Photo-identification of Beluga Whales in Upper Cook Inlet, Alaska: Final Report of Mark Analysis, Mark-Resight Estimates, and Color Analysis from Photographs Taken in 2008.

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INTRODUCTION TO THE 3-CHAPTER REPORT

Alaska's Cook Inlet beluga whale (CIBW) population (*Delphinapterus leucas*) is considered a distinct population segment (DPS) by the National Marine Fisheries Service (NMFS) and was listed by NMFS as endangered under the Endangered Species Act in October 2008 (NMFS 2008a). There are many information gaps and uncertainties associated with the current understanding of the CIBW population (NMFS 2008b). Information needs include precise annual abundance estimates of the overall 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 CIBW photo-identification study has been ongoing since 2005, and has demonstrated that a large number of beluga whales in Upper Cook Inlet possess distinct natural marks that persist across years, and that these marks can be effectively identified and re-sighted with digital photography (McGuire et al. 2008, McGuire and Kaplan 2009, McGuire et al. 2009). Photo-identification of Cook Inlet beluga whales has proven to be a useful tool for learning about distribution, residency, movements, social grouping, and life histories of Cook Inlet beluga whales (McGuire and Kaplan 2009, McGuire et al. 2009). Ultimately such information may help to explain observed population dynamics and trends in abundance, and therefore provide important guidance for management decisions. Methods and results of the project were presented to NMFS scientists at the National Marine Mammal Laboratory (NMML) in 2007, and the ensuing workshop report stated their support of the project and utility of the information it provides (Appendix F in McGuire et al. 2008).

The current CIBW photo-id catalog contains records for approximately 200 individually-identified whales, including social association histories of belugas that have been seen in every year of the study, and preliminary information on life history characteristics such as survival and calving intervals (McGuire et al. 2008, 2009). The information about CIBW provided by the photo-id study is unique and is not available from other studies of CIBW, such as aerial surveys, satellite-tagging, acoustic monitoring, or visual observations.

The original objectives of this study were to:

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

A fifth objective, added in 2007, was to:

5. determine CIBW life history characteristics, such as calving frequency, calving interval, period of maternal care/association, survival rates of calves, and survival rates of identified individuals.

This report addresses progress made in meeting objective 4 and part of objective 3 ("describe age-class distribution"), and is the third report in a series of three this year. The first report (McGuire and Kaplan 2009) provided a summary of field effort and survey results from 2008, as well as descriptions of modifications to photo-identification field methods implemented in 2008. The second report (McGuire et al. 2009) addressed progress made in meeting objectives 1, 2, 3, and 5, and presented analyses of photographs of whales encountered and identified in 2008, including sighting rates, distribution, movement patterns, group associations, and information on mother/calf associations.

This report is divided into three chapters. Chapter 1 presents results of an analysis of mark types and mark locations seen in photographs of CIBW. The purpose of Chapter 1 was to examine mark-longevity, -causation, -change over time, and -accumulation rate, in order to understand and document markings that persist across years. Chapter 2 describes the selection and processing of photographs, a suitable mark-resight model, and mark-resight abundance estimates of beluga whales obtained from photographs taken in the summer and fall of 2008. The purpose of Chapter 2 was to examine the feasibility of using photographs of CIBW and mark-resight methods to estimate abundance. A precise method of abundance estimation will provide more power for detecting trends in the population. Chapter 3 summarizes techniques and analyses developed in 2008 to quantitatively determine whale color from photographs. The purpose of Chapter 3 was to develop methods that will allow us to document the chronology of color change by identified whales, which will contribute to a better understanding of the relationship between age-class and whale color. The potential to derive demographic indices for the population by using color as a proxy for age-class represents a tool for monitoring the status of this population through changes in age structure.

All boat-based photo-identification surveys in 2008 were conducted under NMFS General Authorization LOC # 481-1795-01, PI Tamara McGuire.

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Chapter 1:

Longevity and Causes of Marks Seen on Cook Inlet Beluga Whales

Final Report

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INTRODUCTION

LGL Alaska Research Associates, Inc. (LGL) began development of a photo-identification (photo-id) catalog of Cook Inlet beluga whales (CIBW) in 2005. Photo-id of CIBW has been proven to be an effective way to gain detailed information about movements and seasonal distribution of known individuals and groups of whales (McGuire et al. 2008a, 2008b, 2009; McGuire and Kaplan 2009). Future photo-id work promises to add critically needed information about fine-scale beluga habitat associations (Moore et al. 2000, Hobbs et al. 2005, Goetz et al. 2007) and generate baseline data about CIBW age class and social structure. Photo-id has also been used to develop survival and abundance estimates for several different cetacean species (reviewed in Hammond et al. 1990). Photo-id techniques can be used to complement aerial surveys for CIBW conducted annually by the National Marine Fisheries Service (NMFS 2008) and can be helpful in determining abundance estimates and trends. The use of photo-id techniques to develop abundance estimates for CIBW is discussed in Chapter 2 of this report.

Researchers from the National Marine Mammal Laboratory (NMML) and LGL discussed the utility of the Cook Inlet beluga photo-id catalog at a workshop hosted by NMML in October of 2007 (Appendix F in McGuire et al. 2008a). Among other topics, several approaches to developing survival and abundance estimates were discussed. Workshop participants concluded that the feasibility of all approaches depended on the reliability and longevity of marks used to identify individual beluga whales and on the ability to estimate the fraction of the population that is unmarked.

In order to produce unbiased survival or abundance estimates, it is necessary to understand and document marks that persist across years. Photographic histories of known individual belugas photographed during 2005-2007 were compared to more recent photographs of the same whales taken in 2008. The four main objectives were to gain a better understanding of mark: (1) longevity, (2) development (i.e., when marks originated and their changes through time) (3) locations on the whales' bodies and (4) causes. The cause of marks was an important aspect of this analysis because knowing sources of marks may provide insight into mark longevity, sources of mortality, and potential stressors present in the environment.

METHODS

Two main categories of marks were observed and designated as *primary* or *secondary* marks. Primary marks were the "lasting" marks used to identify whales both within a season and across years and were typically white in color. Secondary marks were the approximately circular, fresh or healed lesion-like blemishes that were either dark or white, and more recent cuts or other wounds such as rakes, etc. (see below for more details). Secondary marks were sometimes used to aid in matching within season but were usually not considered reliable to use for matching individuals among years. Fresh cuts that were typically initially dark in color with raised and separated adjacent edges (Geraci and Bruce-Allen 1987; Figure 1.1) were also regarded as secondary marks until they could be followed across years after a lasting scar was formed.

This analysis was done using individually identified whales in the catalog (Figure 4 in McGuire et al. 2009) that were photographed in 2008 and also in one or more earlier years (2005–2007). Cataloged individuals were encountered (an encounter was an observation on a single field day) one or more times in each year. Photographic records for each individual were examined in regard to: (1) primary mark longevity, (2) the formation of new primary marks (3) location of marks on the body (4) the likely causes of marks.

Primary marks were thought to be caused by conspecifics, predation, bullet wounds, satellite tagging, ship strikes, entanglements or unknown sources. Secondary marks were believed to be caused by disease (lesions) or new wounds, which could be from any of the same primary sources, but appeared sometime after the first encounter of a whale.

Prior to this analysis, a single analyst familiar with the catalog had compared individual whales within and among years by examining each new photograph to determine if there was a match to records of individual belugas identified within that year or in previous years. A second analyst then confirmed all matches. If a match was made to a previous record, the new photos were admitted into the catalog (McGuire et al. 2009). Nearly all whales had a minimum of three primary marks (across all cells); three whales were matched using combinations of roughly white circles (old lesions), considered secondary marks in this analysis.

Each available cell (Figure 1.2) within each photograph was scanned for available marks in each category. Only one mark of each type (the most prominent) for each cell was searched for and recorded if present in each photograph. Mark totals were tallied into a Microsoft® Excel spreadsheet by a single analyst scanning photographs (JPEGs) on a high-resolution monitor using a sequential pane viewer application built into the photo-id database (Appendix C in McGuire et al. 2008a). Primary and secondary marks used to identify cataloged whales were examined chronologically beginning with the first encounter of a whale, then within a field season, then across years, with analysts noting any changes to the marks. As individually identified whale folders were scanned, any new marks that might have partially or completely obscured any primary mark were recorded. Not all individuals had photographs suitable for analyzing and/or primary markings, so a variable number of marks was examined per whale depending on the available number of photographs of each individual. Only the photographs of "acceptable" quality (2-; see Chapter 2 of this report) and above were examined.

Primary Mark Longevity

We are in the process of developing a mark-resight model that estimates mark survival (i.e., longevity; see the section entitled Future Work). For now, we tested to see if the average number of years between the first and last sighting was affected by the number of cells (range 1-6) with primary marks. The number of years between the first and last sighting was a minimum estimate of longevity; in other words, we know the mark lasted at least that long, but would likely have lasted longer. If primary marks were lost at some decaying rate, having more marks should increase the average length of time between first and last sightings. Finding no relationship would suggest that having more than one primary mark did not increase our minimum estimate of longevity, and in turn that the mark loss rate was low. Further, this analysis provided the minimum length of time primary marks were sightable. We used Poisson regression with a log-link function to regress minimum longevity from the number of primary marks.

Formation of New Marks

We searched for new marks within seasonal encounter records and then across years to determine if lasting scars formed. New marks were those that were notably absent in earlier photographs, then appearing in later ones. Typically new marks were darker than the surrounding skin with raised edges (Figure 1.1). Once a new mark was found, the location was scrutinized in each subsequent year's photographs to determine if the mark had persisted. Changes to the mark shape or color were recorded. New marks could not always be seen in subsequent years, and this often depended on the portion of the whale's body visible in photographs.

New marks seen for the first time in 2008 were recorded and assessed separately. As with primary marks, the possible source of the marks was recorded. New marks seen in 2008 were summed across all individuals' cells and presented as totals by cell.

Locations of Marks

The locations of marks in photographic records of individual whales in this analysis were recorded according to body cell (Figure 1.2). A cell may have contained zero to several different mark types. The locations of marks that were classified according to possible cause are presented as a percentage of total marks seen on all individuals examined.

Causes of Marks – Natural, Anthropogenic and Unknown

Mark cause was divided into three main categories: natural, anthropogenic, and unknown. Natural marks may have come from predation, interaction with other belugas, and disease. Additionally, though not regarded as a "mark", molting of skin was also examined. Anthropogenic marks included those suspected to have come from bullets, ship strikes (bow or propeller), entanglement, and satellite tagging (Hobbs et al. 2005). Mark types were summed across all body cells (Figure 1.2) for each identified individual, and then presented as percentage of all individuals that had one or more marks.

Natural marks

Tooth-rake marks in photographs were defined as those composed of two or more parallel lines (Figures 1.3 and 1.4). Tooth rake marks assumed to be caused by other belugas were those estimated to be <2 cm (0.8 in) apart based on published reports of inter-tooth spacing of ~ 1 cm (0.4 in) in belugas (George et al. 1994) and our observations of beach-cast belugas with a tooth center distance ranging from 1.5 to 2 cm

(0.6 – 0.8 in) and maximum spacing between teeth of 1 cm (0.4 in; Figure 1.5). To estimate sizes of tooth rake marks in photographs, the relative sizes of the rakes were compared to the dorsal ridge height (Cell C; Figures 1.2 and 1.4). Ridge height was previously estimated to be 4 cm (1.6 in) using laser metrics (McGuire et al. 2008a) but this distance included the rising area at the base of the ridge. Recent measurements of adult beach cast whales (*n* = 2) indicated that the actual raised portion of the ridge was approximately half of that, or two centimeters. We also considered that juvenile whales would have a smaller ridge and that variability inevitably existed among individuals. Using two centimeters as a general reference height, tooth rake-mark separation that appeared smaller than the ridge height were attributed to conspecifics and larger tooth rake-mark separation was classified as possible predation attempts by killer whales (*Orcinus orca*). To further aid in classifying rakes as caused by killer whales, photographs were compared to known killer whale rake marks (Craig Matkin, personal communication) and photographs of marks attributed to killer whales from the literature (George et al. 1994, Steiger et al. 2008). Pictures of mortal wounds inflicted during a known killer whale predation event in Cook Inlet were also evaluated (Figure 1.6; Hobbs and Shelden 2008). CIBWs in photographs were examined for possible signs of shark predation, such as ragged rake marks or bite marks, as described for sharks (Heithaus 2001, Scott et al. 2005) known to occur in Alaska.

Marks thought to be caused by disease were lesion-like circles attributed to herpes-like viruses in studies of free-ranging and captive belugas (Martineau et al. 1988; Barr et al. 1989; Burek Huntington 2000, unpublished data; Measures 2007). For mark-resight purposes (see Chapter 2 in this report), these marks were considered as secondary marks (described above) and used for preliminary matching only; they were not used in the abundance model. Marks from lesions were not relied on as primary marks judged capable of being followed over several seasons since these lesions in photographs have been observed to appear abruptly within the summer-fall season (Figure 1.7). Marks caused by lesions were divided into "fresh" and "healed" categories. Marks that were listed as fresh lesions were approximately circular with raised or lowered margins (Martineau et al. 1988; Barr et al. 1989; Burek Huntington 2000, unpublished data). Those classified as healed lesions were white in color with no raised margin. The attributes assigned to healed lesions were primarily based on observations of wound healing in photographs of CIBW within and across years, where the wound healing process showed a progression from a raised margin and lowered center to flattened, and a color change from dark to white (Figure 1.7).

Molting skin in photographed individuals was evaluated for "old" yellow or "new" white skin noted by Native hunters in the spring and fall, respectively (Frost et al. 1993). Notable changes in skin such as sloughing or discoloration were also examined (St. Aubin et al. 1990).

Anthropogenic marks

Classification of marks suspected to be caused by bullets, ship strikes, or entanglements was based on comparisons of scars and deformities seen in catalog photographs to descriptive classifications and photographs of injuries to other marine mammal species in the literature (Figure 1.8; Figures 19-22 in McGuire et al. 2008a, Wells and Scott 1997, Read and Murray 2000, Rommel et al. 2007, Azevedo 2008, Bradford et al. 2009).

Eighteen Cook Inlet belugas were equipped with satellite tags by NMFS between 1999 and 2002 (Hobbs et al. 2005) and the scars left by these now-shedded tags were obvious. Satellite-tag attachments created unique primary marks that were used along with other primary marks to identify individuals in photographs. We attempted to match the non-satellite scars seen in photographic records of tagged individuals in the 2005-2008 catalog to photographs taken at the time instruments were attached.

Unknown marks

Unknown marks were those marks that could not be attributed to any known source. These included single or multiple scar lines that were not notably parallel with any other line, undefined deformities, and non-uniform bleach-like marks (Figure 1.9a). Also included in the unknown category were the thicker dark-colored marks that were rarely seen on CIBW (Figure 1.9b).

RESULTS

In total, 110 individual whales photographed and identified in 2008 were also identified in one or more years from 2005 to 2007. A total of 3,502 photographs of acceptable quality (2-; see Chapter 2 in this report) were examined.

Primary Mark Longevity

Seven individual whales in the photo-id catalog had one or more primary marking that changed notably over the period they were photographed (one to three years, depending on the whale). Five of the seven had marks that were initially dark in color that later turned white, while the overall mark shape stayed about the same. One individual had a mark that appeared white in initial photographs, then later turned black (or was filled with silt) in photographs during the subsequent two seasons. On one beluga whale, a darker mark turned white and became more diffuse and spread out, and looked as though it would soon disappear. Most whales were identified by multiple primary marks. Less than 4% of the primary marks evaluated in the 110 individual whales photographic-data sets changed significantly enough across years to the point a single mark might be missed or misidentified, but no mark completely disappeared. All changes occurred slowly (over years) and therefore were sufficient to identify whales for the 2008 abundance estimate (Chapter 2 in this report).

