Photo-identification of beluga whales in Upper Cook Inlet, Alaska

2007 Annual Report

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Prepared for:

Chevron
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EXECUTIVE SUMMARY

Introduction

This report provides results from field effort and analyses conducted from September 2006 through October 2007, as part of an ongoing study which has used photo-identification techniques to develop a catalog of individually identified beluga whales from Upper Cook Inlet, Alaska. The original objectives of the study were to:

1. Assess the feasibility and utility of photo-identification for studying Cook Inlet beluga whales.
2. Build a photo-identification catalog of distinctively marked individuals, describe re-sight rates and discoveries of new individuals over time.
3. Develop abundance estimates of Cook Inlet beluga whales using mark-recapture models.
4. Describe population characteristics of beluga whales in Upper Cook Inlet, including age-class distribution, residency/movement patterns, behavior, and social group structure.

We discuss the current status of the photo-identification catalog with respect to the project's original objectives and requirements for continued development of a photo-identification catalog for Cook Inlet beluga whales.

Methods

Field surveys and field data

Dedicated surveys and opportunistic sampling of Upper Cook Inlet were conducted from small vessels in the Susitna River Delta, Knik Arm, and Chickaloon Bay/Southeast Fire Island, and from shore along Turnagain Arm and at the Port of Anchorage. Data forms were used to record beluga whale sightings and environmental conditions, including GPS position, group size, and behavior. Body color and relative size of whales in the group were recorded as "white", "gray", and "calf". Digital photographs of beluga whales were collected using a Nikon D70, 6.1 megapixel digital SLR camera, with Nikkor 70-300 mm and 80-400 mm zoom telephoto auto focus lenses. Photographs were taken in large fine JPG format and underexposed to increase contrast.

Positions of beluga whale sightings and survey routes were mapped in ArcGIS 9 Version 9.1. Sighting histories (i.e., dates and locations of sightings) were compiled for all identified beluga whales. Color composition for each group was determined from field counts and from cataloged photographs obtained during each encounter. Group color compositions by season and survey area from the two methods were compared.

Primary and secondary behaviors of beluga whale groups were compared among the locations.

Processing and cataloging of photographs

Photographs were sorted according to quality with the use of ACDSee photo software. Images of belugas were cropped, separated into images of left and right sides of the whales, and then classified as white or gray. Left-side images were archived, and right-side images were examined to determine whether or not there was a match to photographs in the catalog. Rigorous criteria were established for including a “new” individual in the catalog.

Catalog development

Steps were taken to increase the accuracy and usefulness of the catalog. All photograph matches in the existing catalog were reviewed and verified by at least three people. Improvements were made to expedite the sorting, cropping, and cataloging of photographs. Each set of photos was re-evaluated for color, based on the current beluga color-classifications used by the National Marine Fisheries Service (NMFS). All photo-identification data (2005-2007) was consolidated into a single, comprehensive and integrated database.

To further strengthen the catalog, LGL and colleagues with NMFS convened a workshop in October 2007. LGL gave a presentation covering the history, methods, current status, and future plans of the project. The presentation was followed by a discussion of the utility of photo-identification as a tool for studying Cook Inlet beluga whales. A subset of photographs of cataloged whales was used in a group exercise to evaluate and refine protocols for “scoring” photographs as a qualification for later mark-recapture analyses.

Results

Surveys

Ninety-four beluga whale groups were counted and photographed during 34 surveys conducted from the fall of 2006 through the fall of 2007. Total number of belugas sighted per survey day ranged between 0 and 100. The most-commonly encountered group size was three whales, and groups ranged in size from one to 74 whales. Group color composition ranged from 52% - 65% white belugas, 18% - 39% gray belugas, and 2% - 10% calves, and varied according to location, season, and survey method. Travel was the most commonly observed primary behavior and diving was the most commonly observed secondary behavior.

Sighting histories

Whales were photographed in the Susitna River Delta in the summer and in Knik and Turnagain Arm in the fall. The presence of whales in these areas during these time periods is consistent with seasonal distribution patterns found in previous studies (Moore et al. 2000, Funk et al. 2005, Hobbs et al. 2005, Markowitz and McGuire 2007, Nemeth et al. 2007).

Twenty-six identified beluga whales were photographed in all three years of the study. All of these whales moved between different areas of Upper Cook Inlet. Beluga whales were rarely observed traveling between areas, but were instead encountered in distinct areas (i.e., along the Susitna River Delta, in Eagle Bay in Knik Arm, or traveling up and down Turnagain Arm). Additionally, sixty-two identified whales were photographed in two years of the study, and 190 identified whales were only photographed in a single year. One identified whale was photographed on 20 different days, while 46% of the identified whales were photographed on one day only.

Thirty-seven identified beluga whales were presumed to be reproductive adult females based on the close proximity of calves. Ten identified mothers were gray in color. Seventeen females with calves were photographed over a two-year period, and one female was photographed with a calf in all three years of the study. We did not detect localized areas for calving and calf rearing, as calves were seen in all locations surveyed. Likewise, we did not detect a clearly defined calving season, as calves were encountered in all months surveyed (April through October).

Nine photo-identified belugas have unique scars from satellite tags used by NMFS researchers between 1999 and 2002. These sighting records indicate that these individuals not only survived capture and tagging but, depending on when they were tagged, can provide between three and eight years of survivorship data. Three of these whales were identified as mothers with calves, indicating they reproduced post-tagging.

Catalog development and current status

Following the review, the 2005-2006 catalog contained 156 “adults” and 169 “subadults” for a total of 324 individuals. Prior to the review, the right side catalog contained 158 “adults” and 172 “subadults” for a total of 330 individuals.

As of December 2007, the 2005-2007 beluga catalog contained 2,890 photographs of individual whales found in 316 groups encountered during 99 surveys conducted between 2005 and 2007. This catalog contains 151 “adults” and 127 “subadults” for a total of 278 potentially unique individuals. Uncataloged photographs taken in 2007 may contribute an additional 39 individuals to the catalog, although these photos must still undergo the complete review process before they can be fully incorporated into the catalog.

We examined the 278 sets of right-side photographs used to identify potentially unique whales in the current catalog, and 188 of the sets were found to be complete (i.e., they contained photographs of all three body segments commonly seen when a beluga surfaces). Considering the combination of the completeness of each individual’s photograph set, the likely permanence of the marks, and how well marked each whale was (identifiability), 141 individuals were considered highly likely to be matched if photographed annually. Of the 39 potentially new unique individuals from 2007 still under review, a total of 33 whales were considered highly likely to be matched if photographed annually.

During each of the three years of surveys, white belugas outnumbered gray belugas by more than 25%. Of the identified beluga whales currently in the combined 2005-2007 catalog, 42% percent of identified whales are classified as white, and 58% as gray, based on their appearance in photographs.

Discussion

The major results from this project were the documentation that a large number of beluga whales in Upper Cook Inlet possess distinct natural marks that persist across years, and that these marks can effectively be identified and re-sighted with digital photography. The study has begun to demonstrate the utility of photo-identification of Cook Inlet beluga whales, as the photo-identification catalog and associated surveys from three years of effort have provided information about the distribution and movement patterns of dozens of individually identified beluga whales (including mothers with calves).

These results indicate *the feasibility and utility of photo-identification for studies of Cook Inlet beluga whales* as outlined in the first objective of this study. The second objective of *building a photo-identification catalog to examine re-sight rates and discovery of new individuals over time* has also been met, though this is an ongoing process. The third objective, *to develop abundance estimates of Cook Inlet beluga whales using mark-recapture models,* has not yet been met, but the implementation of methods of photographic analyses developed this year will allow this objective to be met in the near future.

The fourth project objective, *to describe population characteristics of beluga whales in Upper Cook Inlet, including age class distribution, residency/movement patterns, behavior, and social group structure,* is being met, and results will continue to develop with increased field work and refinements of methods. When drawing inferences about population age-structure and conservation status (i.e., recovering, declining, or stable) based on colors of whales, three caveats must be considered:

1. The color of the whale may not be a reliable indicator of age/reproductive status.
2. The probability of encountering and photographing a whale during a survey may vary according to color.
3. The probability of a whale being photo-identified and re-sighted may vary according to color.

A fifth objective should be added: *to determine life history characteristics of Cook Inlet beluga whales*. In addition to the methodological adaptations described above, plans for 2008 include an increase in the scope of survey effort, with more surveys overall, and a more even distribution of survey effort throughout different locations.

Conclusion

This study demonstrates the effectiveness of photo-identification for the study of aspects of the life history of Cook Inlet beluga whales. Establishment of a long-term data-set that provides insight into the population dynamics and life history of Cook Inlet beluga whales can help to identify appropriate conservation measures to preserve the population in Cook Inlet.

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INTRODUCTION

This report provides results from effort in 2006 and 2007 on an ongoing study which, since 2005, has used vessel- and land-based photo-identification techniques to develop a catalog of individually identified beluga whales from Upper Cook Inlet, Alaska (Figure 1). The original objectives of the study were to:

1. Assess the feasibility and utility of photo-identification for studying Cook Inlet beluga whales.
2. Build a photo-identification catalog of distinctively marked individuals, describing re-sight rates and discoveries of new individuals over time.
3. Develop abundance estimates of Cook Inlet beluga whales using mark-recapture models.
4. Describe population characteristics of beluga whales in Upper Cook Inlet, including age-class distribution, residency/movement patterns, behavior, and social group structure.

We present results from field effort and analyses conducted from September 2006 through October 2007. In addition, we discuss the current status of the photo-identification catalog with respect to the project's original objectives and requirements for continued development of a photo-identification catalog for Cook Inlet beluga whales. Markowitz et al. (2006) presented preliminary findings from the first two years of the study (2005, summer 2006). Results presented here supersede those from earlier interim and annual (Markowitz et al. 2006) project reports.

A dramatic decline of the population of beluga whales inhabiting Cook Inlet occurred in the late 1990s, coincident with several consecutive years of unsustainably high harvests (Mahoney & Shelden 2000, Hobbs et al. 2006). Subsequently, the subsistence hunt was severely curtailed and the Cook Inlet beluga whale population was designated as depleted in 2000 under the Marine Mammal Protection Act. In April 2006, after finding little evidence to demonstrate the population was recovering, the National Marine Fisheries Service (NMFS), the federal agency responsible for the management and protection of beluga whales in Cook Inlet, was petitioned to list Cook Inlet beluga whales as endangered under the Endangered Species Act. In April 2007, NMFS issued a proposed rule to list the Cook Inlet beluga whale DPS (distinct population segment) as an endangered species, and is expected to finalize a determination of listing by April 2008. Should the population be listed as endangered, NMFS will likely make a critical habitat designation, which prescribes particularly valuable habitat for the survival and recovery of the population.

Whether listed or not, there are many information gaps and uncertainties associated with the current understanding of the Cook Inlet beluga whale (Hobbs et al. 2006). Current information needs include precise annual abundance estimates of the entire population and age-specific cohorts, habitat preferences, and life history characteristics associated with population growth (births, calving intervals, age at sexual maturity, etc.) and mortality (natural and human-induced).

The primary sources of information used by NMFS to assess the status of Cook Inlet beluga whales are annual abundance estimates developed from aerial survey results, which have been conducted in June of each year since 1993 (Rugh et al. 1998, 2000, 2004, 2005, 2006). Currently, these annual abundance estimates are the only source of information used to determine whether the population is stable, recovering, or continuing to decline. Given the imprecision of these estimates (coefficient of variation of 11%-44%), and some difficultly quantifying sources of bias (e.g., dive intervals, visibility of gray animals, variation in group behavior; Hobbs et al. 2000), modest changes in abundance may be difficult to detect and it may require many years of estimates to determine whether conservation measures are having a positive, neutral, or negative effect on the population.

The currently available sources of information that would be used to identify and characterize critical habitat are the distribution of whales sighted from the annual aerial surveys, tidal flow models, and movement data from 15 satellite-tagged individuals from 1999 to 2002 (Hobbs et al. 2005, Goetz et al. 2007). This information will play a key role in characterizing habitat needs, as will any new information on movement and residency patterns (Funk et al. 2005, Markowitz and McGuire 2007, Nemeth et al. 2007).

Photo-identification has proven to be a reliable tool for characterizing abundance, residency, movements, social grouping, and life history of many marine mammal species in the wild (reviewed by Mann 2000). Photo-identification has proven useful for nearly every cetacean it has been used to study (reviewed by Whitehead et al. 2000), including Amazon River dolphins (boto, *Inia geoffrensis*) which, like Cook Inlet beluga whales, lack a dorsal fin and live in turbid water (Trujillo 1994, McGuire and Henningsen 2007). Photo-identification has been used to study the distribution, population dynamics, and social structure of beluga whales in Canada's St. Lawrence Estuary (Michaud 1996), and in the White Sea of Russia (Kryukova 2005).

Hammond et al. (1990) summarized the many applications of photo-identification for estimating cetacean population parameters, including the use of photographs in developing mark-recapture abundance estimates. Photo-identification studies make use of mark-recapture models by treating the first photographic record of an individual as the initial "capture" for the sampling period, with each subsequent photographic record in a different sampling period as a "recapture". Mark-recapture models of data from photo-identification studies provide a potential alternative approach to estimating the abundance of Cook Inlet beluga whales, and this could provide additional insight into the annual abundance estimates derived from aerial surveys.

Photo-identification surveys can be used to characterize distribution and movement patterns of individual beluga whales, which can augment information from aerial surveys and tagging-tracking studies. Photo-identification has been used to examine group structure and association patterns (Whitehead 1995). Knowledge of individual residency and movement patterns, movements of mothers and calves, and associated descriptions of behavior can aid in the identification of critical habitat, including movement corridors and grounds for feeding, calving, and rearing of young.

METHODS

Field Surveys

Survey effort

Dedicated surveys and opportunistic sampling of Upper Cook Inlet, Alaska (Figure 1) were conducted from small vessels and from shore. Surveys varied according to those combinations of season, location, and tide which provided the greatest likelihood of detecting whales. These combinations were determined by results from NMFS aerial surveys (Hobbs et al. 2006) and other studies of Cook Inlet beluga whales (Funk et al. 2005, Prevel-Ramos et al. 2006, Markowitz et al. 2006, Markowitz & McGuire 2007, Nemeth et al. 2007). Knik Arm (Figure 2) was surveyed in late summer/fall (August-October) during low tide. The Susitna River Delta (Figure 3) was primarily surveyed in summer (May-August) during low tide. Turnagain Arm (Figure 4) was surveyed from the Seward Highway in late summer/fall (August-October) during high tide. One vessel-based survey of Chickaloon Bay (Figure 5) was made on 26 July 2007. All vessel surveys were conducted under General Authorization # LOC 481-1795-01. Surveys were coordinated with NMFS to avoid beluga subsistence hunts and NMFS aerial surveys.

Vessel surveys

Most photographs were taken from vessels. During fall 2006, vessel surveys were conducted from the *R/V Nerka*, a 7.9 m (26-ft) aluminum boat powered by a 4-stroke 250 hp Yamaha outboard motor (Figure 6), or from the *R/V Leucas*, a 4.9 m (16-ft) inflatable Proman 9 Zodiak powered by a 4-stroke 50 hp Yamaha motor. Vessel surveys in 2007 were conducted only from the *R/V Leucas*. Vessel position was recorded at 2-minute intervals with a Garmin 12XL GPS (Global Positioning System) or Garmin GPS Map 76C. Whale groups were approached once per encounter and followed in the manner described by Würsig and Jefferson (1990). The research vessel approached slowly, parallel to the group, matching group speed and heading in order to obtain images of lateral sides of individuals while minimizing disruption of the group. Researchers noted the position of whales relative to the vessel and GPS-logged tracks were used to estimate approximate whale group position.

Land-based surveys

Photographs were also taken from shore. An observer drove south and east from Anchorage along the Seward Highway, generally beginning three hours before high tide. Stopping at pullouts along the highway, the observer searched with binoculars and the naked eye for marine mammals. When beluga whales were seen, the observer attempted to follow them up and down the Arm as they moved with the tide. While most photographs taken from shore were taken along Turnagain Arm, on one occasion photographs of whales were obtained from shore near the Ship Creek boat ramp adjacent to the Port of Anchorage, after we received a report of beluga whales in the area.

Field data (vessel and land-based surveys)

Standardized data forms were used to record beluga whale sightings and environmental conditions. For each beluga whale group sighting, observers (2-4 per vessel survey) recorded: time of day, group size, GPS position of the vessel, magnetic compass bearing to the group, estimated distance of the vessel from the group (distance at first detection, and minimum distance to the group), water depth (under vessel), group formation, direction of travel, movement patterns, average distance between individuals, and any human activities near the sighting. For groups with multiple records on a single day, the best record was selected at the end of the survey, which was either the highest count (for groups that merged), or the count considered most accurate. Behavioral data were collected using focal group sampling (Mann 2000) and behavior was classified into primary and secondary activities. Primary activities were behaviors that appeared to be the dominant behavior of the group, while secondary activities were events that occurred sporadically during primary activities. Body color and relative size of whales in the group were recorded as “white”, “gray”, and “calf”. Calves were dark gray, relatively small, and usually swimming within one body length of an adult-sized beluga. Photo card number, photographer, and photo frame number were also recorded.

Environmental data were collected hourly or when conditions changed. Environmental variables recorded included Beaufort Sea State, swell height, cloud cover, wind speed and direction, air temperature, water temperature at the surface, water depth, visibility, visual conditions, and habitat type (e.g., mudflat, bay, mid-channel, river mouth, depositional bank, erosional bank, island, and shoal).

Digital photographs of beluga whales were collected using a Nikon D70, 6.1 megapixel digital SLR camera, with Nikkor 70-300 mm and 80-400 mm zoom telephoto auto focus lenses. Typical settings included shutter speed priority, dynamic auto-focus, 800 ISO, and shutter speed of 1,000 or greater. Images were underexposed (setting at -1 or lower exposure bias value) to increase contrast and show otherwise faint marks in images of white animals (Robert Michaud, personal communication). Photographs were taken in large, fine JPG format and stored on compact flash memory cards.

Sighting histories, group color composition, and group behavior

Positions of beluga whale sightings and survey routes were mapped in ArcGIS 9 Version 9.1 (http://www.esri.com) and figures were prepared showing the results from each survey conducted in 2007.

Sighting histories (i.e., dates and locations of sightings) were compiled for all identified beluga whales, including mothers and calves. All whale sightings which occurred in each of the three years of the study were plotted and presented graphically.

Color composition for each group was determined from field counts and from cataloged photographs obtained during each encounter. Group color compositions by season and survey area from the two methods were compared.

Primary and secondary behaviors of beluga whale groups were compared among the Susitna River Delta, Turnagain Arm, and Knik Arm.

Processing and Cataloging of Photographs

Photographs were downloaded from the compact flash memory card onto a computer hard drive, named by date, location, group and frame number (based on the order in which photos were taken), and sorted by image quality using ACDSee photo software (http://www.acdsee.com). Photographs of unsuitable quality for identification (e.g., poor focus, whale obscured by splash or too distant; Appendix A) were noted and archived, but not used for subsequent analyses. Some distinguishing features of marks were obvious even in poor quality photographs; in these cases, the photo was placed in the catalog but will not be used for any future mark-recapture analyses.

Images of belugas were cropped to include only the single whale to be matched, separated into images of left and right sides of the whales, and then classed as white or gray. When images contained two or more whales, each whale was cropped individually and given a separate file name. Small calves (usually very dark gray in color) that were directly associated with a larger whale were assumed to be cow/calf pairs, and were cropped together with the larger whale. Small whales (dark to light gray) that were not directly associated with another whale were cropped separately.

Daily photo samples (i.e., consisting of all cropped photos taken on a single survey day) were then sorted into temporary folders. Each temporary folder contained all of the cropped images taken of the same individual on a single day, and was comprised of one to many images. Images within a temporary folder may have been taken seconds or hours apart, and often showed different segments (Figures 7 and 8) of the body as they were photographed when the animal surfaced and submerged. Temporary folders were then examined to determine whether or not there was a match to photographs in the catalog.

Photographs within temporary folders from each survey day were cataloged by comparing them to photographs of identified beluga whales within the catalog. Prior to the internal review of the catalog (below), if no matches were found between photographs in temporary folders and photographs in the catalog, all of the photographs within a temporary folder were assigned a new identification number and placed sequentially in the catalog (i.e., they were considered to be “new” individuals). Following the internal review of the catalog, more rigorous criteria were established for including a “new” individual in the catalog. These criteria included:

1. the whale’s markings had an average to high probability of permanency (see “permanency of markings” Appendix B).
2. a second researcher reviewed the temporary folders to ensure that each temporary folder contained photographs of the same whale.
3. a second reviewer concurred that the proposed new whale did not match one already in the catalog.

Prior to 2007, photographs were catalogued using FINSCAN, a specialized matching software (Hillman et al. 2003, Markowitz et al. 2006). Because this software is primarily designed to be used with cetaceans that have a dorsal fin, application to photographs of beluga whales (which lack a distinct dorsal fin) resulted in some inefficiency, and all matching is currently done manually. To expedite the image recognition process in 2007, photographs were cataloged with the aid of a newly created "search catalog" containing the most representative photographs of each cataloged individual.

An estimated three percent of the photographs in each sorted daily sample of photographs taken in 2007 were of individuals which appeared to be unmarked. These folders are currently set-aside in an "Unmarked" folder for future analyses (such as estimating abundance). A complete accounting of unmarked whales and finalization of draft protocols for scoring photographs (Appendix A) is ongoing.

The catalog contains folders of individual white beluga whales identified alphanumerically by RA (right side "adults") or LA (left side "adults") and a sequential number based on the chronological order in which the animals were cataloged (along with nicknames in some cases to facilitate matching). The catalog also contains photos of gray belugas which were assigned identification numbers that began with RS or LS (right side "subadults") or (left side "subadults"), respectively. The original naming protocol using the A and S to refer to adult and subadults (Markowitz et al. 2006) has subsequently been modified by designating all photographs as white or gray, given that some gray animals are likely adult whales (e.g., seen with calves), but for continuity we have retained the file naming protocol of A (white) and S (gray) for all photos.

Calves and juveniles were not distinguished from older gray beluga whales in the cataloging process (although calves were discriminated by body size and color in counts of whales encountered on surveys). Therefore, the "gray" category included all non-white belugas, regardless of body size or age class. Images from the right sides (RA and RS images) were carried forward for more detailed analyses, and images from the left sides were archived for future catalog development should additional funding become available.

Catalog Development

Review of the preliminary 2005-2006 catalog

In 2007, a rigorous review of the initial catalog from this study (Markowitz et al. 2006) was conducted. At the time of the review the catalog contained photographs taken on 65 surveys from May 2005 through August 2006. Two biologists with experience in photo-identification of belugas and other marine mammals reviewed the existing catalog for errors such as duplicate assignments of the same individual or multiple individuals assigned the same identification number. By the end of the review, all photographic records of cataloged individuals had been verified by a least three people (i.e., the person who had done the original cataloging, plus the two reviewers). In the event of a disagreement between the reviewers, a fourth reviewer with experience in photo-identification of small cetaceans was consulted. All changes to the catalog and the rationale for these changes were documented.

Workshop to address the photo-identification methodology used in this study

In addition to the internal review of the cataloged images, LGL and colleagues from the National Marine Mammal Laboratory (NMML) and the Alaska Field Office, (both divisions within NMFS) convened a workshop in October 2007. The purpose of this workshop was to review the history, current status, and future plans of the project and to provide an opportunity for scientists from NMFS and LGL to discuss photo-identification techniques and their application to this project. The workshop was not a review of the entire catalog, but rather a review of the methods used to create the catalog.

Photo-analysis development

During the internal review of the catalog, it became clear that several additional steps in the cataloging process would improve the utility of the catalog for future analyses. These steps included characterizing and quantifying the features used to catalog individuals. These steps are prerequisites for estimates of population abundance and of most life history parameters that may be derived from the catalog and future photo-identification surveys. Improvements were also made to expedite the sorting, cropping, and cataloging of photographs.

We evaluated the 2005-2007 photo-catalog for the potential of individual whales to be re-sighted annually, in order to characterize the variety of identifying marks, establish threshold criteria for entering “new” individuals into the catalog, and to portray the scope of the catalog. This preliminary rating of the potential to be re-sighted annually was based on four criteria: completeness, permanency, quality, and identifiability of the marks.

<u>Completeness of photographic record with respect to number of body segments photographed</u>

As a beluga whale surfaces, different portions of its body become available to photograph. We defined the areas on belugas most often photographed, and available to compare markings, as “segments” (Figures 7 and 8). Segments are currently referenced by the dorsal ridge area (Appendix A), although laser lights attached to the camera may be used as a reference in future studies (Durban and Parsons 2006). Markings may occur in all three segments. Marks are also found outside segment regions, such as around the caudal peduncle or nearer to the head, but these areas are rarely seen or photographed.

Individual folders in the catalog contain a single or several photographs of marked whales. Each photograph may contain one, two or all three segments depending on when the photograph was taken as the whale surfaced. The completeness of the set of photographs of an individual whale affects the likelihood of re-sighting an individual and the potential for accidental duplication with other individuals in the catalog. For example, the posterior segment of one incompletely documented individual might belong to the anterior segment of another incompletely documented individual. A breakdown of the completeness of the current catalog and newly documented individuals can be found in Tables 1 and 2.

Permanency

The likelihood of identification within a field season and across multiple years depends, in part, on the permanency of the markings. Photographs of whales identified in all three years of the study were assessed for mark changes and how easily the marks could be re-identified. Finer, bright white markings were the most reliable and long-lasting type of markings on white animals (Figure 9). On gray and darker animals, slightly wider bands of white appeared to be long lasting (Figure 10).

Quality

To address heterogeneity of capture probabilities in future mark-recapture analyses, we rated the quality of the catalog photographs (Hammond 1986, Hammond et al. 1990). Quality was judged on a five-point scale (1+, 1-, 2+, 2-, 3; Rugh et al. 1998) with 1+ being the highest quality and 3 being the lowest quality (Appendix A). Photographs of quality 3 that could be positively matched were left in the catalog for some analyses (e.g., movement patterns, individual associations), and were used in the assessment for the potential of individual whales to be re-sighted annually, but will not be used in future abundance estimation.

Identifiability

Identifiability refers to the relative ability of unique or distinctive markings to be recognized. Some whales have more distinct and visible markings than others and are therefore more easily identified. In mark-recapture analyses, as noted in the quality scoring above, different segments of individual whales in photographs are rated separately (Appendix A). In this evaluation of the potential of an individual whale to be re-sighted annually, each whale was considered qualitatively as a whole (i.e., as the sum total of each photographed body segment).

Neither the numbers of individual whales resighted annually nor the numbers of folders of individual whales in the catalog are estimates of population size. To rigorously estimate population size, each individual segment in each cataloged photograph must be scored for quality and identifiability (Rugh et al. 1998, Schweder 2003, Schweder et al. In review). Toward this objective, a draft protocol was developed for scoring photographs (Appendix A). This technique allows for the relative identifiability of each individual to be assessed in a likelihood framework, which is a necessary precursor for estimating population abundance from mark-recapture models. To score photographs, the best photographs of each encounter of cataloged individuals were identified, and a subset of these photographs (ca. 100) was scored in preparation for a technical review by NMML photo-experts familiar with this process. Scoring of the entire catalog is ongoing.

During the internal review, drawings of each cataloged whale were created to facilitate future matching and as an initial step toward the analysis of identifiability (above). Selected marks were also classified according to probable origin, such as gunshots, harpoons, and propellers, or from skin conditions (Figure 11), or from predation from sharks or killer whales. These classifications may be useful for characterizing natural and human-induced impacts on the population.

Color grades (white, light gray, dark gray) of belugas are used by NMML researchers as a reference for determining different age classes in video taken during aerial surveys (Simms et al. 2003, 2007). In an effort to standardize our catalog to better represent color categories used by NMML, each set of photos of an identified whale was re-evaluated. During this evaluation, the color of the whale in each photograph was classified with regard to the photo properties (exposure bias, light conditions, etc.), which may distort the true color of the whale.

Database Development

In 2007, we worked with a database specialist to consolidate all photo-identification data (2005-2007) into a single, comprehensive, and integrated database (Appendix C). Data from surveys included the survey route, environmental conditions, and group size, color, and behavior. Data associated with each photograph included the "metadata", such as the original camera settings, the time the original photograph was taken, and the lighting conditions. Finally, data included the number of photos in the catalog, the dates and locations when photos were taken, the number of individual whales represented in the catalog, the number of temporary files yet to be matched and the number of unmarked photos. Consolidation of all the project files into a database is ongoing.

RESULTS

Surveys

Survey effort and number of whales and whale groups encountered

Ninety-four beluga whale groups were counted and photographed during 34 surveys conducted from the fall of 2006 through the fall of 2007 (Table 3). Survey effort was unequal among locations and seasons. Survey effort was highest in Knik Arm and lowest in Chickaloon Bay/Southeast Fire Island. Beluga whales were photographed at the Port of Anchorage on one occasion, after we received a report of whales in the area. Average group encounter rates were highest in the Susitna River Delta (3.5 groups per survey) followed by Knik Arm (2.6 groups per survey). The single survey of Chickaloon Bay/Southeast encountered 2 groups, and one group was seen near the Port of Anchorage. Across all areas and both survey methods, an average of 2.8 groups was observed per survey event.

The number of whales sighted showed considerable variability between land and vessel surveys, even after stratifying by season and location (Tables 4-7). Total number of belugas sighted per survey day varied between 0 and 100. Survey routes varied among days for each area. Appendix D provides whale group sighting locations from both land-based routes and from vessels for fall of 2006 and all of 2007.

Size and color composition of groups encountered during surveys

The most-commonly encountered group size was three whales, and groups ranged in size from one to 74 whales (Figure 12). Relative color composition of groups varied according to location, season, and survey method (Table 8). Group composition ranged between 52% and 65% white belugas, 18% and 39% gray belugas, and 2% and 10% calves.

Behavior of whales

Travel was the most commonly observed primary behavior and diving was the most commonly observed secondary behavior (Figures 13 and 14). In 2006, feeding as a primary behavior was noted more often in Knik Arm than in either the Susitna River Delta or Turnagain Arm. In 2007, feeding behavior was noted more often in the Susitna River Delta than in Turnagain Arm, and was not observed at all in Knik Arm.

Sighting Histories

Sighting histories of whales seen in all three years of the study

Twenty-six identified beluga whales were photographed in all three years of the study. In addition, sixty-two identified whales were photographed in two years of the study, and 190 identified whales were photographed in a single year only.

One identified whale was photographed on 20 different days, while 46% of the identified whales were photographed on one day only (Figure 15). Individually identified white beluga whales were sighted more often (maximum of 20 different days) than were individually identified gray beluga whales (maximum of 12 different days), and many more gray identified belugas than white identified belugas were seen only once (Figure 16).

Of the twenty-six individually identified beluga whales that were photographed in each of the three years of the study (2005, 2006, and 2007; Table 9), none were observed exclusively in one area. Most whales (73%) were photographed in both Knik Arm and the Susitna River Delta, although they were not photographed in Turnagain Arm or Chickaloon Bay/Southeast Fire Island. Photographs of 19% of the whales were taken in Turnagain Arm as well as in the Susitna River Delta and in Knik Arm, and the two identified individuals photographed around Southeast Fire Island were also photographed in the Susitna River Delta and in Knik Arm. Individual sighting histories and photographs of these 26 whales are presented in Appendix E.

Sighting histories of mothers and their calves

Thirty-seven identified beluga whales were presumed to be reproductive adult females based on photographs in which they were closely accompanied by calves (Table 10). Ten identified mothers were gray in color. Sixty percent (22 of 37) of identified mothers were photographed in both Knik Arm and the Susitna River Delta, while 24% (9 of 37) were only photographed in Knik Arm. Two identified mothers were photographed in Knik Arm, the Susitna River Delta, and Turnagain Arm. No identified mothers were photographed in Chickaloon Bay/Southeast Fire Island.

Seventeen identified mothers were photographed with calves over a two-year period, and one female was photographed with a calf in all three years of the study. Examples of two and three-year old calves of identified mothers are presented in Figures 17-20.

Sighting histories of belugas identified by satellite tag scars

Nine photo-identified belugas have unique scars from holes used by NMFS to affix satellite tags in the past. These individuals were identified and distinguished based on a combination of natural marks and the tag scars to avoid mistakenly matching similar scar patterns caused by the same tag type. Three previously tagged belugas were photographed with calves, and two of these were photographed with calves in more than one year (Table 11). Two previously tagged belugas were photographed only in Knik Arm, and one previously tagged beluga was photographed only in the Susitna River Delta. Five previously tagged belugas were photographed in both Knik Arm and the Susitna River Delta. One previously tagged beluga was photographed in Turnagain Arm, and this animal was also photographed in Knik Arm and the Susitna River Delta. No previously tagged animals were photographed in Chickaloon Bay/Southeast Fire Island during the one survey conducted in the area. Fifteen Cook Inlet belugas were tagged with satellite tags by NMFS between 1999 and 2002 (Hobbs et al. 2005). Tag type and attachment varied among years (Rod Hobbs and Barbara Mahoney, NMFS, personal communication) and it may be possible to assign a capture/tagging date based on scar type, which in turn would provide information on survivorship, wound healing, and longevity of these types of marks (Figures 21-23).

Catalog Development and Current Status

Review of the preliminary 2005-2006 catalog

During the internal review process, changes were made to the total number of photos in the catalog, and to the number of identified animals. We reviewed all photos taken of the right and left sides of whales and those individual whales identified from both right and left sides (referred to as "dual" side whales; Markowitz et al. 2006). Although we reviewed the entire catalog, in keeping with the content of this report, we limit our catalog review results to photographs of the right sides of belugas.

