still has no-neck look, meaning that outline slopes outwards continuously from tip of head to body (no defined head with shoulders that flare out) in an overhead view.

Dark (small) gray (DG)

These are small, dark gray in color, and they are still very short, so the amount of body showing out of the water is distinctly small and short compared to medium or light gray whales. There is usually no sign of a crease posterior to the blowhole (which occurs when whales lift the head). Scratches still mostly show as dark. Little in the way of bright white scratches are apparent (but there can be exceptions, which are likely healed scratches). Some have a more prominent development of a dark pigment area posterior to the blowhole (not seen as well in neonates or yearlings). By definition, a 2- or 3-year-old whale should fall into this category, but older whales may also be in this category. McGuire et al. (2020) reports that most calves photographed alongside their mother are 1-4 years of age, but older calves may not be constantly alongside their mother. In our experience not all small dark gray whales are closely associated with their mother when photographed, so this category may also include some whales older than 3 years-old.

Overhead view: These whales still look very short in overhead photos. They still have a no-neck look, meaning that outline slopes outwards continuously from tip of head to body (when viewed from overhead), with no shoulders that flare out.

Medium gray (MG)
These whales no longer look like a calf or very small juvenile, but do not yet look like a large adult whale. The size is intermediate, so the body seen out of the water when the whale rolls looks longer than a calf, but is still not as long as an adult size whale. The color is not light gray, but is also not as dark as the very small juveniles. In general, the whale is starting to look like it has an adult shape, rather than a calf or young juvenile shape. There can be a mix of dark and white scratches. Some whales are just beginning to show the start of a protrusion of the pontoons along the anterior flank.
Overhead view: These whales can be beginning to get an indentation behind the blowhole, and the body outline is starting to curve out posterior to the head. The head has a relatively constant width, so a straight line along head and neck, then a distinct start of a curve out to "shoulders", that help defines the straight look of head/neck in overhead photos. Most are starting to show a crease posterior to the blowhole if the whale has lifted its head when surfacing. The dark pigment area posterior to the blowhole can appear wider, stretching across the width of neck.

Large (light) gray (LG)
Large, lighter gray whale, which look similar in shape and size to an adult white whale. Bright white scars and scratches show prominently against a slightly darker light-gray background, so this is a useful indicator that is somewhat independent of photo exposure or lighting. A few dark scratches (probably from fresh or fresher wounds) can sometimes be seen. Some may have fairly developed pontoons. The darker pigment area posterior to the blowhole may have faded. LG whales may have dark grey on the posterior edges of the pectoral fins and tail.

White-dirty (Blanc sale) (DW)
Whale appears mostly white with just a small amount of slight gray showing. In shape and size they are similar to adult white whales. Generally, the coloration can be a bit splotchy or slightly dirty looking, as if it is a white background with a bit of gray or dirty areas on it. Scratches still show as distinctly lighter white against the background, but just barely. The dark pigment posterior to the blowhole is usually gone, or if still visible, is usually thinner or shorter, sometimes appearing as a line across the whale behind the blowhole. Often, or usually, have well-developed pontoons. DW whales can still have light grey on the posterior edges of the pectoral fins and tail. They can also have a somewhat dark dorsal crest.

White (WH)
Fully white adult whale. White scratches appear on a bright white background, so little coloration contrast between the two. No dark scratches except for occasional scratches that are likely relatively fresh. Often or usually have well-developed pontoons.
Overhead view: Darker pigment area posterior to the blowhole is usually gone, though the area where the crease appears when the head is lifted can sometimes seem slightly darker, but this is likely from lighting or shadow from a different angle.

Appendix V. Summary of strengths and weaknesses of each survey method

Traditional aerial survey

- Strengths
  - There is an explicit analysis for estimating correction factors for group sizes (availability, perception).
  - The surveys have been conducted with very similar methods since 1994 so provides a long-term historical trend for the population.
  - Relatively precise with CVs of annual abundance of 0.08-0.12 (usually, for a variety of reasons, 2021 had a poor CV of 0.51).
- Weaknesses
  - There are a number of assumptions to the method that are difficult to test or verify. Some of those most important are:
    - All groups in the upper Inlet are seen.
    - Whales in a group do not dive or surface synchronously.
  - The survey depends upon whales behaving in a certain way, especially occurring in relatively few large groups.
  - The surveys have to fly at low tide when the whales are most aggregated. Line-transect surveys have shown whales moving offshore at high tide, so timing relative to tide is very important -- sometimes groups take a long time to circle so by the time we get to other groups -- tide has changed and belugas are dispersing.
  - The survey does not cover the entire upper Inlet (mainly just the coastline), though that is where most whales usually occur.
  - There is no method available for quantifying a correction for missed groups; this would require some additional expensive field work such as repeating the entire survey from a second plane on the same day.
  - For the group size analysis, the prior distribution for dive intervals is based on a single tagged whale, though it should be noted that some sensitivity analyses (Shelden and Wade 2019) indicated the group size estimates were not sensitive to the prior.
- Other Issues
  - The group size analysis method is complicated with multiple distributions being estimated simultaneously, making it difficult to follow what effects the estimation process in detail; the recent change in methods caused large changes in some group size estimates, and consequently some daily estimates.
  - The survey design and group estimation process (video, analysis) is a custom method that is quite specific to Cook Inlet beluga in many ways, so it may be more difficult to keep institutional knowledge if not done frequently.