There was a 71% chance that minimum longevity (years between first and last sighting) was unaffected by the number of primary marks that each whale had when first sighted (i.e., the intercept model was favored 2.5:1; Figure 1.10). The average minimum longevity estimated with the intercept model was 2.7 years (n = 110, range = 1-3). It is worth mentioning that the lower range value of one indicated that all whales with primary marks were seen at least one year later.

Formation of New Marks

Marks classified as "new" were identified and followed across years in photographic records of 27 individually-identified whales. New marks disappeared within a single year in eight cases, within 1-2 years in eight cases where sightings of individuals skipped an interim year, and within 1-3 years in four cases where interim year data were not available. New marks persisted into 2008 in five cases, lasting from 1-3 years. On two individuals the locations of new marks from prior years were not visible in photographs to confirm whether or not they were there (Table 1.2).

Ten individuals (9% of cataloged whales) had a total of 19 new marks in 2008 (Table 1.3). Conspecific rake marks were noted on four individuals, fresh lesions on two, predation rakes were seen on one individual, and the mark source was unknown for three individuals. None of the new marks completely masked the primary marks that were used to identify whales in previous years.

Mark Locations

Of all the primary marks evaluated, 4% occurred on Cell A, 19% on Cell B, 13% on Cell C, 31% on Cell D, and 33% on Cell E (Figures 1.11 - 1.13). Lesions were recorded in all cells, although healed lesions were not observed in the ridge area (Figures 1.14 and 1.15). Satellite-tagged whales typically had marks in Cell B from bolt-through tags or the dorsal ridge (Cell C) from spider tagging (Hobbs et al. 2005).

Causes of Marks – Natural, Anthropogenic and Unknown

Tooth-rake marks from other belugas were noted on nearly a quarter of individuals identified in 2008 (Table 1.1). Tooth-rake marks deemed large enough to have resulted from predation attempts were observed on 16 individuals. A total of 62 lesions (fresh and healed) were noted and assigned to 11 and 15 percent of all individuals, respectively. Obvious signs of molting skin were not observed in any photographs. Five individuals that were resighted in 2008 had marks from satellite tags. Possible bullet holes were observed on three whales. Ship strikes were considered the most likely cause of marks on four whales. Unknown mark types were the most common primary marks used to identify whales. Most individuals had at least one unknown primary mark. Of the 110 individuals evaluated, 53% possessed at least one natural mark, 11% had at least one anthropogenic mark, and 85% had at least one mark of unknown origin.

DISCUSSION

Overall Mark Assessment

Understanding mark formation and longevity is a key aspect of photographic identification. In order to continue to track individuals over years or to perform quantitative assessments of vital rates, mark evaluation is required. This examination provided confirmation that the white primary marks used for identifying beluga whales were lasting and changed little across years. By defining different mark types and recording the locations where marks were found on each whale's body, we determined locations where the various types of marks were most abundant, which helps to provide insight into mark causes. For example, marks may be unevenly distributed across the body depending on the source of the mark (e.g., predation, conspecifics, anthropogenic).

Primary Mark Longevity

The chosen sample (*n* = 110; a sizeable portion of the population) may represent individuals that have a greater proportion of primary marks. Since scars are acquired over a lifetime, it stands to reason that older whales would exhibit more primary marks than younger whales and therefore this sample was probably composed of older, well-marked whales. Nevertheless, all primary marks were seen at least one year later. Minimum longevity (years between first and last sighting) was more likely the same across whales that differed in the number of primary marks they had on the first sighting (Figure 1.10); this finding suggested that the mark loss rate was very low. If it was high enough, then a more pronounced difference in minimum longevity would have been observed because whales with many marks would have a greater chance of retaining a primary mark for longer. For example, a whale with six marks would have six chances at retaining a mark versus one chance for a whale with just one mark. However, if no marks were lost, longevity would be about the same regardless of the number of marks present; this latter scenario was more likely (71% chance). There was a 29% chance that minimum longevity increased with more marks (Model 2; Figure 1.10), but the effect size was low. The slope was an increase of 0.06 years (about 21 days) in minimum longevity for every mark added.

The primary marks used to identify whales across years did not change substantially in nearly all cases. Some primary marks did evolve in shape and color, changing slightly in overall appearance, but were still recognizable in photographs taken over several years. In one case, two of the main marks that were used to initially identify a whale had faded nearly completely away; fortunately this individual had several other smaller marks that could still be recognized.

Most primary marks were white. Of the small number of darker-colored marks chosen to follow individual whales across years, six of the seven changed to white. These were probably newer marks in early photographs that were forming lasting scars. Severe wounds that caused disfigurement, or deep scars, may intermittently fill with silt, causing these marks to appear dark in photographs. Based on these findings, further efforts will use multiple white primary marks and evaluate darker marks with caution.

No primary marks were completely obscured by new marks, although in two cases, new marks did overlap some part of the original marks used to identify whales. Using multiple marks over all of the body cells to identify each individual reduced the chance that whales became unrecognizable over seasons. CIBW appeared to have marks that were less ephemeral than those of some other cetacean species (e.g., dolphins; see Scott et al. 2005), however to maintain a working catalog of identified individuals, it is evident that consistency and continuity in photographing effort each season must continue.

Formation of New Marks

Few new marks noted in photographed individuals in 2005-2007 have remained and lasted into 2008 (Table 1.2). This suggests that the overall mark accumulation rate is low.

Younger whales have a faster-growing dermis and epidermis (Reeb et al. 2005) and therefore would be likely to have more rapidly-changing marks than would older whales. Few neonates (classified by fetal folds and peanut-shaped heads) were photographed. The small number of photographs of what were believed to be neonates showed few or no marks on individuals, or if marks were available, in most cases they appeared superficial. Because they have a rapidly changing epidermis, it is doubtful that neonates will be able to be identified and followed (photographically) from birth; however, neonates (and older calves) might be followed using the mother as proxy for the mark (Kaplan et al. 2008) until the calf develops its own marks. In general, younger beluga whales probably have few marks because they have had less time to accumulate them. If older whales are better marked, they should be more likely to appear in the catalog than younger whales.

The best marks to identify whales are probably from wounds through the epidermis into the dermis layer that heal to form white scars (Geraci and Bruce-Allen 1987). These scars persist and can be used to identify individual whales over time, learn about individual movement patterns, group and habitat associations, and life history characteristics (McGuire et al. 2008a, 2008b, 2009; McGuire and Kaplan 2009). These lasting marks can also be used in mark-resight analyses within and across years if they are carefully selected from high-quality photographs (see Chapter 2 in this report).

Locations of Marks

Primary marks were predominantly found in cells D and E (Figure 1.11 - 1.13). Marks caused by disease lesions appeared more evenly spread across whale's bodies in photographs than did marks from other sources (Figures 1.14 and 1.15).

The majority of marks were found at the rearmost cells of whales' bodies. Intraspecific (and interspecific) interactions in which a whale is swimming away from an aggressor would result in posterior rake marks. Killer whales are known to attack the tail areas of larger whales (George et al. 1994) and may use this same approach for smaller whales.

The pattern in the location of unknown marks by cell resembles that of the rake-mark categories. This suggests that many of the unknown marks may also be due to either conspecific or predation sources.

Causes of Marks – Natural, Anthropogenic and Unknown

Natural

Only anecdotal information about conspecific rake marks among wild beluga whales is available. It is not known whether conspecific rake marks are more common in male or female CIBW, because sexual dimorphism is not overtly obvious and the opaque water of the Inlet hides most of their bodies from view. If scarring continues over a lifetime, then we would expect scars to be more prevalent in older individuals than in younger ones. If, as in sperm whales, males are more commonly scarred from intraspecific competition (Kato 1984), older male belugas would be more highly scarred than younger males. Color and age markers that can be used to better understand conspecfic scarring (and other scar creation), can be revealed through continued photo-id work with Cook Inlet whales, but also through collaboration with researchers currently working with: native beluga subsistence hunters (statewide), beluga satellite tagging studies, belugas in aquaria, and studies of belugas conducted in other countries (e.g., Group for Research and Education on Marine Mammals and Nunavik Research Centre both in Canada).

Large ocean predators known to prey on whales include sharks, killer whales, and polar bears. The shark family is represented in Alaska most commonly by the salmon shark but great white sharks may also venture at least into the Gulf of Alaska (http://www.sharkresearchcommittee.com/dist.htm, accessed 27 October 2009) and sleeper sharks are commonly found in Alaska (Sigler et al. 2006). Salmon sharks can withstand the colder temperatures of northern waters and are becoming even more common in the Gulf of Alaska with warming ocean shifts (Weng et al. 2005). Sleeper sharks are opportunistic scavengers that eat carrion and occasionally prey on small cetaceans (Compagno 1984) and possibly on harbor seals (Sigler et al. 2006). Bite marks from sleeper sharks appear crescent shaped and rounded in seals (Hoff and Morrice 2008). A small number of CIBW photographs have marks that look similar to bite marks from sleeper sharks. Cetacean tissues have been found in sleeper shark stomachs in Alaska (Orlov 1999, Hulbert and Rice 2002) but it is not known whether live whales are consumed by sleeper sharks. Bites from great white sharks are wide and parabolic and usually ragged-looking (Heithaus 2001). There is little information available about the appearance of salmon shark bites. To date there have been no reports of shark attacks on beluga whales or of beach-cast whale carcasses with embedded shark teeth.

The only predator known to CIBW (other than humans) is the killer whale. The contraction of beluga whale summer range to the Upper Inlet has been suggested as a possible adaptation to escape predation by killer whales (Shelden et al. 2003) because the upper reaches of Cook Inlet are shallow and may put killer whales at risk for stranding when pursing beluga whales. Recent studies suggest killer whales may be targeting endangered western stock Steller sea lion juveniles, potentially impeding the recovery of the population (Horning and Mellish 2009). Top-down control by killer whales on populations of sea otters showed that a small number of whales could drive declines in sea otter populations (Estes et al. 1998, Williams et al. 2004). Killer whale attacks may play a role in the rate of any future recovery of the depressed CIBW population, particularly if reproductive females protecting their calves are being killed. Female beluga whales may potentially incur greater scarring from predation than male belugas if females protect their calves from attacks as has been mentioned in eyewitness reports (Shelden et al. 2003). Of the whales that were determined to have predation scars in the catalog set that was analyzed, eight (50%) were considered female by calf association. This information is preliminary and some of the other eight whales may be females that were not yet seen with calves in photographs.

Lesions

Herpes-like viruses have been identified on beach-cast beluga whales from the Saint Lawrence Estuary and the Churchill River in Canada (Martineau et al. 1988, Barr et al. 1989). These lesions have been described as "paler than the normal skin, circular or elliptical and slightly in relief" (Van Bressem et al. 2007). Herpes viruses have been reported during necropsies of CIBW (NMFS 2008). Photographs taken from 2005 through 2008 show single lesions (Figure 1.16), and multiple aggregations of lesions (Figure 1.17) on whales' bodies. Roughly a quarter of whales from the CIBW photo-id sample had at least a single lesion (fresh or healed) on their bodies.

Histopathology tests are currently being conducted on the single lesion shown in Figure 1.16 (Kathy Burek Huntington of Alaska Veterinary Pathology Services, personal communication). Knowledge gained from events such as the stranding of whale RA058 offer the opportunity to strengthen inferences made from photographs by confirming the causes of known lesions. Whale RA058 was photographed and identified five times in years 2005, 2007 and 2008, and was only sighted in Knik Arm (photographs from 2009 are still being analyzed).

Although a voluntary moratorium on subsistence hunts for Cook Inlet beluga whales has been in effect since 2007, the examination of beluga whales killed in subsistence hunts elsewhere in Alaska offers the opportunity for lesions to be simultaneously photographed and sampled for pathology and toxicology. A lesion could be the result of the skin's response to an injury, or it could be indicative of something toxic or stressful in the ocean environment. By teaming with stranding experts, we will be able to make learn more about the lesions seen in photographs and to eventually develop baseline information about disease where no handling is required. In addition, knowing the life-histories and movement/residency patterns of identified whales (e.g., whale RA058) from their photographic records may allow us to identify sensitive geographic areas.

Molting

Molting in CIBW is not well understood and has not been previously studied. Molting, described in northern beluga stocks as a shedding of a thick outer layer of "yellowed skin" (Finley 1982, St. Aubin et al. 1990), has not been reported in CIBW. Molting was not noted in any of our project photographs from 2005 through 2008, and we suspect that molting is more diffuse in Cook Inlet, possibly due to the fact that Cook Inlet whales spend their lives in relatively warmer, fresher waters than do belugas found in higher latitudes. Belugas are found in the St. Lawrence River at latitudes south of Cook Inlet, and their molting has also been described as diffuse and unremarkable (Robert Michaud, personal communication). It would be informative to compare our observations with those of other researchers and the traditional knowledge of subsistence users in Cook Inlet and other parts of Alaska. Typically ice prevents boating in Upper Cook Inlet until May, and it is therefore possible that molting occurs in winter or early spring before field photographs were taken.

Anthropogenic marks

To date CIBW entanglement in fishing gear or other discarded human debris has not been documented. No obvious hooks or other recreational fishing gear have been noted, nor have we photographed definitive marks caused by previous entanglement in fishing line or netting. These findings support conclusions from other studies that direct mortalities from fishing gear are probably uncommon in CIBW (Moore et al. 2000, NMFS 2008).

Small-boat propeller strikes typically leave a series of parallel, cupped-shaped marks that are thicker toward the centers (Read and Murray 2000, George et al. 1994). Each propeller will leave a different shape of mark based on several factors, including trajectory, propeller pitch angle, torque and speed at impact (Rommel et al. 2007). Two individual whales were photographed in 2005 that had healed scars caused by small boat propellers (Figure 1.8). Only one of the two was resighted in 2008. The three percent of marks that were attributed to large propeller strikes were probably the most highly speculative of all the subjective causal assignments; arguably they could all be from other causes such as entanglement in marine debris (Read and Murray 2000), or large bite wounds from predators. Large ships regularly transit near beluga whales in and around Cook Inlet. Whales are known to use areas near Port MacKenzie and the Port of Anchorage, and during photo-id surveys are commonly seen in and around large ships. Blunt trauma suggestive of a ship strike was reported during a CIBW necropsy in 2007 (NMFS 2008).

Marks from bullet or harpoon wounds that were noted in photographs were not fresh and may have been from whales that were "struck and lost" during past subsistence hunting that ended in 2006 (http://www.fakr.noaa.gov/newsreleases/2007/beluga041607.htm, accessed on 6 November 2009) or from poaching. Recent credible reports (currently under investigation) from other Cook Inlet beluga researchers of what appeared to be fresh gunshot injuries to CIBW are an indication that poaching probability still occurs. A photograph taken by the CIBW photo-id project in 2007 shows what appears to be either a harpoon or arrow shaft protruding from the side of a Cook Inlet whale. By monitoring known whales that have recorded movement histories (McGuire et al. 2008a, 2009) we may be able to identify geographic areas where poaching may be occurring, thus helping to focus law-enforcement efforts.

The 2005-2008 photo-identification catalog contains seven beluga whales identified by unique scars from holes used to affix satellite tags no longer on the animals. These seven individuals were identified based on a combination of natural marks and the tag scars in order to avoid mistakenly matching similar scar patterns caused by the same tag type. Five of these belugas were sighted in 2008.

No primary, non-satellite tag marks from whales in the photo-id catalog were matched to photographs taken during captures for satellite tagging. This could mean either that (1) scars used in cataloging whales (rakes, etc.) do not last for this length of time, (2) capture photographs did not include whales we see now, or (3) marks in capture photographs were obscured. Most photographs taken at the time whales were captured and instrumented were unsuitable for identification of the non-tag primary marks used to photo-identify whales. Marks were either obscured by water, mud, or researchers working on attachments, or were taken at oblique angles that were not useful for identifying marks. In addition, not all captured whales were photographed, and few photos were taken of those that were photographed. We recommend that future satellite tagging teams (statewide) should take high-resolution, full-profile photographs of all captured whales whenever feasible because the potential data gathered through photographic identification extends far beyond the life of the tag.