Reviewers attempted matching left and right sides of dual animals (n = 20) with <50% success. Based on this uncertainty, dual animal data was archived for future analysis and their left and right photograph encounters copied into the respective catalogs.

Following the review and with the addition of the right sides from the "dual" whales, the 2005-2006 catalog contained 156 "adults" and 169 "subadults" for a total of 324 individuals. These individual folders contained from one to several photographs of one or more segments of individuals. Prior to the review, the right side catalog contained

158 “adults” and 172 “subadults” for a total of 330 individuals. Some photographs of individuals were considered by the LGL review panel to be of too poor quality to evaluate, and were eliminated from the catalog. A number of folders had initially been considered to be unique individuals, but closer examination of marks revealed that they were actually whales found in other folders within the catalog (e.g., linked within the catalog).

Workshop to address the photo-identification methodology used in this study

A 3-day workshop was held at NMML in Seattle, WA, from 10 through 12 October 2007. LGL presented an overview of the project that included the project history, objectives, methods, results, and a list of work in progress. The presentation was followed by a general discussion about the utility of photo-identification as a tool for studying Cook Inlet beluga whale population parameters, including abundance estimates, as well as characterizing color categories (gray and white), database attributes, photo matching techniques, photograph scoring (Rugh et al. 1998), and the sources of heterogeneity in sampling and techniques to address them.

Several slides were reviewed that depicted the different types of natural markings used to identify beluga whales. Participants were shown slides of individuals re-sighted over each of three years (Appendix E) with a representative photograph from each year within each slide. These slides were used to illustrate of the types of lasting marks that appear useful for photo-identification of Cook Inlet beluga whales.

A subset of cataloged whales was used in a group exercise to evaluate and refine our protocols for scoring photographs (Appendix A; Rugh et al. 1998). Participants had approximately one hour to individually review and score the photos using the protocol. The group then reconvened to compare scores, discuss any inconsistencies and difficulties applying the scoring protocol, and to make recommendations for modifications to the protocol (Appendix F).

Current status of the catalog

As of December 2007, the beluga photo-identification catalog contained 2,890 photographs of individual whales found in 316 groups encountered during 99 surveys conducted between 2005 and 2007 (Table 12). In 2005, 245 potential individual belugas were identified. In 2006, 102 potential individual belugas were identified (of these, 69 were matched to whales photographed in 2005, and 33 new belugas were added to the catalog in 2006). In 2007, photographs of 44 potential individual belugas were matched to whales within the catalog, including 17 also photographed in 2005 (but not in 2006), one which was also photographed in 2006 (but not in 2007), and 26 which were photographed in all three years of the study.

Revisions to the combined 2005-2007 catalog continued through the additions of fall 2006 and 2007 photographs. Further discoveries were made of linked individuals within the catalog and several (n = 11) single-image photograph folders were removed because they were considered unmarked or unable to be reliably matched to future photographs. This current revision reduced the main body of the catalog to 127 “subadults” and 151 “adults” (before further color analysis of photographs into gray, light gray and white) for a total of 278 folders of potentially unique individuals. Furthermore, uncataloged photographs taken in 2007 may contribute an additional 39 individuals to the catalog (Table 1), although these photos must still undergo the complete review process before they can be fully incorporated into the catalog.

Photo-analyses: number of potential individuals in the catalog, mark quality and re-sightability

We examined the completeness of the 278 sets of photographs used to identify the 278 potentially unique whales in the current photo-identification catalog, and 188 of the sets were found to contain complete lateral right side photographs of all three body segments. One hundred and seventy six of these sets were estimated to have marks with a high probability of permanency. Considering the combination of the comprehensiveness of each individual's photograph set, the likely permanence of the marks, and the identifiability of marks on each whale, 141 individuals were considered highly likely to be matched if photographed annually (Table 2).

Of the 39 potentially new unique individuals (Table 1) identified from photographs taken in 2007, 36 whales contained complete photo sets covering all three body segments. Twenty-seven individuals were considered highly likely to carry permanent markings, and a total of 33 animals were considered highly likely to be matched if photographed annually.

Group color composition of cataloged whales compared to whales observed in the field

Figure 24 compares the relative color composition of groups observed during yearly surveys to the color composition of identified individuals in the photo-catalog. During each of the three years of surveys, white belugas outnumbered gray belugas by more than 25%. In contrast, gray belugas slightly outnumbered white belugas in the 2005 catalog. Cataloged photographs taken in 2006 represented more white belugas than gray belugas, but the relative differences between the color classes were less pronounced than they were for surveys conducted during this same year. Cataloged photographs taken in 2007 represented a higher proportion of white belugas than was recorded during surveys in 2007. Of the identified beluga whales in the combined 2005-2007 catalog, 51% were classified as white and 49% were classified as gray, using the color classification methodology of Markowitz et al. (2006). Under the current methodology, 42% percent of identified beluga whales currently in the combined 2005-2007 catalog were classified as white, 39% as light gray, and 19% as dark gray; combining light and dark gray results in a total of 58% gray.

Lesions were noted on 11 (10%) of the light gray individuals and 14 (26%) of the dark gray individuals, but were not noted on any of the white individuals. Molting/sloughing skin was noted in four (3%) of white, one (1%) gray and one (2%) of the dark gray whales. Large scars which appeared to be the result of predation were noted on 2 (2%) of the white whales, none of the light gray, and two (4%) of the dark gray whales. The frequency of other wounds that appeared to be caused by bullets or harpoons and propellers remains to be quantified.

DISCUSSION

Results presented here confirm the feasibility of photo-identification for studies of Cook Inlet beluga whales. The major results from this project were the documentation that a large number of beluga whales in Upper Cook Inlet possess distinct natural marks that persist across years, and that these marks can effectively be identified and re-sighted with digital photography. The study has begun to demonstrate the utility of photo-identification of Cook Inlet beluga whales, as the photo-identification catalog and associated surveys from three years of effort have provided information about the distribution and movement patterns of dozens of individually identified beluga whales (including mothers with calves). The strength and utility of the catalog will grow as the proportion of the population that is photographed and archived grows. In addition, this work suggests that continued photo-identification efforts might help to fill gaps in knowledge about life history parameters of the Cook Inlet beluga whale population.

Whales Encountered During Surveys

Whales were photographed in the Susitna River Delta in the summer and in Knik and Turnagain Arm in the fall (Knik Arm was surveyed once in the summer of 2007, but whales were not encountered). The presence of whales in these areas during these time periods is consistent with seasonal distribution patterns found in previous studies (Moore et al. 2000, Funk et al. 2005, Hobbs et al. 2005, Markowitz and McGuire 2007, Nemeth et al. 2007).

When making inferences about the greater population of Cook Inlet Beluga whales based on sighting histories of individually identified whales, it is important to consider the results within the context of survey effort. Photo-identification surveys in 2007 were not systematic relative to the entire Upper Cook Inlet, and were infrequent. Instead, we focused effort in areas during particular times of the year that would maximize the probability of encountering whales to photograph. Therefore, the seasonal and spatial aspects of sightings from 2007 reflect our bias toward where we expected to find whales. In addition, sighting histories that we obtained from the catalog are a function of which whales within a group were photographed and which of these had marks that can be reliably identified through time. Therefore, survey effort and catalog results must be considered together.

The maximum numbers of beluga whales encountered in a single survey day was never more than 100, which indicates that some of the population was elsewhere (population estimated at 375 in 2007; Rod Hobbs, pers. comm.). Groups encountered in 2007 were often small (groups of three whales were encountered more often than other group sizes), suggesting that beluga whales not encountered during surveys may have been dispersed in several small groups, rather than clumped in a single large group.

Age/Color Composition of Groups

The timing and location of beluga whale calving in Cook Inlet is not known. Based on the presence of calves sighted in summer aerial surveys, Calkins (1983) speculated that calving might occur between mid-June and mid-July in the larger estuaries of upper western Cook Inlet. Groups of belugas in the Canadian Arctic were found to have seasonal differences in proportions of calves, juveniles, and adults (Smith et al. 1994), which was used to ascertain seasonality of calving. We did not detect localized areas for calving and calf rearing, as calves were seen in all locations surveyed. Likewise, we did not detect a clearly defined calving season. Calves were encountered in all months surveyed (April through October) and comprised between 2% and 10% of groups across seasons and locations.

The “calf” category we used during field surveys did not differentiate newborn calves from those now known to be one- and two-year old calves (determined by sighting histories of calves of identified mothers), which indicates that any peak in newborn calves may not have been captured in the data recorded during field surveys. One exception was a calf encountered on the July 27, 2007 survey of the Susitna River Delta: the calf was assumed to be a newborn based on its small size, uncoordinated manner of swimming, wrinkled-looking flippers, peanut-shaped head, and dark gray color. In future surveys, we will attempt to classify calves as newborns or older calves.

In the two previous years of this study, body color (white, gray, dark gray) of whales encountered during surveys and of whales in the photo-identification catalog were used together as a relative index of age structure of groups and the population (Markowitz et al. 2006). Whales were characterized as white (assumed to be an adult), gray (assumed to be a subadult) or calf (dark gray, relatively small); age-class was associated with color based on previous work by Hazard (1988), and Martin (1996).

When drawing inferences about population age-structure and conservation status (i.e., recovering, declining, or stable) based on colors of whales, three caveats must be considered:

1. The color of the whale may not be a reliable indicator of age/reproductive status.
2. The probability of encountering a whale may vary according to color.
3. The probability of a whale being photo-identified and re-sighted may vary according to color.

The color of the whale may not be a reliable indicator of age/reproductive status

Almost one third (10/33) of the identified and suspected mothers in the catalog were gray. Based on color alone, these individuals would have been classified as subadults under the protocols used in Markowitz et al. (2006), although photographic documentation of close proximity of calves suggests these gray beluga whales were reproductive adult females, thus the percentage of white and gray colored whales (from survey data and from catalog data) may not represent the percentage of mature and immature whales in the population. Belugas are reported to change from gray to white when they reach sexual maturity (Hazard 1988), and age at first birth for females is estimated between 5 and 11 years (Burns and Seaman 1986). Gray mothers we documented may be reproducing at an early age or they may not turn white until later than is commonly thought. There are reports of gray female belugas as old as 21 years, which is also the reported age of senescence (Burns and Seaman 1986). If calves can be followed over time, an ongoing photo-identification study may provide information on age and color at first reproduction.

Color variation in Cook Inlet beluga whales may also be related to both age and sex, as with the Amazon River Dolphins (*Inia geoffrensis geoffrensis*), which are born dark gray and become pink as they age, with males generally a brighter pink than females (Martin and da Silva 2004). Pregnant female *Inia* have been documented that were as pink as older adult males (Tamara McGuire, personal observation), which indicates that color may vary considerably among individuals of some cetacean species.

Probability of encountering and photographing a whale during a survey may vary according to color

Although not quantified, observers on the survey vessels had the impression that white whales were more likely than gray whales to be detected, as gray whales tend to blend in with the turbid gray waters of Cook Inlet. This suspected bias in detection towards white whales seemed greater with distance between whale and observer. However, behavioral differences between white and gray belugas may have resulted in an opposite bias. Gray animals appeared more likely to both approach the survey boat and to remain near the boat. Therefore, it seems that although white belugas were more likely to be detected at a distance, gray whales may have been more likely to be photographed, and perhaps yield better photographs because they were photographed at closer range.

Groups encountered during separate surveys from vessels and aircraft in June 2006 had similar ratios of white animals to gray animals, although a slightly lower percentage of white animals were seen during vessel surveys (Table 13). Differences may be due to actual differences in groups composition on different days (aerial and vessel surveys were never conducted on the same days), differences in definition of color classes, and/or differences in probability of detection of color based on survey method (gray animals may be harder to detect from the distances and speed flown by aircraft). The differences in the proportion grays between on-water surveys and aerial surveys could be interpreted as the aerial surveys having bias away from detecting and counting gray belugas whales, which appear to be a significant portion of the Cook Inlet beluga population. Conversely, boat-based surveys may have a bias towards detection of gray whales. When they become available, we can compare the proportion of grays from June 2007 aerial surveys to those obtained from the vessel.

Given the importance of detectability of gray whales from the aerial surveys on the annual abundance estimates, photo-identification and vessel surveys in general (i.e., field counts from a boat) may provide a means of testing for any biases in detectability of gray whales from the air.

Probability of a whale being photo-identified and re-sighted may vary according to color

Environmental conditions and photographic settings (most notably ambient light and camera exposure settings) influence where whales are classified on the gray-to-white scale (Markowitz et al. 2006), and therefore the color assigned to a whale during a field survey may not match the color assigned to the photograph of the same whale once the photograph is cataloged.

Distinguishing marks on white individuals appear to persist longer than marks on gray individuals, so that with continued years of study, the percentage of re-sighted animals in the photo-catalog will be increasingly weighted towards white animals. Also, beluga whales whiten as they age, so that identifiability of an individual may increase with age.

During cataloging, numerous examples were found of the same individual classified as white on one survey and as gray on another. For the reasons noted above, a great deal of care should be taken when attempting to use the relative color composition of *the photographs in the catalog* to make inferences about the color composition or age-class of the population. Color composition from field counts made at the time when first encountering the group will be less vulnerable to the many sources of bias described above, although some bias may be introduced by the survey method.

Behavior

Traveling and feeding were the predominant behaviors observed for groups encountered in the Susitna River Delta (surveyed during the summer) and in Knik Arm (surveyed during the fall). The distinction between behavioral categories is somewhat artificial as the terms only describe behaviors seen when the whales were briefly at the surface, and in reality whales were often probably simultaneously feeding, diving, and traveling as they pursued and captured prey in seasonal fish runs at river mouths (i.e., the Susitna River, the Little Susitna River, Eagle River, and Ship Creek). The largest group recorded during the study was of 74 beluga whales encountered on 27 July 2007, diving, traveling, and feeding along the Susitna River Delta. This large group was presumed to be pursuing salmonids, based on observations of fish jumping near the whales.

Feeding was less-commonly observed in Turnagain Arm than in other locations, and whales appeared to be traveling rapidly with the tide as it moved up and down the Arm. It is possible whales were feeding in areas out of view to an observer, such as in the deep channel on the south side of the Arm, or in the stretch of the Arm just west of the Twenty-Mile River. On a few occasions in September, whales traveling rapidly east with the incoming tide were observed to suddenly circle around near the rip-rap north shore approximately 1 km east of Bird Point, pursue fish, and then continue traveling rapidly eastward.

Whales were much easier to photograph when feeding or traveling than when diving. Feeding and traveling animals remained at the surface longer, had higher surfacing profiles, and exhibited less response (attraction or avoidance) to the survey vessel, while diving animals often remained submerged for long periods of time and were unpredictable in their surfacing locations and patterns.

Sighting Histories

Individual sighting histories of 26 beluga whales photographed in all three years of the study indicate that most of these whales moved between different areas of Upper Cook Inlet. All of these whales were photographed in Knik Arm and the Susitna River Delta, and some were also photographed in Turnagain Arm and Chickaloon Bay/Southeast Fire Island. Increased sampling effort in Turnagain Arm and Chickaloon Bay/Southeast Fire Island is required to determine if these whales exhibit some preference for these areas.

Beluga whales were rarely observed traveling between areas, but were instead encountered in distinct areas (i.e., along the Susitna River Delta, in Eagle Bay in Knik Arm, or traveling up and down Turnagain Arm). There are two exceptions: a group of 19 belugas observed between Fire Island and Point Woronzoff on 26 July 2007, and a group of 12 belugas observed at the Port of Anchorage on 16 August 2007. Similar patterns of localized aggregations and rapid and directed travel between areas of localized aggregations has been reported for satellite-tagged Cook Inlet beluga whales (Hobbs et al. 2005) and beluga whales in Norway (Lydersen et al. 2001).

Sighting histories of the 37 individually identified mothers with calves were similar to those of the whales seen during all three years. Most identified mothers were photographed in both Knik Arm and the Susitna River Delta, and identified mothers photographed in Turnagain Arm were also photographed in Knik Arm and the Susitna River Delta. Identified mothers were not photographed in Chickaloon Bay/Southeast Fire Island, although calves were observed in these areas during surveys (but not photographed). Twenty-four percent of all identified mothers were photographed in Knik Arm and nowhere else. This may be due to greater survey effort in Knik Arm, higher site fidelity of mothers to Knik Arm, or these animals may be easier to photograph and/or recognize.

Life History

Progress has been made toward determining some aspects of life history including calving interval (minimum time period between calving events), calving frequency (how often females give birth), period of maternal care/association, and survival rates of calves. Of the 37 identified mothers, 17 were photographed with calves in two consecutive years, and one identified mother was photographed with a maturing calf in all three years of the study. Additional years of photo-identification effort are needed to determine how long these calves remain with their mothers, and when these mothers give birth to new calves.

To date, all multiyear photographs of mothers with calves are of maturing calves. Mothers with relatively large calves in one year were not photographed with smaller calves in subsequent years. Continued fieldwork and tracking of identified mothers and their calves will offer insight into calving intervals.

Sighting histories for nine belugas known to have been tagged between 1999 and 2002 indicate that these individuals not only survived capture and tagging (and three of these have been identified as mothers with calves, indicating they reproduced post-tagging) but provide between three (if tagged in 2002 and re-sighted in 2005) and eight (if tagged in 1999 and re-sighted in 2007) years of survivorship data on these individuals. Continued photographic documentation of non-lethal wounds (from predation, infection, and anthropogenic sources) may provide information about the incidence of risk factors, such as shark attacks, boat strikes, or disease, which may be indicative of factors preventing the recovery of this species. Matching of photographs of dead belugas (Appendix G) to identified individuals in the catalog will provide information for understanding survivorship and population dynamics.

Catalog Status

The current working catalog contains 141 marked individuals considered to have a high probability of being re-sighted across years, 84 marked individuals with an average probability of being re-sighted across years, 53 with a low probability of inter-annual re-sighting, and an additional 39 potentially unique individuals in review. It is important to characterize the level of confidence associated with these statistics if interpreting these numbers as a minimum population estimate. As noted earlier, complete, lateral, right-side photographs (i.e., the individuals we are highly certain are unique from one another) are available for 188 individuals, and there are an additional 33 in review from this category. Matches of folders with others in the catalog are still likely, particularly in cases where only a single segment of a marked individual is available. A far more precise and unbiased population estimate can come from scoring the catalog photographs and entering them into a likelihood based analysis similar to that which is used to estimate bowhead whale population size (Schweder 2003; Schweder et al. In review). Such a likelihood analysis for Cook Inlet beluga whales is a future objective of this project.

Status of the Study with Respect to its Original Objectives

The photo-catalog currently contains information on sighting histories of 26 individual whales seen in all three years of the study. Additionally, we have identified thirty-seven individuals thought to be mothers. These results indicate *the feasibility and utility of photo-identification for studies of Cook Inlet beluga whales* as outlined in the first objective of this study. The second objective of *building a photo-identification catalog to examine re-sight rates and discovery of new individuals over time* has also been met, though this is an ongoing process.

The third objective, *to develop abundance estimates of Cook Inlet beluga whales using mark-recapture models,* has not yet been met. Before an abundance estimate can be produced from the catalog, some work remains. Several factors have been identified (Appendix F) which must first be quantified before estimating abundance: mark persistence, heterogeneity (non-uniformity) of photographic samples, and limitations of sampling locations.

One of the fundamental assumptions of mark-recapture estimation techniques is that marks are not lost during the study period (Seber 1982). It is important to characterize mark types and permanence so that cataloged whales used to generate mark-recapture abundance estimates will have similar re-sighting probabilities (Gowans and Whitehead 2001, Auger-Méthé and Whitehead 2007). A total of 34 individual whales were encountered in 2005 and again in 2007 with either no visible changes or minor changes to the primary marks that were used to match whales between years. Continued documentation and analysis of existing photosets of the various marks are needed to estimate mark persistence on Cook Inlet belugas. With further cooperation from government agencies, examination of archived NMML photographs from early beluga studies and of photographs taken during necropsies by NMFS, we can further our knowledge of mark permanency in beluga whales. Whales hunted for subsistence purposes (statewide) and those photographed by Fort Richardson Army Base biologists while conducting beluga studies are additional potential sources of mark information.

Another assumption of mark-recapture estimation is that marks are noted and recorded correctly (during photographic sorting and matching in our case; Seber 1982, White et al. 1982). Modifications to our photo handling protocols have greatly increased the accuracy of the catalog contents. By having all matches reviewed by two or more researchers before accepting photographs of individuals into the catalog, there is a much lower chance that animals will be improperly matched. Also, new protocols to score the photographs of individual whale body segments separately for quality and identifiability (Appendix A; Rugh et al. 1998) require analysts to examine photographs for details that might otherwise be overlooked, serving as additional proofing of the data.

Scoring photographs also offers several other advantages. Matching is the most time-consuming portion of the cataloging process, requiring an experienced researcher fifteen minutes, on average, to match each single encounter of an individual to the catalog. Searches of potentially new individuals, which require looking at the entire catalog, can take up to an hour for individuals with subtle markings. By initially "batch" scoring and screening poorer quality photographs, most of the difficult-to-process photographs are eliminated before the time consuming labor of sorting, cropping, and matching occurs. Most importantly, this technique allows for the relative identifiability of each individual to be assessed in a likelihood framework allowing for stronger inference from the data (Schweder 2003, Schweder et al. In review). Simply put, these models account for the fact that some markings are more visible than others and some whales may not show any markings at all.

Our sampling of Upper Cook Inlet waters is constrained by tide, weather, ice-free months, and cost of surveys. As noted in the methods section, survey schedules and locations are constrained based on their proximity to Anchorage (where the survey vessel is based) and the greatest chance of encountering whale groups based on tide and season. This non-standardized sampling may lead to the disproportionate sampling of locations that are easier to access, such as the relatively close and calm waters of Knik Arm, in comparison to more logistically challenging locations such as south of Tyonek and in Chickaloon Bay. Durban et al. (2005) offer a model for non-uniform sampling of cetaceans, which addresses these problems and fits the Upper Cook Inlet study area well.

We are also examining new sampling locations and economical field techniques to sample these areas from land and water.

The fourth project objective, *to describe population characteristics of beluga whales in Upper Cook Inlet, including age class distribution, residency/movement patterns, behavior, and social group structure,* is being met, and results will continue to develop with increased field work and refinements of methods.

Age-class distribution - As mentioned previously in the discussion, the use of body color as an index for age class needs to be examined more closely and revisions to current techniques to observe and quantify body color are being explored. Revisions include the use of a high definition digital video camera to pan across beluga groups and record group color at the onset of an encounter (to reduce the possibility of gray animals moving closer and white animals moving away) and, in collaboration with NMML, the development of a numerical scale to quantify gradations of gray based on pixel coloration, with calibrations made for varying photographic conditions.

Residency/movement patterns - Chronological maps of individual sighting histories illustrating residency and movement patterns have been provided in this report and may be used to examine the potential occurrence of spatial/temporal stratification of the population around Upper Cook Inlet. Knowledge of the existence of population stratification is important for impact assessment of human activities in and around Upper Cook Inlet.

Behavior - Current methods of recording behavior provide a general sense of the behavior of the group during an encounter, but in the future behavior should be sampled with more rigorous methods (sampling and recording rules; Martin and Bateson 1993), using a digital video recorder and/or dedicated observer and shore stations when feasible.

Social group structure - To better understand social group structure, relationships among individuals may be quantified with indices of association (Markowitz et al. 2006), but this should be done only after the heterogeneity of sampling and markings has been addressed via scoring of all cataloged photos and the development of a likelihood analysis (Schweder 2003, Schweder et al. In review).

A fifth objective should be added: *to determine life history characteristics of Cook Inlet beluga whales*. As already discussed, photo-identification techniques can be used to study calving frequency, calving interval, period of maternal care/association, survival rates of calves, and survival rates of identified individuals, which will increase our knowledge of the life history of Cook Inlet beluga whales.

Future Work

In addition to the methodological adaptations described above, plans for 2008 include an increase in the scope of survey effort, with more surveys overall, and a more even distribution of survey effort throughout different locations. Increased sampling in those areas (Chickaloon Bay/Southeast Fire Island) and in those seasons which have had patchy survey effort in the past will provide the sample sizes necessary to rigorously test patterns that are beginning to emerge but have not been tested statistically.

Conclusion

This study demonstrates the effectiveness of photo-identification for the study of aspects of the life history of Cook Inlet beluga whales. It also demonstrates the technique's potential as a tool to better understand the population dynamics of these whales. The value of a long-term, dedicated photo-identification study with the ability to follow known individual beluga whales as they move throughout Upper Cook Inlet will increase over time with continued effort. Establishment of a long-term data-set that provides insight into the population dynamics and life history of Cook Inlet beluga whales can help to identify appropriate conservation measures to preserve the population in Cook Inlet.

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Table 1. An accounting of the 39 *potentially unique* newly identified whales from fall 2006 through 2007 to be added to the photo-identification catalog. Each individual's folder contains sets of photographs covering portions of a single whale's right side. These folders are listed below by their completeness, or number of segments photographed (anterior the dorsal ridge, the dorsal ridge and below, and posterior the dorsal ridge), the potential to exhibit permanent marks, and by the potential to be re-sighted annually.

Completeness of Photograph Sets	
Segments Photographed	Number of photo-sets
3	33
2	5
1	1
Permanency of Markings	
Estimated Probability	Number of photo-sets
High	27
Average	12
Low	0
Annual Resights	
Estimated Probability	Number of photo-sets
High	33
Average	1
Low	5

Table 2. An accounting of the 278 potentially unique whales in the current photo-identification catalog. Each individual's folder contains sets of photographs covering portions of a single whale's right side. These folders are listed below by their completeness, or number of segments photographed (anterior the dorsal ridge, the dorsal ridge and below, and posterior the dorsal ridge), the potential to exhibit permanent marks, and by the potential to be re-sighted annually.

Completeness of Photograph Sets	
Segments Photographed	Number of photo-sets
3 (complete)	188
2	57
1	33
Permanency of Markings	
Estimated Probability	Number of photo-sets
High	176
Average	75
Low	27
Annual Resights	
Estimated Probability	Number of photo-sets
High	141
Average	84
Low	53

Table 3. Photo-identification survey effort and beluga whale groups encountered during fall 2006 and summer/fall 2007.

	Surveys from Vessels			Surveys from Land		
Season / Year	Susitna River Delta	Knik Arm	Chickaloon Bay/ Southeast Fire Island	Turnagain Arm	Port of Anchorage	Total
Fall 2006	0	12	0	5	0	17
Summer & Fall 2007	4	4	1	7	1	17
Total Number of Surveys	4	16	1	12	1	34
Total Number of Beluga Whale Groups	14	41	2	36	1	94
Mean Number of Groups per Survey	3.5	2.6	2.0	3.0	1.0	2.8

Table 4. Group size, color composition and total belugas sighted during vessel surveys in Knik Arm during 2006 and 2007. (Unk = beluga of unknown color/size)

Date	# Groups	# White	# Gray	# Calves	# Unk	Total Belugas Sighted
<u>2006</u>						
6-Sep-06	2	29	16	9	2	56
7-Sep-06	7	28	16	8	10	62
9-Sep-06	6	50	17	13	4	84
14-Sep-06	1	4	1	0	0	5
16-Sep-06	2	23	12	4	0	39
19-Sep-07	1	18	5	1	0	24
23-Sep-06	2	29	11	3	3	46
25-Sep-06	2	28	21	6	0	55
26-Sep-06	1	0	0	0	32	32
27-Sep-06	2	28	20	6	0	54
3-Oct-06	9	53	11	0	1	65
5-Oct-06	2	19	0	0	3	22
Total Knik Arm 2006	37	309	130	50	55	544
<u>2007</u>						
28-Jun-07	0	0	0	0	0	0
27-Sep-07	1	10	6	2	0	18
26-Oct-07	2	3	1	0	0	4
27-Oct-07	1	2	0	0	1	3
Total Knik Arm 2007	4	15	7	2	1	25

Table 5. Group size, color, composition and total belugas sighted during land surveys of Turnagain Arm during 2006 and 2007. (Unk = beluga of unknown color/size)

Date	# Groups	# White	# Gray	# Calves	# Unk	Total Belugas Sighted
2006						
11-Sep-06	5	16	7	3	4	30
12-Sep-06	3	13	6	3	2	24
14-Sep-06	7	26	15	5	0	46
15-Sep-06	4	19	2	2	0	23
28-Sep-06	4	16	4	1	0	21
Total Turnagain Arm 2006	23	90	34	14	6	144
2007						
24-Aug-07	3	10	4	0	61	75
25-Aug-07	5	58	27	0	5	90
1-Sep-07	1	17	3	0	0	20
2-Sep-07	0	0	0	0	0	0
3-Sep-07	1	30	5	3	0	38
21-Sep-07	1	4	3	1	2	10
22-Sep-07	2	5	2	0	0	7
Total Turnagain Arm 2007	13	124	44	4	68	240

Table 6. Group size, color composition and total belugas sighted during vessel surveys in the Susitna River Delta during 2007. Surveys were not conducted in the fall of 2006 in this location. (Unk = beluga of unknown color/size)

Date	# Groups	# White	# Gray	# Calves	# Unk	Total Belugas Sighted
2007						
28-Jun-07	1	6	1	1	0	8
13-Jul-07	5	17	15	4	0	36
17-Jul-07	4	29	14	2	0	45
27-Jul-07	4	51	43	6	0	100
Total Susitna Delta 2007	14	103	73	13	0	189

Table 7. Group size, color composition and total belugas sighted during vessel surveys in Chickaloon Bay/Southeast Fire Island (vessel survey) and the Port of Anchorage (land survey) during 2007. (Unk = beluga of unknown color/size)

Date	Area	# Groups	# White	# Gray	# Calves	# Unk	Total Belugas Sighted
26-Jul-07	Chickaloon/Southeast Fire Island	2	15	5	2	1	23
16-Aug-07	Port of Anchorage	1	7	5	0	0	12

Table 8. Percent color composition of beluga whale groups observed during surveys from vessels and land according to area and dates surveyed.

Area	Dates	# Days	# Groups	% White	% Gray	% Calves	% Unk
Susitna River Delta	28 June - 27 July 2007	4	14	54	39	7	0
Knik Arm	6 Sep - 5 Oct 2006	12	37	57	24	9	10
	27 Sep - 27 Oct 2007	3	4	60	28	8	4
Turnagain Arm	11 Sep - 28 Sep 2006	5	23	62	24	10	4
	24 Aug - 22 Sept 2007	7	13	52	18	2	28
Chickaloon Bay/Southeast Fire Island	26 July 2007	1	2	65	22	9	4

Table 9. Sighting records according to year and location of individual beluga whales identified in all three years of the study (2005, 2006, and 2007). (P = photographed)

	Knik Arm			Susitna River Delta			Turnagain Arm			Chickaloon Bay/Southeast Fire Island		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
# of Surveys	31	12	4	17	16	4	1	5	7	0	0	1
RA001	P	P	P		P	P						
RA002	P	P			P	P						
RA009	P	P	P	P		P						
RA013	P	P			P							P
RA024	P	P	P	P	P	P						
RA025	P	P		P		P						
RA029	P	P				P						
RA036	P			P	P	P						
RA054	P	P	P	P								
RA063	P				P	P						
RA079	P			P		P		P				
RA100	P				P	P		P				
RA102	P				P	P			P			
RA123	P				P	P		P				
RA145	P	P				P						
RA148	P	P	P	P	P							
RA154	P	P				P						
RA155	P	P	P	P	P							
RA160	P					P		P				
RS002		P		P	P	P						
RS044	P	P	P	P	P							
RS110	P	P			P							P
RS118	P				P	P						
RS124	P				P	P						
RS139	P	P			P	P						
RS222	P	P			P	P						

Table 10. Sighting records according to year and location of 37 individual beluga whales presumed to be mothers based on the close accompaniment of a calf at least once during 2005-2007. (C = photographed with a calf, P = photographed without a calf)

	Knik Arm			Susitna River Delta			Turnagain Arm			Chickaloon Bay/Southeast Fire Island			# of Years Seen with a Calf
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	
# of Surveys	31	12	4	17	16	4	1	5	7	0	0	1	
RA 012	P		P						C				1
RA 024	C	C	P	P	P	P							2
RA 027	C					P	P						1
RA 033	C												1
RA 035	C												1
RA 036	C			P	C	P							2
RA 039	C	C											2
RA 042	C												1
RA 054	C	P	P	P									1
RA 064	C	C											2
RA 066	P					C							1
RA 071	C												1
RA 079	P			P		C		P					1
RA 085	C					C							2
RA 108	C	C											2
RA 119	C					C							2
RA 121					C								1
RA 123	C				C	P		P					2
RA 125	C		C										2
RA 133					P	C		P					1
RA 139					C	P							1
RA 145	C	C				C							3
RA 148	P	C	C	P	P								2
RA 155	C	C	P	P	P								2
RA 156	C					C							2
RA 157	P	C		C									2
RS 007	C			P									1
RS 009	P	C		P									1
RS 049	P	C											1
RS 054	P					C							1
RS 059	P	C			P								1
RS 066	C												1
RS 082	C			P	P								1
RS 118	C				C	P							2
RS 124	C				P	C							2
RS 139	P	C			C	P							2
RS 222	P	P			C	P							1

Table 11. Sighting records according to year and location of nine individual beluga whales tagged with satellite tags by NMFS between 1999 and 2002. (C = photographed with calf, P = photographed without a calf)

	Knik Arm			Susitna River Delta			Turnagain Arm			Chickaloon Bay/Southeast Fire Island		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
# of Surveys	31	12	4	17	16	4	1	5	7	0	0	1
RA 105	P	P										
RA 139					C	P						
RA 148	P	C	C	P	P							
RA 156	C					C						
RA 159	P			P								
RA 160	P					P		P				
RA 161		P										
RA 163			P	P		P						
RS 220	P			P								

Table 12. Survey effort and beluga whale encounters constituting the 2005-2007 photo-identification catalog as of December 2007.