Line transect survey

- Strengths
  - Line-transect surveys are standard methods used widely in cetacean research.
  - The initial results from 2021 and 2022 seem to show pretty consistent results from day to day.
  - Even if not corrected for submerged whales et cetera, it may provide a reliable data series on relative trends of the population.
  - There are many other similar surveys for beluga whales and other cetaceans that might provide information about the magnitude of correction factors for submerged whales, missed groups, and lack of detection of small dark calves.
  - Line-transect surveys with parallel lines are well designed to also provide information on habitat use and distribution, although multiple surveys would be needed to characterize seasonal distribution.
- Weaknesses
  - Precision is lower than other methods (CV = 0.24 in 2021 and 0.14 in 2022), though that can be improved by flying on more days.
  - The calculation of correction factors has seemed difficult and inconsistent in the literature.
  - It is likely that there will need to be specific studies in Cook Inlet to be confident in correction factors for estimating absolute abundance, such as
    - Focal follows for estimating dive behavior.
    - V. Lesage study shows that it is important to consider observer searching behavior and calculate corrections for submerged whales including perpendicular distance.
    - To assess perception bias reliably requires flying in a full double-platform configuration, and there may not be suitable aircraft available with two bubble windows on each side of the plane.
  - Analysis of corrections factors may be a considerable field and analytical task to accomplish, and may take several years.
- Other issues to consider
  - May be important to time surveys away from minus low tides in some regions to try to avoid animal clustering to an extent that groups cannot be distinguished/counted.

Photo-identification mark-recapture

- Strengths
    - The sense is that the assumptions of mark-recapture can be met well enough that the abundance estimate will not be too negatively biased.
        - For example, passive acoustic recorder data confirm that no or few whales are outside the boat-based survey area at the time of the survey.
    - Preliminary analyses show that the estimated precision (CVs of 0.07-0.08) is very good.
    - The photo ID data is valuable for many other studies, including:
        - Estimating calf production.
        - Using whales with permanent marks to estimate of survival across years.
        - Estimating the number of whales in color/size/age classes, providing age distribution data for the population.
        - Estimate relative lengths of whales using photogrammetry data.
    - Mark recapture is a standard technique with a rich literature in cetacean research, and there are many available sophisticated packages for analysis already available.
- Weaknesses
    - There are still assumptions that need to be tested, so further data exploration is needed to try to better document how the surveys sample from the entire population, and how well other assumptions are met.
    - The boat-based surveys can cover nearly all of the high-use habitat in summer, but there may always be the issue of trying to document this is the case (e.g., in some years, aerial surveys show some whales in Trading Bay in June, which is not covered by the boat surveys as yet).
    - It is often difficult to get overhead photographs of very small groups (say, 1-5 whales), so unless those whales mix into large groups, the survey might miss some component of the population.
- Other Issues to consider
    - Mark longevity (especially of juveniles) within season.
    - Mark acquisition within season (possible false negatives).
    - Heterogeneity in capture probability.
    - Monitoring (acoustic, visual observers) of areas not covered by the photo-identification survey to confirm whether whales were there during the survey.
    - Capture probability for whales in various color classes (i.e., specifically white whales versus small dark whales).

Appendix VI. Recommendations to consider for improving each method or analysis

Traditional aerial survey

- A field experiment could be considered to estimate the number of missed groups.
- Some possibilities include:
  - Fully replicating the entire survey with a second plane and full crew flying at some interval (e.g., 30 minutes) behind the first plan.
  - Use of a second airplane or several boats to systematically survey offshore waters along the Susitna Delta during the time the traditional survey airplane surveys that area.
- Issue – the suggested field studies would be relatively expensive, without a guarantee of immediate results (i.e., it is possible that no substantial groups are missed on some days, so the experiment may have to be conducted across a substantial number of days).

Line transect survey

- Using a camera on the belly of the airplane to take photographs or video of the trackline, could be used to estimate detection on the trackline.
- A stratified survey design could be designed to provide a complete survey of the inlet (or at least the upper inlet). The transect lines could be spread out more than in the preliminary surveys, even in regions with higher aggregations.
- It may be possible to add a UAS or boat-based focal follow study to estimate dive times.
- A study is planned for May 2023 to attempt to put DTAGs on CI beluga, which could provide valuable data on dive intervals.

Photo-identification mark-recapture

- It was suggested that the Pledger closed capture models might work well for this dataset.
- Consider genetic identification of individuals. However, one cannot collect adequate sample sizes for abundance estimation using biopsy samples. Conceptually, eDNA from water samples could be used to create a sufficient sample size, though at this point amplifying sufficient sequences for individual identification from water samples has not be demonstrated for cetaceans. However, the field is advancing rapidly, with one example that genotyping of individuals has been demonstrated by taking eDNA samples from terrestrial mammal footprints in snow.

U.S. Secretary of Commerce
Gina M. Raimondo

Under Secretary of Commerce for
Oceans and Atmosphere
Dr. Richard W. Spinrad

Assistant Administrator, National Marine
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July 2023

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