Unknown

The majority of marks in the photo-id catalog were of unknown cause (Figure 1.11). Probably many are the result of tooth raking by other belugas. Entrapment in ice is a known cause of mortality in beluga whales (Tomlin 1957, Mitchell and Reeves 1981, Burns and Seaman 1985), and some CIBW might sustain wounds from ice. CIBW are known to venture into the upper Inlet in winter (Hobbs et al. 2005) when fresh water forms bergs of ice several feet thick weighing many tons. It is likely that many of the irregular shaped marks (Figure 1.9) we see in photographs of beluga whales were caused by wounds from ice. Marks may also be caused by natural debris in high currents, or by belugas scraping against rocks or other hard benthic substrates.

FUTURE WORK

This was an initial examination of the types of marks seen in photographs in the CIBW photo-id catalog. Photographic records of individual whales used in this analysis varied with respect to both the number and quality of photographs they contained. As a result, some photographic records of individually identified whales contained a greater proportion of lower-grade photographs, which may have caused some mark types to be undetected and underrepresented. There is a possibility that some marks that were considered to have newly appeared in high-quality photographs were in fact older marks that were not as obviously visible in the previous average-quality photographs of a cataloged individual. For this reason, further analyses will be designed to use only higher-quality photograph sets to more rigorously examine mark development and longevity.

Cataloged individuals used in this analysis had one to several more marks that could be considered as primary that were not closely followed. Currently it was not feasible to document and follow all primary marks seen in photographs. Recent advances in the photo-identification database (Appendix C in McGuire et al. 2008a) will allow for greater control and larger sample sizes in further analyses.

Using a mark-recapture model (e.g., Jolly-Seber) on all marked individuals will provide a more exact estimate of mark loss and survival in the future. The survival parameter can be estimated or held constant at one, and the Akaike Information Criterion (AIC) can be used to derive the probability of one model over the other (i.e., mortality and/or mark loss did or did not occur). The survival parameter in this case is a confounded combination of survival and one minus the mark loss. Ultimately, we would want this parameter to equal one, but mortality or mark loss may intrude and need to be estimated (in Chapter 2 of this report we assumed mortality and mark loss were zero).

Using a single analyst who was familiar with the cataloged whales may have introduced bias in assigning the primary marks reviewed for longevity. Recently we received funding to process the left-side photographs that were formerly archived to conserve project resources. The left-side photograph sample is similar in size to the right side, and so offers a valuable test set to examine primary mark designations simultaneously along with other variables such as photo quality and identifiability (discussed in Chapter 2 of this report). Using a statistical framework similar to that used in a recent study of North Atlantic humpback whales (Friday et al. 2008), we plan to test for consistency among analysts in scoring for quality and identifiability, along with the selection of persistent marks.

Reliability of matches (misidentification) was not addressed in this chapter. A serious error can occur if the same whale is assigned multiple catalog numbers (false negatives), causing over-estimates of the number of identified individuals. To limit this occurrence, stringent criteria for accepting new individuals into the catalog of identified whales were developed (See McGuire et al. 2009 for details). Additionally, any single photograph entered into the catalog was confirmed by at least two experienced analysts. A third analyst was enlisted if any uncertainty was evident, ultimately leaving any uncertain matches out of the catalog of known individuals. The mismatching error rate was therefore considered to be small. The left-side test set would provide useful information such as assessing the potential rate of false negatives and false positives (assigning more than one individual the same catalog number) and serve to direct the selection of samples for future analyses of survival and abundance.

A quantitative method of determining the size of various marks might improve our ability to assign possible mark cause. For example, seemingly minor rake marks might be caused by a smaller killer whale. Likewise, larger rake marks attributed to predation could potentially be caused by larger beluga whales. The variability in the sizes of individual whales makes judging the relative sizes of marks and other morphometrics difficult. We experimented with lens-mounted lasers to aid in determination of mark sizes (Durban and Parsons 2006, McGuire et al. 2008a), but the resulting sample size was small due to problems with calibration of the laser mount. Currently, laser measurements are not feasible for this study until improvements are made in mounting hardware and calibration equipment (as in Rowe and Dawson 2009).

A greater understanding of mark sources came from examination of beluga mortalities. Examination of any beluga whales preyed upon by killer whales will help to better define this source of marks. Following trends in this type of mark could help detect changes in predation rates. Collaboration with subsistence hunters, satellite tagging teams, and researchers engaged in killer whale photo-id could also increase the ability to assign possible cause to marks in photographs by providing more direct evidence of mark source.

Worldwide, the industrialization of the ocean coastline and expanding human populations have resulted in increased stress on cetaceans (Van Bressem et al. 2008). To effectively deal with the associated problems on an ecosystem-wide scale, more collaboration among researchers is recommended (Gulland and Hall 2005). For example, studies of Saint Lawrence River belugas are multidisciplinary and employ a combination of photo-identification, behavioral, toxicological, and other methods to better understand threats to the population (Measures 2007).

The information provided by photo-id increases over time (Mann 2000). Similar to other cetacean photo-identification studies underway (Bradford et al. 2009), we hope to help identify the sources of marks found in CIBW as a foundation for other researchers and resource managers to answer questions related to conservation. Necropsies of whales allow postmortem assessments (Read and Murray 2000, George et al. 1994) of sources of mortality. Photo-identification offers a tool to assess natural and human-caused stresses to whales preemptively.

Table 1.1. The percentage of mark types recorded one or more times on 110 individually identified beluga whales in 2008 and at least one other year during 2005-2007. Most whales had more than one type of mark.

Mark Type	Percentage of Individually Identified Whales Showing at Least One Mark
Conspecific	22%
Predation	15%
Fresh Lesions	11%
Healed Lesions	15%
Bullets	3%
Satellite Tag Marks	5%
Large Ship Strike	3%
Small Ship Strike	1%
Unknown	85%

Table 1.2. Individual beluga whales (*n* = 27) photographed in 2008 and in one or more years during 2005-2007. The year the new marks first appeared and how long they persisted is noted. In some cases photographs showing the location of the mark were not available in following field seasons and were noted as "area not visible".

Individual Sighting Years	Year New Mark was First Seen	Year New Mark was No Longer Visible	Maximum Number of Years Mark Persisted
2006, 2007, 2008	2006	2007	1
2006, 2007, 2008	2006		persisted into 2008
2006, 2007, 2008	2007	2008	1
2006, 2008	2006	2008	2
2006, 2008	2006	2008	2
2006, 2008	2006		persisted into 2008
2005, 2008	2005	2008	3
2005, 2008	2005	2008	3
2005, 2008	2005	2008	3
2005, 2007, 2008	2005	2008	3
2005, 2007, 2008	2005	area not visible	uncertain
2005, 2006, 2008	2006	2008	2
2005, 2006, 2008	2006	2008	2
2005, 2006, 2008	2006	2008	2
2005, 2006, 2008	2005	2006	1
2005, 2006, 2008	2006	2008	2
2005, 2006, 2007, 2008	2005	2006	1
2005, 2006, 2007, 2008	2005	2006	1
2005, 2006, 2007, 2008	2005	2006	1
2005, 2006, 2007, 2008	2006	2007	1
2005, 2006, 2007, 2008	2007		persisted into 2008
2005, 2006, 2007, 2008	2007	area not visible	uncertain
2005, 2006, 2007, 2008	2006	2008	2
2005, 2006, 2007, 2008	2005		persisted into 2008
2005, 2006, 2007, 2008	2006	2008	2
2005, 2006, 2007, 2008	2007	2008	1
2005, 2006, 2007, 2008	2007		persisted into 2008

Table 1.3. Individually identified cataloged beluga whales (110 total) photographed in 2008 and one or more previous years, were analyzed for new marks found in 2008 that were not previously recorded in their photographic records. Presented here are the possible causes of the new marks and the sum total of all new marks in 2008 by location[1] on the beluga whale profile.

Possible Cause	Location of Mark	Number of New Marks
Conspecific	Cell A	
	Cell B	1
	Cell C	1
	Cell D	1
	Cell E	3
Conspecific Total		6
Lesion	Cell A	1
	Cell B	2
	Cell C	1
	Cell D	2
	Cell E	
Lesion Total		6
Predation	Cell A	
	Cell B	1
	Cell C	
	Cell D	1
	Cell E	1
Predation Total		3
Unknown	Cell A	
	Cell B	
	Cell C	
	Cell D	1
	Cell E	3
Unknown Total		4

[1]Cell A: From the blowhole to ½ the way to the midpoint of the ridge. Cell B: Center point of the ridge to the ½ way point forward to the blowhole. Cell C: The dorsal ridge. Cell D: From the midpoint or the dorsal ridge to ½ the way to the base of the tail. Cell E: From the base of the tail to ½ the way to the midpoint of the dorsal ridge. Cells A, B, D, and E have an estimated depth of ½ the thickness of the whale.

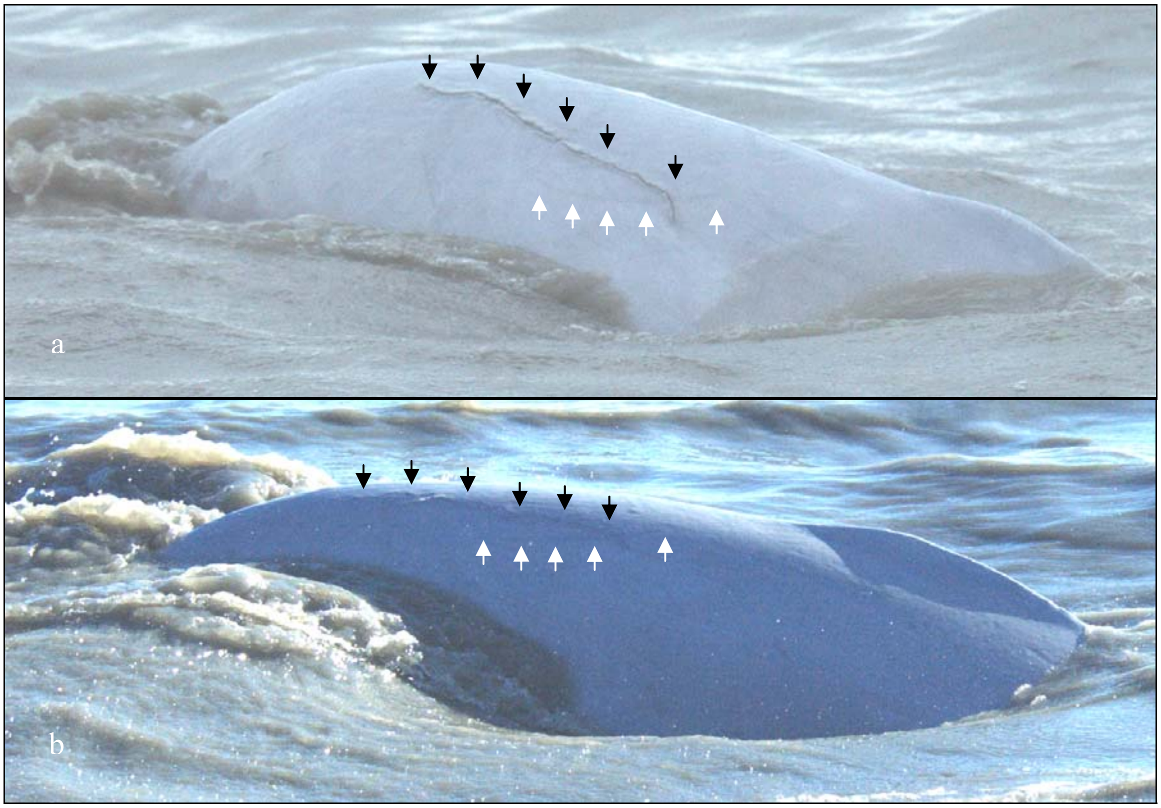

Figure 1.1. The dorsal posterior of the right side of a beluga RS140 showing a mark probably acquired in the spring or summer of 2008. Black arrows indicate the new mark, while white arrows show a healed reference mark. This mark was not seen in high quality 2007 photographs. The photograph at the top (a) was taken on 24 July 2008. Note the jagged and raised edges of the wound. The photograph at the bottom (b) was taken on 8 August 2008. Photograph (a) is of higher quality, so some difference is due to this, but the wound margins appear to be closing and smoother in (b), taken 14 days later.

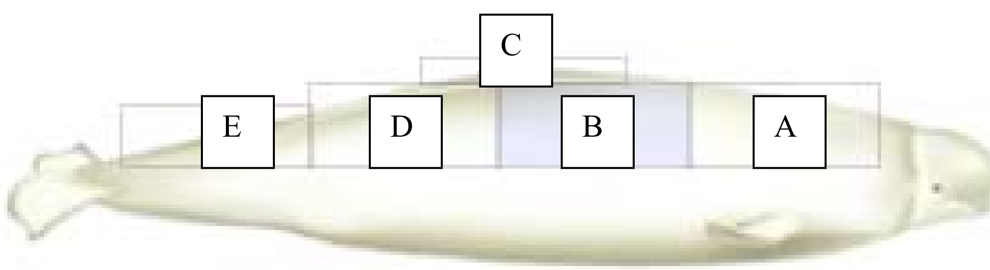

Figure 1.2. Cells of a beluga whale that were used to identify locations of marks in photographs. Cell A: From the blowhole to ½ the way to the midpoint of the ridge. Cell B: Center point of the ridge to the ½ way point forward to the blowhole. Cell C: The dorsal ridge. Cell D: From the midpoint or the dorsal ridge to ½ the way to the base of the tail. Cell E: From the base of the tail to ½ the way to the midpoint of the dorsal ridge. Cells A, B, D, and E have an estimated depth of ½ the thickness of the whale. Beluga illustration courtesy of Uko Gorter.

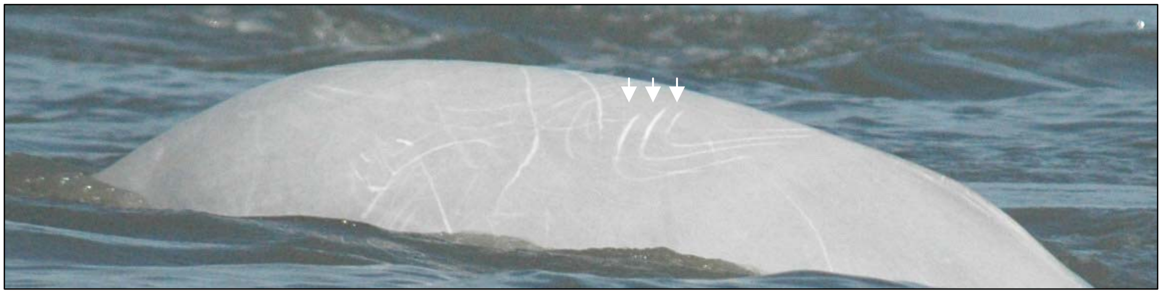

Figure 1.3. Right side of a beluga whale with the dorsal ridge at the right of the photograph. White arrows indicate rake marks that may have been caused by a killer whale.

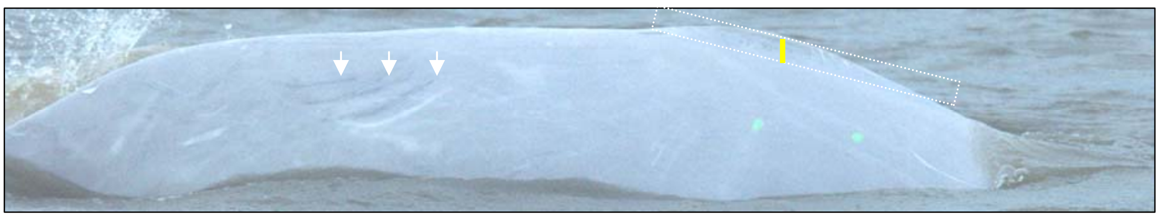

Figure 1.4. Right side of a beluga whale with the head just below the surface at right. The dorsal ridge (inside white box at right) cell includes the area next to it along its length. The distance between the green laser lights is 16 cm (6.3 in) and the yellow line is ~ 4 cm (1.6 in). Actual ridge height is estimated at about 2 cm (0.8 in). White arrows indicate rake marks that may have been caused by a killer whale.