	2005	2006	2007	Total
# Photo-identification Surveys	49	33	17	99
# Photos Taken	44,878	21,244	4,193	70,315
# Groups Photographed	120	162	34	316
Range of Surveys	14 April - 21 Oct	12 May - 5 Oct	28 June - 27 Oct	
Span	6 months	5 months	4 months	
Areas Surveyed	Knik Arm, Susitna River Delta, Turnagain Arm	Knik Arm, Susitna River Delta, Turnagain Arm	Knik Arm, Susitna River Delta, Turnagain Arm, Chickaloon Bay/ Southeast Fire Island	

Table 13. Color composition of beluga whale groups observed during field surveys, according to area, study, and date. LGL surveys were conducted from vessels and NMFS surveys were conducted from aircraft. (Unk= beluga of unknown color)

Area	Study	Dates	# Days	# Groups	% White	% Gray	% Calves	% Unk
Susitna River Delta	LGL[1] vessel survey	1 - 29 June 2006	6	10	71	26	3	0
Susitna River Delta	NMFS[2] aerial survey	6 -15 June 2006[3]	7	15	83	13	4	0

[1] Markowitz et al. 2006, [2] Sims et al. 2007, [3] Christy Sims, NMML, pers comm.

Figure 1. Map of Cook Inlet, Alaska, showing major features discussed in the text.

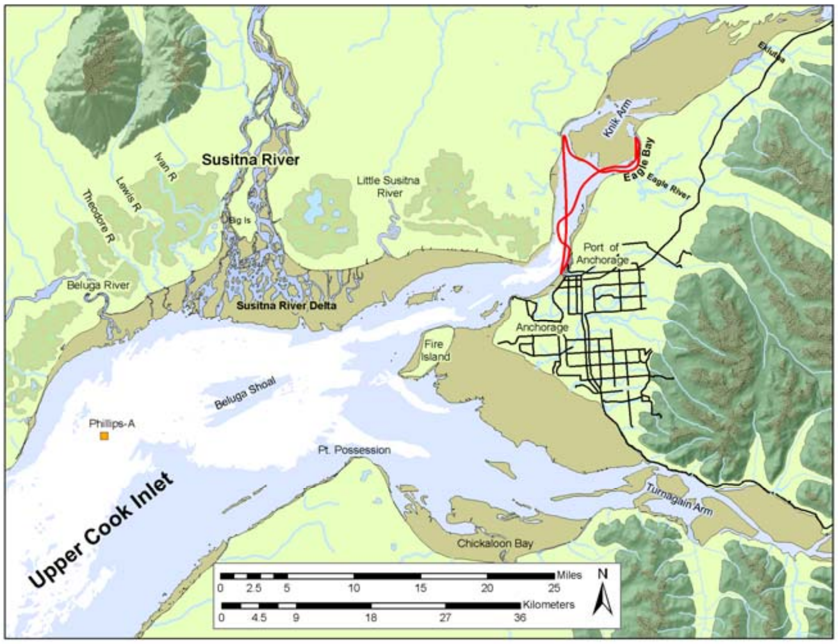


Figure 2. Knik Arm vessel survey route (red) used in 2006 and 2007 to observe and photograph beluga whales.

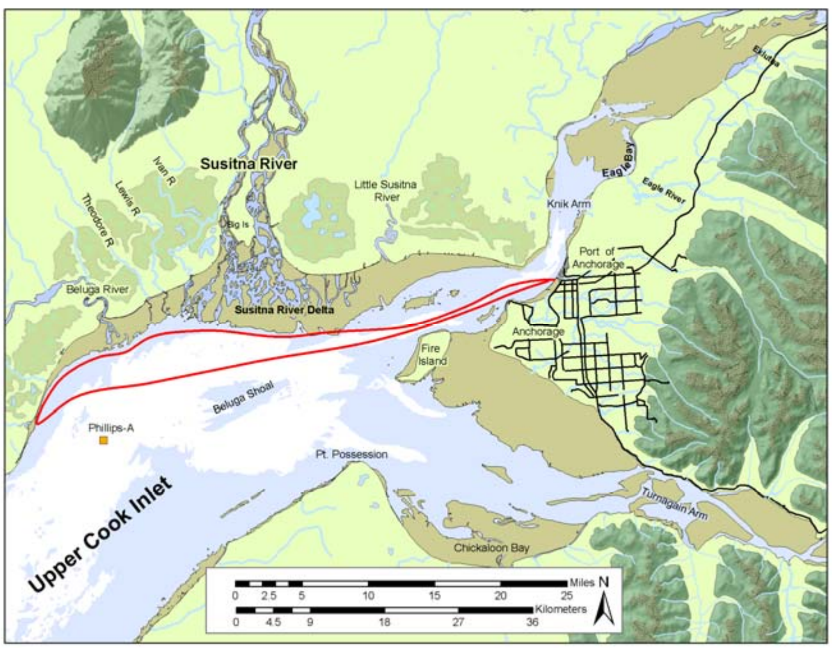


Figure 3. Susitna River Delta vessel survey route (red) used in 2006 and 2007 to observe and photograph beluga whales.

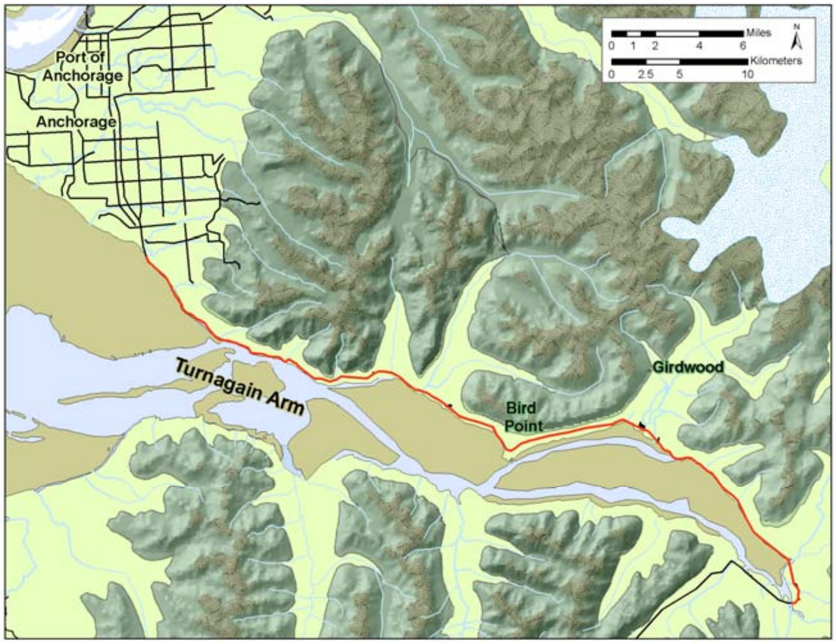


Figure 4. Turnagain Arm land survey route (red) along the Seward Highway, used in 2006 and 2007 to observe and photograph beluga whales.

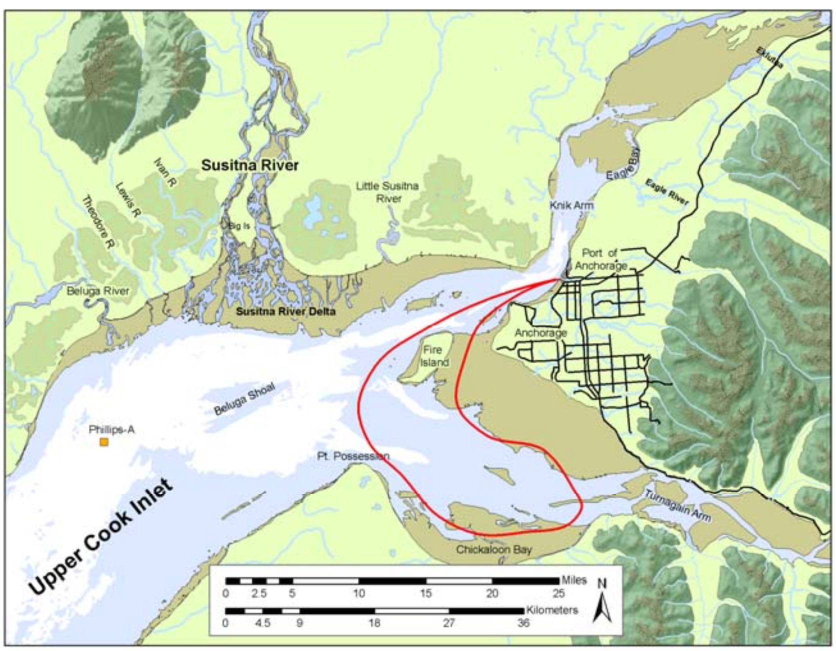


Figure 5. Chickaloon Bay/Southeast Fire Island vessel survey route (red) used in 2007 to observe and photograph beluga whales.

Figure 6. The two vessels used to survey beluga whales in Upper Cook Inlet, Alaska. The R/V Leucas, left, is a Zodiac ProMan 9, 16 ft (4.9 m) rigid-hull inflatable that was used in 2006 and 2007, and the R/V Nerka, right, is a 26 ft (8 m) aluminum craft was used in 2006 only. Both vessels were equipped with 4-stroke Yamaha motors (50 hp and 250 hp, respectively) during the summer of 2006.

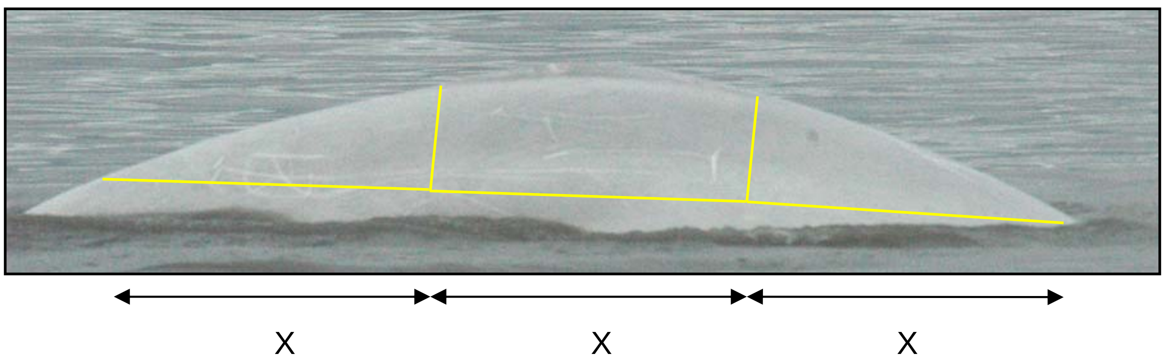


Figure 7. Photograph showing the three segments commonly seen when a Cook Inlet beluga surfaces. Segment sizes and locations are referenced using the length of the dorsal ridge (X). Image is of the right side of the whale.

Figure 8. Photograph showing only the posterior segment of a Cook Inlet beluga whale. Image is of the right side of the whale.

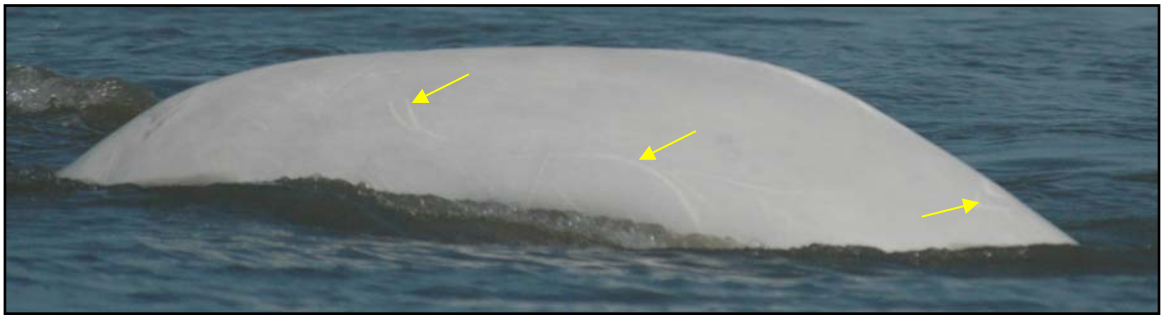


Figure 9. Yellow arrows indicate the narrow, bright white markings, which have been photographed on the same whale in 2005, 2006, and 2007, and appear to be long lasting on white beluga whales. Image is of the right side of the whale.

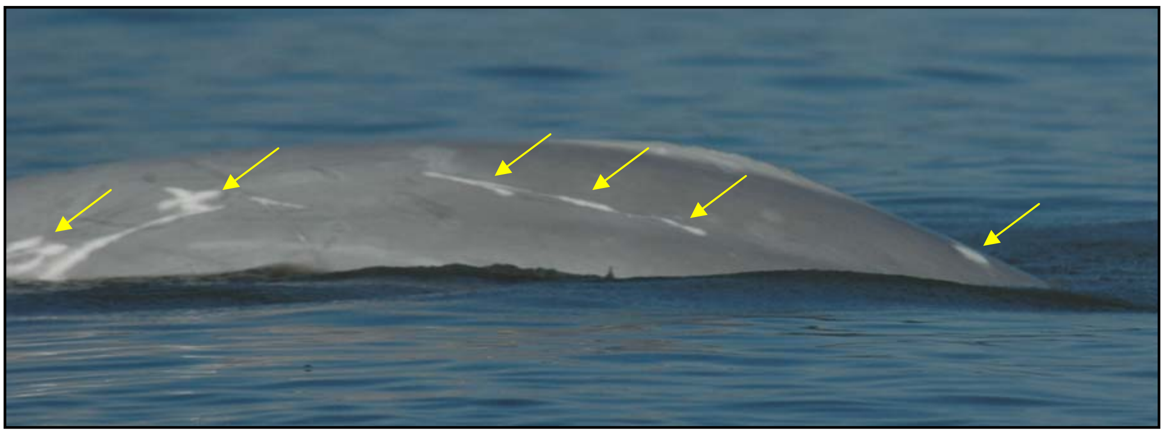


Figure 10. Yellow arrows indicate the broad white markings, which have been photographed on the same whale in 2005, 2006, and 2007, and appear to be long lasting on gray beluga whales. Image is of the right side of the whale.

Figure 11. Yellow arrows indicate typical lesions that appear on Cook Inlet beluga whales. Image is of the right side of the whale. The whale has just surfaced and the dorsal ridge is on the left side of the photograph.

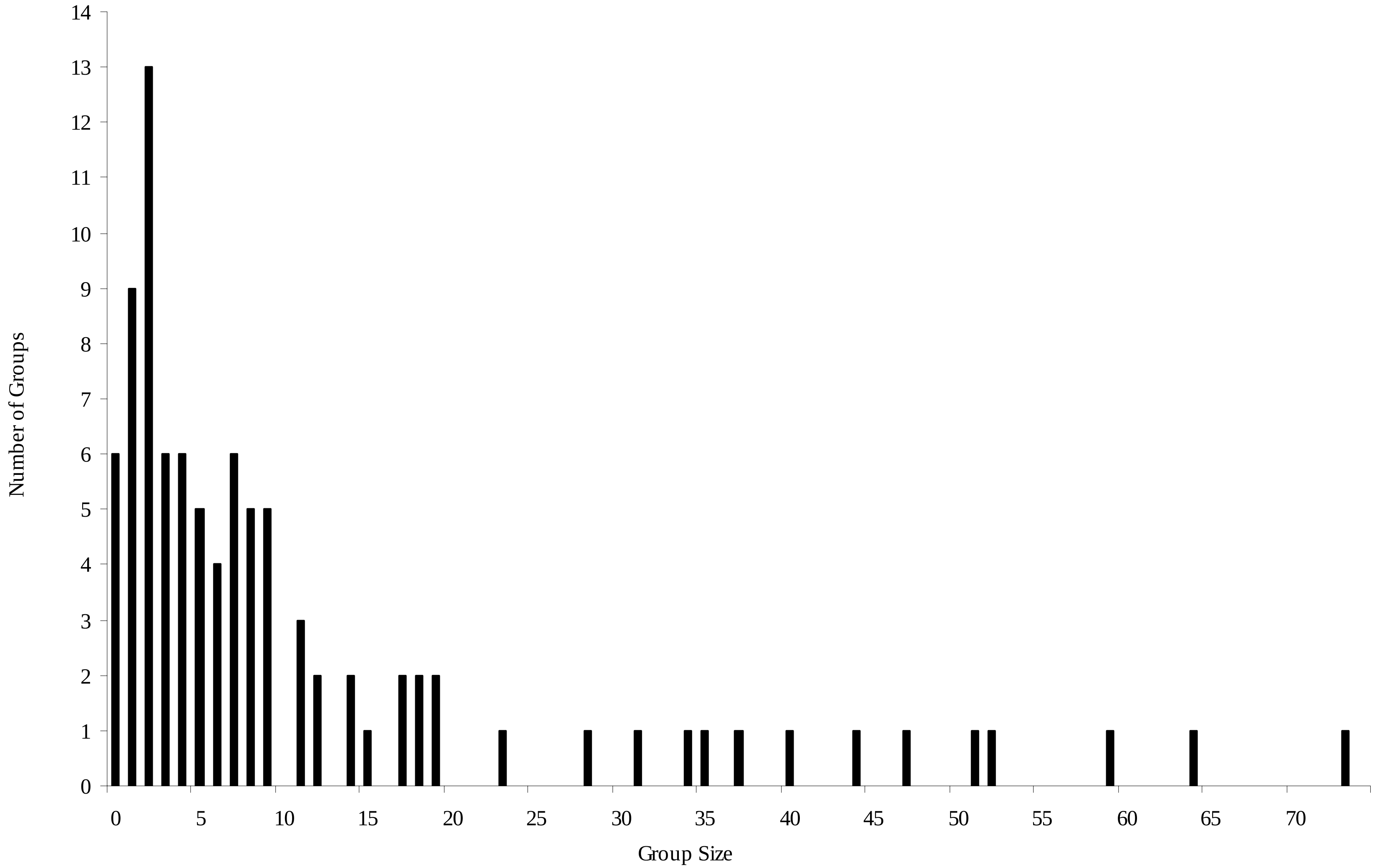


Figure 12. Group-size frequency distribution of beluga whales encountered during photo-identification surveys conducted in fall 2006, summer 2007, and fall 2007. (*n* = 94 groups)

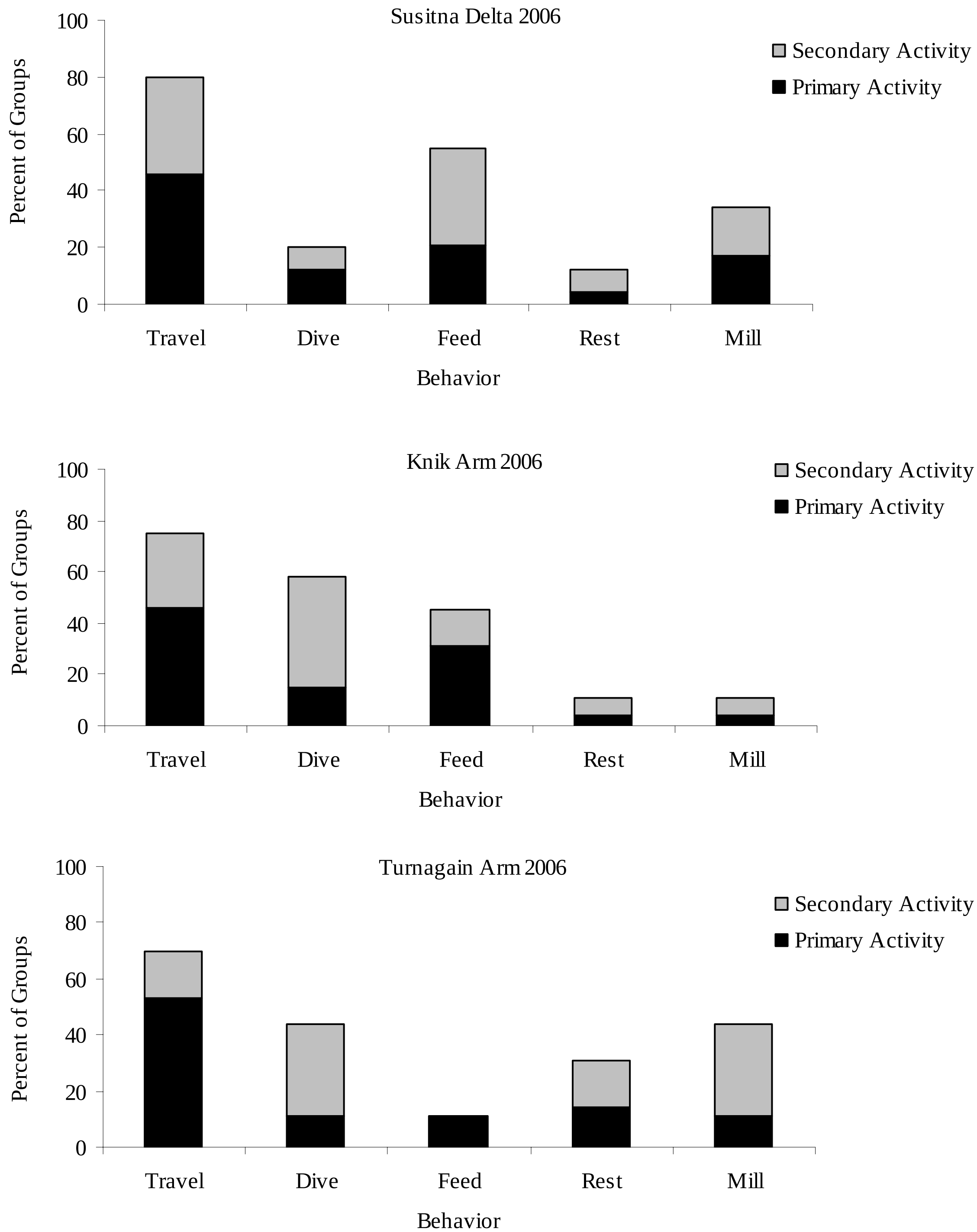


Figure 13. Summary of behavior of beluga groups encountered in 2006 during vessel and land surveys of three areas in Upper Cook Inlet, Alaska (fall 2006 data combined with summer 2006 data from Markowitz et al. 2006).

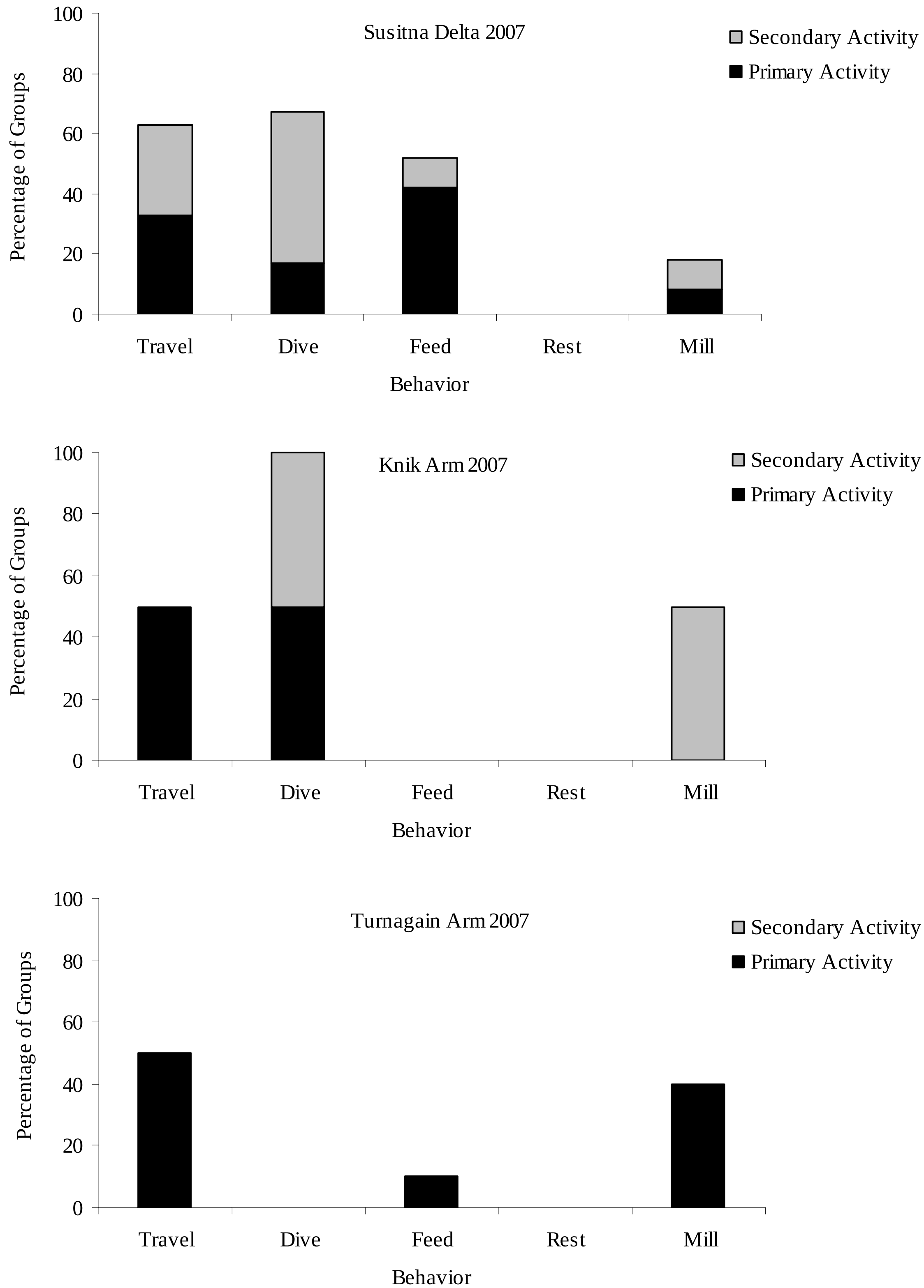


Figure 14. Summary of behavior of beluga whale groups encountered in 2007 during vessel and land-based surveys of three areas in Upper Cook Inlet, Alaska.

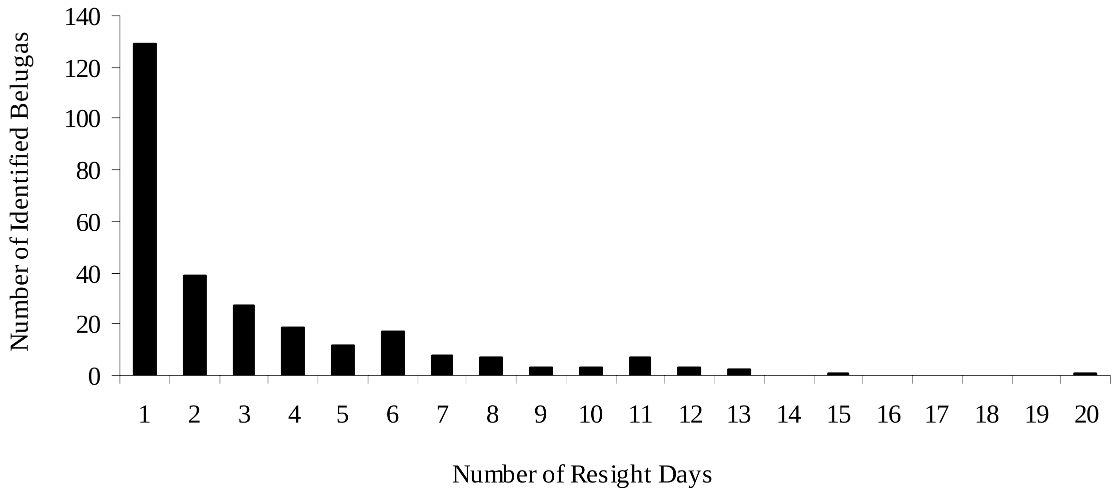


Figure 15. Frequency distribution of sightings of identified beluga whales photographed from 2005 to 2007 in Upper Cook Inlet, Alaska.

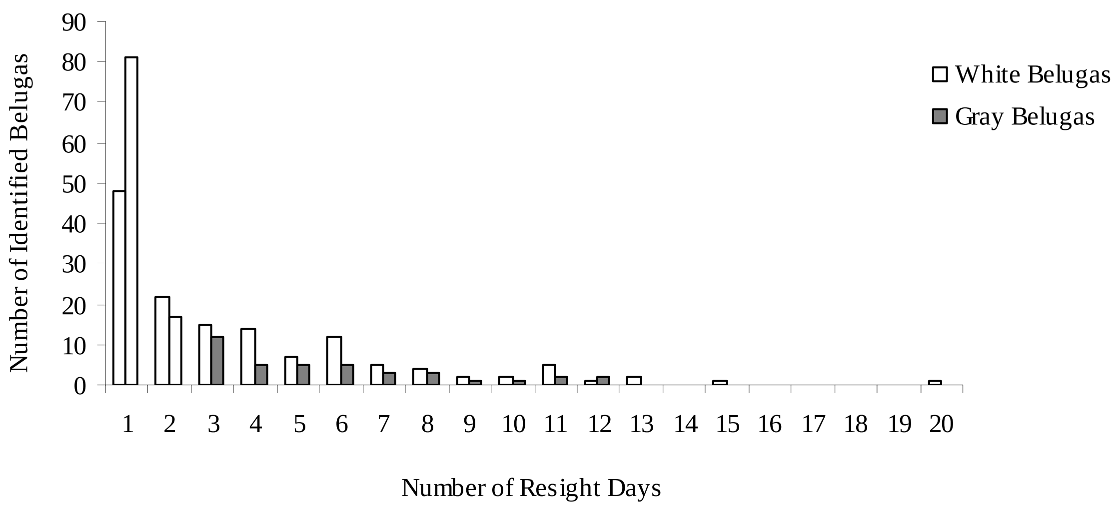


Figure 16. Frequency distribution of sightings of identified beluga whales photographed from 2005 to 2007, stratified by color.

Figure 17. Beluga RA 039 was photographed with a calf in two consecutive years in Upper Cook Inlet, Alaska: a. 5 August 2005, Knik Arm; b. 9 September 2006, Knik Arm.

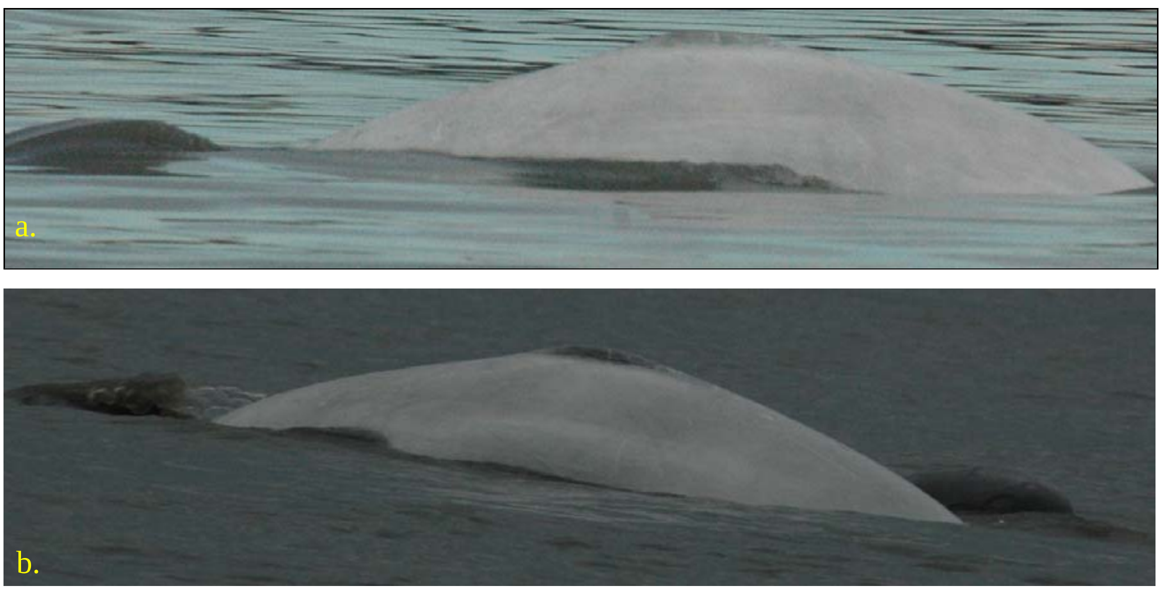


Figure 18. Beluga RA 064 was photographed with a calf in two consecutive years in Upper Cook Inlet, Alaska: a. 30 September 2005, Knik Arm; b. 16 September 2006, Knik Arm.