Figure 1.5. Center to center distance of the lower jaw teeth and spacing between teeth of dead female beluga whale RS058 found off the beach in downtown Anchorage, Alaska on 9 October 2009. Center to center distance across teeth measured 1.5 – 2 cm (0.6 – 0.8 in) and spaces were 0.7 – 1 cm (0.3 – 0.4 in). Upper jaw tooth spacing was similar.

Figure 1.6. Ventral and dorsal sides (respectively) of the peduncle and flukes of a Cook Inlet beluga whale that was attacked by a killer whale (photographed on 19 September 2009). The dark lines are tooth rakes from the event (Photograph courtesy of National Marine Fisheries Service, Anchorage, AK).

Figure 1.7. Beluga RS218 showing white arrow where (a) a lesion has not yet appeared on 6 June 2005, (b) the lesion has appeared by 23 July 2005, (c) the lesion turned white by 15 September 2005, and (d) the lesion is barely visible by 27 July 2007. Black arrows indicate what appear to be three lesions that also appeared 23 July 2005 and were present throughout and still visible, though lighter, on 27 July 2007.

Figure 1.8. Right sides of two Cook Inlet beluga whale individuals showing what appear to be scars from a small propeller (indicated by white arrows; photographed in 2005). In Figure (b) the black arrow indicates what appears to be a scar from the lowermost end (skeg) of an outboard motor.

Figure 1.9. Marks seen on the right sides of two Cook Inlet belugas that were caused by unknown sources. Both whales have marks that have remained unchanged since 2005. Lasting marks that are dark in color, such as the one in Figure b, are extremely rare; most lasting marks are white.

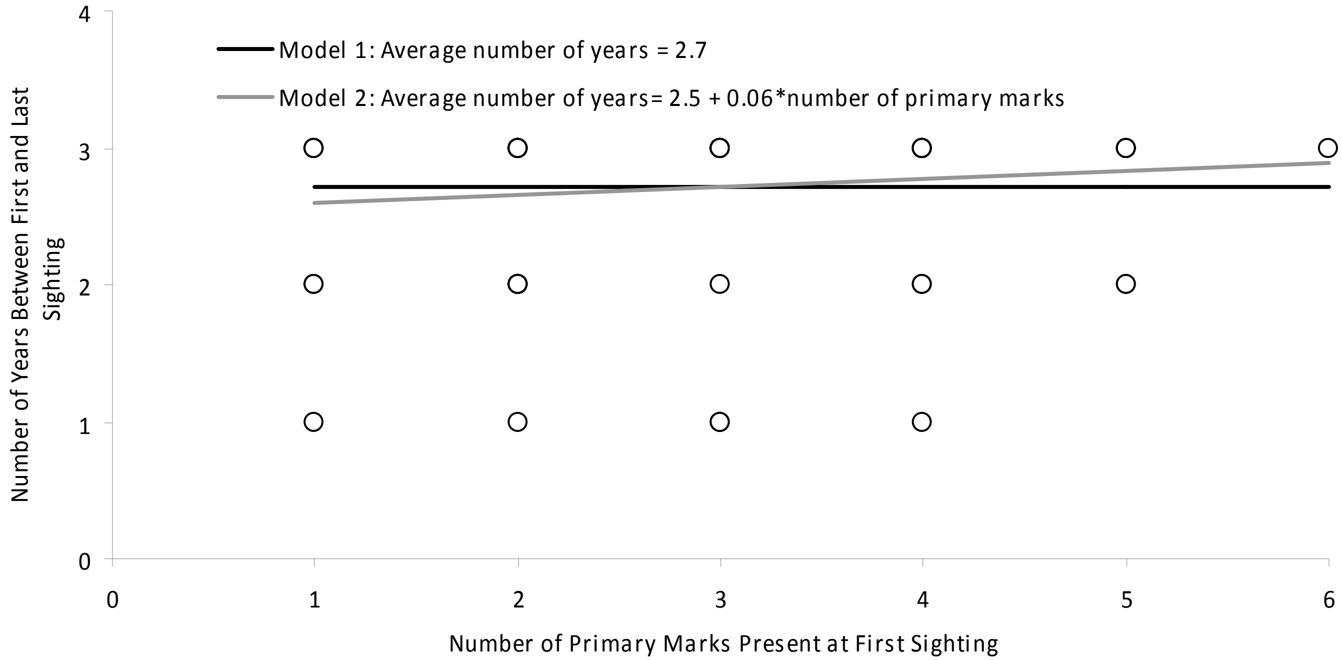

Figure 1.10. Poisson regression estimating the number of years between first and last sighting versus the number of cells with primary marks. Model 1 is a simple average (or intercept only model; intercept = 2.7 years) and Model 2 adds a parameter for the number of marks. Using Akaike weights, Model 1 was 71% likely versus Model 2 (29%). Said another way, odds are 2.5:1 that the number of primary marks did not influence sighting longevity. All primary marks were resighted at least one year later (n = 110).

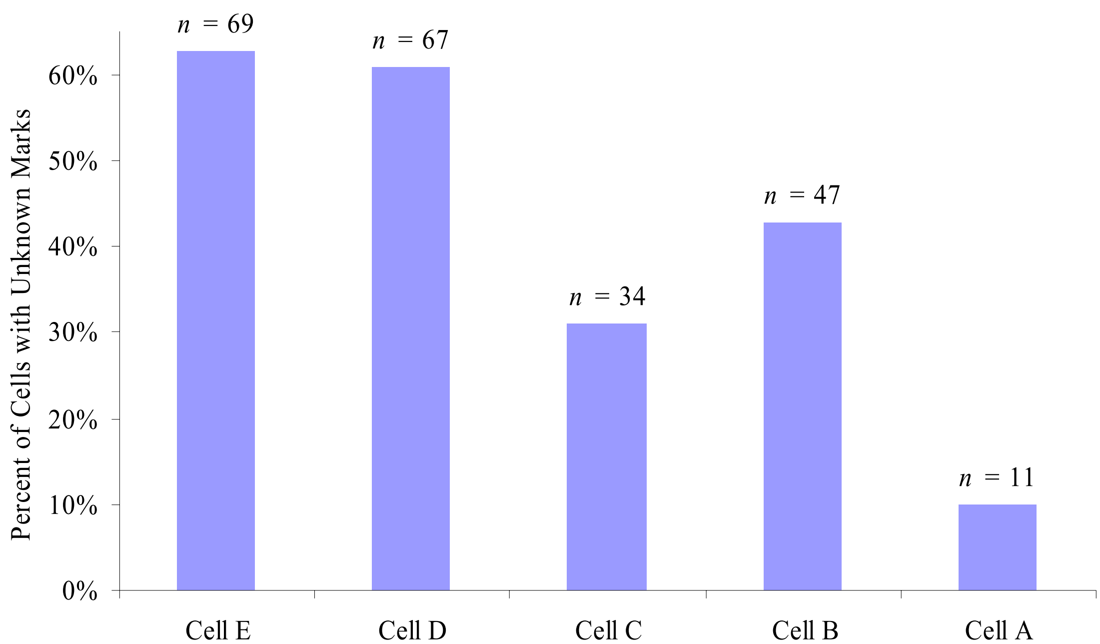

Figure 1.11. The locations of primary marks attributed to unknown causes from a sample of 110 beluga whales. Cell C covers the dorsal ridge. Cells A, B, D, E cover the dorsal half of the whale roughly by quarters from behind the head to the base of the tail, respectively.

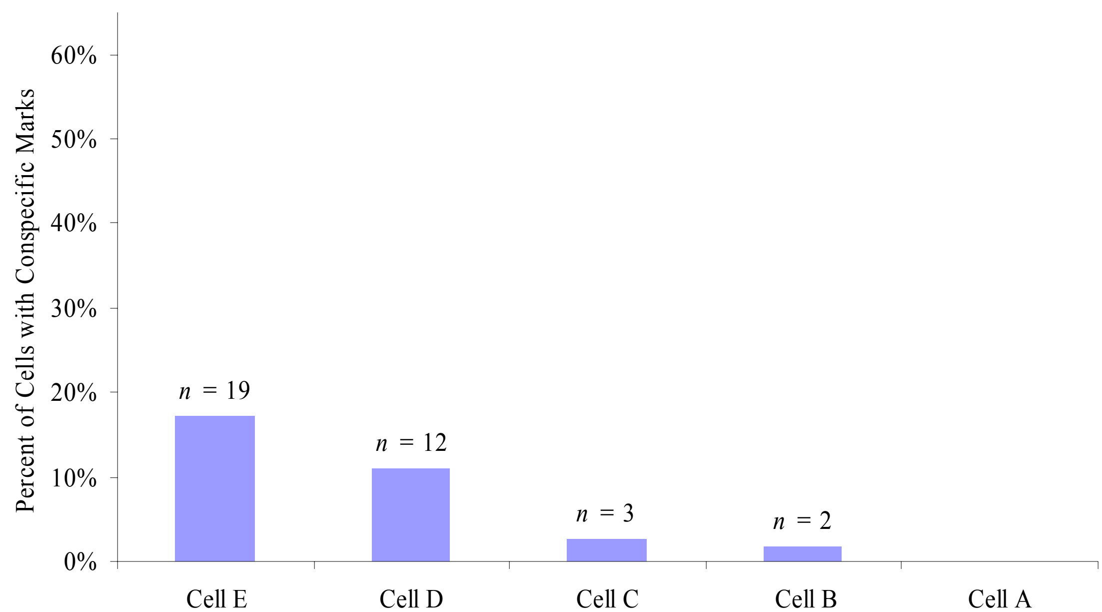

Figure 1.12. The locations of primary marks attributed to conspecifics from sample of 110 beluga whales. Cell C covers the dorsal ridge. Cells A, B, D, E cover the dorsal half of the whale roughly by quarters from behind the head to the base of the tail, respectively.

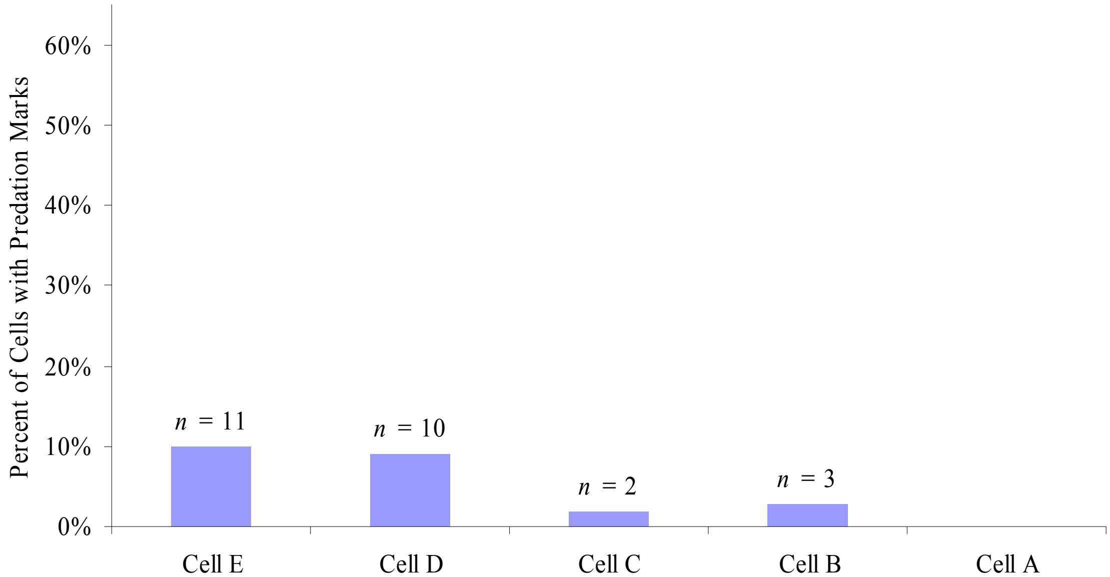

Figure 1.13. The locations of primary marks attributed to predation from a sample of 110 beluga whales. Cell C covers the dorsal ridge. Cells A, B, D, E cover the dorsal half of the whale roughly by quarters from behind the head to the base of the tail, respectively.

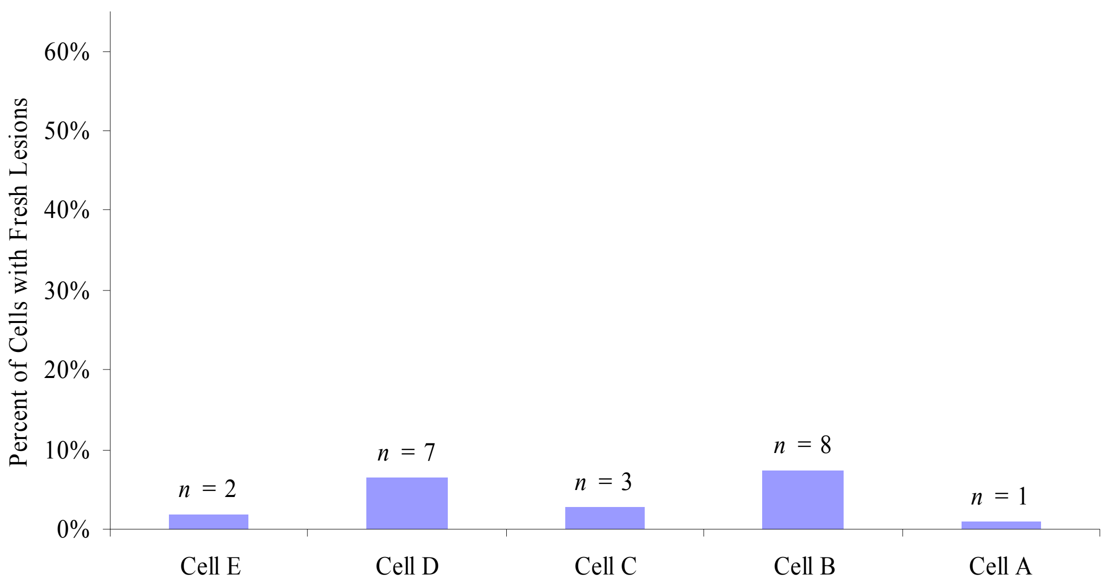

Figure 1.14. The locations of secondary marks attributed to fresh lesion-like marks from a sample of 110 beluga whales. Cell C covers the dorsal ridge. Cells A, B, D, E cover the dorsal half of the whale roughly by quarters from behind the head to the base of the tail, respectively.

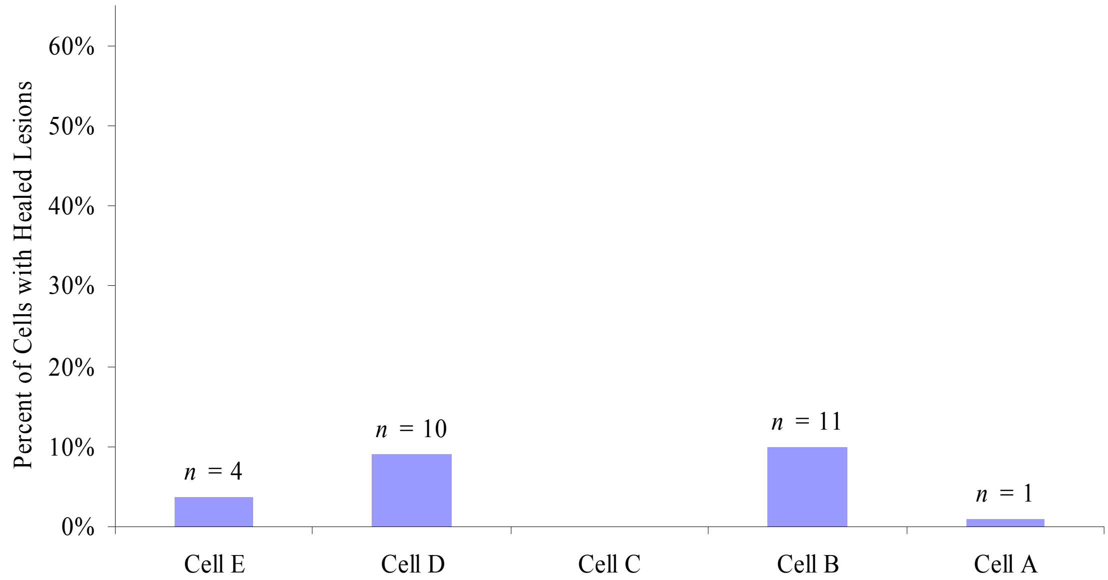

Figure 1.15. The locations of secondary marks attributed to healed lesions from a sample of 110 beluga whales. Cell C covers the dorsal ridge. Cells A, B, D, E cover the dorsal half of the whale roughly by quarters from behind the head to the base of the tail, respectively.

Figure 1.16. Figure showing what appears to be a fresh lesion on a dead identified female beluga whale number RS058. This female was found off the beach in downtown Anchorage, Alaska on 9 October 2009. Previously she was sighted five times in years 2005, 2007 and 2008, all in Knik Arm, Alaska. A veterinarian contracted by NMFS sampled this lesion to determine possible cause (K. Burek, personal communication, Alaska Veterinary Pathology Services, Eagle River, AK).

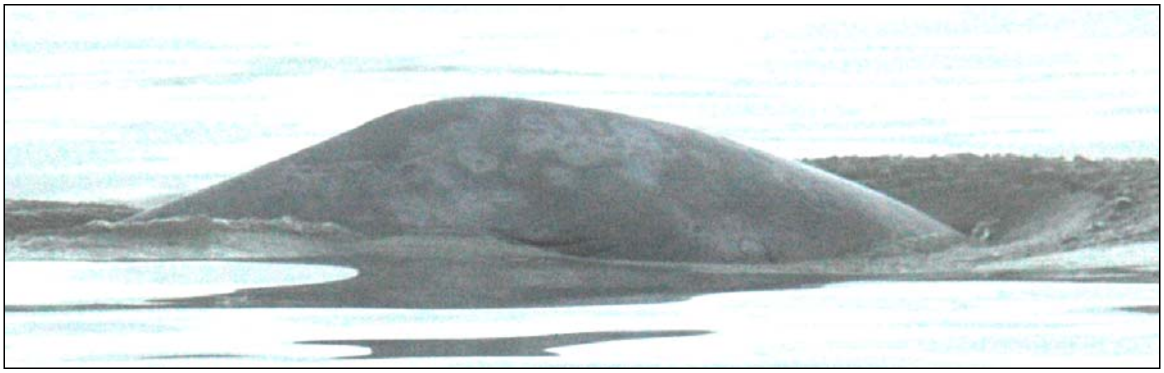

Figure 1.17. The right side of a Cook Inlet beluga whale and what appear to be multiple lesions in the process of healing and becoming lighter in color.

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Chapter 2:

Application of Mark-Resight Methods to Estimate Abundance of Cook Inlet Beluga Whales

Final Report

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INTRODUCTION

Photo-identification (photo-id) of Cook Inlet beluga whales (CIBW) has proven to be a useful tool for learning about residency, movements, social grouping, and life histories of individuals in this population (McGuire and Kaplan 2009, McGuire et al. 2009). Since its inception, an objective of the photo-identification project has been to provide an abundance estimate for this population. Photo-identification has been used to estimate abundance for a number of cetacean species, including (but not limited to) humpback whales (e.g., Straley et al. 2009), bowhead whales (da Silva et al. 2000, Schweder 2003), western gray whales (Bradford et al. 2008), several species of dolphins (Wilson et al. 1999, Durban et al. 2005, Gormley et al. 2005, Elwen et al. 2009), northern bottlenose whales (Whitehead and Wimmer 2005), blue whales (Calambokidis and Barlow 2004), southern right whales (Bannister 2001) and killer whales (Williams and Thomas 2009). These studies rely on mark-resight methodology. This method estimates the abundance of a population of animals from the number of marked and unmarked animals. In cetaceans, marks are caused by patterns in skin color and natural and human-caused scars from injuries to skin, dorsal fins, and flukes, and these marks are visible when the animals surface.

Analysis techniques for mark-resight studies vary due to several factors, including the original use intended for the data, available resources, survey conditions, proportion of marked animals, and the identifiability and permanency of marks. In general, estimates of abundance from mark-resight studies rely on models that are based on discrete sampling events during which an individual is either seen or not seen. The simplest example is a two-event study where the first event is application of marks (or identification of existing marks on animals) and the second event examines a sample from the population to determine the proportion with marks (e.g., the Lincoln-Petersen model; Seber 1982).

In the early stages of this study, it was not clear if photographs of beluga whales could be used to estimate abundance and, if so, whether simple or complex mark-resight models would be required. CIBW are uniform in color (gray to white), do not have a dorsal fin, and rarely reveal their flukes when surfacing. If marks on animals in the population were common, obvious, and lasted across years, and high quality photographs could be obtained from large numbers of animals, a simple two-event mark-recapture model could be used to estimate their abundance. In such a case, the marked animals could be represented by those whales in the photo-id catalog (e.g., 2005-2007) and the second or "sampling" event would be represented by the photographs taken in 2008. By early 2007, it had become clear that generating a robust abundance estimate for CIBW would be challenging and require more sophisticated models than a simple two-event mark-resight study.

In late 2007, a workshop was convened at the National Marine Mammal Laboratory (NMML) in Seattle to examine the contents of the 2005-2007 CIBW photo-identification catalog and to assess the potential for these data to render an abundance estimate (a summary of the workshop is in Appendix F in McGuire et al. 2008). The participants of the 2007 workshop (including two of the authors of this report and their peers from NMML) concluded that photographs of Cook Inlet beluga whales were suitable for this purpose. Workshop participants developed recommendations for the collection, processing, and analyses of photograph and survey data. These recommendations were used to guide our subsequent efforts, the results of which are presented here.

The process for developing an abundance estimate required several steps. We needed to characterize the identifiability and permanency of marks on Cook Inlet beluga whales (Chapter 1). Photographs of a wide range of quality are typically collected and we had to characterize the degree to which photo quality affected a researcher's ability to recognize a marked animal in a photograph. An estimation model was needed that could incorporate sightings of both marked and unmarked animals and that was robust to potential biases that can be caused by differences in behavior among individuals photographed (i.e., differences in the probabilities of the individual animals being sighted). In this chapter we describe the selection and processing of photographs, a suitable mark-resight model, and mark-resight abundance estimates of beluga whales obtained from photographs taken in the summer and fall of 2008.

METHODS

Field Surveys

Survey effort and field data

Dedicated surveys and opportunistic sampling of Upper Cook Inlet, Alaska were conducted from a small vessel and from shore during May through October 2008 (Figures 2.1 and 2.2). Paper data forms were used to record GPS positions of beluga groups, group size, group behavior, and body color and relative size of individual whales in the group. Detailed survey methods are presented in McGuire and Kaplan (2009). All vessel surveys were conducted under NMFS General Authorization # LOC 481-1795-01.

Digital photographs of beluga whales were collected using a Nikon D70, 6.1 megapixel digital SLR camera with a Nikkor 80-400 mm image stabilized zoom telephoto auto-focus lens. Typical camera settings were: 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 of the Group for Research and Education on Marine Mammals, personal communication). Photographs were taken in RAW (not compressed) format and stored on compact flash memory cards.

Processing and Scoring of Photographs

The sequence of steps involved in processing, scoring, and analyzing photographs is described below and summarized in Figure 2.3. All photographs taken during surveys were downloaded from the camera's compact flash memory card onto a computer hard drive and archived to DVDs to preserve the original data before any further processing.

Copies of photographs taken in RAW format were reformatted into JPEGs (JPEG files are smaller than RAW files) for more efficient processing. Images were sorted according to 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) were inventoried and archived, but not used for subsequent analyses.

Acceptable quality photographs of whales (marked and unmarked whales) were cropped to include only the image of the whale. Photographs containing images of more than one whale were copied and then cropped so that each copy contained an image of a single whale. All cropped photographs were sorted into images of left and right sides of the whale. Limits to project funding precluded analysis of both left and right sides and only photographs of the right sides of the whales were further processed. Images of the left sides of belugas were archived[1] for later analysis.

Daily photographic samples (i.e., all cropped photographs taken on a single survey day) were sorted into temporary folders of individuals. Each temporary folder contained all of the cropped, right-side photos taken of the same individual beluga on a single survey day, and contained one to many photographs. Photographs within a temporary folder of an individual may have been taken seconds or hours apart, and often showed different sections of the body as the beluga surfaced and submerged.

Photographs in temporary folders from different survey days were compared, and folders of individuals from new survey dates were placed into folders of individuals from previous surveys when photographs were matched among folders (i.e., when photographed marks used to identify an individual on one survey day were matched to the same marks photographed on a different day). All marks, regardless of mark identifiability and photograph quality (see scoring methods below), were used for this initial sorting. At this stage, folders of individuals contained photographs from multiple survey days (if the individual whale was photographed on more than one day) or from a single survey (if the individual whale was only seen once during the 2008 season).

As a beluga surfaced, different portions of its body were available to photograph. Side-profile photographs (i.e., taken more or less perpendicular to the length of the whale) were most useful for seeing marks used to identify individual whales. Photographs of whale profiles were initially divided into 11 sections along the right half of the whale from behind the blowhole to the base of the tail using the center of the dorsal ridge as the main reference point. However, sections containing the head, tail and ventral half of the whale were not regularly captured in photographs. Therefore, the five main sections (referred to hereafter as "cells") of the body that were most commonly photographed were used in the analysis (Figure 2.4).

Scoring for quality and identifiability

Initially, two biologists experienced in viewing and matching photographs of belugas (Blees and Kaplan) evaluated all photographs in the folders of individual whales for photographic quality and mark identifiability. This evaluation and the assignment of

[1] Funding was secured from the North Pacific Research Board in 2009 to begin cataloging the left side photos from 2006 through 2008. That work will occur during the winter of 2009/2010.

numerical ranks to the photograph quality and mark identifiability were referred to as "scoring". To ensure consistency among those scoring photographs, a standardized scoring protocol was developed and tests were conducted in which eight different sets of photographs (62 photographs total) were scored independently by each biologist for comparison. To prevent drift in scoring methodology over the course of the analysis, the biologists regularly scored the same sets of photographs, compared scores, and together discussed reasons for score assignment.

Each folder, which contained one to many photographs of an individual, was examined to identify the highest-quality photographs that represented at least one "acceptable" quality (i.e., with a minimum score of 2-; Table 2.1) view of each of the five primary cells. For each survey day, each folder of an individual was required to have one or more photographs of acceptable quality with at least one cell in view (otherwise the day's photographs of that individual were excluded from further analysis). Photographs considered to be of unacceptably low quality (<3; Table 2.1) were archived and were not used in the mark-resight analysis. Photographic quality scores took into account how well a single cell in each photograph was depicted: the amount in view, exposure, focus, angle, and other factors (Table 2.1; following the approach of Rugh et al. 1998). Cells in photographs were only scored if >90% of the cell was in view. The photographs of highest photographic quality were then scored for mark identifiability.

Mark identifiability scores characterized how well each photographed cell was marked. Categories of mark types were created that included the relative size, shape, and distinctiveness of the different scars or irregularities in photographs (Tables 2.2 and 2.3). The photo-id catalog provided examples of marks that were observed in each year over a four-year period from 2005–2008 and these marks were used to help distinguish between lasting and temporary mark types for the mark-resight dataset. Secondary marks (Chapter 1 in this report) that appeared superficial or temporary were noted, but were not used to characterize the mark identifiability of the cell because they were not anticipated to persist throughout the field season.

Building the Dataset for Mark-resight Analysis

The mark-resight model required that each scored cell in the dataset be classified as definitively marked or unmarked. At this stage of describing the process, it is critical to distinguish between a "mark", which can be used to help initially identify individual whales from a sequence of photographs and a "marked cell", which was restricted to cells that contained a long-lasting and easily identifiable mark that could be unequivocally confirmed in other photographs. Photographs of good and poor quality can help to distinguish among individuals in groups of photographs but the poor-quality photographs cannot be used for the mark-resight dataset for reasons explained below.

We did not select and process photographs from the entire 2005-2008 photo-id catalog. Instead, we carefully selected photographs obtained in 2008 to develop the mark-resight dataset. This decreased the total photograph processing effort (a time intensive task) and reduced the chance of violating the assumption of demographic and geographic closure (see Assumption 1 below).

After completion of the scoring of each cell for photographic quality and mark identifiability, a single analyst most familiar with the photographs re-evaluated all of the photographs that had at least one cell rated as the highest quality. The researcher then selected a subset of those high-quality photographs that contained cells of "excellent" photographic quality (i.e., capable of showing even the smallest and finest marks clearly across photographs from different days). Each cell in the "excellent"-quality photographs was scored as either "marked" or "unmarked" (for the mark-resight analysis) based primarily on its mark identifiability scores from the initial scoring.

Those cells considered highly marked (i.e., with mark identifiability scores of H+ or H-) in the initial analysis were classified as "marked" if markings were not near the lower margins of body cells A, B, D, E or the forward or rear portions of cells A and E, respectively (Figure 2.4). These low-lying marks and less-obvious marks were often useful for matching photographs of individual whales in the catalog, but could not be reliably classified as "marked" across photographs from different days and therefore could not be used in the mark-resight analysis.

A critical assumption of the mark-resight model is that photographs of marked cells are not misclassified as unmarked (see Assumption 4 below). Misclassifying unmarked cells as marked is also important, but doing so is less likely to occur and creates less of a bias.

Individual beluga profiles (one photo that contained a view of two to five cells) might contain both marked and unmarked cells. Likewise, certain individual profiles may have contained only marked (or unmarked) cells.

The Model to Estimate Abundance

As outlined above, the mark-resight dataset was made up of cells that were classified as marked or unmarked. It is important to clarify that these cells are from a *subset* of the animals found in the photo-id catalog. As a result, we did not know the total number of each of the marked cells in the whale population. To illustrate the reason why these represent only a subset, an animal can be cataloged by a group of photographs that show a long-lasting mark over time and some or all of these photographs might be of moderate quality. We could have 180 whales in the catalog but cannot know how many of cells A through E are characterized (in a very restrictive way) as marked for the mark-resight analysis. We cannot use poor-quality photographs for the mark-resight analysis because misclassifying marked individuals (as unmarked) creates a serious bias in the abundance estimate (discussed below).

Given that the underlying number of marked and unmarked cells in the population was unknown, we were unable to use more traditional mark-resight models. Therefore, we adopted a recently developed mark-resight model that is particularly well suited for these situations. The model we used is known as the zero-truncated Poisson log-normal mixed effects model (ZPNE; McClintock et al. 2009). Unlike more traditional models (e.g., the Lincoln-Petersen) the ZPNE model takes into account mark-resight data where the exact number of marked and unmarked individuals is unknown over the sampling period (in our case, the summer and fall of 2008). This feature allows a larger sample of the photographs to be used in the analyses, and hence increases the precision of the resulting estimates. Additionally, the information to be gained from sightings of unmarked individuals can be explicitly incorporated during the estimation process. This not only provides an estimate combining marked and unmarked whales, but it also simplifies the variance calculations for the abundance estimate (as opposed to applying *ad hoc* correction factors). Finally, a major challenge for mark-resight methods is that individual differences in the rates that individuals are resighted will bias mark-resight estimates (Seber 1982). These differences, referred to as heterogeneity in resighting rates, would be present in our study if some animals were more likely to be photographed than others. There were reasons to expect that this heterogeneity existed. The ZPNE model takes heterogeneity in resight rates among individuals into account, and therefore minimizes bias with respect to this concern.