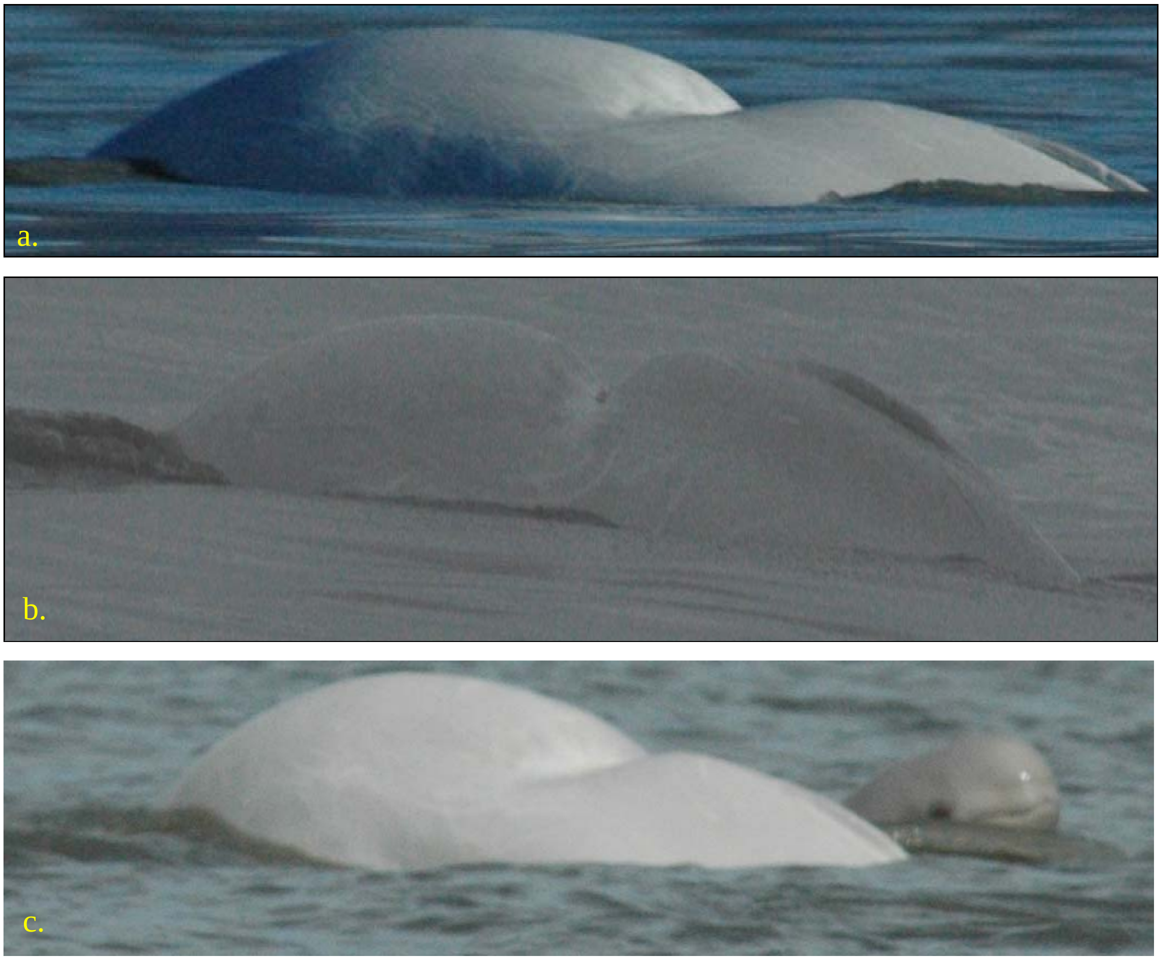


Figure 19. Beluga RA 145 was photographed with a calf in three consecutive years in Upper Cook Inlet, Alaska: a. 8 September 2005, Knik Arm; b. 17 September 2006, Knik Arm; c. 27 July 2007, Susitna Delta.

Figure 20. Beluga RA 125 was photographed with a calf in two non-consecutive years in Upper Cook Inlet, Alaska: a. 15 September 2005, Knik Arm; b. 27 September 2007, Knik Arm.

Figure 21. Photograph of the right side of a beluga whale as it dives. Indentations on the upper right side of the whale are likely scars caused by the attachment of satellite tags used by NMFS in 1999 during telemetry research in Cook Inlet, Alaska.

Figure 22. Photograph of the right side of a beluga whale as it dives. Holes on the upper right of the whale are likely tag scars caused by the attachment of satellite tags used by NMFS in 2000 and early 2001 during telemetry research in Cook Inlet, Alaska.

Figure 23. Photograph of the left side of a beluga whale as it dives. The indent in the whale's dorsal ridge (top center) and also the black dots, indicated by yellow arrows, are likely caused by the attachment of satellite tags used by NMFS in late 2001 and 2002 during telemetry research in Cook Inlet, Alaska.

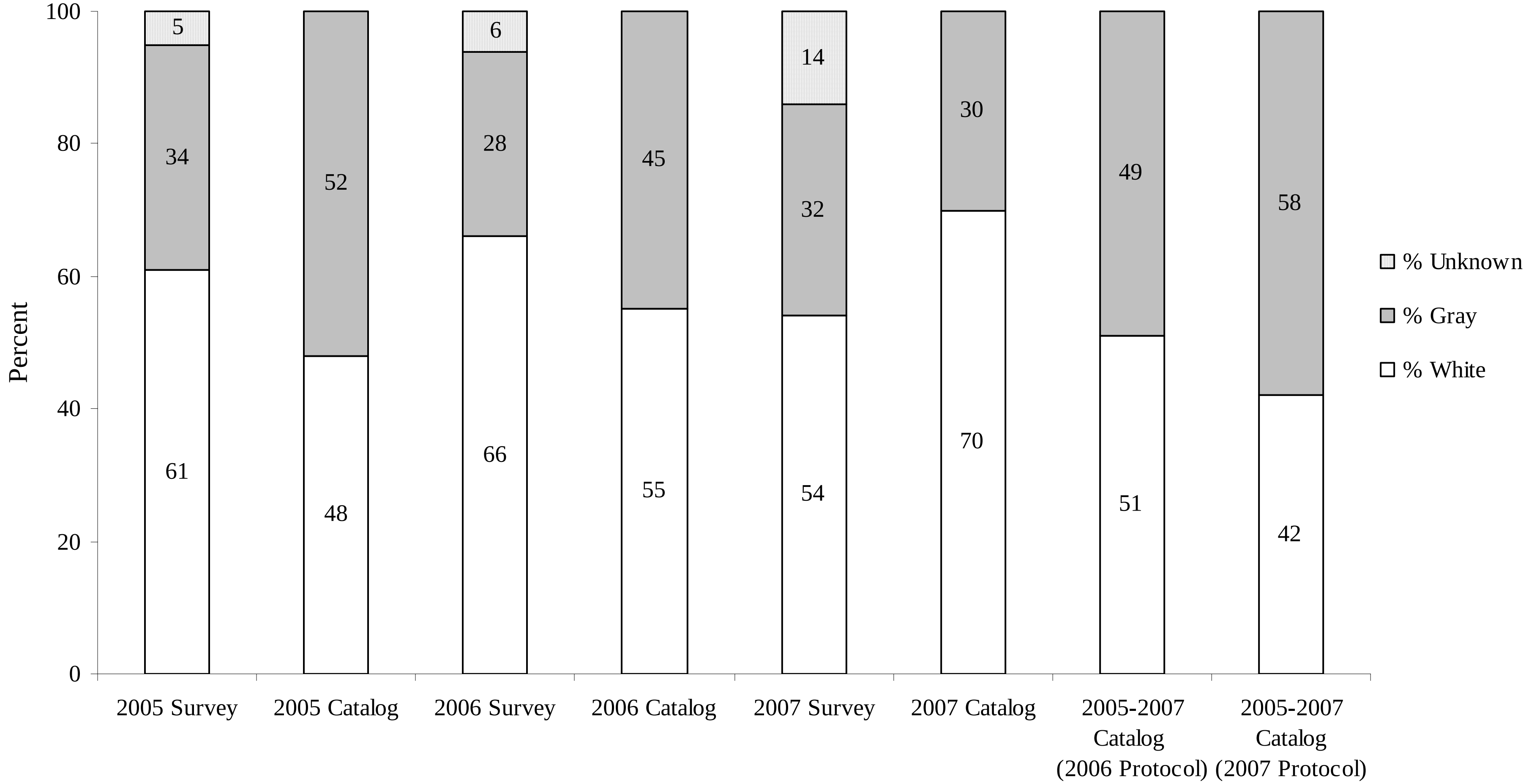


Figure 24. Color composition (percent) of whale groups observed during surveys and of identified whales in the photo-identification catalog, for each year of photographs in the catalog and for the combined 2005-2007 catalog.

APPENDIX A.

DRAFT PROTOCOLS FOR SCORING PHOTOGRAPHS FOR QUALITY AND MARK IDENTIFIABILITY

Screening Field Photographs

Field photographs are first screened to archive or isolate the poorer quality (3) photos before any cropping or sorting. Photographs of water or other non-whale images are deleted. Some photographs are of too poor quality to be used in mark-recapture analyses but still may show markings. These photographs are still valuable and are not deleted, but are instead isolated from scored photographs so they can be used for other analyses. Figure A5 shows an example of the type of photograph that is removed from mark-recapture analyses and is initially screened from field samples of photographs. Figures A1-A4 are examples of photographs that would be further sorted, cropped and catalogued. These examples can be used to reference the quality of each photo at first screening and as an index for scoring the quality of individual segments that is necessary for later mark-recapture analyses (Figure A6). Detailed protocols and archetype scoring photographs for mark-recapture analyses are currently being developed (see below "Draft scoring protocols for mark-recapture analyses").

Figure A1. The right side of a Cook Inlet beluga whale. The whale is traveling from left to right. Quality is 1(+) on a five-point scale (1+, 1-, 2+, 2-, 3; best to worst). The image is correctly exposed, in good focus, and does not require any magnification.

Figure A2. The right side of a Cook Inlet beluga whale. The whale is traveling from left to right. Quality is 1(-) on a five-point scale (1+, 1-, 2+, 2-, 3; best to worst). Most of photo has correct exposure and focus is good. Some magnification will be required.

Figure A3. The right side of a Cook Inlet beluga whale. The whale is traveling from left to right. Quality is 2(+) on a five-point scale (1+, 1-, 2+, 2-, 3; best to worst).

Figure A4. The left side of a Cook Inlet beluga whale. The whale is traveling from right to left. Quality is 2(-) on a five-point scale (1+, 1-, 2+, 2-, 3; best to worst). The photograph is properly exposed but is not well focused. With magnification, it may be matched.

Figure A5. The left side of a Cook Inlet beluga whale. The whale is traveling from right to left. Quality is rated as 3 on a five-point scale (1+, 1-, 2+, 2-, 3; best to worst). Exposure and lighting are good but the image is poorly focused and blurry. Despite at least one segment being visible, even large markings could not be positively confirmed.

Draft Scoring Protocols For Mark-Recapture

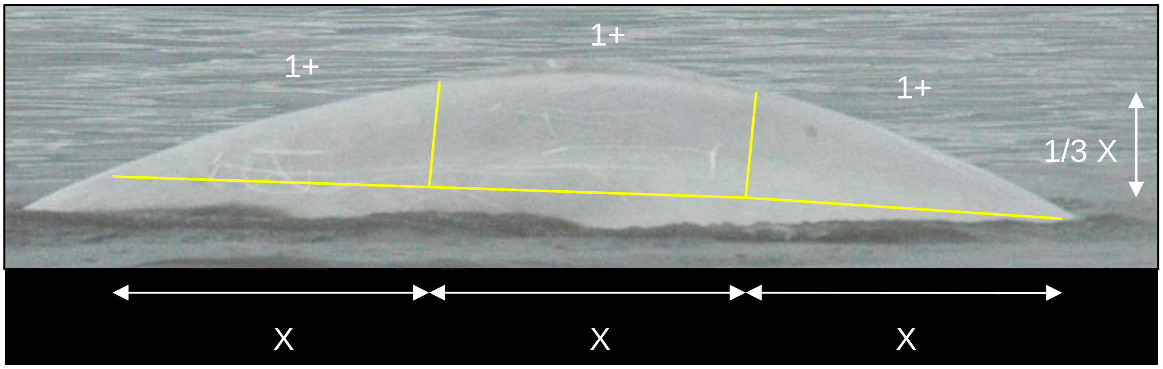


Figure A6. From left to right, the posterior, middle and anterior segments of the right side of a Cook Inlet beluga whale. The length of the dorsal ridge (X) is used to reference segments. Each segment is given a separate score (all 1+ in this example).

Quality

After being placed in the catalog, photographs are scored separately for each segment (Figure A6).

Scores

- 1+ = Excellent. Focus is sharp and exposure is correct. No washed out areas. No magnification is required to see even small marks (if available). Visibility is not compromised in any way.
- 1– = Good. Focus is good and exposure is correct. Some magnification may help to make marks easier to see. Some smaller marks may be missed.
- 2+ = Fair. Focus is good. May be over/under exposed or exhibit glare/shadows in some areas. Photo may require magnification. Large and most medium marks if present are visible but may not be clear. Some medium and smaller marks may be missed.
- 2– = Below Average. Focus is not sharp. May be washed out or over/under exposed. Still can make out features and some markings, but some medium and even a large marks might be missed.
- 3 = Poor. Focus is blurred. Too grainy, washed out or over/under exposed to make out features or markings accurately. Large marks may be missed.
- X = No evaluation of the segment can be made due to too little (<75%) available due to being obscured by water, splash, etc.

Identifiability of Marks

Catalogued photographs are then scored separately for each segment based on how well they are marked based on size, distinctiveness and permanency (Figure A7).

<u>Mark Attributes</u>

Sizes (see reference photograph Figure A7 below)

- Large > ½ X
- Medium ½ to ¼ X
- Small < ¼ X

Scored marks for multi-year abundance estimation

- *Distinct* or uniquely shaped lasting markings: Curved scars, intersecting scars, gouges, bullets holes, large bites or other body irregularities. Groups of 2 or more smaller nondescript marks.
- *Indistinct* lasting marks: Nondescript marks such as smaller straight scratches or nicks. Simple small slightly curved marks.

Marks not scored (temporary marks)

- Molting or sloughing skin
- Skin lesions
- Superficial new skin wounds

<u>Scores</u>

- H+ = Highly marked (easily re-identified within a single segment). Must have at least one large (>½ X) distinctive mark and two or more medium marks (distinctive or indistinctive) within the segment.
- H– = Well marked. Must have one large (>½ X) indistinctive mark two or more medium marks (distinctive or indistinctive) within the segment.
- M+ = Moderately marked. One medium size distinctive mark (¼ – ½ X) and two or more small (distinctive or indistinctive) lasting marks. Small distinct mark and three indistinct marks that can be seen within the segment.
- M– = Barely marked. Two or fewer indistinctive marks of any size showing.
- U– = Unmarked. No marks of any significant size showing.
- X = No evaluation of the segment can be made due to too little (<75%) available due to being obscured by water, splash, etc.

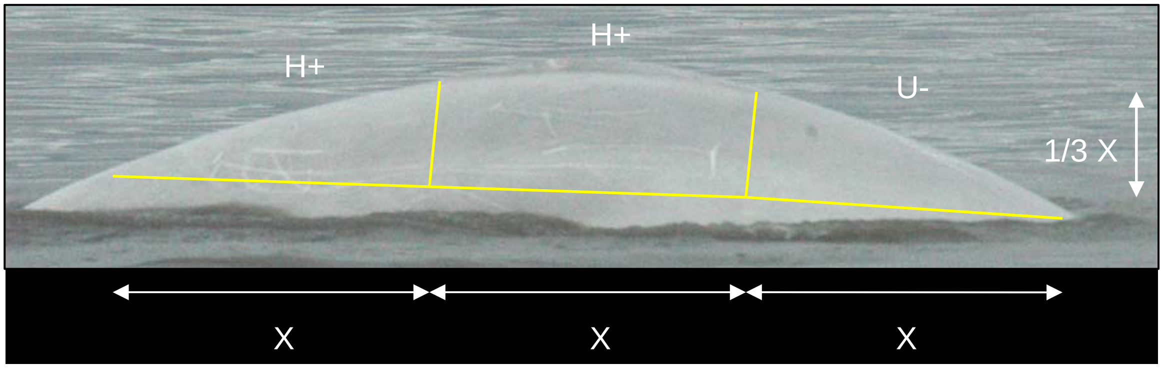


Figure A7. From left to right, the posterior, middle and anterior segments of a Cook Inlet beluga whale. The length of the dorsal ridge (X) is used to reference segments. Each segment is given a separate score for how well it is marked from the (H+, H-, M+, M-, U-; from highly marked to unmarked). In this example the posterior and middle segments are considered highly marked and the anterior segment is unmarked. The white markings on this individual are long lasting and the best type of marks to follow belugas through mark-recapture analyses.

APPENDIX B.

GLOSSARY OF TERMS USED IN THIS REPORT

Capture Probability The chance of a whale being photographed and matched to the catalog on occasions when whales are photographed.

Complete Cataloged individuals that contain side profile images of all three body segments typically seen as a whale surfaces.

Encounter A single day's photographic record of one individual. A single encounter may contain one or multiple photographs of the individual.

Heterogeneity Non-uniformity. Capture probabilities differ by individual animals (individual heterogeneity) or sampling technique (sampling heterogeneity).

Identifiability Relative ability of unique markings to be recognized.

Likelihood (Theory) A statistical inference tool that is the basis for deriving estimates of parameters such as survival or abundance, given data. It allows for multi-model inference with minimal variance. The best model is that which is most consistent with the observations.

Mark-recapture Also mark-resight, capture-recapture. Techniques used to gather information on population dynamics such as movement, survival and abundance.

Permanency of Markings Longevity of marks throughout a season (May-Oct) or over multiple years.

Quality Refers to photograph quality as judged on a five point scale (1+, 1–, 2+, 2–, 3), with 1+ being the highest quality and 3 being the lowest quality.

Segments The three regions on the side profile of a beluga referenced by the length of the dorsal ridge: anterior to the dorsal ridge, the dorsal ridge and below and posterior to the dorsal ridge. See Appendix A for more detail.

Sequence Two or more photos of a whale taken in series on the same day showing different portions of the body as the animal surfaced and submerged.

APPENDIX C.

DATABASE DEVELOPMENT AND CONSOLIDATION EFFORTS

by

Rod Bochenek, Axiom Consulting & Design, Anchorage Alaska

Summary of Data Management Efforts

Data collection and LGL staff data processing activities have produced detailed information regarding beluga whale observations and photographs of belugas in Cook Inlet. However, the associated information was in three different primary file types (JPEG photographs, Microsoft® Access Database and Garmin Database) that each contained multiple fields that needed to be linked to efficiently access, store and back-up the data. The following actions were undertaken to create a usable data management framework for organizing the various data resources associated with the Photo-ID database.

- Creation of unified data model for Photo ID database
- Transformation and Loading of Legacy Beluga Photo ID datasets into the unified data model (UDM).
- Generation of reports and statistical output

These efforts worked toward the primary goal of integrating all relevant data into a single data structure utilizing a relational database management system. The text below provides more insight and detail into each one of these processes. These activities provide a framework for the information resources to be efficiently accessed, queried, updated and managed. The final product of this effort also provides a platform for data visualization, report generation and efficient analysis of the information contained within the system.

Specific Data Management Activities

Creation of unified data model for Photo ID database

The first step in organizing data associated with the Photo-ID database required the creation of single data structure, which contains all current relevant data fields with the correctly modeled relations intact. The perfect model for doing so is the normalized relational database structure. The Photo ID catalog was chosen as the starting point for the effort due to the homogeneity of the Photo ID catalog. The following database diagram (Figure C1) displays the data model component of the database, which pertains to the Photo ID catalog.

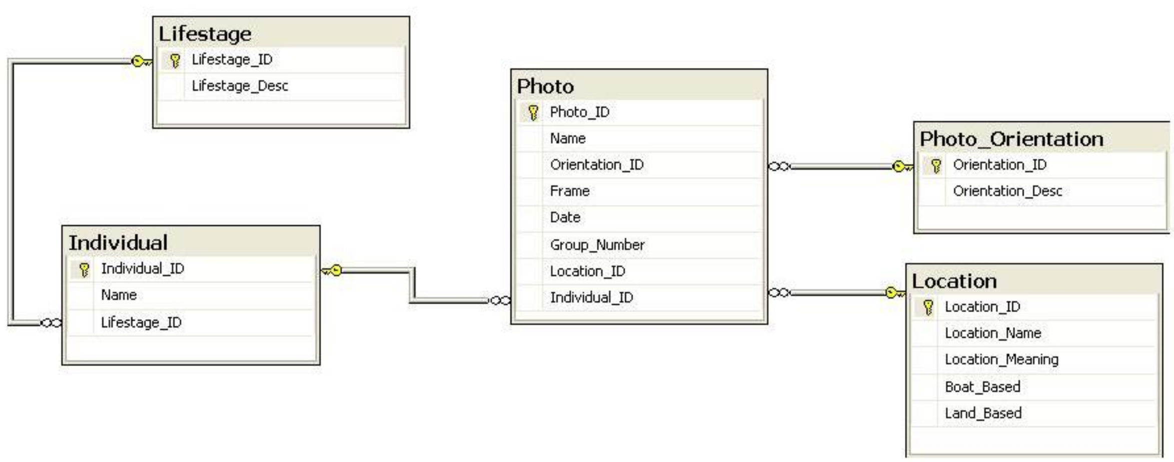


Figure C1. Database Diagram for Photo ID Catalog

The above structure provides a "container" to store the information, which was extracted from the Photo ID Catalog image names. This process is further elaborated in the following section (Transformation and Loading…). Once the photo catalog data was processed out of the image file names the above database structure was extended to store information regarding the survey efforts, individual whale group observations in addition to environmental cruise data. The following diagram (Figure C2) portrays the Photo _ID database in its entirety.

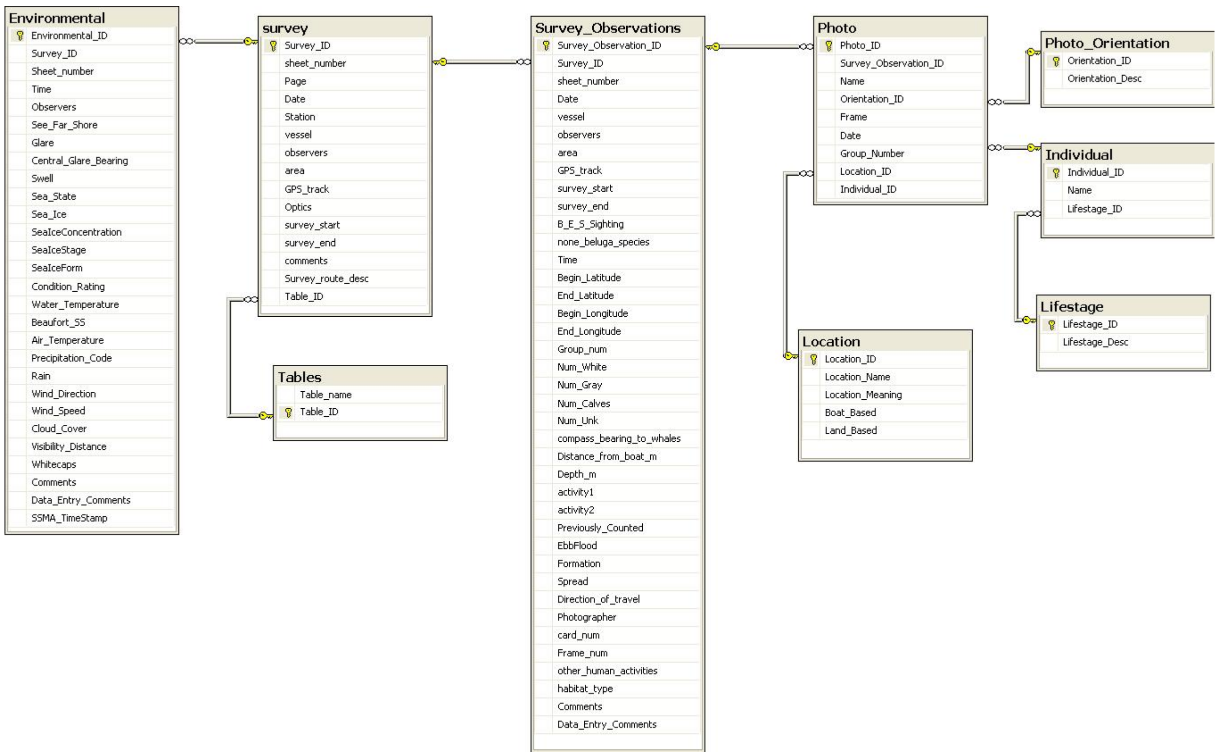


Figure C2. Complete Database Diagram for Photo _ID Catalog study

This full data model provides a standard container for all relevant information collected and tracked through this project. This model also provides an efficient method for reporting and statistical analysis through the use of Standard Query language (SQL).

Transformation and Loading of Legacy Beluga Photo ID datasets into UDM

Once the data model was complete and relatively static, existing data were organized, transformed and inserted into the database structure with corresponding primary and foreign key relationships kept in check. Most of the data associated with the Photo-ID database study existed in standard, easily ingested form (excel, Access DBs). This was with exception of the photo file names, which contain multiple pieces of information. The photo file names needed to be parsed via text algorithm to extract individual fields and subsequently loaded into the data structure. The survey effort, individual whale group observations and additional environmental cruise data, though stored in excel and MS Access databases, was challenging to incorporate; although the same types of data were collected between studies, not all the data fields were the same size or in the same order. The following diagram portrays the datasets which were incorporated into the UDM via unique mapping and data transformation functions.

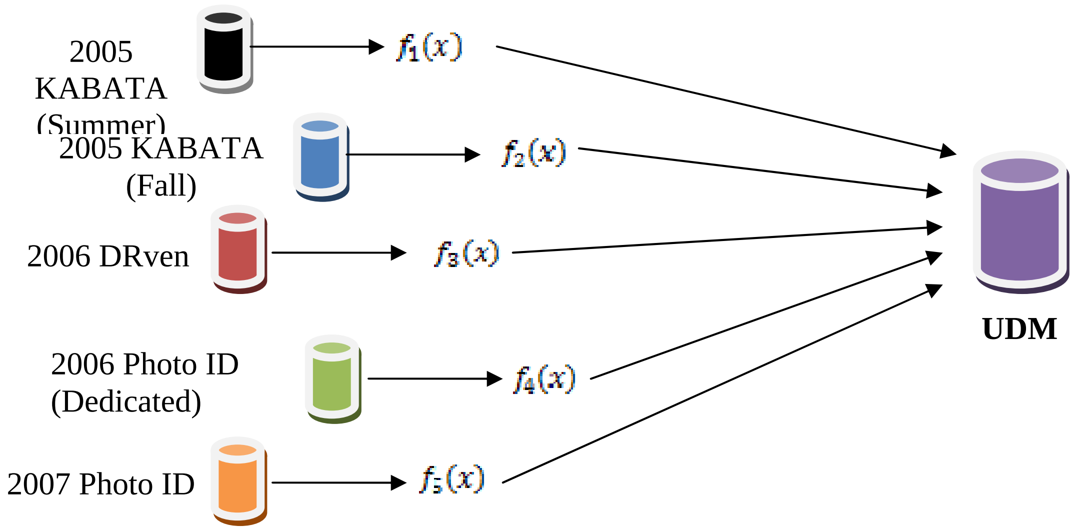


Figure C3. Data Transformation and Loading of data into Unified Data Model

Once data ingestion was complete, logical parent child relations were created within the relational database and validated. This validation served as a QA/QC and scrubbing exercise to ensure that data contained within the database was logical organized and linked. Data relation anomalies (less than 10%) were isolated and are being addressed by the principal investigators.

Generation of Reports and Statistical Output

Centralizing and standardizing study data to a normalized relational database provides a platform for rapid report generation and statistical analysis. Many available statistical and reporting software tools (MS Access, SAS, Crystal Reports, etc…) connect seamlessly to a normalized relational database structure. These tools provide a simple and user-friendly framework to generate statistical queries and reports.

APPENDIX D.

BELUGA WHALE GROUPS ENCOUNTERED DURING LAND- AND VESSEL-BASED SURVEYS CONDUCTED IN UPPER COOK INLET, ALASKA

Daily Survey Tracks and Locations of Whales, Fall 2006

Figure D1. Beluga whale groups encountered and survey route of 6 September 2006 vessel survey of Upper Cook Inlet, Alaska.

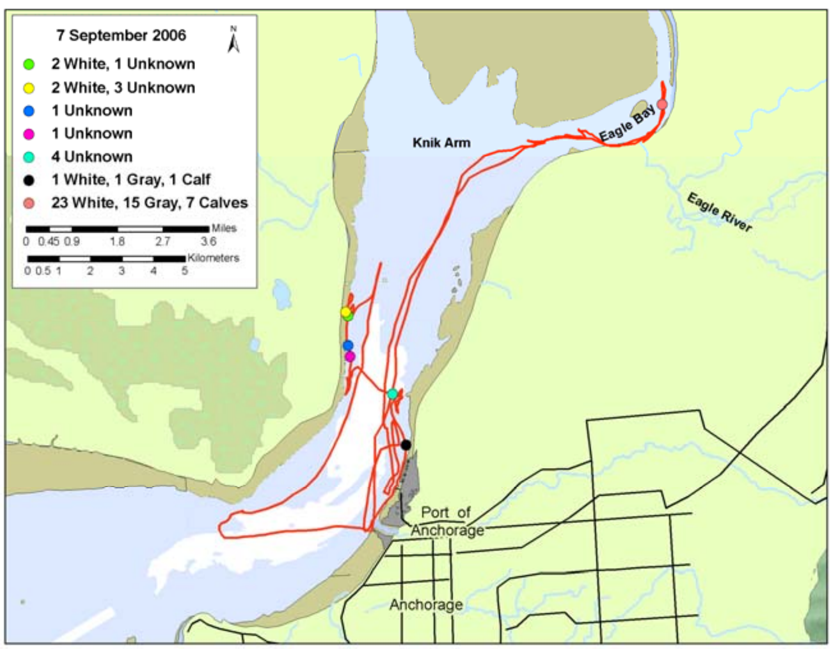


Figure D2. Beluga whale groups encountered and survey route of 7 September 2006 vessel survey of Upper Cook Inlet, Alaska.

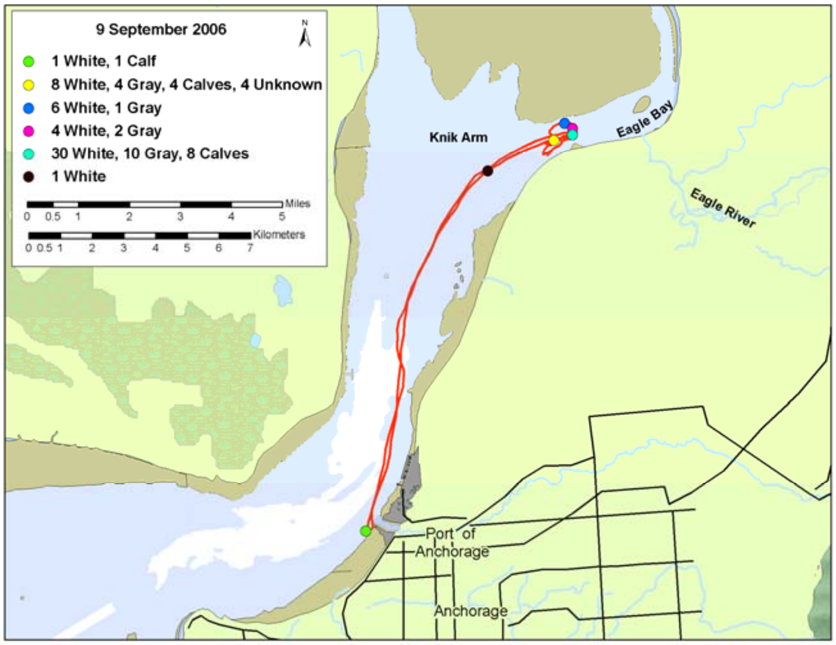


Figure D3. Beluga whale groups encountered and survey route of 9 September 2006 vessel survey of Upper Cook Inlet, Alaska.

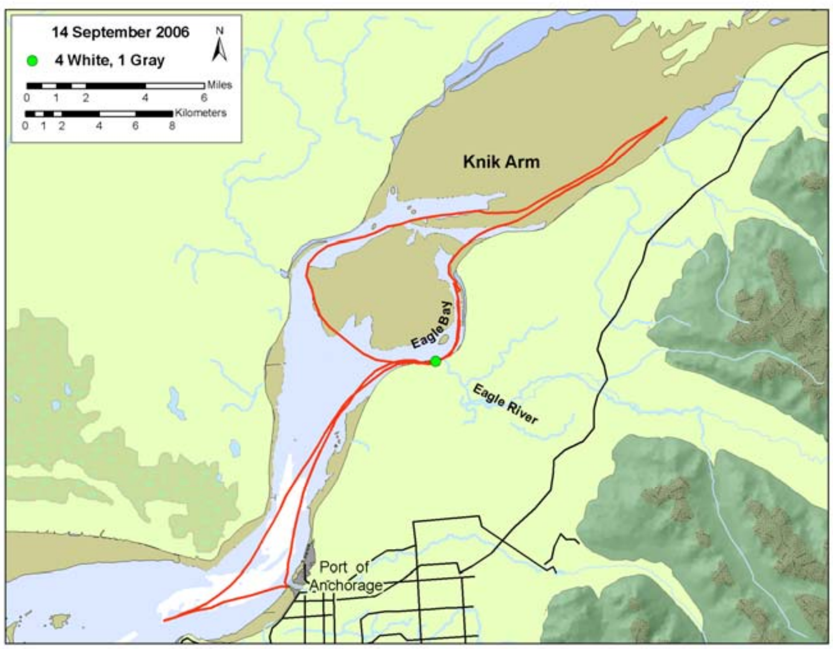


Figure D4. Beluga whale groups encountered and survey route of 14 September 2006 vessel survey of Upper Cook Inlet, Alaska.

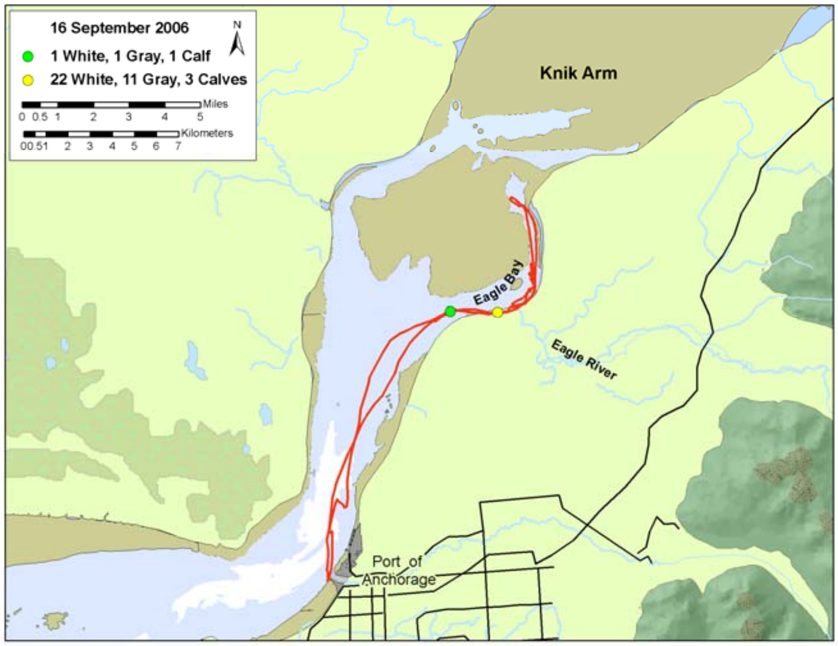


Figure D5. Beluga whale groups encountered and survey route of 16 September 2006 vessel survey of Upper Cook Inlet, Alaska.

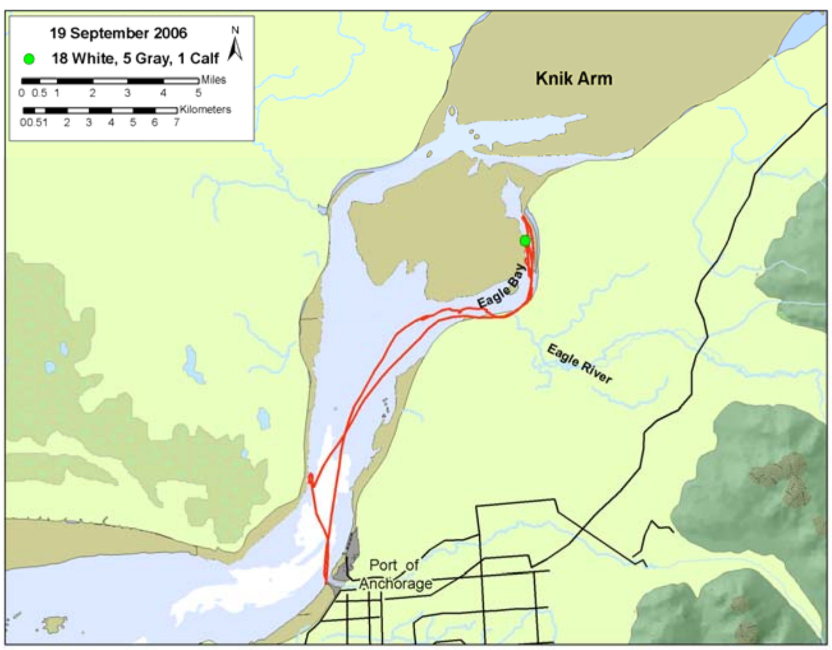


Figure D6. Beluga whale groups encountered and survey route of 19 September 2006 vessel survey of Upper Cook Inlet, Alaska.

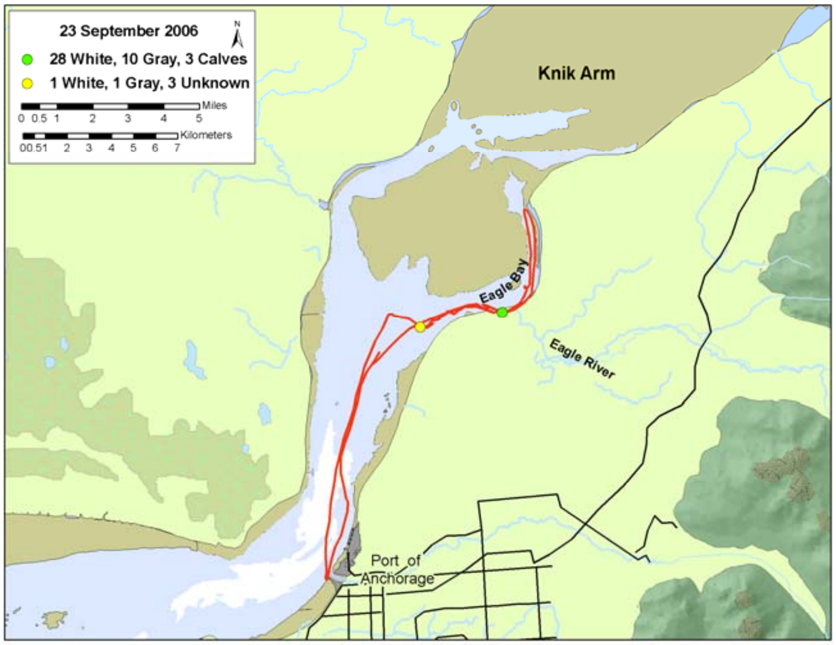


Figure D7. Beluga whale groups encountered and survey route of 23 September 2006 vessel survey of Upper Cook Inlet, Alaska.

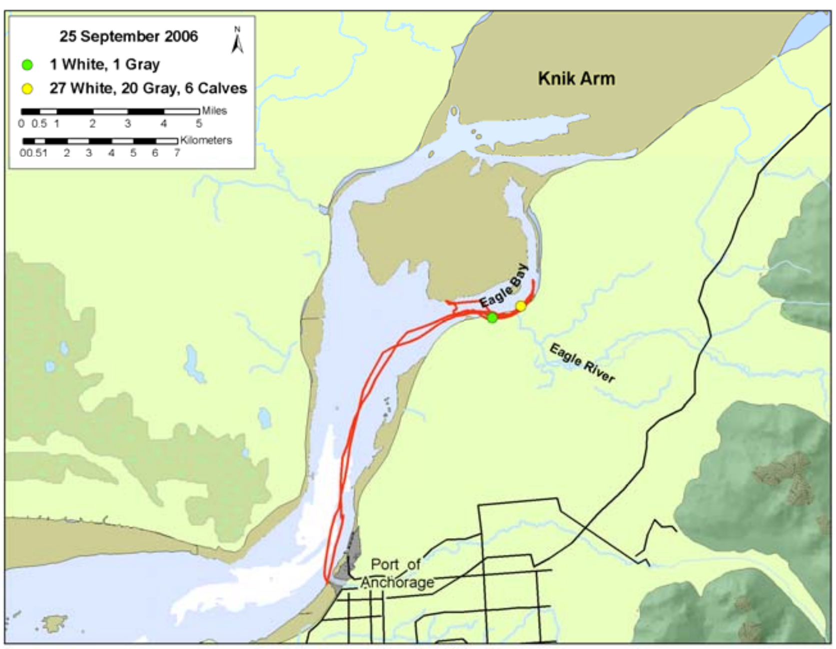


Figure D8. Beluga whale groups encountered and survey route of 25 September 2006 vessel survey of Upper Cook Inlet, Alaska.

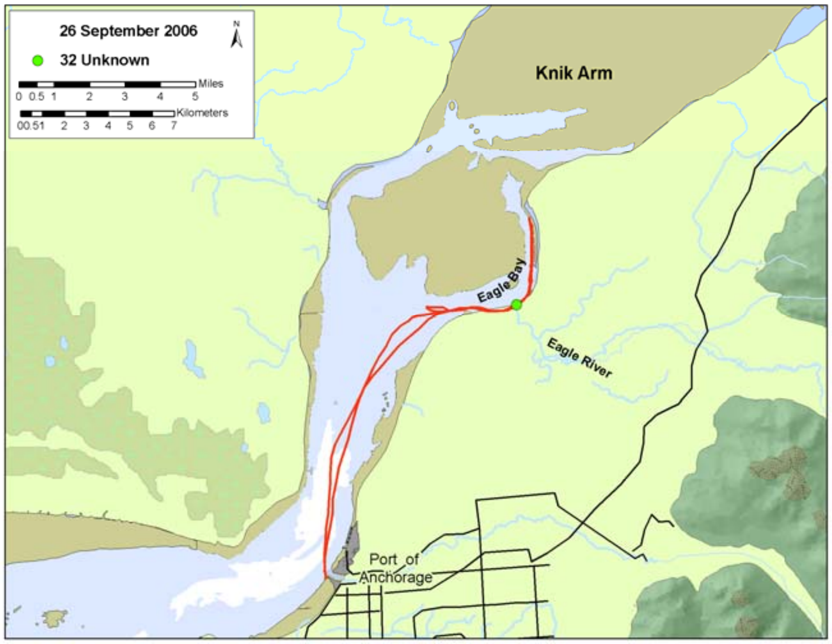


Figure D9. Beluga whale groups encountered and survey route of 26 September 2006 vessel survey of Upper Cook Inlet, Alaska.

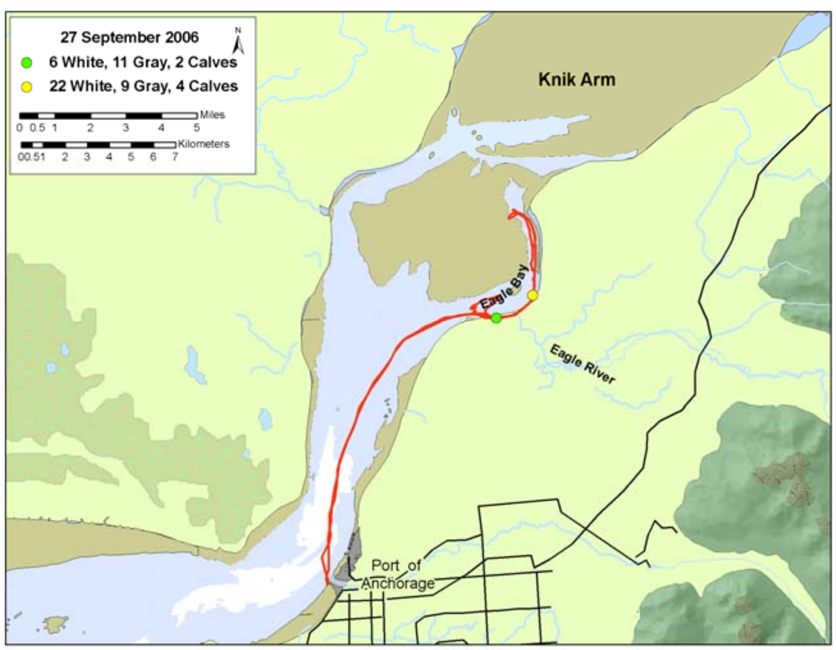


Figure D10. Beluga whale groups encountered and survey route of 27 September 2006 vessel survey of Upper Cook Inlet, Alaska.

Figure D11. Beluga whale groups encountered and survey route of 3 October 2006 vessel survey of Upper Cook Inlet, Alaska.

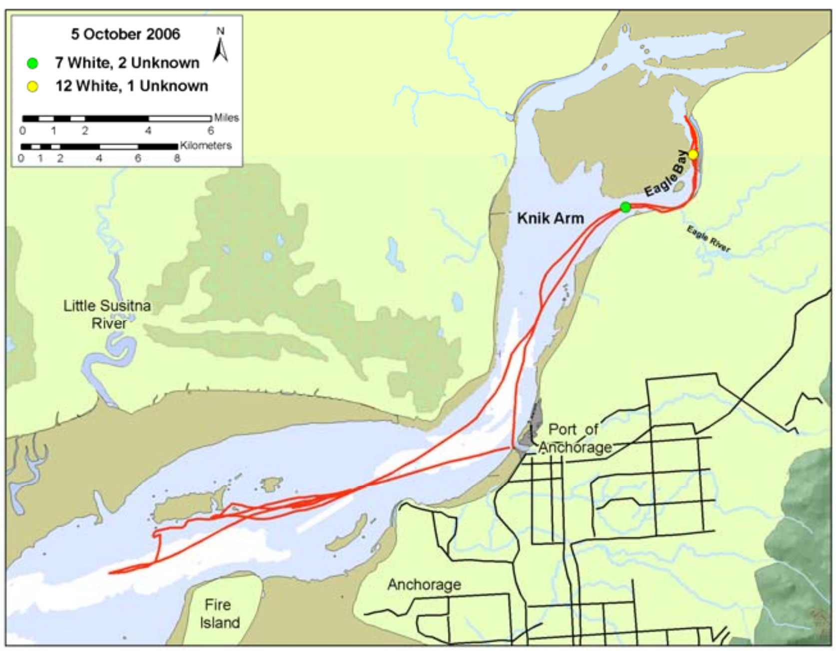


Figure D12. Beluga whale groups encountered and survey route of 5 October 2006 vessel survey of Upper Cook Inlet, Alaska.

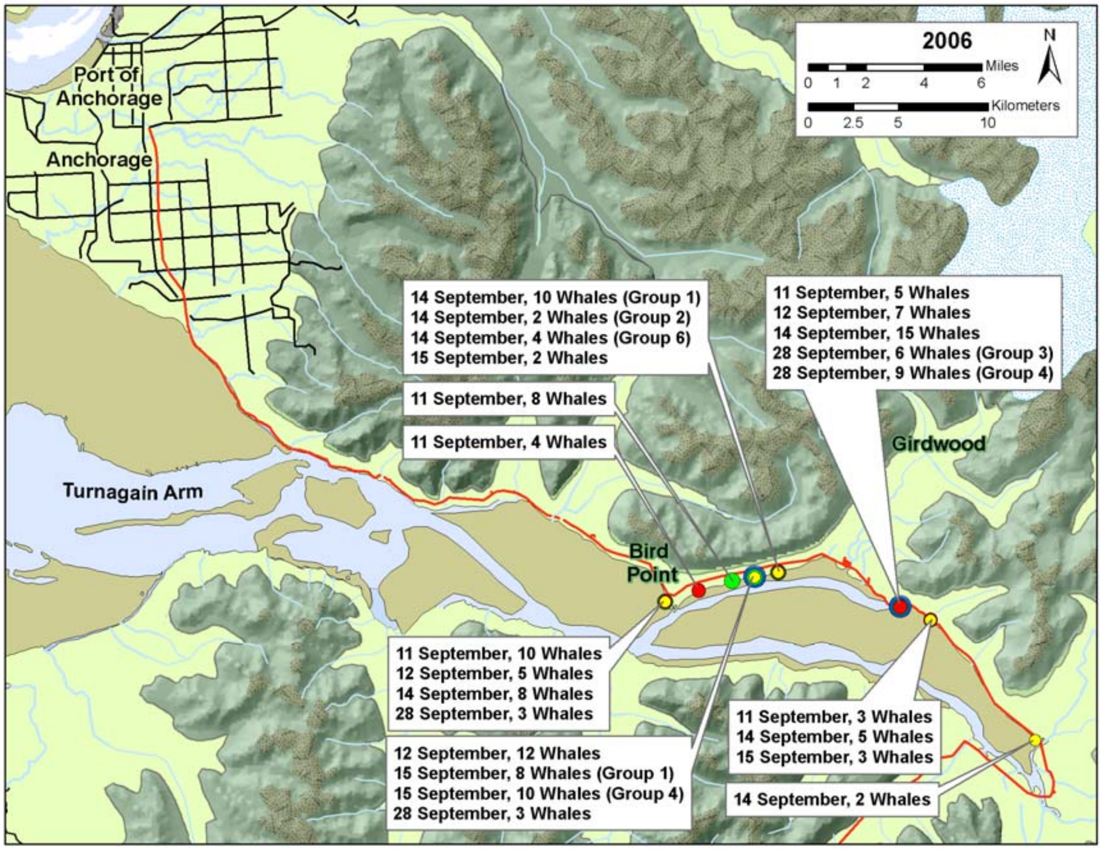


Figure D13. Beluga whale groups encountered and survey route of all five 2006 land-based surveys along the Seward Highway near Girdwood, Alaska.

Daily Survey Tracks and Locations of Whales, Summer and Fall 2007

Figure D14. Beluga whale groups encountered and survey route of 28 June 2007 vessel survey of Upper Cook Inlet, Alaska.

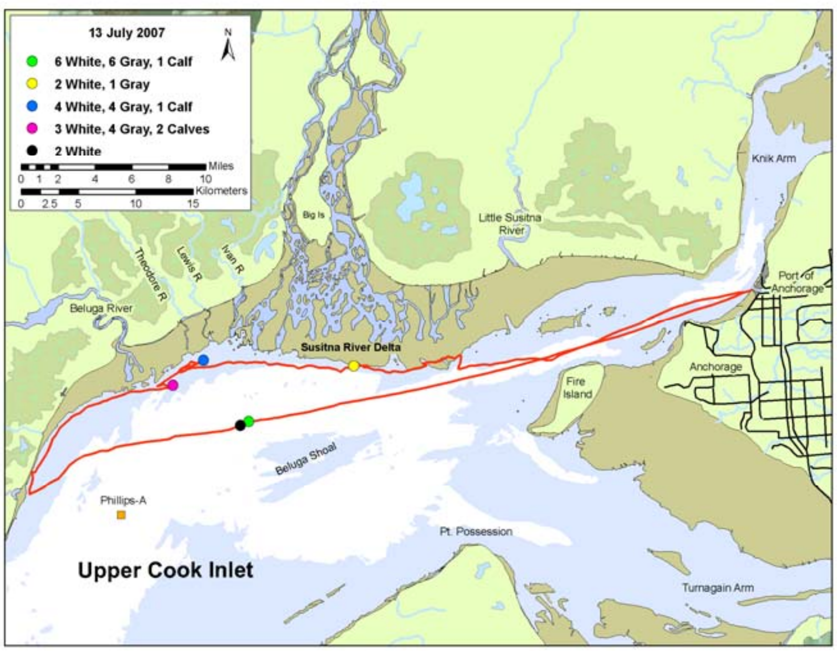


Figure D15. Beluga whale groups encountered and survey route of 13 July 2007 vessel survey of Upper Cook Inlet, Alaska.

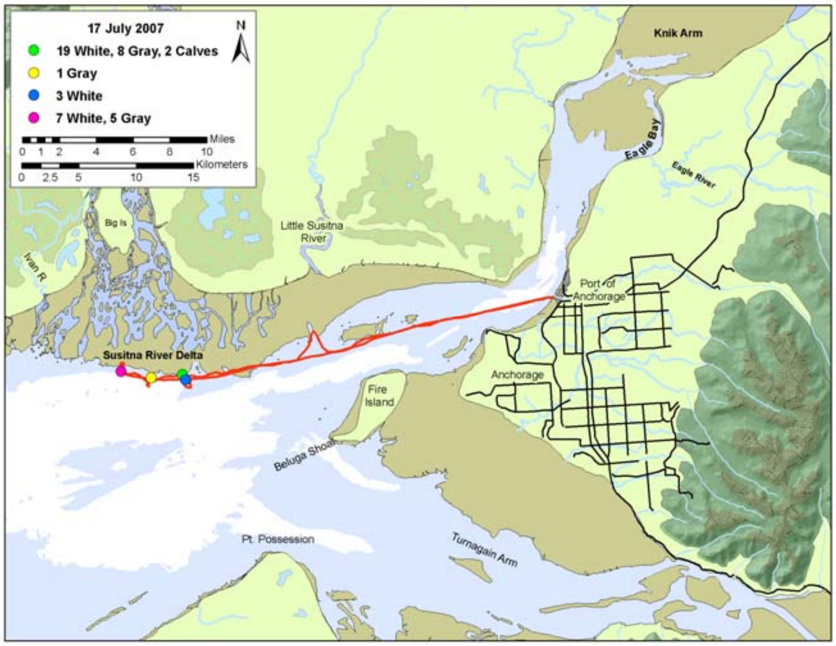


Figure D16. Beluga whale groups encountered and survey route of 17 July 2007 vessel survey of Upper Cook Inlet, Alaska.

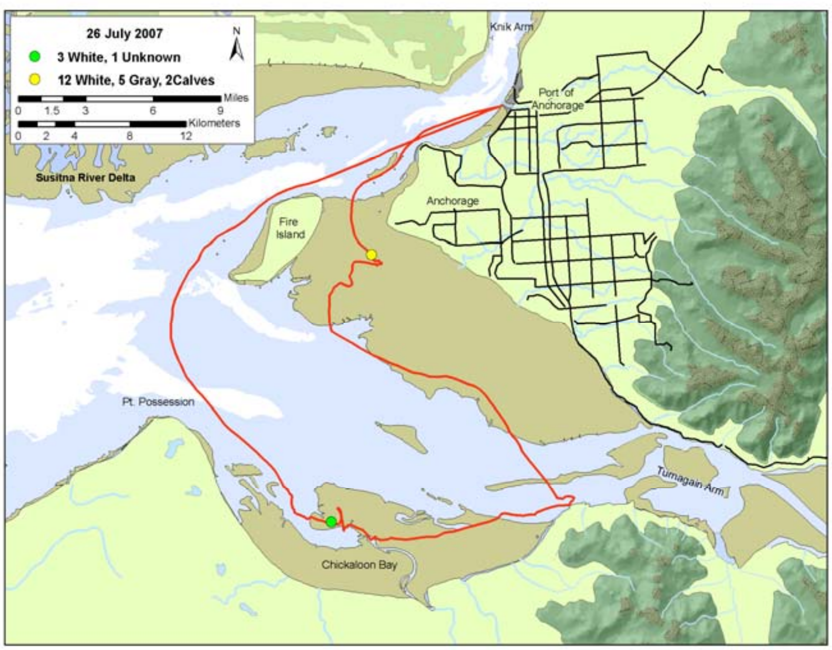


Figure D17. Beluga whale groups encountered and survey route of 26 July 2007 vessel survey of Upper Cook Inlet, Alaska.

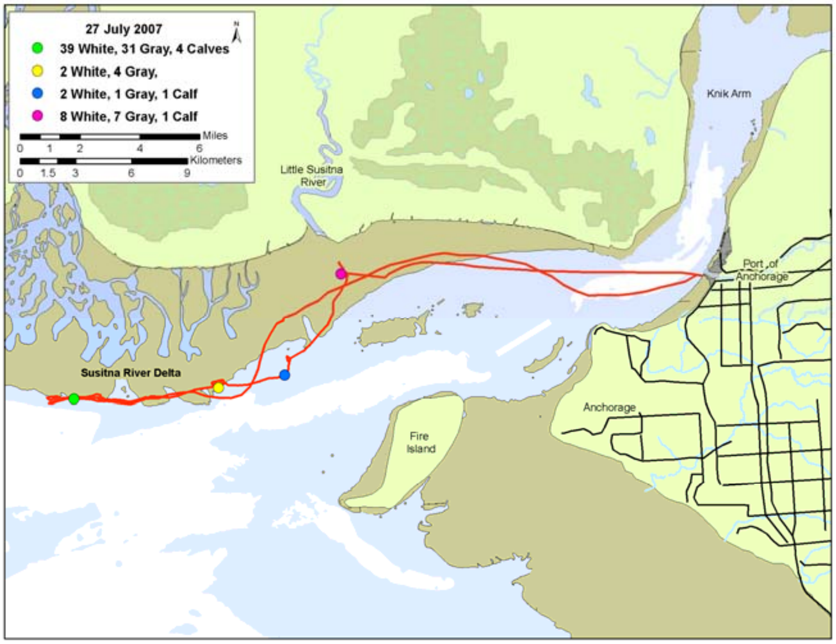


Figure D18. Beluga whale groups encountered and survey route of 27 July 2007 vessel survey of Upper Cook Inlet, Alaska.

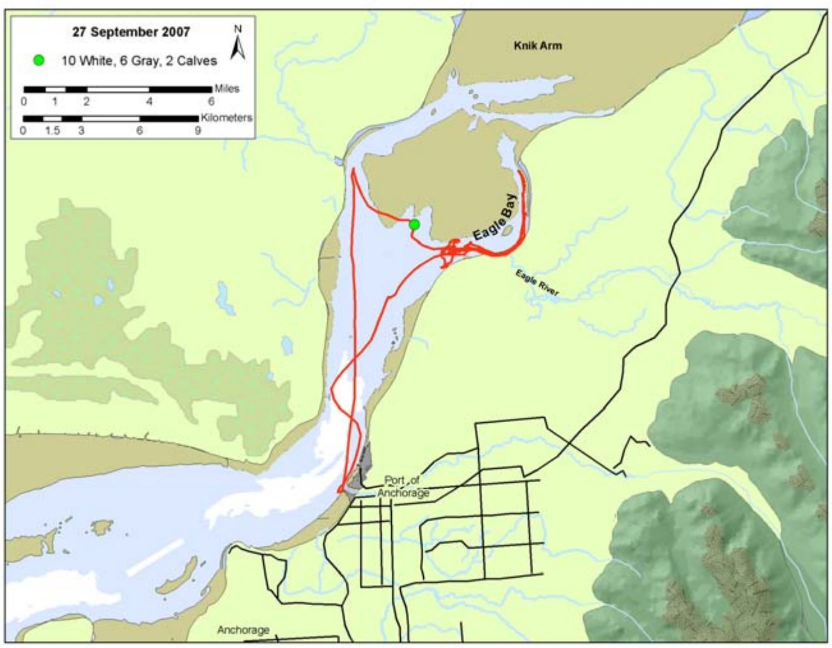


Figure D19. Beluga whale groups encountered and survey route of 27 September 2007 vessel survey of Upper Cook Inlet, Alaska.

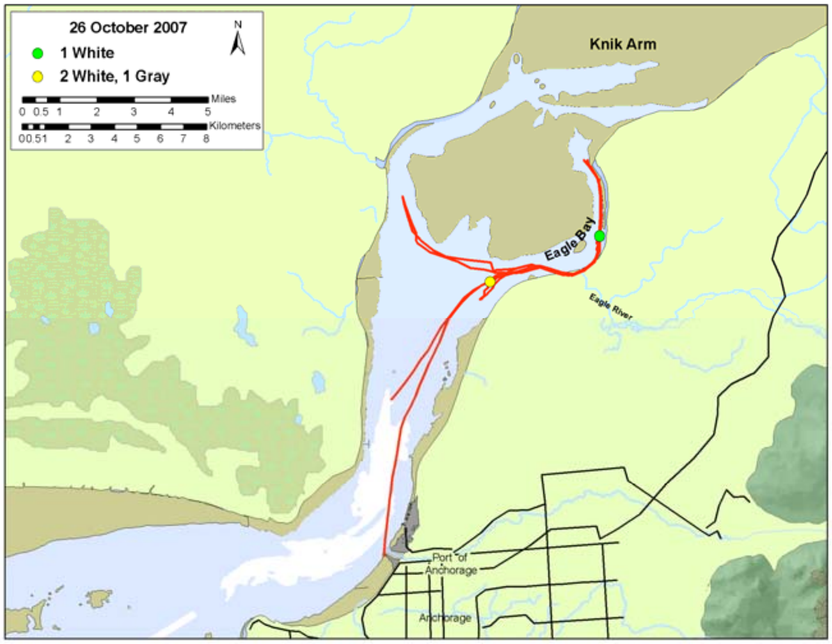


Figure D20. Beluga whale groups encountered and survey route of 26 October 2007 vessel survey of Upper Cook Inlet, Alaska. Note the global positioning system (GPS) quit working on the return leg (center left).

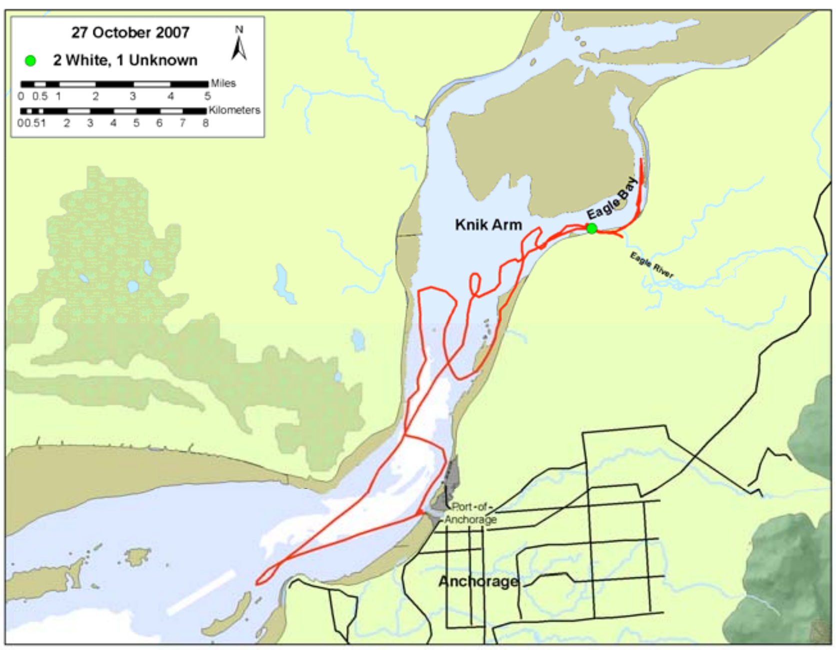


Figure D21. Beluga whale groups encountered and survey route of 27 October 2007 vessel survey of Upper Cook Inlet, Alaska.

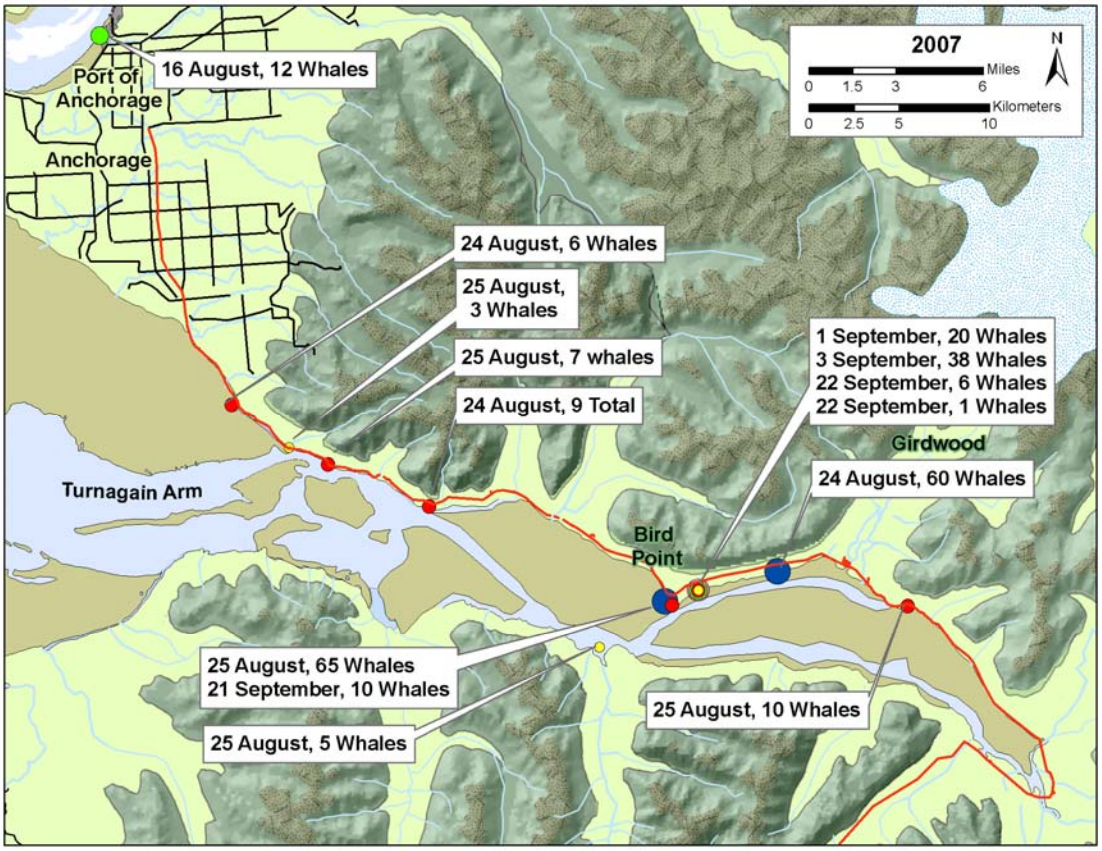
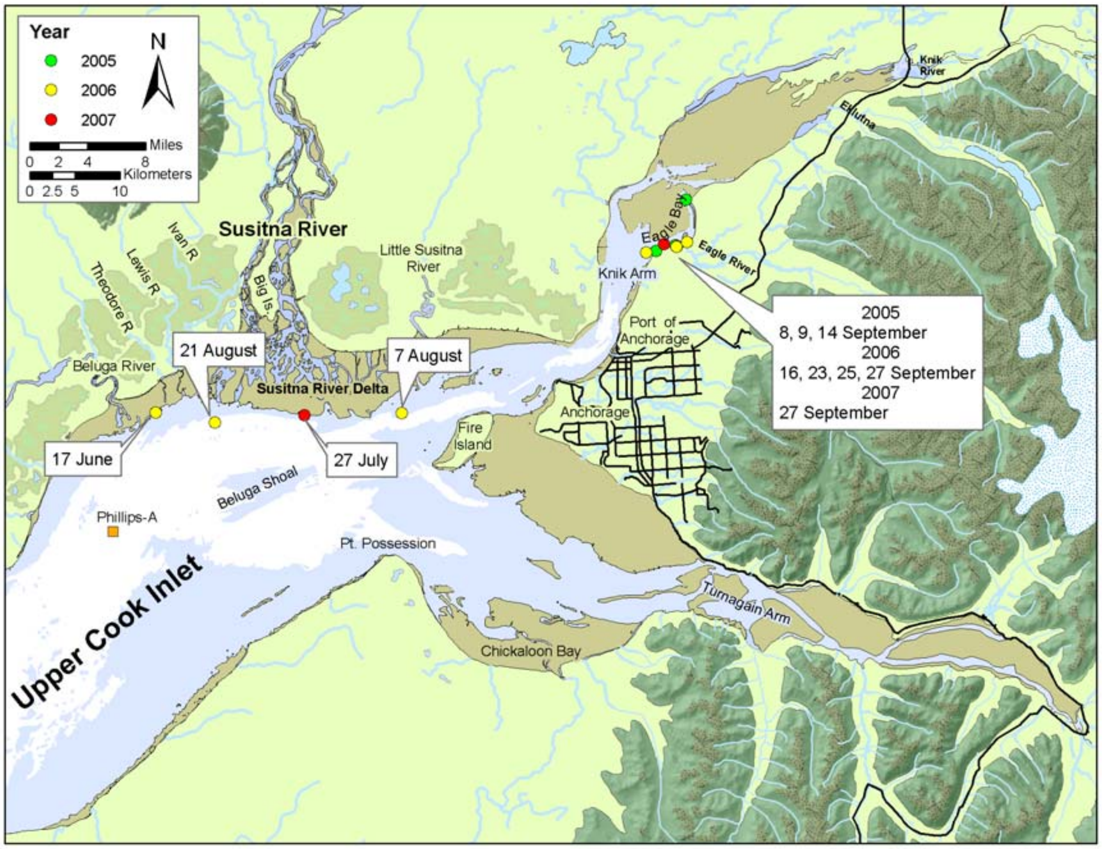


Figure D22. Beluga whale groups encountered and survey route of all 2007 land-based surveys along the Seward Highway of Upper Cook Inlet, Alaska.