ZPNE is essentially a generalized linear mixed effects model with a log-link function and a modified Poisson likelihood that accounts for the aforementioned information and individual differences in resighting rates. Further details and additional applications of this framework are provided by McClintock et al. (2009) and McClintock and White (2009). The relevant assumptions of the underlying model are discussed below (see section below entitle Model Assumptions). Appendix 2-A provides the mathematical details of how this framework was applied to the CIBW mark-resight dataset to generate the abundance estimates reported below.

In a broad sense, the model estimated three quantities (although the actual number of estimated parameters varied by model, as described below): 1) α is the average individual resighting rate (in log-space), which is based on distribution of the number of times marked animals were seen; 2) σ is the standard deviation (in log-space) of the resighting rate and corresponds to the extent of individual heterogeneity in resighting rates of marked individuals, and; 3) U is the number of unmarked animals. The estimate of total abundance $\hat{N}$ (both marked and unmarked animals) was calculated as a derived parameter from the maximum likelihood estimates of $\hat{\alpha}$, $\hat{\sigma}$ and $\hat{U}$.

Mark-Resight Analysis to Estimate Abundance

The software "Program MARK" (White and Burnham 1999) was used to implement the ZPNE model. Photograph-score data were exported directly from the LGL Cook Inlet beluga whale photo-id database (Appendix C in McGuire et al. 2008) into Microsoft® Excel and used to construct input files for MARK. These input files contained the total number of times uniquely-marked cells were resighted (e.g., 60 once, 30 twice, etc.) and the total number of unmarked sightings of each cell.

A suite of six model scenarios (Table 2.4) was used to evaluate whether α should be estimated individually for each cell, or as a single parameter common across the cells. Likewise, σ was estimated individually for each cell, as a single parameter across the five cells, and was also fixed to zero to evaluate whether there was important individual heterogeneity in sighting rates (White et al. 1982). *U* was always estimated as a cell-specific parameter, because there was no reason to believe that the number of unmarked individuals in each cell was equal. Denoting a common parameter across cells as "(.)"

and a parameter which was estimated individually for each cell by "(cell)", the resulting model scenarios were:

1. {α (.) σ (.) = 0 U (cell)}
   All resighting rates are the same within a cell and among cells. There is no individual heterogeneity in resighting rates.
2. {α (.) σ (.) U (cell)}
   There is a single average resighting rate, which is equal among cells. However there is individual heterogeneity in the resighting rates within a cell. The extent of this individual heterogeneity is assumed to be equal among cells.
3. {α (cell) σ (.) = 0 U (cell)}
   The average resighting rate varies among cells. However, the resighting rate within each cell is assumed equal across individuals.
4. {α (cell) σ (.) U (cell)}
   The average resighting rate varies among cells. Additionally, there is also individual heterogeneity in the resighting rates within a cell. The extent of this individual heterogeneity is assumed to be equal among cells.
5. {α (.) σ (cell) U (cell)}
   The average resighting rate is constant across cells. There is however individual heterogeneity within cells. Further, the extent of this heterogeneity is allowed to differ among cells.
6. {α (cell) σ (cell) U (cell)}
   The average resighting rate is allowed to vary among cells. There is also individual heterogeneity within a cell. Further, the extent of this heterogeneity is allowed to differ among cells.

We compared the fit of the different model scenarios using Akaike's Information Criterion corrected for small sample sizes (AIC*c*; Burnham and Anderson 2002). In order to take into account model selection uncertainty, model averaging was performed based on the relative AIC*c* weights for each model (Burnham and Anderson 2002). Note that even though the data for each of the five cells were treated as independent, a sampling covariance was induced in the model-averaged estimates because the parameters α and σ are common across cells for some of the models considered. Therefore, the variances of the model-averaged estimates of abundance for each cell were calculated from the model unconditional variance-covariance matrix using Program MARK (Burnham and Anderson 2002).

To compute the final abundance estimate ($\hat{N}$), the mean of the cells was used (i.e., the cell-specific abundance estimates were averaged). The SE of the cell-averaged $\hat{N}$ was computed as the square root of the sum of the variance-covariance matrix of the appropriate model-averaged estimates divided by the number of estimates squared (i.e., the Delta Method; Seber 1982).

Underlying Model Assumptions

1. Geographic and demographic closure during the primary sampling interval (i.e., all surveys between 19 June and 28 October 2008)
2. No loss of markings during the primary sampling interval
3. No errors in distinguishing marked and unmarked animals
4. Resighting rates were equal for marked and unmarked whales
5. Unmarked whales were not sampled with replacement (i.e., no multiple counting of the same whale) on a single survey
6. All individuals had some chance of being sampled

1. *Closure*—If mortality, recruitment from births, emigration, or immigration occurred during the 2008 sampling period, then the closure assumption was violated. If we assume mortality was constant across all marked and unmarked individuals, then an unbiased estimate of *N* at the beginning of the sampling interval is still possible (Seber 1982). Conversely, if newborns were recruited during the sampling interval, an unbiased estimate is possible for the end of the sampling interval. The effects of emigration are equivalent to mortality and immigration is equivalent to recruitment (Seber 1982). If both mortality (and/or emigration) and recruitment (and/or immigration) occurred, then our estimate of *N* will be biased high (Seber 1982) and not applicable to either end of the sampling interval.

2. *Loss of marks*—Violating this assumption would bias our estimate high. Two main categories of markings were observed in beluga whale photographs and designated as either primary or secondary markings. Primary markings were defined as long-term markings capable of distinguishing individual whales across years and were typically white in color. Secondary markings were circular, fresh or healed lesion-type blemishes that were either dark or white and also included more recent cuts or other wounds such as rakes (see Chapter 1 for more details). Secondary markings were sometimes used for the initial matching of individuals into preexisting folders (see photo processing methods above) but were not used in the final determination of resightings for the mark-resight abundance estimate.

3. *Correctly distinguishing marked and unmarked animals*—Inconsistent classification of individual cells as marked or unmarked across survey dates biases the estimate of abundance high. In other words, designating a cell as unmarked that had previously been designated as marked would bias the estimate of abundance high. Conversely, designating a cell as unmarked on a previous survey date, but calling it marked later results in the same outcome. This error is especially egregious because it simultaneously increases the number of unmarked cells and decreases the number of resightings, both of which inflate the abundance estimate. Failure to match a resighted cell to its original mark and calling it a new mark would also bias the estimate high, but not as much as does calling it unmarked.

4. *Resighting rates were equal for marked and unmarked whales*—It was essential that resighting rates not differ between marked and unmarked individuals. Sighting marked whales at a higher rate relative to unmarked whales would bias the estimate low.
5. *Unmarked whales were not sampled with replacement*—Marked cells had no chance of being sampled with replacement for a given survey date. If the unmarked cells were sampled with replacement, then the unmarked number was inflated (relative to the marked population), which would in turn bias the abundance estimate high.
6. *All individuals had some chance of being sampled*—Our estimate of abundance only applies to whales that were vulnerable to being well photographed (i.e., they had a chance of making it into our mark-resight dataset). If some portion of the population never had a chance of being photographed, then our estimate is biased low. Moreover, if some portion of the population had an extremely low probability of being resighted, then the estimates could still be biased low (despite the allowance for individual heterogeneity with ZPNE; McClintock et al. 2009).

RESULTS

Effort

We define attempted effort to be the number of photographs taken as distinct from effective effort, which is the number of photographs used in the mark-resight model. Approximately 8,595 photographs (right side only) of belugas were taken from 19 June to 28 October 2008. After processing (scored for photograph quality and mark identifiability), 310 photographs were of high-enough quality (designated as “excellent”; see Table 2.1 for quality definitions) to be used in the mark-resight model. The original sample used in the mark-resight model was based on 717 excellent- and “good”-quality photographs. However, relaxing the quality criterion to include good-quality photographs caused us to underestimate the marked fraction by about 30% and inflate the estimate (Table 2.5); thus only excellent-quality photographs were used. The ratio of attempted effort to effective effort was then 8,595:310 or 28:1; in other words, we had to take on average 28 photographs of whales to obtain one photograph usable for estimating abundance (this 28 does not include blank photographs of, say, water only). The Susitna River Delta received the most effective effort (62%), followed by Knik Arm (35%), Turnagain Arm (3%), and Chickaloon Bay (0.3%; Table 2.6). June received 0.3% of the total effective effort, July 45%, August 38%, September 14%, and October 3%.

The 310 photographs depicted 695 cells, 428 of which were designated as marked (Table 2.5). We cannot speak to the number of uniquely-identified whales included in the 310 photographs. Because we derived cell-specific population estimates, we were able to make use of cells from incomplete whale sequences (a full photograph sequence contains high-quality photographs of all five body cells for an individual). While the mark-resight model accounts for this eventuality, there is a chance that the same whale was counted twice across cells because not all of its body cells were depicted in the same photograph. Several photographs only showed a single cell. Summing the number of cells seen once, twice, three times, and so on would cause us to overestimate the number of unique individuals.

Model Comparisons and the Abundance Estimate

Six models were used to allow heterogeneity in sighting probability to be held constant or vary across all cells and individuals (see Methods for detailed descriptions of each model). These models were compared with respect to most-parsimonious fit using AIC*c* as per Burnham and Anderson (2002). The best model indicated that the sighting rate was constant across all cells and that there was no individual heterogeneity in this rate within cells (Table 2.4). Summing the AIC*c* weights for the two models with $\sigma = 0$ gives the weight of evidence (we convert the proportion to percent) that individual heterogeneity in sighting rates did not occur—54%. There was a 44% chance that individual heterogeneity occurred, but was constant across cells and a 2% chance that it occurred and was cell specific. With respect to cell heterogeneity (controlled by the parameter α), there was 62% chance that sighting rates were constant across cells. Because no single model carried the majority of AIC*c* weight, the abundance estimate for each cell was computed as the model-averaged estimate across the six models considered.

The model averaged predictions for the frequencies of the number of times an individual beluga whale was sighted fit the observed frequencies reasonably well (Figure 2.5). The cell-specific model-averaged estimate of abundance showed good agreement across cells B-E, but cell A had particularly sparse data. In the final analyses, it was determined that there were not enough sightings from this cell (i.e., this part of the body was not above the water often enough) to provide reliable estimates. Thus, only cells B–E were averaged to provide a final abundance estimate of 212 (lognormal 95% confidence limits = 183-245).

DISCUSSION

We have demonstrated that data from a photo-identification study can be used in a mark-resight model to estimate abundance of Cook Inlet beluga whales (CIBW). This mark-resight analysis is a first for beluga whales. CIBW appear relatively well marked, these marks persist over time, and we can access a large number of whales from a vessel and to a lesser extent land. However, in general beluga whales pose a particularly challenging opportunity for mark-resight analysis compared to other cetaceans and require a complex model and careful attention to photo selection, scoring, and mark identification.

Several technical issues arise from this dataset that must be addressed in order to allow an unbiased population estimate. If each is dealt with appropriately, the potential for a highly precise estimate exists because such a large portion of the population appears marked and available for sampling with a camera. Below we describe the factors affecting mark identifiability, compare the mark-resight model to other existing models, expand further on the extent to which model assumptions were met, compare our estimate of abundance to the annual NMFS aerial-survey-based estimate for 2008, and suggest direction for future work.

Mark Identifiability and Photographic Capture

The nature and location of marks made the process and criteria for selecting photographs critical to developing an unbiased estimate. Photo quality and mark identifiability affect the ability of researchers to consistently identify these marks across photos and among survey days. Beluga whales tend to be uniform in color (from gray to white across individuals but uniform within an individual) precluding use of pigmentation patterns for individual marks like has been used for bowhead whales (da Silva et al. 2000) and killer whales (Matkin et al. 1997, Williams and Thomas 2009). The lack of a dorsal fin further limits the opportunities for marks, compared to resight studies of most other cetaceans. Likewise, the very turbid waters of Cook Inlet and beluga dive behavior present few opportunities to photograph flukes, which have been used for identifying individual humpback whales (e.g., Straley et al. 2009).

In spite of these apparent challenges, we have shown that marks on CIBW are numerous and are spread over a large section of the dorsal area that is exposed in part and occasionally in its entirety when the animals surface (Chapter 1 in this report). The amount of dorsal area of whales exposed during a single surfacing and the quality of photographs over the dorsal area varied. Hence, many photos contained only a subset of the cells, and some contained only single cells. Therefore, in order to maximize sample sizes we stratified the dorsal area into cells and treated them independently for use in the mark-resight analysis. Cell-specific mark rates ranged from 17-88% and, excluding cell A, the average cell mark rate was 67% (cell A was the most difficult cell of the body to photograph well and few marks were found in this cell). The range of point estimates across the cell-specific abundance estimates from cell B through E was 151-251 (Table 2.7).

Comparing ZPNE to Other Models

One method for using this type of data could have been to divide the 2008 field season into two events and approach it as a traditional two-event mark-capture analysis. The first half of the season, considered the "marking event", could be used to determine the number of marked whales (marks released). The second half of the field season, considered the "recapture event", could be used to resample the population to check for previously-seen whales in the first half (i.e., recaptures). A model appropriate for this resulting dataset would be the familiar Lincoln-Petersen estimator (or variations of it); or, the partially-stratified Petersen (Darroch) model could be used to handle unequal capture probabilities among the different areas (Knik Arm, Susitna River Delta, Chickaloon Bay and Turnagain Arm).

There are several drawbacks to a two-event mark-recapture approach. First, because whales without marks could not be individually identified, the estimate would only apply to the marked portion of the population. In order to arrive at an estimate of the total abundance of marked and unmarked whales, an *ad hoc* scalar (1/marked proportion in the population) would have to be multiplied by the abundance estimate of marked whales. This "marked proportion" scalar could be estimated by assuming that marked and unmarked whales were photographed at the same rate (marked proportion = number of marked photographs/total number of photographs). However, this approach does not make use of the information contained in the sightings of unmarked whales (or completely incorporate all of the information for resightings of marked whales) in order to increase the precision of the estimate of total abundance. Further, it is not always straightforward to arrive at an estimate of the variance of the total abundance in this case (da Silva et al. 2000). Finally, it is not possible to take into account individual differences (heterogeneity) in capture probabilities using this approach; not accounting for this heterogeneity can lead to bias in mark-recapture estimates (Seber 1982).

Alternately, the dataset could be treated as a series of resight events to make use of the models that can handle individual heterogeneity. Straley et al. (2009) review several models differing in complexity and use such an approach for the estimation of humpback whales in Southeast Alaska. However, virtually all sighted humpbacks possess distinguishable marks and so the problem of estimating the number of unmarked individuals is not an issue in that study. We needed a model that could simultaneously make use of marked and unmarked individuals while allowing for individual heterogeneity.

The zero-truncated Poisson log-normal mark-resight model (McClintock et al. 2009) was particularly well suited for this type of data. The ability to evaluate individual heterogeneity of sighting probabilities was provided by the parameter σ. There was little evidence of individual heterogeneity; nevertheless, because the abundance estimate was averaged across models, any existing heterogeneity was accounted for (in proportion to the evidence provided by the data) in the final abundance estimate.

Model Assumptions

1. Closure—We suspect mortality during the study was low and equal for marked and unmarked whales. If mortality occurred, then either our estimate is applicable to the beginning of the sampling period (19 June 2008) or biased high for the last survey date (28 October 2008). We have no formal statistical tests available to validate the closure assumption. However, the short sampling period (about 19 weeks) coupled with the low rates of annual mortality and recruitment (Hobbs et al. 2006) suggested that violations to demographic closure were nominal. Ancillary data from the 2008 NMFS aerial surveys of Cook Inlet (Shelden et al. 2008a, b, c) were used as some indication of geographic closure, as no belugas were observed outside of the sampled areas during NMFS surveys. A few anecdotal reports (e.g., fishermen) of beluga whales in Lower Cook Inlet were reported. If individual whales ventured outside of the sampled areas but returned at some point during the study, this would have been a source of individual heterogeneity in resighting rates. The model incorporating individual heterogeneity accounted for differences among individuals with respect to the number of sampling events they were exposed to.