APPENDIX E.

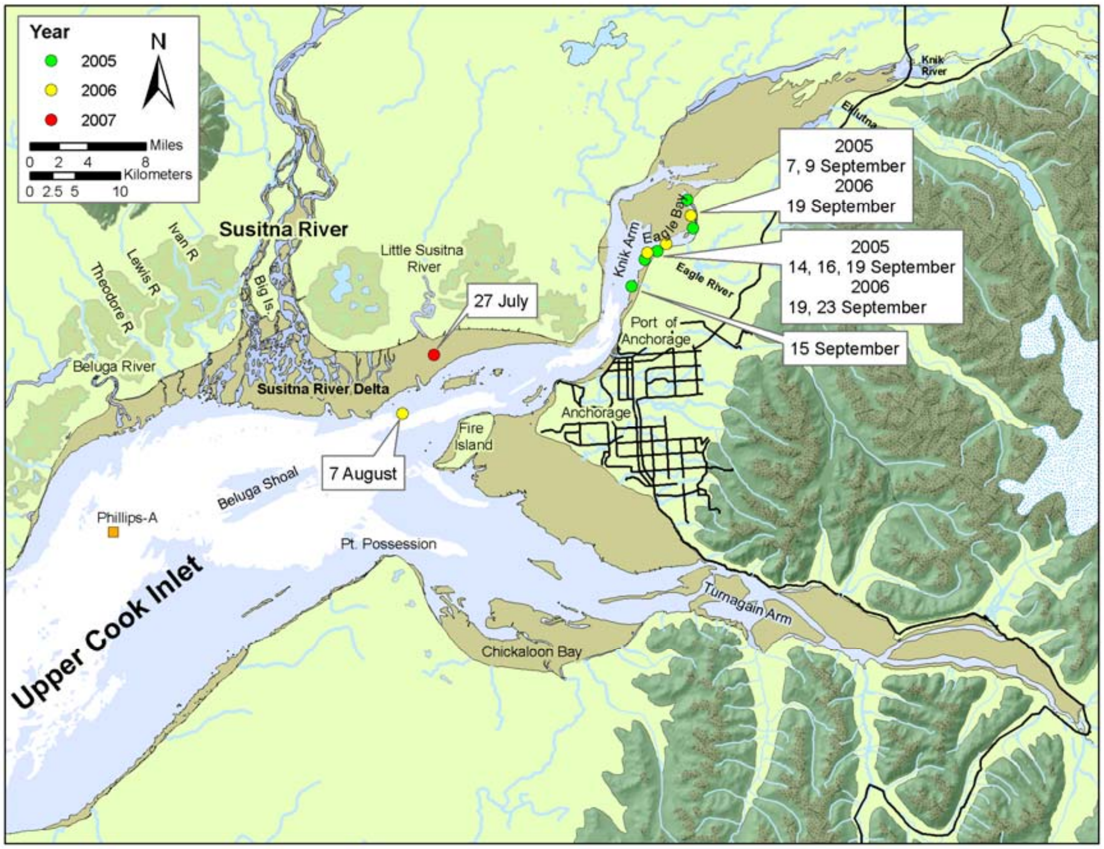
INDIVIDUAL SIGHTINGS HISTORY MAPS OF CATALOGED WHALES ALONG WITH A PHOTOGRAPH OF THE RIGHT SIDE OF EACH INDIVIDUAL



a.

b.

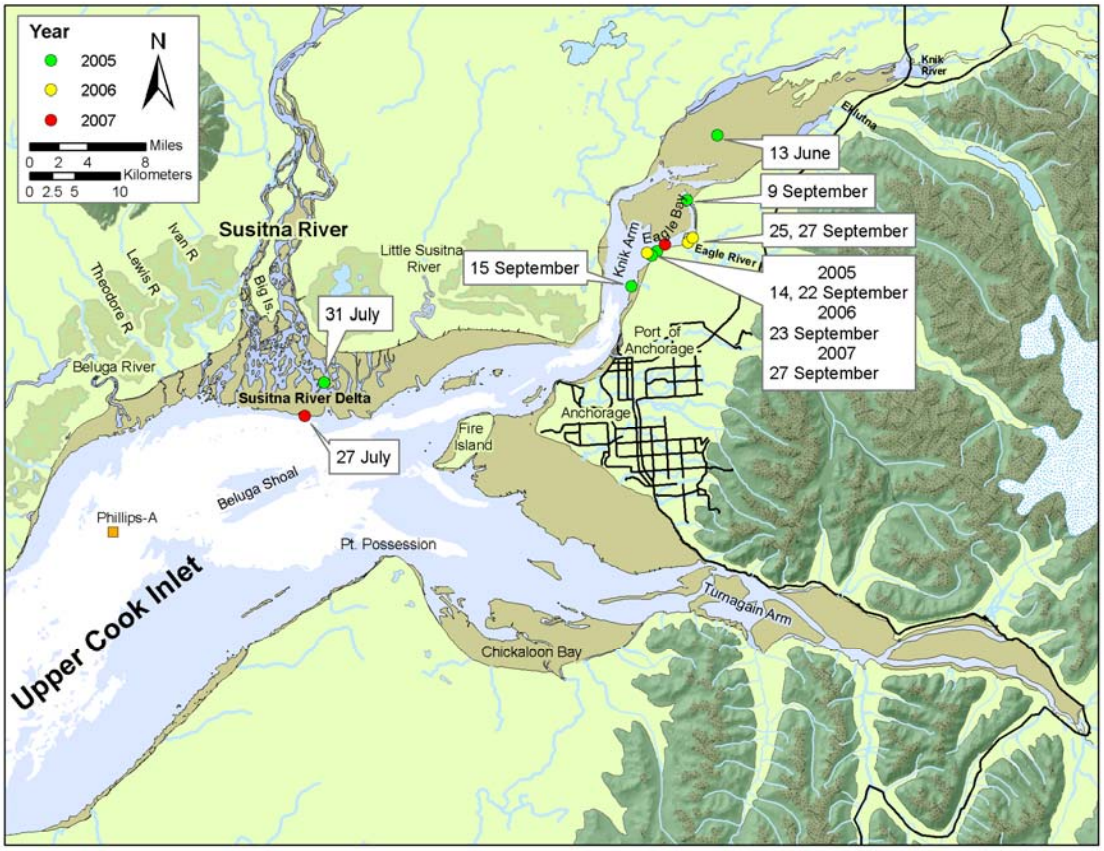
Figure E1. Sighting history (a) and photograph (b) of beluga RA 001.



a

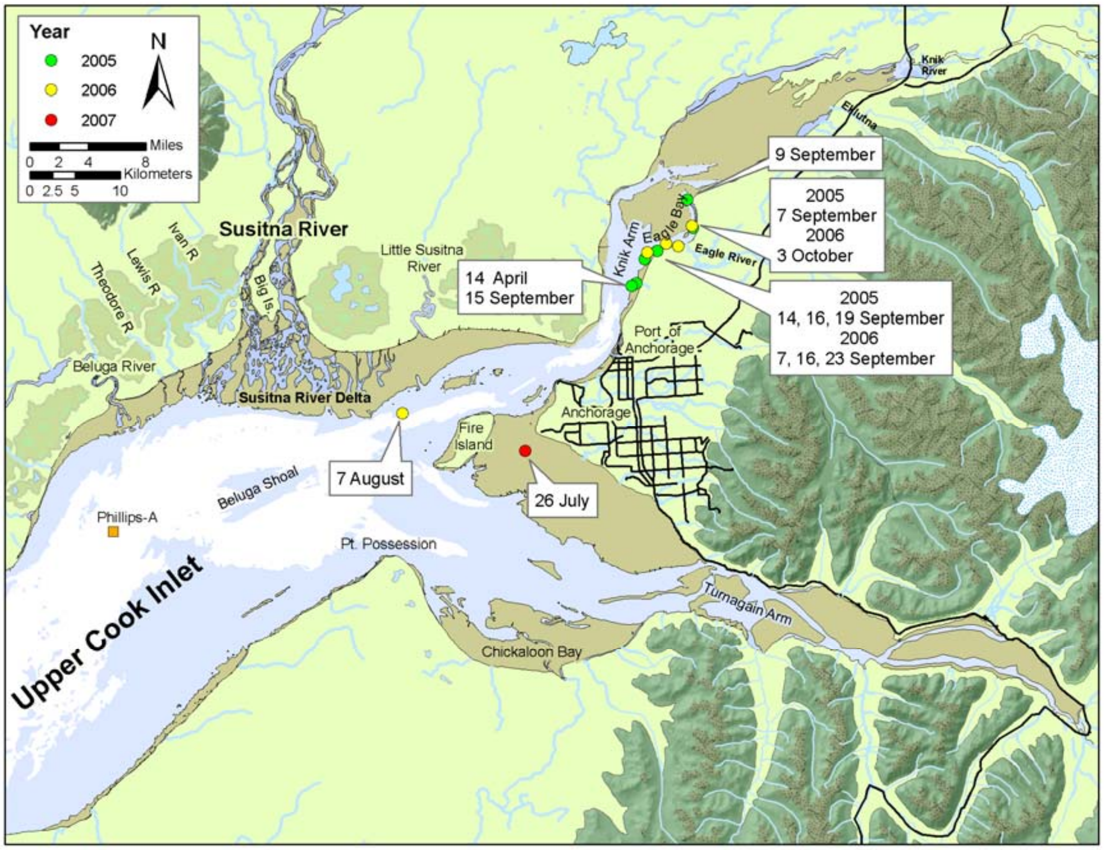

b.

Figure E2. Sighting history (a) and photograph (b) of beluga RA 002.

a.


b.


Figure E3. Sighting history (a) and photograph (b) of beluga RA 009.

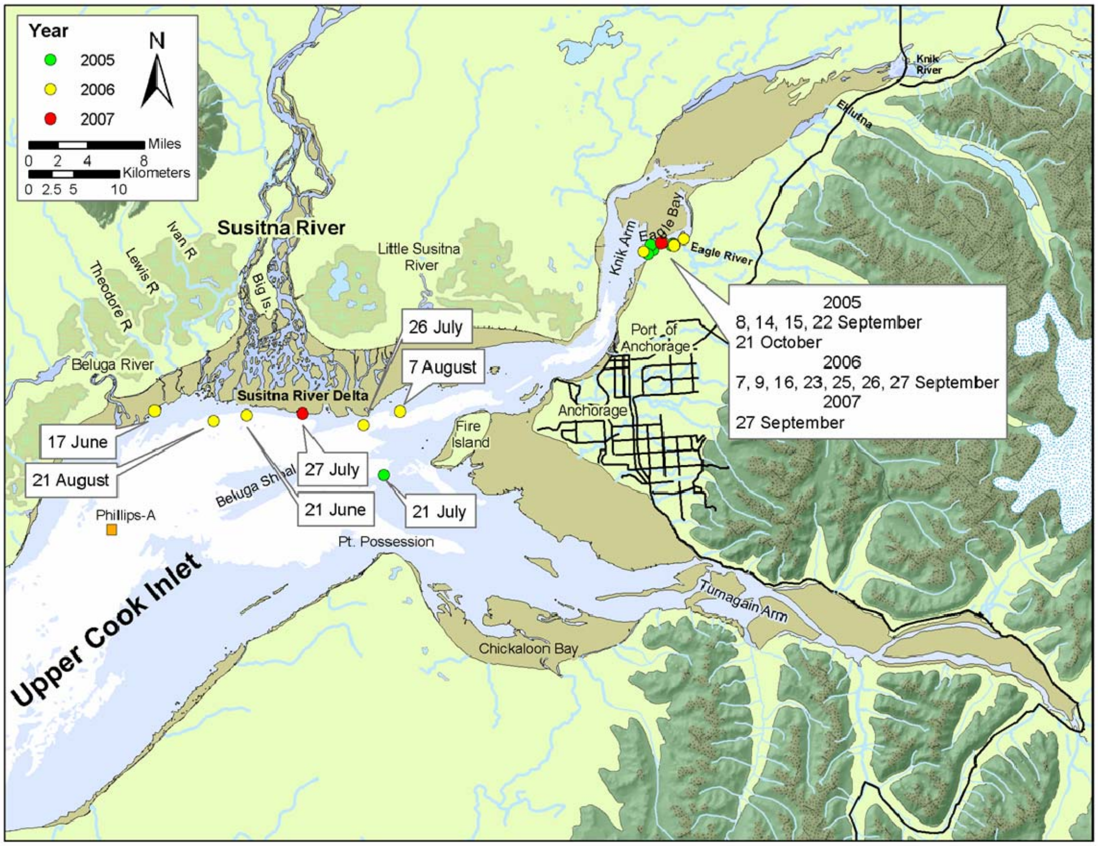


a.

b.

Figure E4. Sighting history (a) and photograph (b) of beluga RA 013.

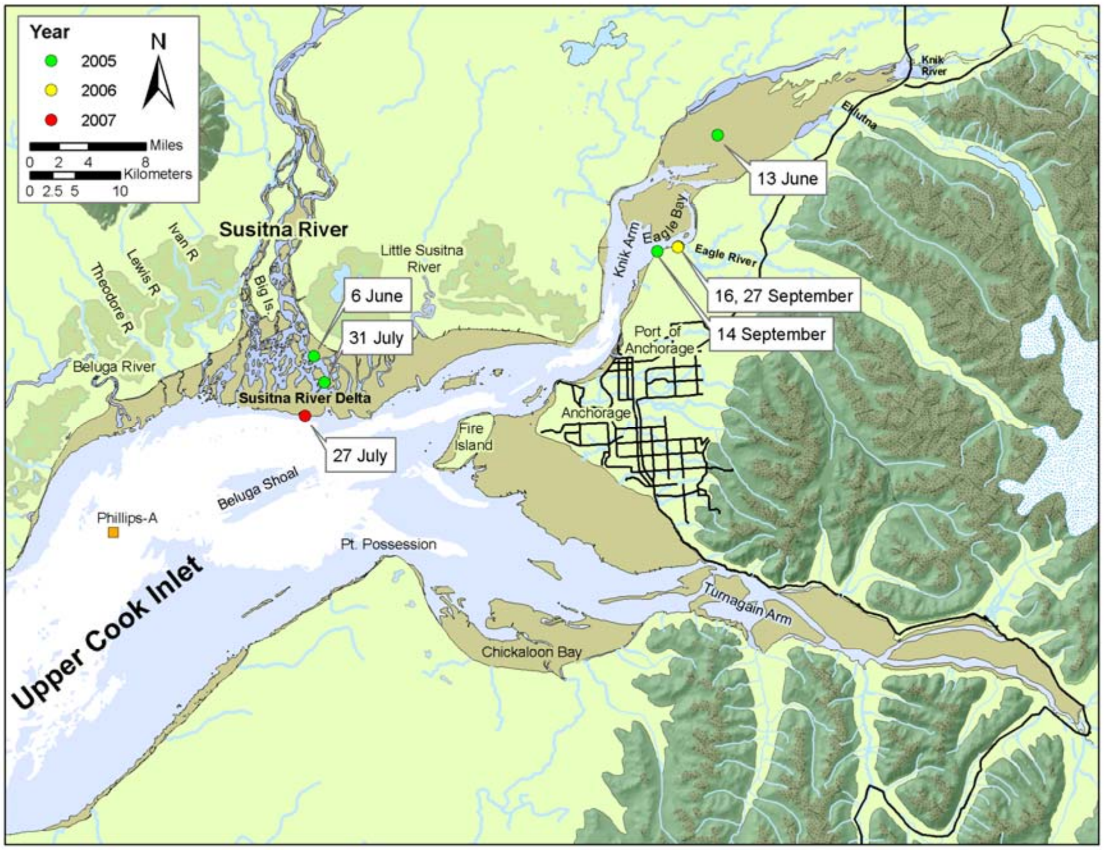
a.



b.

Figure E5. Sighting history (a) and photograph (b) of beluga RA 024. RA 024 was seen with a calf in Knik Arm in 2005 and 2006.

a.

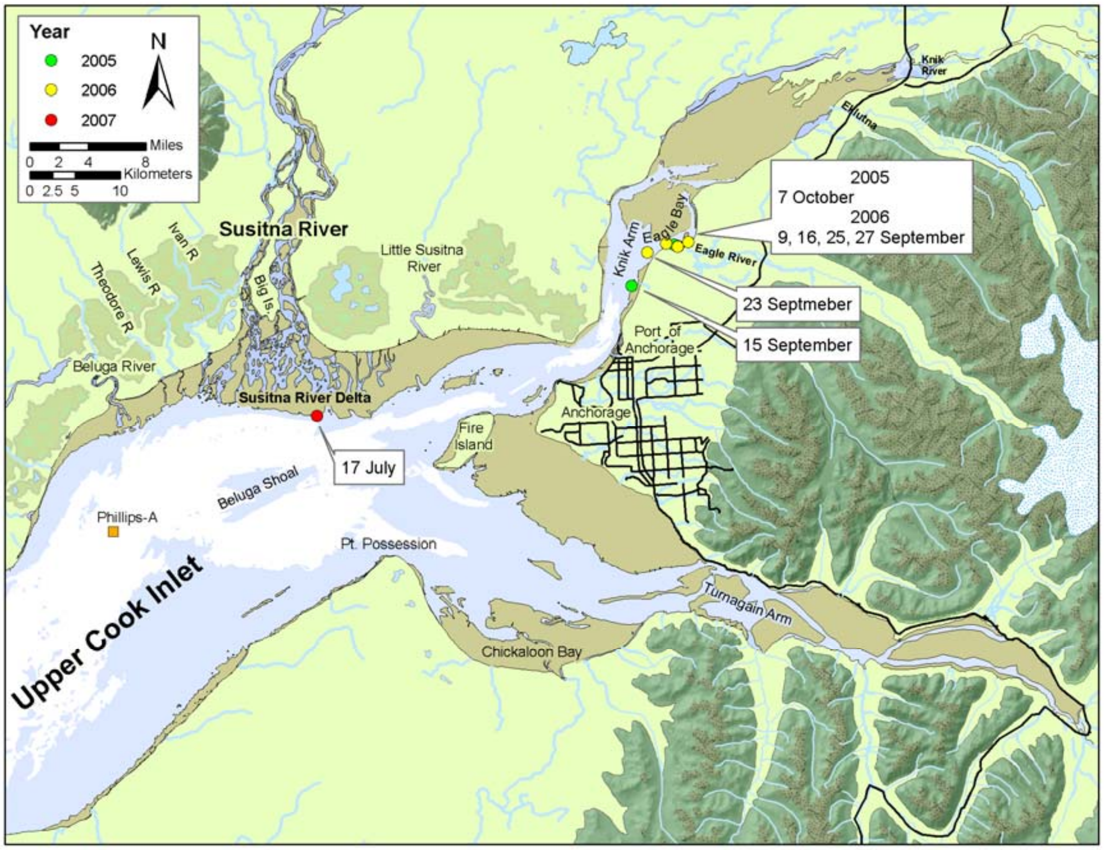


a.

b.

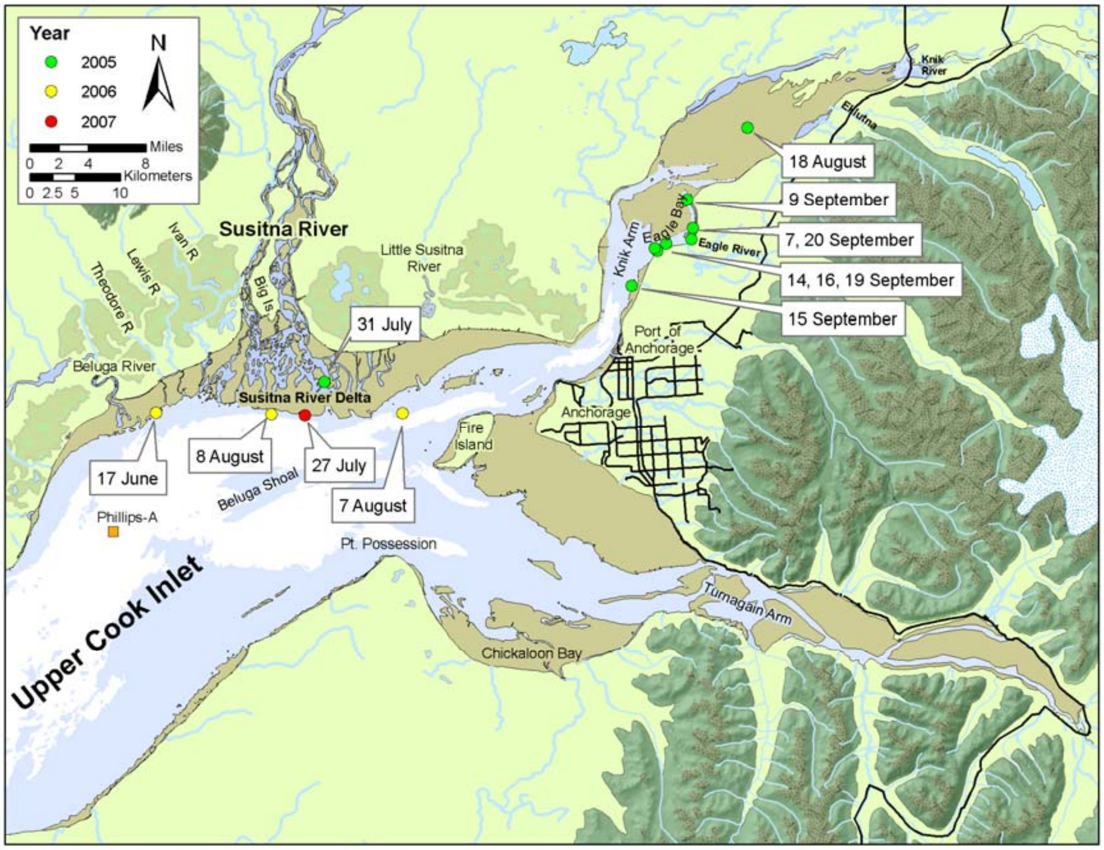
Figure E6. Sighting history (a) and photograph (b) of beluga RA 025.

a.



b.

Figure E7. Sighting history (a) and photograph (b) of beluga RA 029.

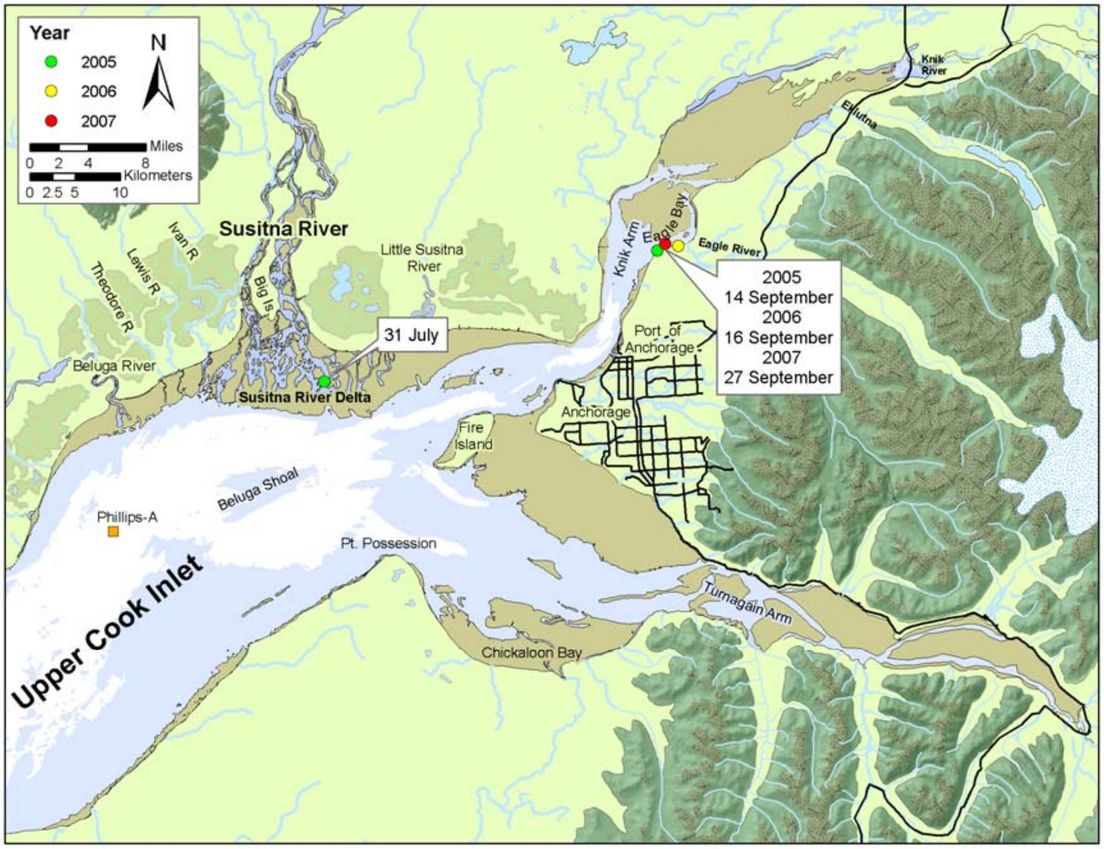


a.


b.

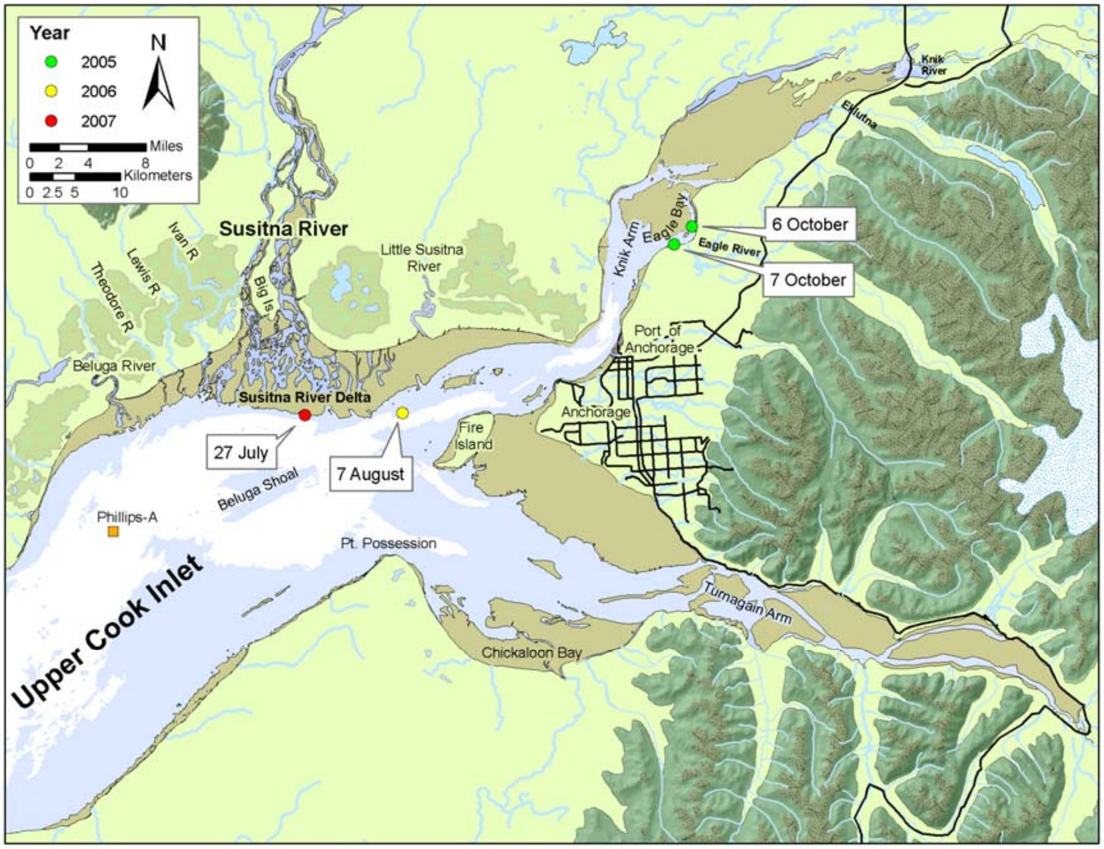
Figure E8. Sighting history (a) and photograph (b) of beluga RA 036. RA 036 was seen with a calf in Knik Arm in 2005 and in the Susitna River Delta in 2006.

a.



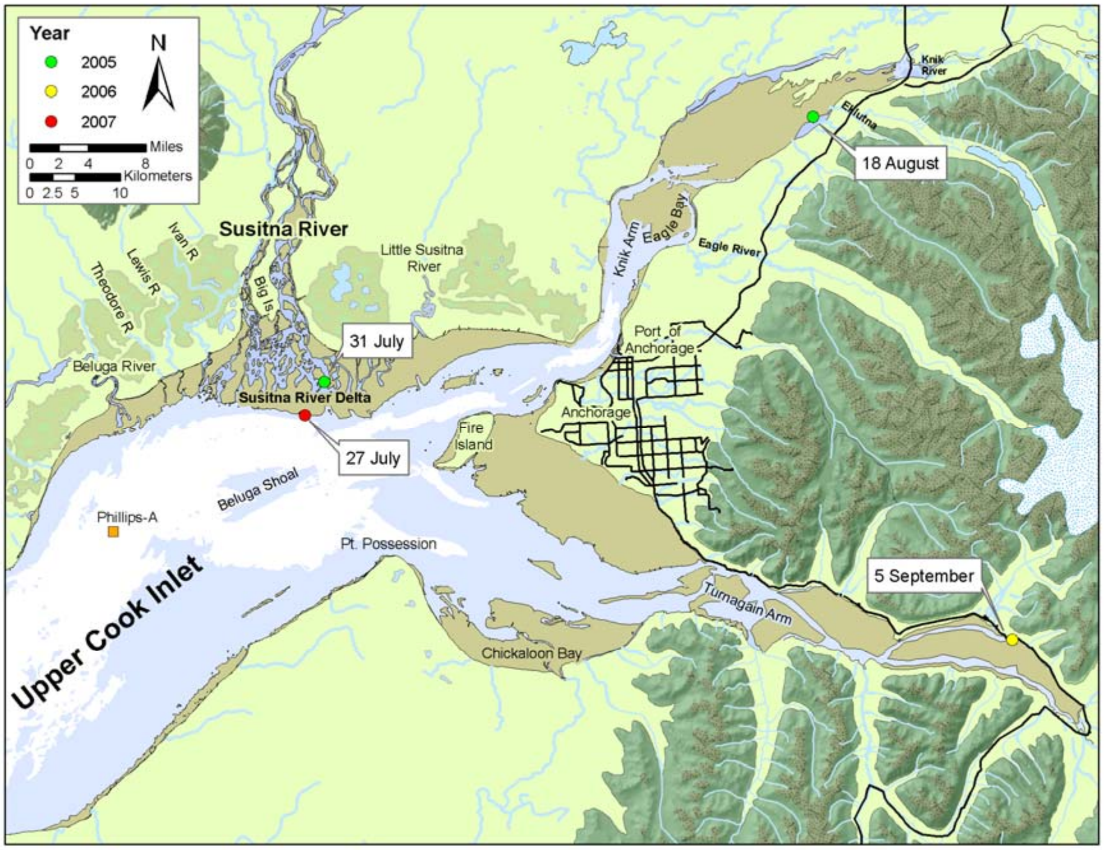
b.

Figure E9. Sighting history (a) and photograph (b) of beluga RA 054. RA 054 was seen with a calf in Knik Arm in 2006.

a.


b.

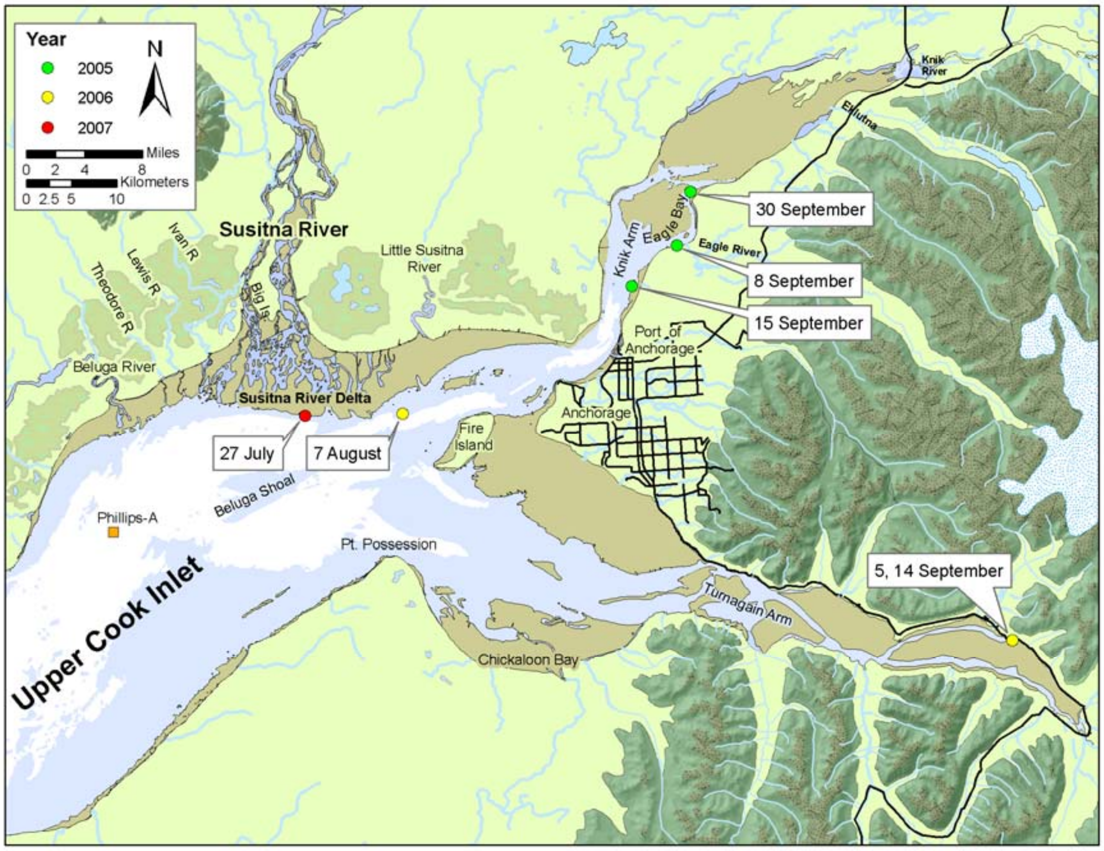

Figure E10. Sighting history (a) and photograph (b) of beluga RA 063.



a.

b.

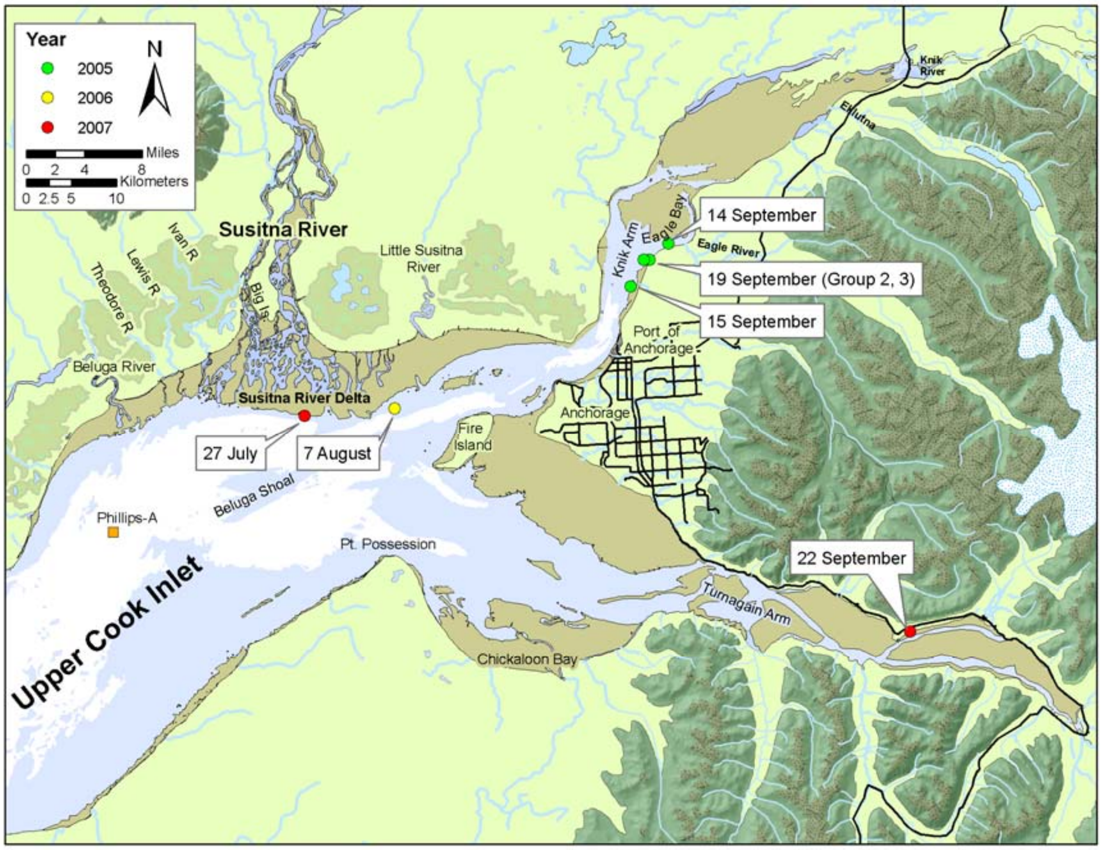
Figure E11. Sighting history (a) and photograph (b) of beluga RA 079. RA 079 was seen with a calf in the Susitna River Delta in 2007.



a.

b.

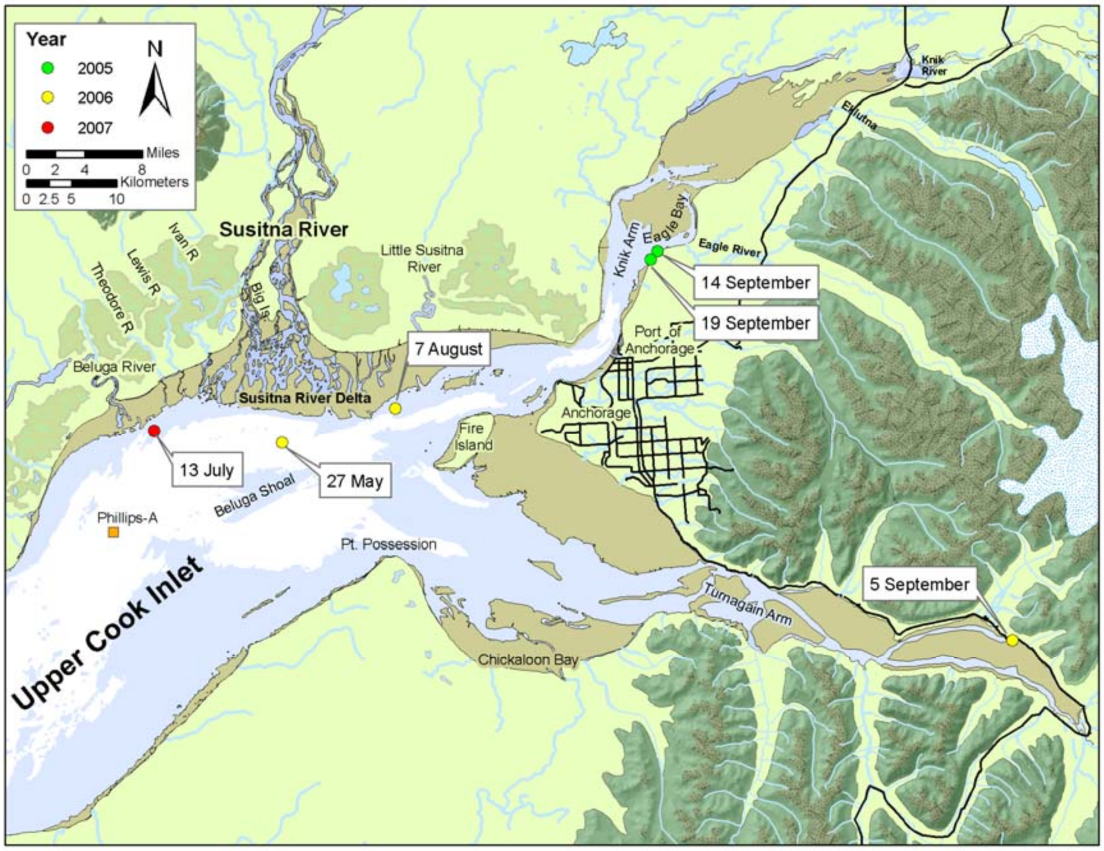
Figure E12. Sighting history (a) and photograph (b) of beluga RA 100.



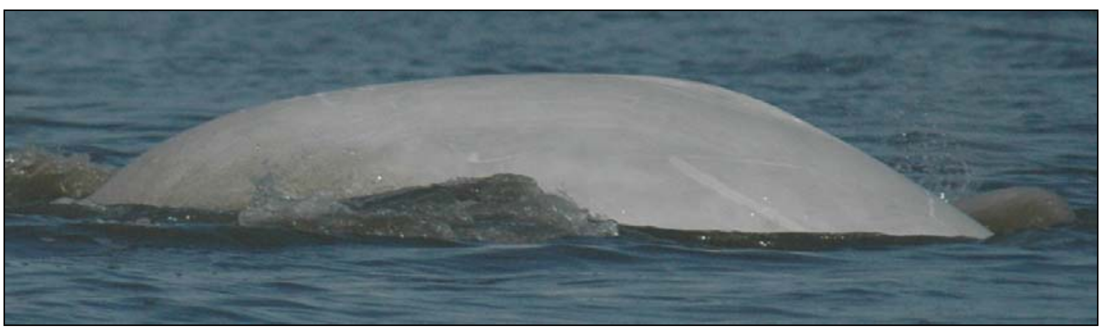
a.

b.

Figure E13. Sighting history (a) and photograph (b) of beluga RA 102.

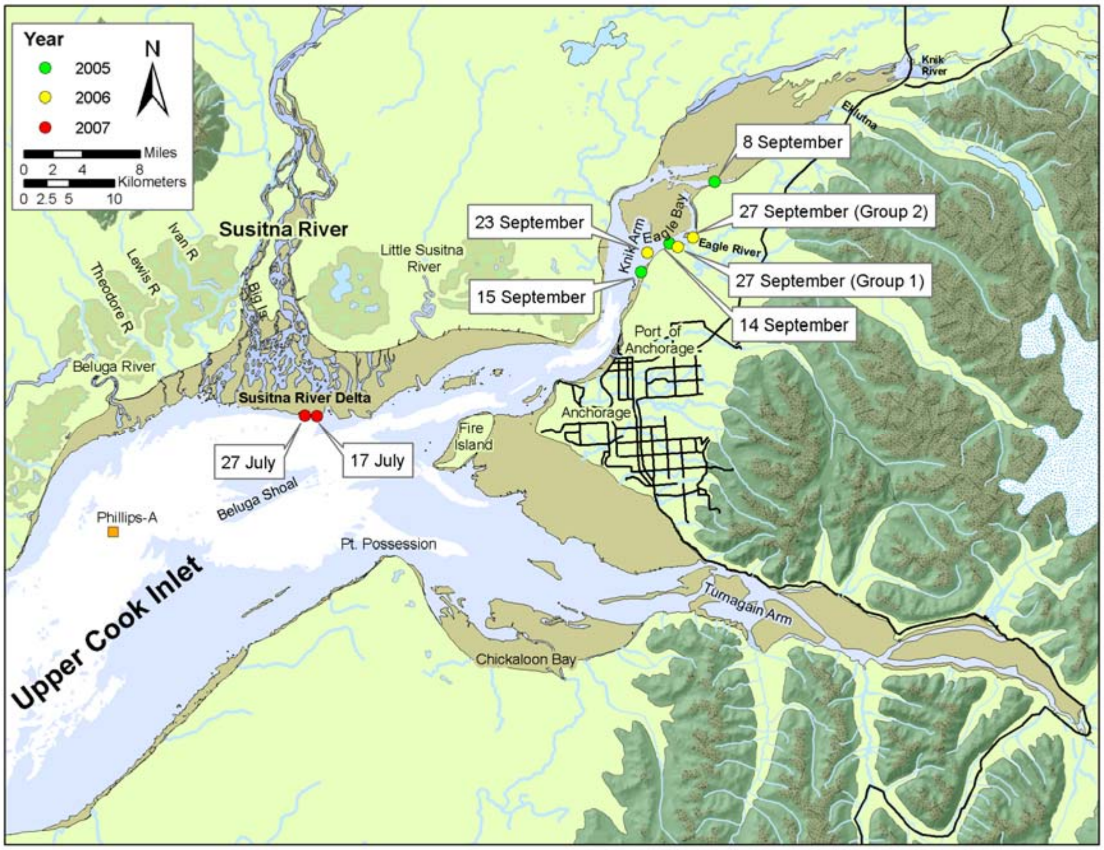


a.



b.

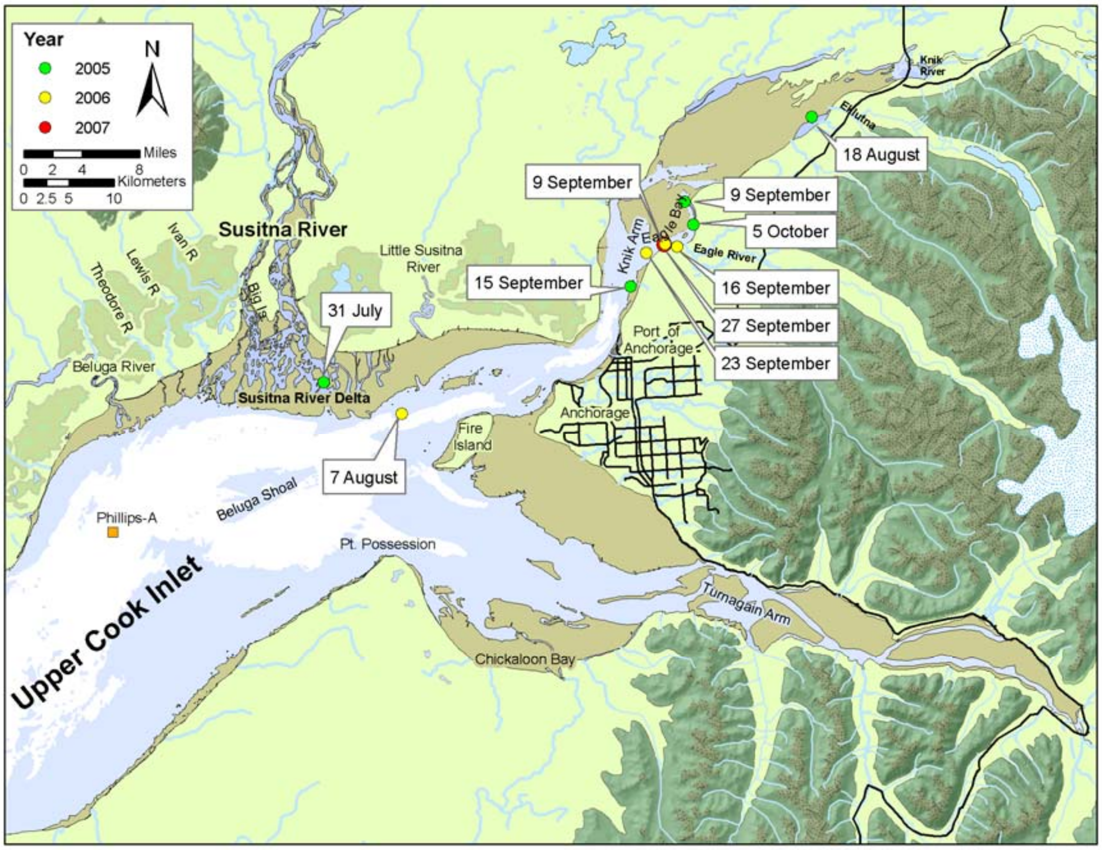
Figure E14. Sighting history (a) and photograph (b) of beluga RA 123. RA 123 was seen with a calf in Knik Arm in 2005 and in the Susitna River Delta in 2006.



a.


b.

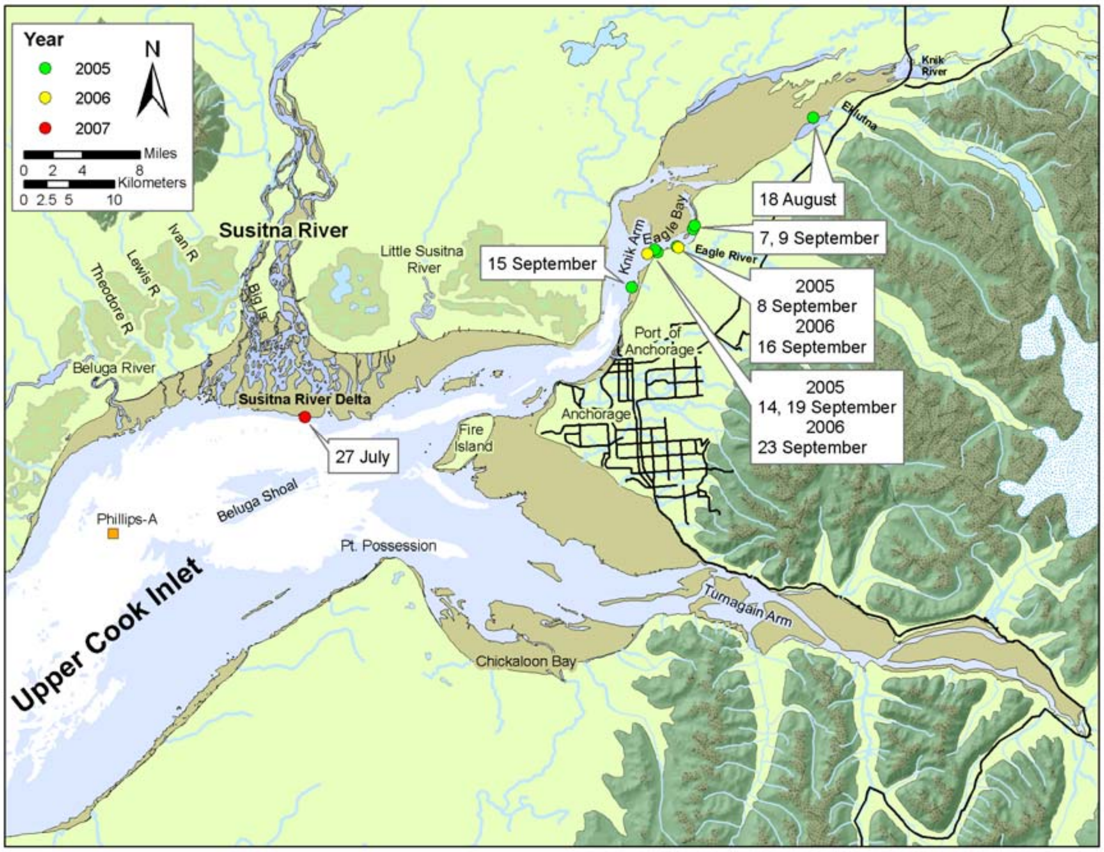
Figure E15. Sighting history (a) and photograph (b) of beluga RA 145. RA 145 was seen with a calf in Knik Arm in 2005 and 2006 and in the Susitna Delta in 2007.



a.

b.

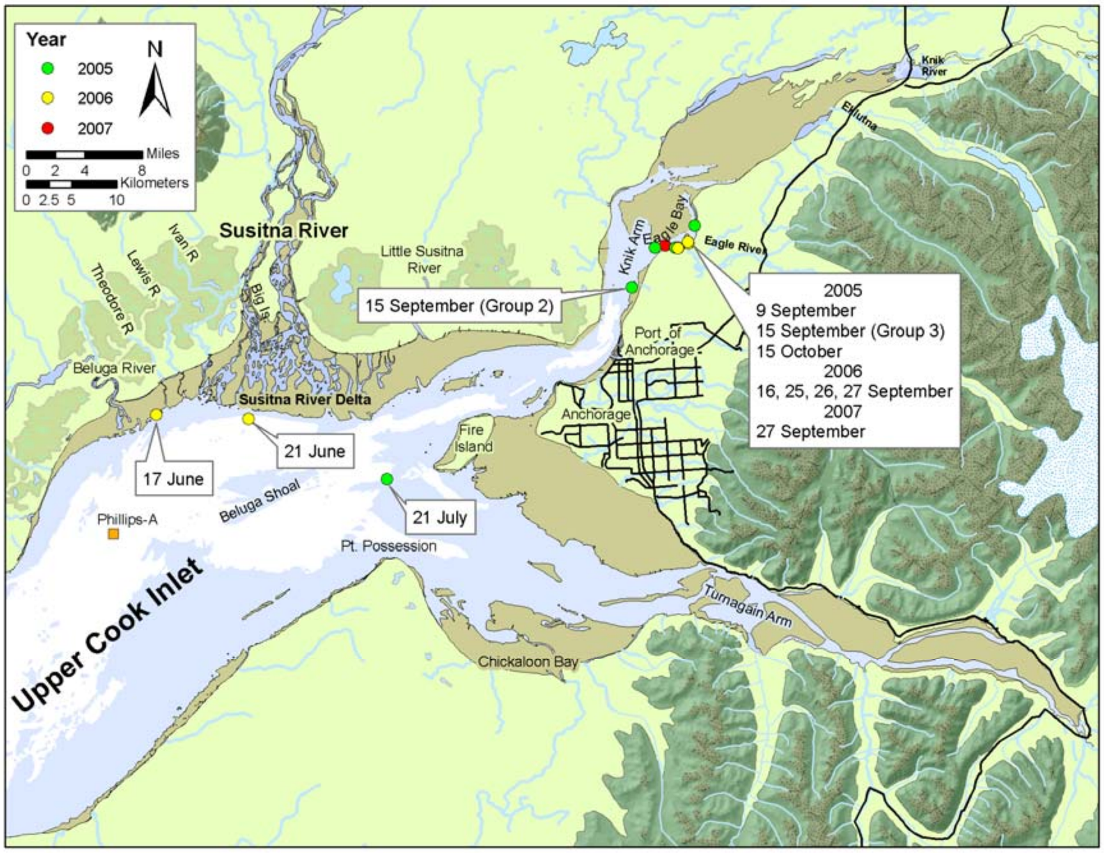
Figure E16. Sighting history (a) and photograph (b) of beluga RA 148. This beluga was tagged by NMFS sometime between 1999 and 2002.



a.

b.

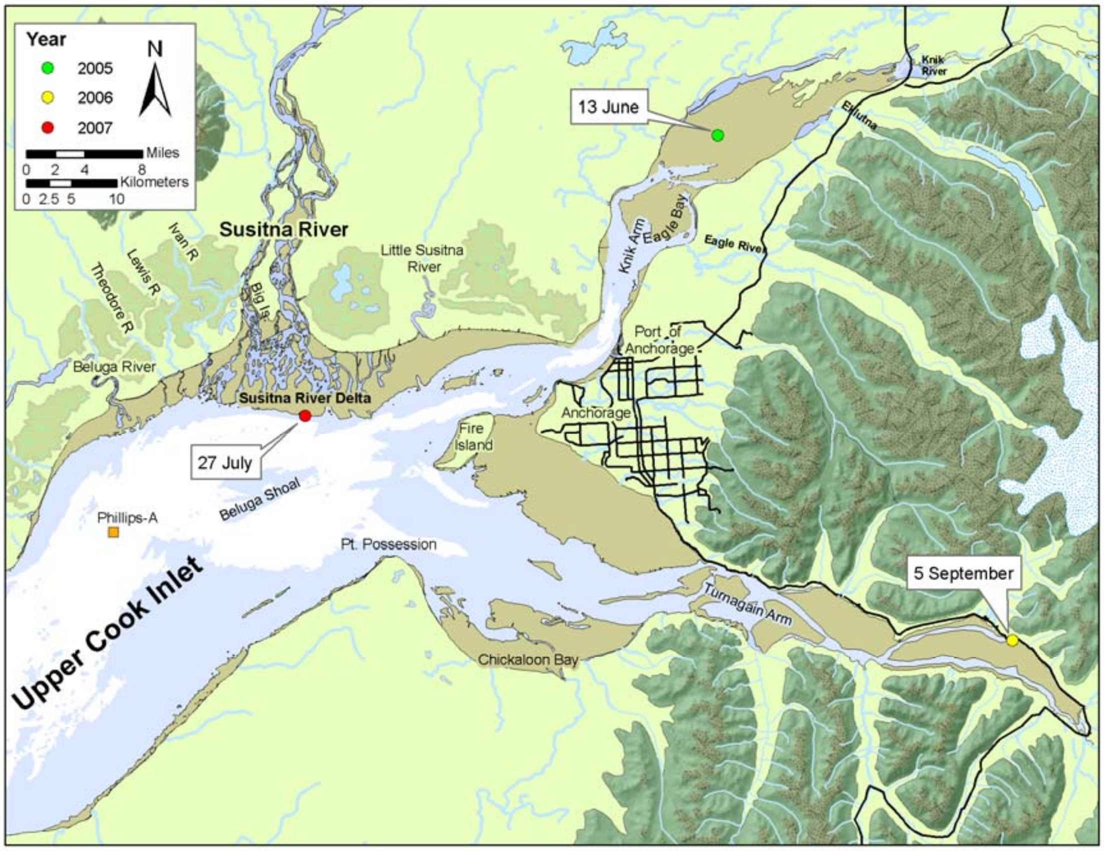
Figure E17. Sighting history (a) and photograph (b) of beluga RA 154.



a.

b.

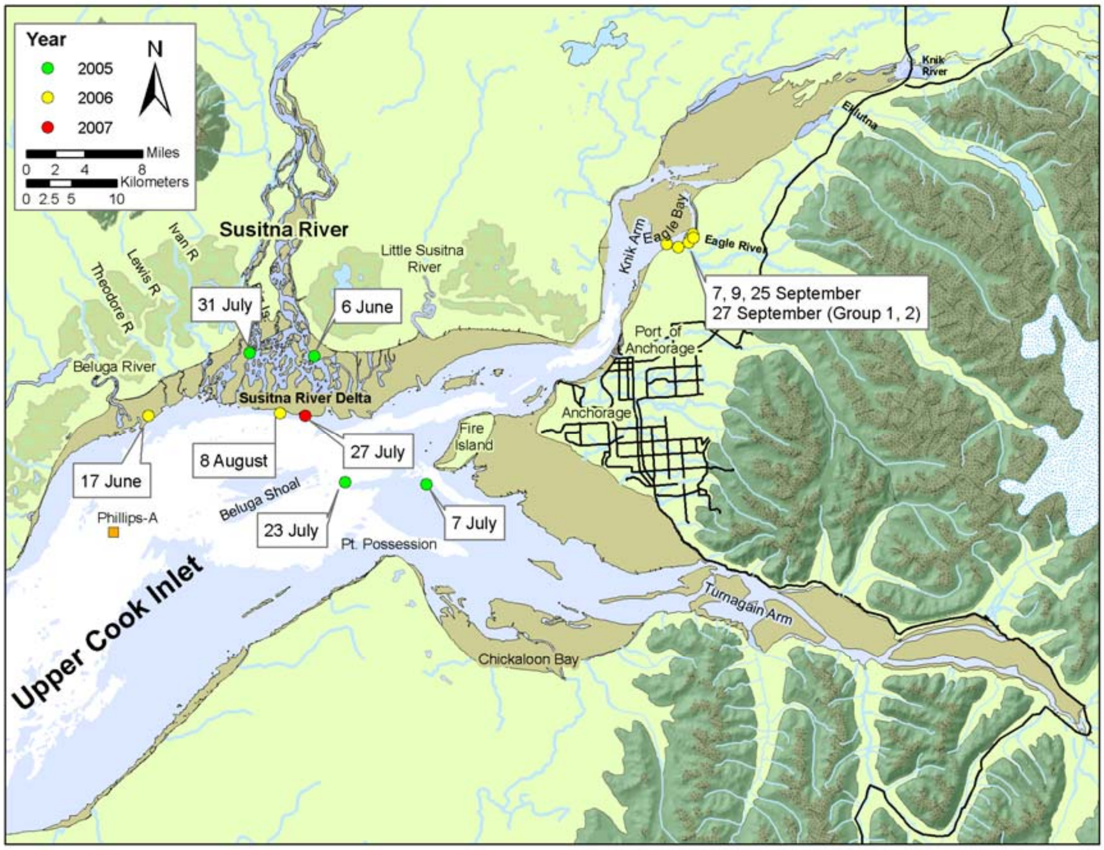
Figure E18. Sighting history (a) and photograph (b) of beluga RA 155. RA 155 was seen with a calf in Knik Arm in 2005 and 2006.



a.

b.

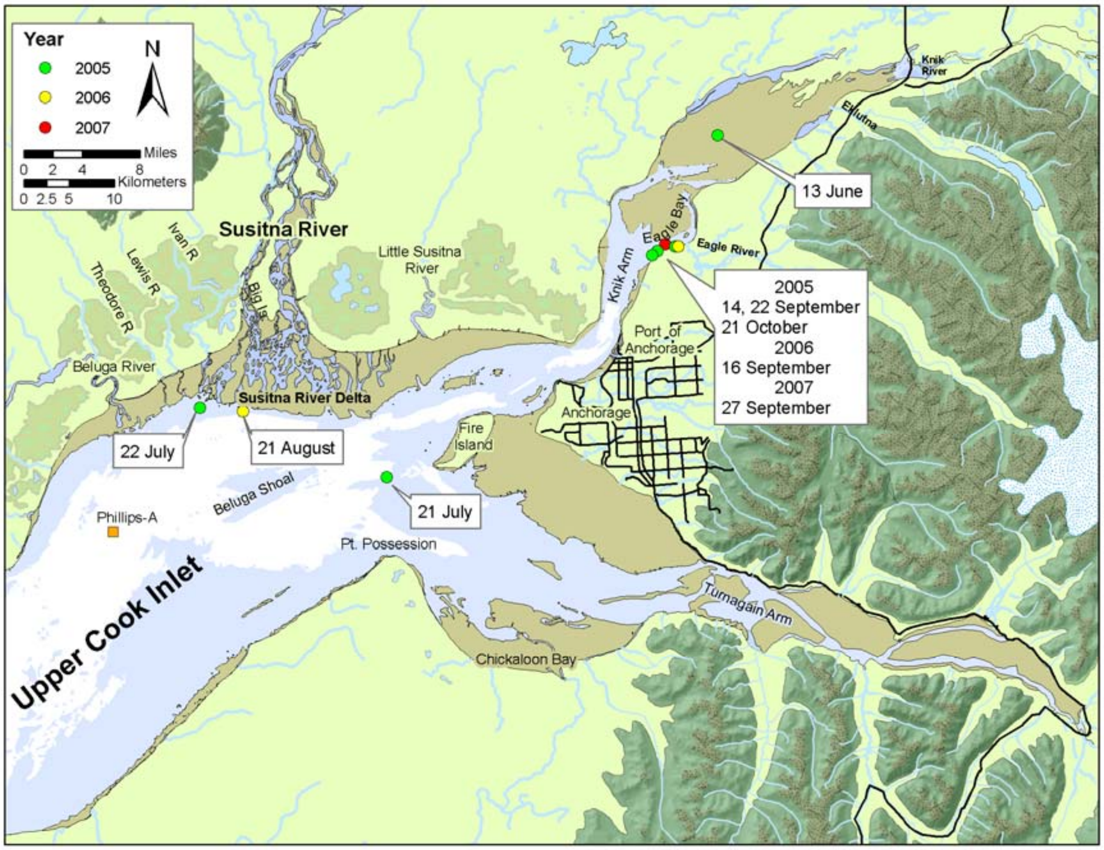
Figure E19. Sighting history (a) and photograph (b) of beluga RA 160. This beluga was tagged by NMFS sometime between 1999 and 2002.



a.

b.