2. *No loss of markings during the primary sampling interval*—Given the consistent identifiability of primary marks used in this analysis, we deem our methods satisfied this assumption (Chapter 1 in this report). The role of the photo-identification catalog in the abundance estimate was limited to documenting mark persistence and identifiability across time. The 2005-2008 catalog provided confidence in choosing primary marks that persisted over time. There was no quantified estimate of mark loss as is sometimes done in mark-recapture studies where animals are double tagged. However, given that all the primary marks analyzed were recognizable for at least one year (based on 110 animals in the 2005-2008 catalog), we suspect that any mark loss over the course of the 2008 study was close to 0%.
3. *No errors in distinguishing marked and unmarked animals*—This was a critical assumption and its violation would result in a significant inflationary bias. We had to use stringent selection criteria for photos to be included in the mark-resight analysis and in doing so we encountered the classic tradeoff between precision and bias in cetacean mark-resight studies (Hammond 1986, Friday et al. 2008). Photograph quality and mark identifiability can greatly affect the classification of whales as marked and unmarked, as we found when we selected photographs of "High" quality in addition to "Excellent" quality (Table 2.5). For the abundance estimate presented here, we imposed a stringent set of criteria in selecting photographs for the mark-resight analysis. Only extremely high-quality photographs were used for analysis and only marks deemed highly distinguishable and persistent over time (Chapter 1 in this report) were used to classify a cell as marked. When a more inclusive threshold of photo quality was used, we obtained a larger sample size. However, including lower-quality photos led to an underestimation of the proportion of marked individuals by an average of 30% across cells (Table 2.5). Such errors lead to a substantial inflationary bias in the abundance estimate. We considered including a parameter in the mark-resight model that adjusted for photograph quality in an attempt to make use of the larger dataset. However, this adjustment would only work if the marked proportion was actually lower for the poorer-quality photographs and was not due to misidentifying marked and unmarked individuals. Because these two possibilities were confounded, choosing only the highest-quality photographs was the only solution.
4. *Resighting rates were equal for marked and unmarked whales*—We have no reason to believe that resighting rates were dependent on whether or not a cell was marked or unmarked. Because all observed whales were photographed and marks were mostly not evident until photographs were processed in the lab, there was little chance for this bias. Furthermore, every effort was made to spend a uniform amount of time photographing individual animals so as not to bias resighting rates through unequal sampling (e.g., by spending more time with cow-calf pairs than lone animals). Thus, we do not believe this assumption was violated from any systematic field collection bias.

   Another avenue for violating this assumption could have occurred during the processing phase of the analysis if the presence of a mark affected the scorer's designation of photograph quality. If a highly-identifiable mark was present, then the scorer may have been more inclined to score the photograph as high quality. This would have caused photographs with marks to be included in the analysis more readily than unmarked photographs of comparable quality, and would bias the estimate low.

Consistent with Friday et al. (2008), it is clear that the initial scores for photograph quality and mark identifiability were correlated, as more of the highest-identifiable marks were observed in the highest-quality photographs (Figure 2.6). These results could have occurred because of two mechanisms: (1) marks could typically be scored as highly identifiable more readily when the photograph quality was high, and/or (2) as mentioned in the preceding paragraph, the presence of a highly identifiable mark biased the scorer to designate a photograph as higher quality than it actually was. If mark identifiability was at least partially a function of photograph quality, then using poorer quality photographs may cause errors in distinguishing marked whales and the violation of Assumption 3 as discussed above. Therefore, the mechanism that generated the results depicted in Figure 2.6 is critical to understand in order to know whether Assumption 3 or 4 was more likely violated. If we assume the first, then we should use only high-quality photographs to prevent misclassification of marked and unmarked animals. However, bias from the second mechanism (violation of Assumption 4) would be reduced if we included lower-quality photographs to counter the biased mark rate in the higher-quality photographs. Because most primary marks used to match individuals are white (see Chapter 1 of this report), even unique marks are difficult to see, particularly on white whales. Based on this knowledge, we suspect that the first mechanism and the risk of violating Assumption 3 was more likely and therefore chose to eliminate lower-quality photographs, as recommended by Friday et al. (2008).

Finally, there was another possibility for violating this assumption during photograph processing. Prior to the scoring phase, photographs were initially matched to preexisting folders based on all marks, regardless of how faint. Only later were individual cells scored for photograph quality, mark identifiability, and deemed as marked or unmarked. Knowledge of a whale's identity (because it was in a known folder) may have biased the scorer's designations of quality and identifiability (violation of Assumption 4) and/or caused false positive resights (violation of Assumption 3). We suspect such occurrences were infrequent and, therefore, not a major source of bias. We plan on investigating amendments to the photograph processing protocol in the future to further preclude this possibility (see the section below entitled Future Work).

5. <u>*Unmarked whales were not sampled with replacement*</u>—We sampled marked cells without replacement for a given day's survey. If the unmarked cells were sampled with replacement, it would introduce an inflationary bias to the abundance estimate. To minimize this bias, we were careful to avoid resampling individual whales during the processing of photo sequences (described above). Furthermore, virtually all whales possess some marks, albeit some are too faint to meet the criterion for being "marked" in the mark-resight model. These faint marks helped to identify photographs of the same individual from a given survey date and further precluded resampling. A sensitivity analysis to examine the potential effect of violating this assumption suggested that low levels of unintended "sampling with replacement"

would have had only a modest effect on the abundance estimate presented here (Table 2.8).

6. *All individuals had some chance of being sampled*—The mark-resight model estimates the abundance of whales that were vulnerable to being sampled by our camera and that yielded high-quality photographs. For that group of whales, the estimates were precise and the potential for bias was minimized with respect to individual differences in resighting rates. However, if some whales in the population never had a chance of producing a high-quality photograph, they were not included in our abundance estimate.

   Potential violation of this last assumption is the biggest limitation of our estimate and therefore the estimate may not apply to the entire population of Cook Inlet beluga whales. There are several reasons to believe that the abundance estimate pertains to a large portion of the CIBW population, but it is difficult to quantify this portion precisely with the available data.

   For our abundance estimates to incompletely represent the entire CIBW population, there would have had to have been some whales in the population that had essentially zero probability of encounter with our camera (and inclusion in our mark-resight dataset) in 2008. That could have occurred in three ways:

   1. If some whales were never in Upper Cook Inlet over the course of our surveys.
   2. If some whales in Upper Cook Inlet were in areas that we did not survey.
   3. If individual whales behaved in ways which led to very little or no chance of being photographed.

   Given the importance of this issue, we delve into considerable detail below to discuss the potential for these situations to have occurred.

Summer and fall distribution of CIBW

Our surveys covered Upper Cook Inlet in areas and at times when the Cook Inlet population of beluga whales is known to congregate. Surveys were conducted from June through October and covered the three main regions where CIBW frequent (Susitna River Delta, Knik Arm and Turnagain Arm). The bulk of the photographic data for the mark-resight analysis were obtained in July and August (83%—Table 2.6) and of those, 62% were from the Susitna Delta and 20% were from Knik Arm.

Intensive aerial surveys for beluga whales (by NMFS) in Cook Inlet in June, August, September, and October 2008 sighted few beluga whales in areas outside those we surveyed (Shelden et al. 2008a, b, c). The focus of the September and October aerial surveys was to survey the Lower Inlet, yet no beluga sightings in the Lower Inlet were made (Shelden et al. 2008c). This concentration of whales in Upper Cook Inlet has been a typical result for annual June surveys over the last 15 years; the most recent sighting of beluga whales in the Lower Inlet was from the June surveys of 2001 (Rugh et al. 2005). Given the consistent lack of sightings in Lower Cook Inlet over many years, it is unlikely that the 2008 surveys missed a substantial aggregation of whales that remain outside the areas covered by our photo-id surveys. Habitat use information obtained from 14 satellite tagged whales from 2000-2003 provides further evidence that most of Cook Inlet belugas remain in Upper Cook Inlet for the summer and fall, and that there is regular movement between the different feeding areas that we surveyed (Hobbs et al. 2005).

Distribution of CIBW in Upper Cook Inlet

Although there is little evidence that a significant portion of the CIBW population was outside Upper Cook Inlet in 2008, there are parts of the Upper Inlet that we did not survey. We were unable to access the near-shore area just south of Point Possession; this is an area where no whales were sighted in 2008 during NMFS aerial surveys but groups have been sighted there during aerial surveys as recently as 2006 (Rugh et al. 2006). Additionally, we did not survey most of the open-water area between Point Possession and the Beluga River (south of the Susitna Delta) in 2008. We did not survey these areas due to a limited ability to safely access them and because beluga whales do not typically congregate in predictable manner in those areas.

Segregation of whales within Upper Cook Inlet by habitat types we did not survey could have resulted in our surveys missing components of the population. In his compilation of traditional ecological knowledge of CIBW, Huntington (2000) reported that some beluga groups were thought to remain in deeper waters, not entering the river mouths as other groups did. If complete segregation occurred in 2008 and some groups of whales only occurred in the deep, open waters of the upper Inlet and never ventured to near the river mouths where our photo-id surveys took place, these whales would not have been encountered by the photo-id surveys. However, comparison of survey results obtained from aerial and photo-id surveys of Upper Cook Inlet during the months of June, August, and September indicate that both survey methods detected whales in the same areas and in similarly sized-groups (with the exception of Chickaloon Bay; Table 2.9).

Sighting histories of the 30 individual beluga whales identified in all four years of the photo-id study are consistent with results obtained from earlier satellite-tagging studies mentioned above, and provide evidence we were exposed to most whales in Upper Cook Inlet. Sighting histories from the photo-id catalog indicate that these whales circulate among the Susitna River Delta, Knik Arm, Chickaloon Bay, and Turnagain Arm (McGuire et al. 2009). In year 2008 of our study, 38 whales included in the mark-resight estimate tended to move more or less randomly among the surveyed areas, with the exception of Turnagain Arm (although low sample sizes for this area prevent any definitive analysis at this stage), and tended to concentrate in Knik Arm (Figure 2.7). Our survey effort was focused in areas and times of the year to maximize the probability of encountering whales based on seasonal whale distribution patterns found by other studies in this decade (Moore et al. 2000, Funk et al. 2005, Hobbs et al. 2005, Markowitz and McGuire 2007, Nemeth et al. 2007). Consistent with historical distribution, whales were encountered and photographed in the Susitna River Delta in the summer (May-August) and in Knik Arm and Turnagain Arm in the late summer and fall (mid-August through October).

Effect of behavioral differences among individual whales

As described earlier, the ZPNE model accounted for heterogeneity of resighting rates among individuals. However, some whales present in the survey areas may have had a zero chance of being captured in our mark-resight photographs. Photo quality decreased with distance from the survey vessel and therefore individuals that consistently remained far from the survey vessel may have had no chance of being included in our mark-resight dataset. Our vessel survey protocol was to parallel and match the speed of the whales (Würsig and Jefferson 1990), photograph each individual that came to view, then move on to other groups or portions of larger groups; thus, time spent photographing a single individual was limited. We did not pursue whales that remained at a distance from the survey boat and only those whales that remained within range were photographed.

Some whales in the survey area may have been wary of vessels and only yielded long-distance, poor-quality photographs. It is reasonable to believe that some whales could have been particularly wary of the surveyors given that this population was recently hunted by humans from small boats. Such behavior would have had to have been consistent and complete for it to have restricted our abundance estimate to less than those animals in our survey areas. However, given the recent history of hunting, we suspect that some older animals may maintain a greater distance from small boats than other animals which have not been chased or shot at. Further, due to the relatively close distances required to obtain high-quality photographs, even subtle behavior of this type would result in any such individuals being out of photo range.

Another possible limitation in our sample coverage could be related to differences in group behavior. We have seen that larger groups of whales tended to be easier to approach and photograph than smaller groups. Whales may have felt less vulnerable in larger groups than in smaller groups, or whales in larger groups may have been engaged behaviors such as feeding, during which time they may be more likely to stay near the survey vessel than when engaged in another activity such as traveling. Alternately, extreme avoidance of the sampling crew could have made some whales unavailable. Previous encounters with hunters or having been injured by a boat could have promoted this behavior in some individuals.

Regardless of the reason for being easier to approach and photograph, to the extent that some individual whales never joined large groups, they may not have been vulnerable to our surveys over the course of 2008. If the abundance estimate presented here is less than the true population size, behavioral segregation may be the most plausible explanation for that difference. Given the importance of this issue, we suggest ways to mitigate and quantify the potential effects of this phenomenon on the abundance estimates in the section below entitled Future Work.

Comparison of this Estimate to the NMFS Estimate of the CIBW Population

The mark-resight model provides an independent abundance estimate which is comparable but not likely identical in scope to the CIBW annual abundance estimate provided by NMFS. The 2008 abundance estimate from the mark-resight data (N = 211, CV = 0.075) was lower than the corresponding estimate (N = 375, CV = 0.230) from the NMFS aerial surveys (Hobbs and Shelden 2008). Likewise, there was minimal overlap between the confidence intervals of the two estimates, which may indicate that these estimates are significantly different; log-normal confidence intervals for the mark-resight estimate were 183-245 vs. 240-585 for the aerial survey estimate. For the reasons noted above, it is possible that the mark-resight estimate presented here is limited to a yet-to-be-quantified portion of the CIBW population.

Future Work

Addressing model assumptions

The observer that scored the photographs was also familiar with matching the individuals. Having knowledge of the different individuals may have caused bias in scoring for photograph quality and mark identifiability. In order to avoid this type of bias in the future, we plan to use different personnel at the various stages of scoring. Ideally quality attributes such as contrast, and exposure could be attained from the photographic attributes, such as is currently underway for assessing color (Chapter 3 this report). Until this can be developed, we will maintain consistent scores for quality by using a person unfamiliar with the markings to score photographs for quality attributes only. A second person experienced with beluga markings that is not closely associated with matching photographs from the right side catalog could score for mark identifiability. By removing the individual that matched the photographs from the scoring process, a less-biased estimate may result.

Our treatment of the cells as independent with respect to the presence/absence of marks was most likely unrealistic. While non-independence might have occurred, our estimate of abundance was not expected to be biased as a consequence; however, it remains unclear how variance was affected. Therefore, adapting the model to account for dependence across cells will be the focus of future modeling.

It may be possible to test the hypothesis that certain individuals are avoiding the survey boat by comparing sightings data from land- and boat-based photographs. All else being equal, land-based photographic data should not be subject to the same effect as the boat-based photographs if certain animals are avoiding the boat. Therefore, a comparison of these data offers an opportunity to determine whether there are individual whales in Upper Cook Inlet that are not ever (or only very rarely) photographed from the boat. The best sites for land-based photography are in Turnagain Arm, where unfortunately the distance between the photographer and the whales was still much greater than during boat-based surveys in other areas. Estimated mean minimum sighting distances (the closest whales came to the survey vessel or shore-based observer) were 12 m (39 ft) in the Susitna River Delta, 71 m (233 ft) in Knik Arm, 61 m (200 ft) at the Port of Anchorage, 2 m (6.6 ft) in Chickaloon Bay, and 109 m (358 ft) along Turnagain Arm (note that sample size differ considerably among areas). Hence, we could not obtain a large enough sample of quality photographs from land in 2008 with which to base any comparisons.

However, if these surveys continue in the future and the number of sightings increases, it may be possible to compare a sufficient number of sightings between land- and boat-based photographs in order to test the hypothesis that certain individuals avoid the survey boat. Likewise, modest equipment changes could improve the sampling distance of photographic effort. An increase in the power of the lenses used to take photographs may allow for a more representative sample of the population if, as mentioned above, high quality photographs are not available for some boat-shy individuals. Further, land-based efforts provide a stable platform for more-powerful lenses to be mounted on tri-pods which would further increase our sampling efficiency and provide data with which to address the robustness of our assumptions with respect to sampling coverage.