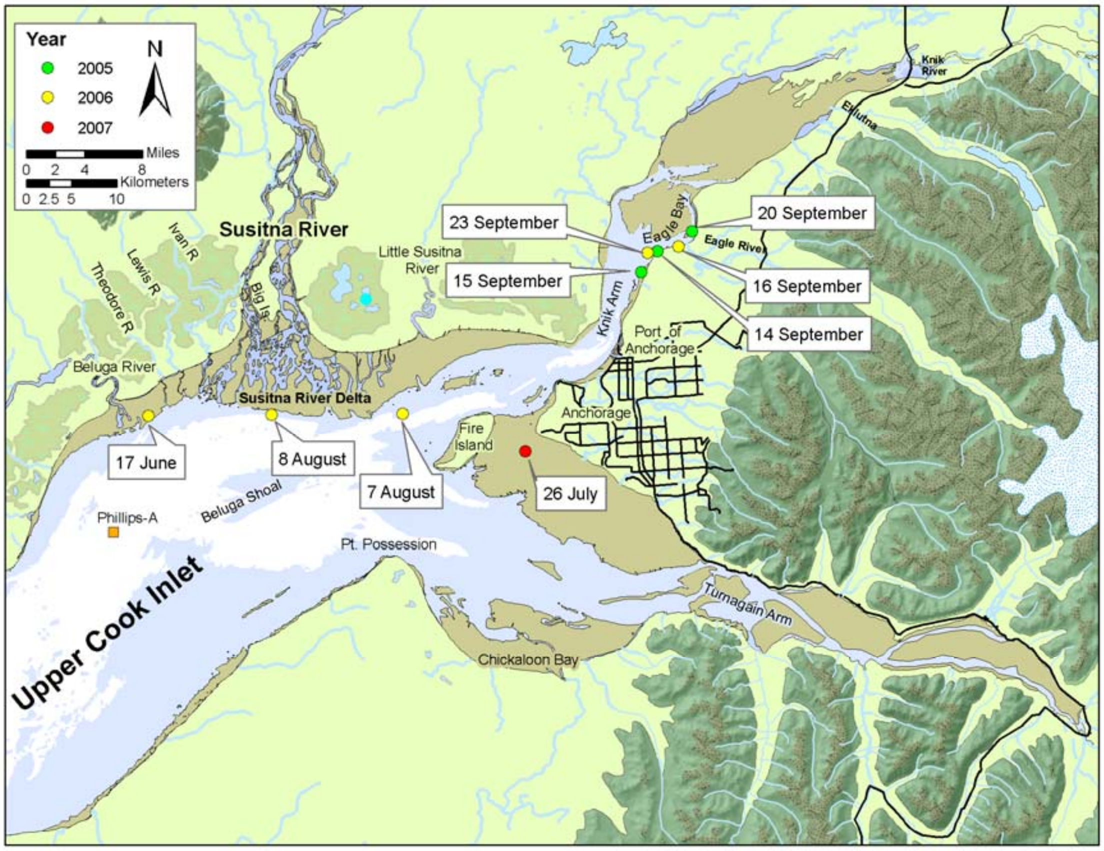
Figure E20. Sighting history (a) and photograph (b) of beluga RS 002.



a.

b.

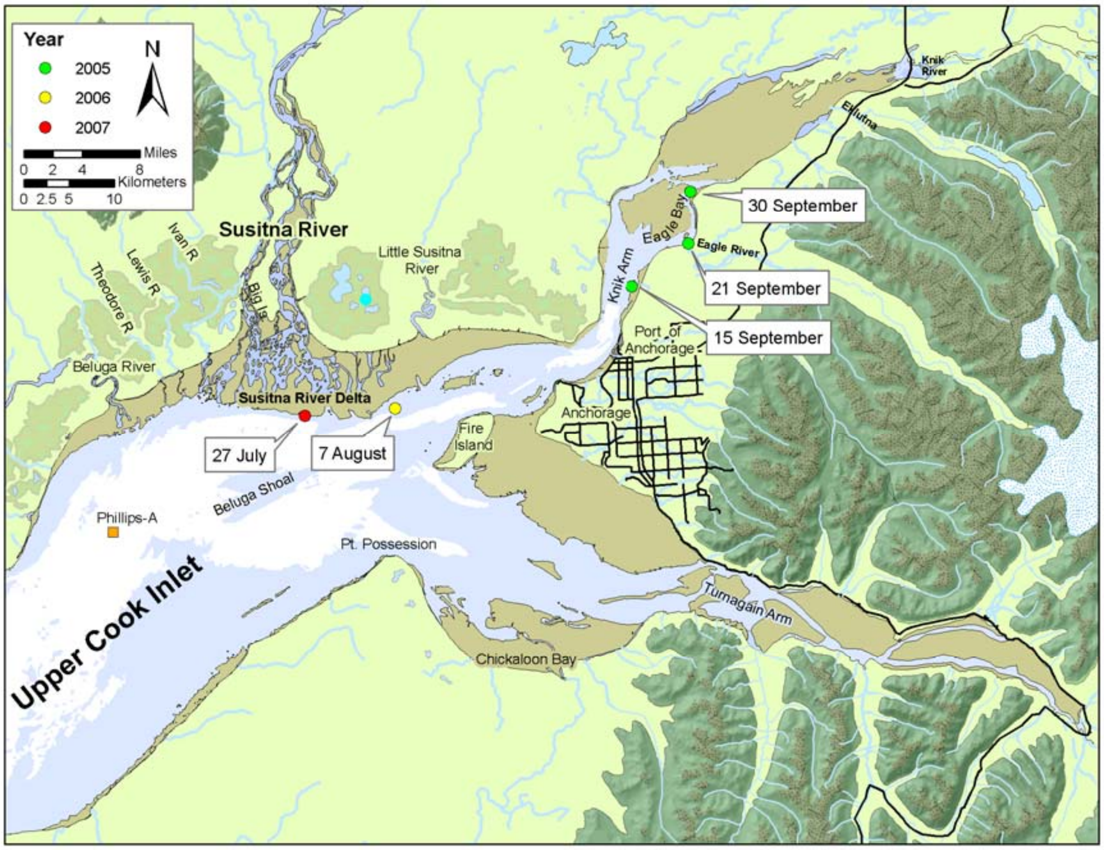
Figure E21. Sighting history (a) and photograph (b) of beluga RS 044.



a.


b.

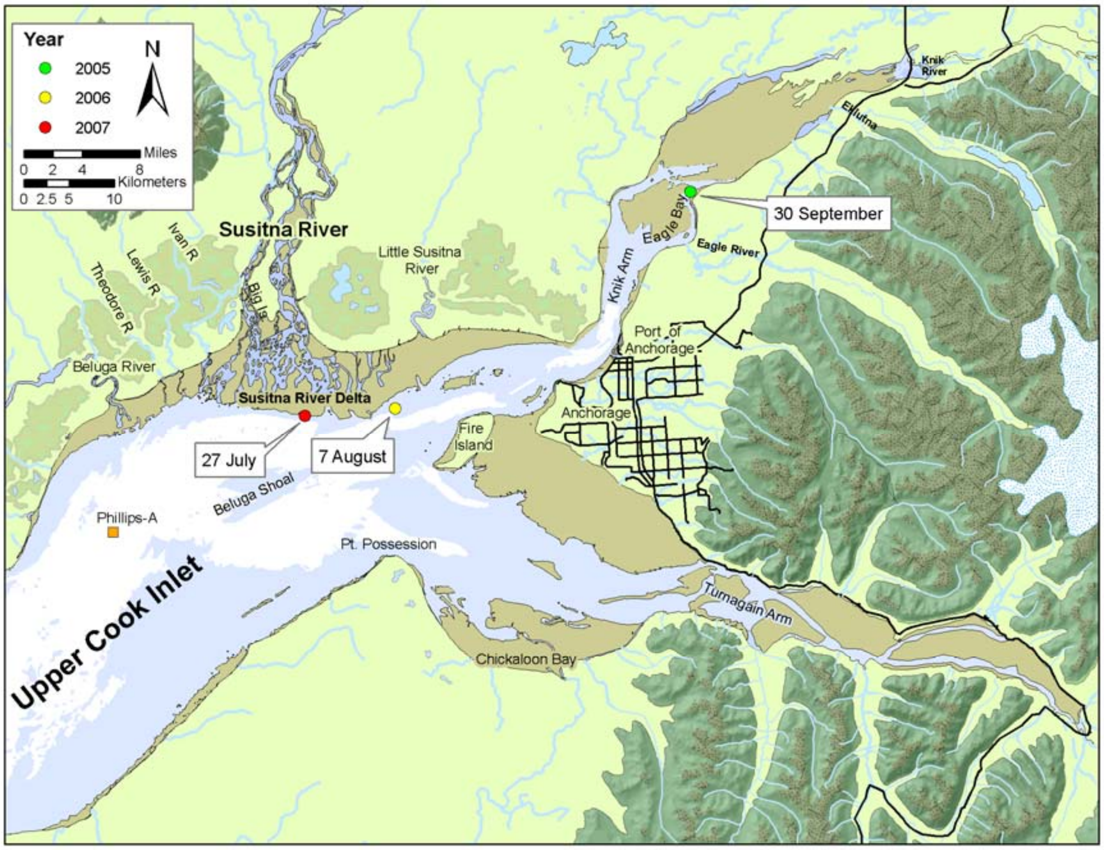
Figure E22. Sighting history (a) and photograph (b) of beluga RS 110.



a.

b.

Figure E23. Sighting history (a) and photograph (b) of beluga RS 118. RS 118 was seen with a calf in Knik Arm in 2005 and in the Susitna Delta in 2006.

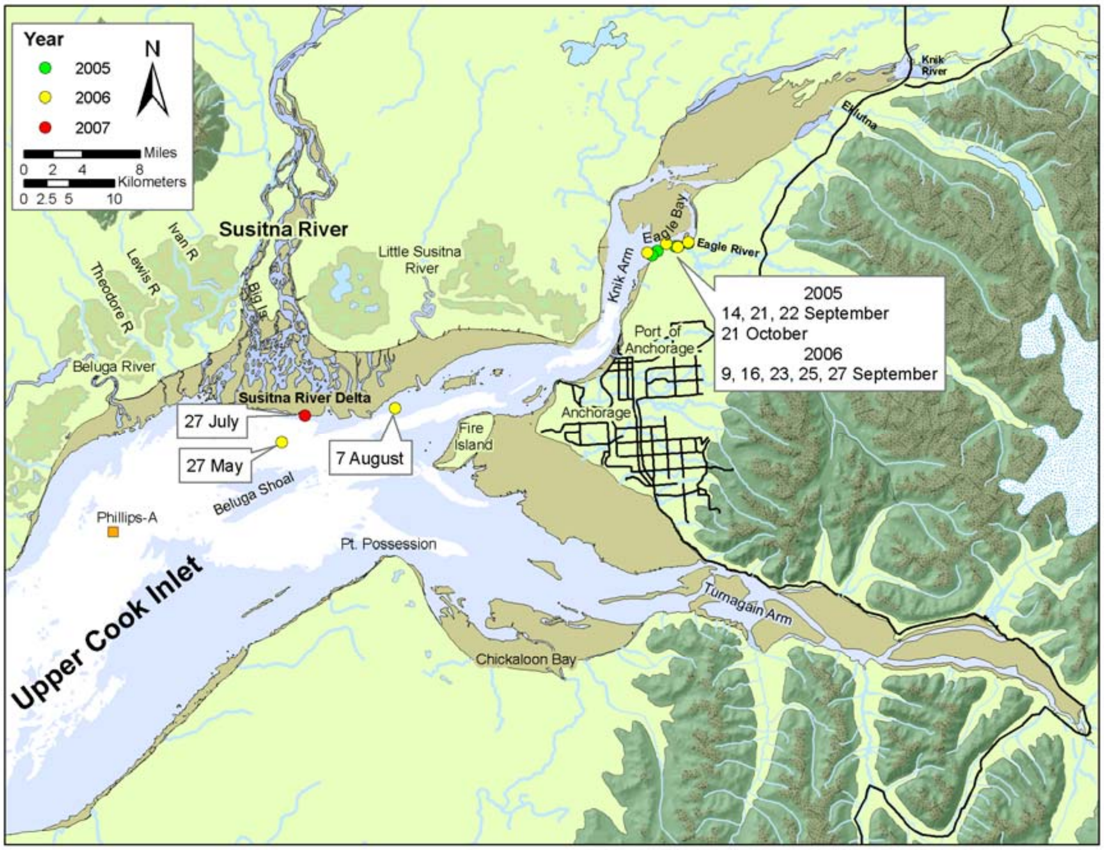


a.

b.

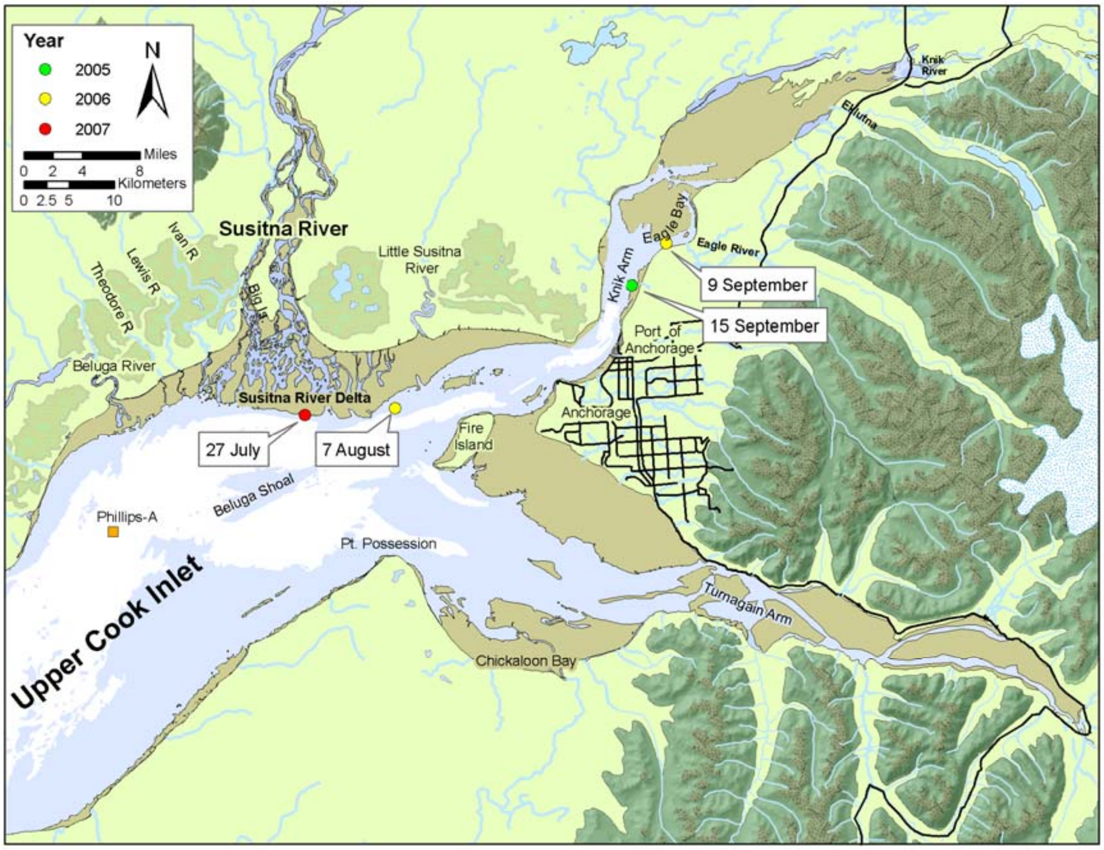
Figure E24. Sighting history (a) and photograph (b) of beluga RS 124. RS 124 was seen with a calf in Knik Arm in 2005 and in the Susitna Delta in 2006.

a.



b.

Figure E25. Sighting history (a) and photograph (b) of beluga RS 139. RS 139 was seen with a calf in Knik Arm and the Susitna Delta in 2006.



a.

b.

Figure E26. Sighting history (a) and photograph (b) of beluga RS 222. RS 222 was seen with a calf in the Susitna Delta in 2006.

APPENDIX F.

REPORT ON THE COOK INLET BELUGA WHALE PHOTO-IDENTIFICATION WORKSHOP HELD ON OCTOBER 16-18, 2007 AT THE NATIONAL MARINE MAMMAL LABORATORY IN SEATTLE, WA

Report on

Cook Inlet Beluga Whale Photo-identification Workshop

Oct. 16-18, 2007

National Marine Mammal Laboratory, Seattle, WA

Prepared by: Rod Hobbs[1], Tamara McGuire[2], Chris Kaplan[2], Sally Mizroch[1]

Participants: Nancy Friday[1], Rod Hobbs[1], Chris Kaplan[2], Barbara Mahoney[3], Tamara McGuire[2], Sally Mizroch[1], Julie Mocklin[1], Dave Rugh[1], Kim Shelden[1], Christy Sims[1], Janice Waite[1]

1) **National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 7600 Sand Point Way, NE, Seattle, WA 98115-6349 USA**
2) **LGL Alaska Research Associates, Inc. 1101 East 76th Avenue Suite B, Anchorage, AK 99518**
3) **Alaska Region Anchorage Office, National Marine Fisheries Service, National Oceanic and Atmospheric Administration,**

Objectives

1) To review the history, current status, and future plans of the Cook Inlet Beluga Whale Photo-identification Project
2) To provide an opportunity for scientists from NMML and LGL to discuss various photo-identification techniques and their application to the study of Cook Inlet beluga whales.

Agenda

Tuesday October 16

10:00 (Observer Training Room, Hobbs moderator) Welcome, Introductions, Overview, Review and accept agenda

10:30-12:30 Presentation by LGL of Beluga Identification Photos and Analysis Q&A and discussion will be limited during the presentation, Hobbs will make a list of discussion topics for sessions and individual meetings as the presentation proceeds.

Lunch

13:30- 14:30 Review of subtopics, scheduling of remaining meeting and catalog reviews.

Break

15:00-17:00 TBA Sessions and catalog reviews.

Wednesday Oct. 17

8:00-15:00 TBA breakout sessions and catalog reviews.

15:00-17:00 Catalog review and discussion.

Thursday Oct. 18

8:00-11:30 Final discussion, recommendations and report writing and review.

Adjourn

Overview of Cook Inlet beluga (CIB) photo-identification project

Chris Kaplan and Tamara McGuire gave a PowerPoint presentation of the CIBW Photo-identification Project. This project was begun by Tim Markowitz of LGL in 2005 and has continued each year since. Kaplan is now the lead biologist for the Project, and McGuire is the Project Manager; Markowitz is no longer with LGL and is currently conducting cetacean research in Kaikoura New Zealand. Photos for identification have been collected both from land and from small boats, in directed studies and opportunistically during other LGL research conducted by LGL on Cook Inlet beluga whales. Three primary groups have supported the research: Chevron (formerly Unocal), Conoco-Phillips, and the National Fish and Wildlife Foundation. Significant support in the form of opportunistic photographs have come from other beluga whale studies including, the Knik Arm Bridge and Toll Authority (KABATA; Funk et. al. 2005), DRven Corporation (Nemeth et. al. 2006) and The Alaska Department of Transportation (Seward Hwy EIS, subcontract through HDR Alaska, Inc.)

Several thousand photos of varying quality and in different formats have been collected. Current efforts are directed toward developing and testing consistent methods for determining quality of photos and suitability of marks on animals for recognition and applying these techniques to the photo collection.

Kaplan presented examples of the types of marks LGL is working with to identify animals and the methods they are using to assess the quality of photos and marks. Both right and left sides of animals are photographed as opportunities arise. Few animals have been matched from the right side to the left (e.g. both sides are known to be of the same individual). Right and left catalogs are of similar sizes. There is some indication that left side photographs are easier to get from land along Turnagain Arm since whales ride the flood tide predictably close to the road on the north side of the Arm. However, since previous analyses focused on the right sides of individuals, and funding was limited, recent research has concentrated on the right side photographs.

There are three sections, or *segments*, of a beluga whale that typically appear and are photographed as it surfaces and submerges: Anterior to the dorsal ridge, the middle dorsal ridge region and posterior to the dorsal ridge. Head and fluke areas rarely break the surface or are photographed. Each segment can be referenced against the length of the dorsal ridge. All three segments are occasionally visible in a photograph, but more often photographs contain one or two segments. Therefore, photograph sequences of a beluga surfacing and submerging are often used to document an individual's complete side (three segments). Two or more photographs taken out of sequence (even hours or days later) can also be used to link two adjacent segments by referencing common markings in each photograph. Marks may be found on all of the segments. The midsection, including the dorsal ridge area and below, appear to be the most readily identifiable, although some well-marked belugas have few or no markings in this area. Examples were given of marks that have persisted for three years and also marks that had faded over the period of the study or even within one summer.

Criteria for assessing photographic quality and "identifiability" of natural marks were presented (Rugh et. al 1998). Photo quality depended on the clarity (exposure, glare, focus, etc.) of the photos, and is judged on a five point scale (1+, 1-, 2+, 2-, 3; best to worst). Identifiability, also judged on a five point scale (H+, H-, M+, M-, U; highly marked to unmarked), is dependent on the size, longevity, and distinctiveness of the marks. Segments that are obscured >75% (e.g., by water or by other belugas) are given an "X" and are not scored. Each segment within the photograph is judged independently and scored for quality and identifiability.

The immediate post-presentation consensus of the group largely supported the conclusion of the LGL researchers that photo identification and re-identification of individual beluga whales is possible, and depending on the markings, could occur over a season or one or more years. There was also agreement on the need to estimate the fraction of the population that could be identified through a summer and from one year to the next; this fraction is required before it would be possible to fully assess the potential utility of these photo id methods for estimating abundance of CIB.

Other technical suggestions included: adding laser pointers (Durban and Parsons 2006) to the camera set up to give a fixed measurement in the id photos in the field, LGL expressed interest in using this tool to measure segment and mark sizes and for estimating other morphometrics (e.g. sizes of individuals, etc.); consider adding a segment for marks on the peduncle region; include "not visible" as a coding for quality of visibility of a sector portion that is partially obscured but can still be scored.

NMML presentations:

Sally Mizroch presented her program for organizing humpback whale photos and recording marks and matches. A separate meeting was set up to discuss camera gear, file formats and image handling; that meeting is presented below. Janice Waite presented the methods used by Durban et al. for collecting and managing killer whale photos. Dave Rugh and Julie Mocklin presented bowhead photo id methods and data management.

Break out meeting to discuss print vs. digital matching, protocols, and databases

Chris Kaplan, Tamara McGuire and Sally Mizroch met to discuss photo and field data editing protocols, data management and Access database efficiencies.
Many photo-ID researchers (including all photo-ID research projects at the National Marine Mammal Laboratory) use the RAW format for digital documentation of individuals because RAW images are the most accurate photo record that a digital camera can produce. RAW photos are akin to a photo negative and can be edited to adjust for lighting conditions and distance. The JPEG format is considered a "lousy" format and JPEG compression algorithms reduce the accuracy of the image and in some cases can add digital artifacts (erroneous markings).

Although the original photo format is RAW, the RAW files can be converted to very accurate JPEG files to be used as working images for matching and for transmittal of data. The RAW files are archived and used as reference photos in case extra magnification or editing is called for.

Protocols for batch processing RAW (uncompressed, high quality) photos into small, high quality JPEG photos were demonstrated (see http://www.afsc.noaa.gov/nmml/pdf/NMMLDigitalPhotoProtocol.pdf). Field photos can be separated into folders for each field encounter and a descriptive encounter number can be assigned to all the photos taken during a particular encounter using ACDSee batch processing tools.

EXIF metadata fields can be edited efficiently using ACDSee batch tools. Descriptive (left or right dorsal) data can be entered in the metadata in batch mode. Photos can be sorted by metadata fields in the ACDSee browser environment, evaluated for resightings of individuals within each encounter and quality graded. A temporary field ID can be assigned and edited directly into the EXIF metadata.

Latitude/longitude of each photo can be embedded directly into EXIF metadata using off-the-shelf software (RoboGeo; www.robogeo.com) which links the date/time stamp in each photo with data from the GPS unit or a GPS trackline database.

Once the EXIF metadata have been input for the field photos, selected photo metadata can be imported directly into an Access database. Once the photos are in Access, hyperlinks can be used to display each photo with a click. Subsequent grading (e.g., best photo per encounter and best photo overall), coding for distinctive characteristics and eventually selections for match can be done.

Access table structure, queries and forms were shown and discussed, including an example data entry form (with combo box/drop down menus), example photo grading form (using a simple access query with hyperlinks), and an example photo matching form (using the FlukeFinder humpback whale system).

Breakout Session to discuss photo issues specific to belugas

Christy Sims presented the beluga aerial survey video and photo data management, the video analysis software used in the Cook Inlet beluga whale abundance estimate, our current and past methods for determining the gray scale of the images, and methods for including metadata with photos and video.

Considerable post-presentation discussions ensued on the possibility of relating the gray scale of animals seen from the air and on the water. While the aerial video has fairly consistent lighting, grayscale of the images in the counting video are unreliable due to pixilation around the edges. However, images in the zoomed video are sufficiently large that the pixels in the interior of the image should relate to the actual gray scale coloration of the whale. The photo id photos have a more variable lighting and as a consequence the same animal can appear dark gray in one photo and white in another photo with different lighting. Consistent lighting was considered the key issue for determining the gray scale of the whales in the photo id data, with three possibilities considered: 1) only using photos with the sun behind the photographer, 2) use of a flash, narrow spot or laser to provide consistent illumination of all or part of the animal and 3) use of a standard gray scale card either mounted on the camera or the sponson of the boat that would be illuminated by the same lighting as the whale and appear in the photo with the whale or photo graphed in the next frame. The second was not considered practical for use with long lenses but could be used at close quarters from a boat. The third option was thought to make the photography a bit awkward, but it offers a simple low cost solution that would allow useable gray scale measures in most lighting conditions. It was agreed that NMML and LGL would work toward developing a common gray scale measurement system that could be used for both id photos and aerial images and also to measure gray scale on stranded, or live captured animals and beach cast carcasses.

Break out session discussions

Feasibility and Usefulness

Three approaches to abundance estimation were discussed: mark-recapture estimates using photos for one season (intra year); photos from several seasons (multiple year);and estimates directly from the catalog (number of identified individuals). The feasibility of each of these depends on the reliability and longevity of marks, the rate of occurrence of new marks, the markedness of individuals in the population and the fraction of unidentifiable individuals.

An estimate of abundance from intra year data would ideally be based on photos collected during a 1 to 2 month intensive survey so that few marks would disappear or new ones appear. Consequently animals with recognizable marks would have equivalent marks through the survey period and some ephemeral marks that would not last to the next year such as skin lesions, bruises, gray and white pigment variation and surface scratches could be used. Recapture probabilities would depend heavily on the spatial distribution of survey effort, so each area should be surveyed several times through the season and effort (time spent at each location) recorded. An advantage of this approach is that the population could be treated as a closed population.

An estimate from multi-year data has the advantage of also estimating survival and recruitment or births. It would require less effort in any one year than the intra year estimate. This approach would require documented effort, spatially distributed through season to minimize heterogeneity. Documentation of mark longevity and estimates of probability of recognition from year to year would be necessary so that changes in marks could be accounted for when estimating survival and recruitment.

Using the number of identified individuals as a minimum population size has the same requirements of photo quality as a mark-recapture estimate but does not require the same level of documentation of effort. Only the best quality, identifiable photos can be used, but one excellent photo per animal is sufficient. This method does not account for mortality and recruitment, so it is problematic to combine years. The likelihood of encountering each whale will determine the total number of recognized individuals so the minimum number will be determined by effort.

The collection of longitudinal data on individuals was also discussed. Life history information including: growth, changes in coloration with age, movements and habitat use, family structure and reproductive history of females can all be collected by following individuals for multiple years. For individuals that are not followed from the birth year, it would be useful to have an estimate of age at some point, so that the birth year could be determined. To this end, it would be important to get yearly photos of calves of the year, older calves and juveniles and the presumed mothers. Because rapid growth may erase or distort marks, the associated adults may be necessary to make identifications from one summer to the next.

Longevity of marks is a key issue. This project can determine longevity of different types of marks by comparisons over several years of well-photographed individuals and known individuals in photo archives. To this end, NMML and AKR will provide photos of tagged whales and recent mortalities where available and photograph future mortalities and captured whales for comparison to the catalog.

Determining the fraction of recognizable animals in the population is difficult and will require careful analysis of the best-quality photos in the collection. One approach would be to consider sectors on each animal separately and determine the probability of marks in each sector and each animal as a random selection of sectors. The number of unmarked animals would be related to the probability of drawing all unmarked sectors. This would also allow testing of rules for determining which sectors are required for a usable photo.

Heterogeneity

In the data and in the analysis

Mark-recapture analysis is sensitive to heterogeneity in the data. The workshop discussed a variety of forms of heterogeneity and recommended approaches to account for them in the analysis. Association among animals: Individuals that are always seen together may be a family or social group. Individuals that are only seen in some areas may be a geographic sub group. Groups of all grays or all white may indicate segregation by age. Groups with a large fraction of calves or no calves may indicate segregation by reproductive status or sex. All of these can be accounted for by documentation of time and location of photographic effort and time sequencing of photos (which has been done throughout the project). Association among animals with similar marks can occur since mark types can be dependent on risks of injuries resulting in recognizable marks that is inherent to the areas different groups inhabit; this can result in heterogeneity of the fraction of recognizable animals by group or location.

In photo capture probability:

This can arise from individual behaviors in response to boats and may vary by age, sex, reproductive status, location, or activities. Behaviors may include moving away from the boat (avoidance), moving toward the boat (attraction), increased dive time, or increased surface time. These avoidance and attraction behaviors may vary by location due to prior experience of whales in that location (e.g. Whales with experience of hunting may have a greater tendency to avoid boats on hunting grounds than other areas) or due to typical behavior in feeding areas and transit corridors.

In detection of animals by the photographer

White animals are more easily seen than gray animals at a given distance from the group and are generally the first animals to be seen. This may result in bias toward photographing white animals. Gray animals are more likely to be photographed closer to the boat both because of their lower detection distance and their greater curiosity about the boat. This may result in better photos of the gray animals that are photographed. Finally, habituation to boat and photo experience may result in changes in behavior of the animals.

Variation in effort coverage: This may result from geography due to access, risk or travel time. Seasonality is an issue, but limiting effort primarily to June to September is OK if consistent from year to year. Annual variation in effort due to funding or personnel can be accounted for in the analysis if effort is documented and quantified.

Variations resulting from changes in personnel: Individual variation among researchers and their prior experience can affect photographic technique and resulting quality, interpretation of photos and marks, boat handling, and success of photographic effort. This can be minimized by having multiple independent readers, well-defined protocols and training and both internal and external peer review.

Review of Catalog

The entire group met to discuss the pilot protocol for scoring beluga photos (based on Rugh et al. 1998). Scoring consists of dividing each photo into body sections, and then assigning a score for photo quality and a score for mark identifiably to each section.

Kaplan provided the group with an assortment of photos from 25 individual beluga whales which have been sighted in all three of the field seasons. Participants had approximately 1 hour to review all photos and were given a list of a selected subset to individually score. The group reconvened to compare scores, discuss difficulties with the scoring protocol, and to make recommendations for modifications to the protocol (below).

1) Photo quality scores should take into account how much of each segment is visible.
2) Consider looking only at the middle sector, dorsal ridge and flank below the ridge for mark/recapture; and include all sections for other analyses. There is a trade off between identifiable individuals and usable photos.
3) Need to define what constitutes an “unmarked” whale. Will need to quantify from field data and from photos the proportions of marked and unmarked whales.
4) Issues of heterogeneity How to estimate the proportion of unmarked whales that are not seen? Analysis goals will determine if unmarked proportions of the population are included or excluded (e.g. will need to include these in an abundance estimate but not for an estimate of calving intervals).
5) Treat left sides independently from right sides. For each identified individual, note if have photos of left side and right side.
6) Ensure that the H+ quality rating (for mark identifiability) indicates only a highly marked segment in a photograph so a useful range of grades is maintained. This category should only be used to rate those marks which are unmistakable enough to be seen in even very blurry photos.
7) Recommend dropping the peduncle region out of mark-recapture analysis, but keep it for other applications.
8) Be sure to consider inter- and intra- observer reliability, and implement checks over time against a reference set of scored photos, to keep scoring standardized.
9) The size of the mark is probably not as important as the distinctiveness of the mark. Make size of mark a subcategory rather than a category.
10) Emphasize the importance of testing specific variables under consideration for scoring criteria, and the importance of documenting these criteria.
11) Conduct several mark-recapture analyses, with different levels of criteria (e.g., one run with only H+’s , another run with only M+’s and above, etc.). This will produce a range of abundance estimates providing inferences related to which models and criteria levels are included.
12) The current use of “focus” as the primary rating is too restrictive, as sometimes the focus is not great, but the photo is still of useable quality.

13) Understanding methods and protocols used by other researchers on other species is important, but this work should be tailored to attributes specific to belugas. (i.e. difficult to define dorsal ridge, animal usually photographed in sections, marks often white on white, etc.).

Conclusions and Recommendations

While further refinement of techniques is required, it was the consensus of the workshop that it is technically possible and quite feasible to develop a photo catalog of recognized beluga individuals for the Cook Inlet population. The group recommended that the annual photo effort should continue but incorporate the recommendations included in the body of this report. Of particular concern were: 1) careful documentation of type and longevity of marks and the rate of occurrence of new marks, to estimate likelihood of reidentification from year to year and longer; 2) documentation and even distribution of effort and 3) analysis of heterogeneity within the data. The group recommended that a second workshop be planned to consider how to estimate abundance and life history parameters after the results from items 1 and 3 above were available.

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APPENDIX G.

PHOTOGRAPHS AND SUMMARIES OF BELUGA WHALE MORTALITIES ENCOUNTERED AND RECOVERED FOR NECROPSY WHILE CONDUCTING PHOTO-IDENTIFICATION SURVEYS OR OPPORTUNISTICALLY

Mortalities Encountered during Surveys

2004

Figure G1. The left side of a dead Cook Inlet beluga whale that was reported by a LGL land-based beluga observer stationed at Cairn Point in Anchorage, Alaska. When first sighted at 4 PM on 29 September 2007, it was drifting offshore approximately ½ mile north of the Port of Anchorage. On 30 September 2004, LGL biologists towed the whale to shore near Birchwood and assisted a NMFS biologist with the necropsy.

2006

Figure G2. The ventral side of a dead male Cook Inlet beluga whale, with the head just below the surface facing away and with the left front flipper in the air. It was encountered drifting 2.75 km offshore of Peters Creek at 6:30 PM on 31 August 2005 during a cetacean survey. LGL biologists collected tissue samples, photographed and towed the whale to shore, tethering it off near the Birchwood airport. NMFS personnel were contacted and a necropsy was performed on 2 September 2005.

Mortality Encountered Opportunistically

2007

Figure G3. On 8 October 2007 LGL biologists tethered, photographed and took skin samples from this dead male beluga beached and lying ventral side up at Northland Dock in Anchorage, Alaska. Information regarding location and conditions were relayed to NMFS.