Expanding the framework of the ZPNE model

The ZPNE model is flexible in its ability to adjust sightings rates for heterogeneity. For now, this heterogeneity was adjusted for cell and individual differences with the parameters α and σ, respectively. Other environmental covariates and categorical variables such as area sampled could be investigated within this framework in order to assess their effects on sighting rates with the potential for reducing residual noise (McClintock et al. 2009).

Assessing trends in abundance with more precise MR data

Independent annual abundance estimates can be generated using data from other years which have been gathered in the same manner as the 2008 data. In general, mark-resight estimates of abundance from populations which are aggregated over relatively small areas tend to be more precise than similar estimates using alternative methods like line-transect sampling (e.g., Calambokidis and Barlow 2004). All else being equal then, mark-resight estimates of abundance will have a higher power of detecting changes in abundance than those that provide less-precise estimates. At present however, a fundamental question about these small-boat surveys is whether or not the sampling would be covering the same component of the population across years. If it is, then it would be possible to develop an index of abundance from this survey, which could be monitored to detect changes in population size (independently, or jointly with the NMFS aerial survey estimates).

Following the methods of Gerrodette (1987), we calculated the power (using a two-tail test) to detect annual rates of change for this population given the CV from the abundance estimate presented here, and either five or 10 years of mark-resight data (Figure 2.8). While the CV for this abundance estimate is relatively precise, five years of survey data would only result in approximately a 50% chance of detecting an 8% annual decline over that time period. In other words, we would do no better than chance alone at detecting a decrease from 211 to 151 animals over five years. While the situation is much better for 10 years of survey data, it is obvious that obtaining auxiliary information pertaining to the underlying population dynamics needs to be a top priority in addition to simply monitoring abundance.

Life history parameter estimates

Although estimates of abundance are often relied on as a key tool for monitoring population status, by themselves they may offer little insight into the reasons for observed trends. On the other hand, estimates of demographic rates for this population could be potentially very informative with respect to those factors which may be limiting recovery. For example, if we are able to monitor survival and calving rates, we should be able to better judge the effectiveness of alternative management decisions. At present however, basic life history information for this population is lacking. The ZPNE model can be extended to take into account multiple years of resightings data in order to generate estimates of survival and other life history parameters (McClintock and White 2009). We hope to be able to extend these analyses in the future, and to estimate survival and other important life-history parameters for this population.

Integrating information from photo-identification into risk assessment

Information provided by the photo-id data could provide a valuable contribution to future risk assessments for this population. There are several ways this information may be integrated into such assessments. In addition to potentially providing independent abundance estimates, any estimates of demographic parameters resulting from the photo-id data could be used to inform risk assessments. For example, in a recent Bayesian assessment of bowhead whales Brandon and Wade (2006) incorporated Zeh et al.'s (2002) mark-resight estimate of bowhead survival through a prior distribution on that parameter in an age-structured model. Further, as more years are added to the CIBW photo-id time series, it may be possible to extend the numbers-at-age population dynamics model used in recent risk assessments (Hobbs et al. 2008, Hobbs and Shelden 2008) to a 'hybrid' individual-based and numbers and age model, which is then fit simultaneously to photo-id histories of individual whales as well as the abundance estimates from the aerial surveys. A similar approach has been adopted for risk assessment of the endangered western gray whale (Reeves et al. 2005).

Conclusion

The potential for the data collected by this research is great. As we have shown, it is possible to estimate abundance for CIBWs using mark-resight methodology. While there remains some uncertainty about the extent to which this estimate represents the entire population, the true value of this research lies in the potential for this data to provide information on many different aspects of this endangered population. In this regard, future photo-id studies of CIBWs may be able to move conservation efforts past the question of what is happening to abundance, and closer to an answer of why it is happening.

Table 2.1. Attributes used to assign photographic quality scores to photographs of Cook Inlet beluga whales. Scores are assigned to each cell.

Score		Description
1+	**Excellent**	Entire cell is visible. Focus is sharp and exposure is correct. No washed out areas, shadows or glare. No manipulation would be required to see even small marks were they available. Edges of the profile against the water are sharp.
1–	**Good**	Entire cell is visible. Focus is good and exposure is correct. Minor glare or shadowing may occur. Some magnification may help to make marks easier to see. Small marks may be missed. Edges of the profile against the water may be slightly blurred.
2+	**Fair**	Most of the cell is visible. Small parts of the cell may be out of view (<5%). May be over/under exposed or exhibit glare/shadows in some areas. Large and most medium marks if present are visible but may not be sharp. Some finer medium and small marks may be missed.
2–	**Below Average**	Visibility of the cell is compromised by 5-10%. Image is not clear. There may be over/under exposed parts of a cell. Can still distinguish features and some large markings, but some finer medium marks and small marks might be missed.
3	**Poor**	The perimeter of the cell is obscured and difficult to see due to splash or glare. Focus is blurred. Too grainy or over/under exposed to distinguish features or markings accurately. Cell may be covered by water, shadow or glare. Large marks may be missed.

Table 2.2. Mark attributes[a,b] used to assign mark identifiability scores to photographs of Cook Inlet beluga whales. Multiple combinations of one or more attributes (including type and size) defined each score. Table values indicate the number of marks of a certain attribute that went into each combination. Size percentages (in parentheses) represent the length of the mark relative to the body cell length.

	Mark Type					
	Very Large, Distinct	**Large or Bright, Very Distinct**	**Large, Fairly Distinct**	**Large, Indistinct**	**Medium Indistinct***	**Small Indistinct***
Score	**Size**					
∀	**(>20%)**	**(>10%)**	**(>10%)**	**(>10%)**	**(5-10%)**	**(<5%)**
H+	1					
		1	1			
		1		1		
			1	1		
			1		3	
			1			4
		2				
			2			
				2		
H-		1				
			1		2	
			1			3
				2	1	
				1	2	
				1		4
M+			1		1	
				1	1	1
				1		2
					3	
						4
M-			1			
					2	
						3
U+				1		
					1	2
U-	No marks of consequence present					
X	<90% cell available to score					

*Clusters of medium or small marks were considered equal to medium or large.
[a]Bumps or irregularities (non colored markings) were considered the same as colored markings.
[b]Rounded shapes and clusters were measured by the greatest diameter or width.

Table 2.3. Mark attributes used to score the dorsal ridge area (cell) of a beluga whale[a]. Multiple combinations of one or more attributes (including type and size) defined each score. Table values indicate the number of marks of a certain attribute that went into each combination. Size percentages (in parentheses) represent the length of the mark relative to the body cell height.

	Mark Type					
	Large Notch	Large Line	Large Circle	Line*	Notch*	Circle*
	Size					
Score ↓	(>50%)	(>50%)	(>50%)	(≤50%)	(≤50%)	(≤50%)
H+	1	1				
	1		1			
		1	1			
	2					
		2				
			2			
H-	1					
		1				
			1			
M+				3		
					3	
						3
M-				2		
					2	
						2
U+				1		
					1	
						1
U-	No marks of consequence present					
X	<90% cell available to score					

*Clusters of medium or small marks were considered equal to medium or large. Used greatest distance for length.
[a]Rounded shapes and clusters were measured by the greatest diameter or width.

Table 2.4. Model selection results estimating population abundance using the zero-truncated Poisson log-normal mark-resight estimator. The parameters α and σ were estimated as both a common parameter across cells (.) and as cell-specific estimates (cell). U was always estimated as five cell-specific parameters. In addition, σ was fixed to zero (σ(.) = 0) to evaluate whether there was important individual heterogeneity in sighting probabilities.

Model Number	Model	AIC*c*	ΔAIC*c*	AIC*c* Weights	Model Likelihood	Number of Parameters	Deviance
1	**{α(.) σ(.) = 0 *U*(cell)}**	563.84	0	0.317	1	6	551.559
2	**{α(.) σ(.) *U*(cell)}**	563.994	0.155	0.294	0.926	7	549.619
3	**{α(cell) σ(.) = 0 *U*(cell)}**	564.532	0.692	0.225	0.708	10	543.786
4	**{α(cell) σ(.) *U*(cell)}**	565.37	1.53	0.148	0.465	11	542.472
5	**{α(.) σ(cell) *U*(cell)}**	570.923	7.084	0.009	0.029	11	548.025
6	**{α(cell) σ(cell) *U*(cell)}**	571.391	7.552	0.007	0.023	15	539.736

Table 2.5. The number of cells classified as marked using two photograph selection criteria and the error rate associated with using the less-stringent selection criteria. The mark-resight abundance estimate was developed using only "excellent" quality photographs (see methods).

Photo Selection Criteria (score used)	**Cell A**	**Cell B**	**Cell C**	**Cell D**	**Cell E**
	Number of Cells Marked				
Excellent and good (1+ and 1-)	62	230	212	373	357
Excellent (1+)	9	67	80	136	136
	Number of Cells Not Marked				
Excellent and good (1+ and 1-)	255	315	562	314	228
Excellent (1+)	44	43	131	30	19
	Percent of Cells Marked				
Excellent and good (1+ and 1-)	20	42	27	54	61
Excellent (1+)	17	61	38	82	88
Actual difference in mark rate (% marked using "excellent and good" criterion minus the mark rate from using "Excellent")	3	-19	-11	-28	-27
Percent relative error in classifying cells as marked using "excellent and good" selection criterion compared to "Excellent"	15	-31	-28	-34	-30
Average error rate (%, cells B-E)					-31

Table 2.6. Photographic effort in 2008 according to month and survey area. Effort is expressed as the number of right-side photographs taken (attempted effort), the number of high-quality right-side photographs used in the mark-resight model (effective effort), and the percent effective effort.

Month	Effort	Susitna River Delta	Knik Arm	Chickaloon Bay	Turnagain Arm	All Areas
June	Attempted effort	81				81
	Effective effort	1				1
	Percent effective effort	0.3				0.3
July	Attempted effort	3230				3230
	Effective effort	139				139
	Percent effective effort	44.8				44.8
August	Attempted effort	1192	1989		315	3496
	Effective effort	52	63		3	118
	Percent effective effort	16.8	20.3		1.0	38.1
September	Attempted effort		779	191	397	1367
	Effective effort		34	1	7	42
	Percent effective effort		11.0	0.3	2.3	13.5
October	Attempted effort		360		60	420
	Effective effort		10		0	10
	Percent effective effort		3.2		0.0	3.2
All Months	Attempted effort	4503	3128	191	772	8594
	Effective effort	192	107	1	10	310
	Percent effective effort	61.9	34.5	0.3	3.2	100.0
	Attempted effort:Effective effort	23:1	29:1	191:1	77:1	28:1

Table 2.7. Model-averaged abundance estimates for the five cells, plus the overall average computed for five cells (A–E), 4 posterior cells (B–E), 3 posterior cells (C–E), and 2 posterior cells (D–E).

Parameter	Estimate	SE	LCI	UCI
Cell A $\hat{N}$	129.7	150.7	21.2	793.9
Cell B $\hat{N}$	151.5	21.6	114.7	200.1
Cell C $\hat{N}$	251.5	40.8	183.4	344.9
Cell D $\hat{N}$	205.4	20.5	169.0	249.7
Cell E $\hat{N}$	238.5	33.1	181.9	312.7
Average $\hat{N}$ **A–E**	195.3	31.9	142.1	268.4
Average $\hat{N}$ **B–E**	211.7	16.0	182.6	245.4
Average $\hat{N}$ **C–E**	231.8	18.5	198.3	271.0
Average $\hat{N}$ **D–E**	221.9	18.1	189.2	260.3

Table 2.8. Result of a simulation test of the data showing the decrease in estimated abundance if poorly-marked whales were counted with replacement.

Percent Change Cells B - E	Estimate	SE	LCI	UCI
0	211.7	16.0	182.6	245.5
5	208.2	15.6	179.8	241.1
10	204.6	15.2	176.9	236.6
15	201.1	14.9	174.0	232.5
20	197.2	14.4	170.9	227.5
25	193.7	14.1	168.0	223.4

Table 2.9. Mean sighting rates and survey effort for belugas encountered in 2008 in Upper Cook Inlet, according to area, survey method, and month.

Survey Area	2008 Survey	June	August	September
		# Belugas per Day (Number of Survey Days)		
Susitna Delta	NMFS Aerial	68 (7)	89 (3)	0 (2)
	Photo-id	29 (2)	118 (1)	Not surveyed
Chickaloon Bay	NMFS Aerial	14 (5)	0 (1)	6 (2)
	Photo-id	0 (1)	Not surveyed	42 (1)
Knik Arm	NMFS Aerial	0 (7)	45 (3)	6 (1)
	Photo-id	0 (1)	57 (3)	44 (4)
Turnagain Arm	NMFS Aerial	0 (6)	25 (3)	26 (2)
	Photo-id	Not surveyed	22 (3)	26 (7)

Figure 2.1. Map of Cook Inlet, Alaska, showing major features discussed in the text.

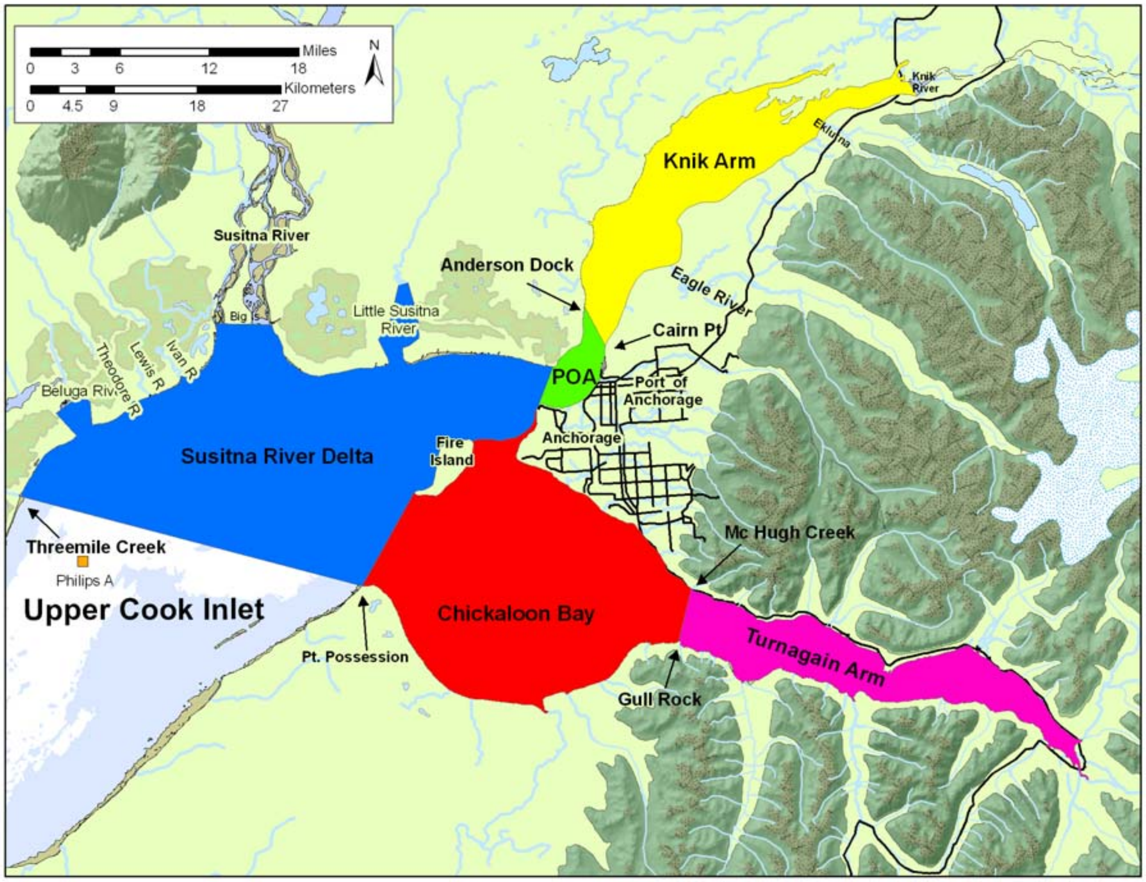

Figure 2.2. Map of Upper Cook Inlet, Alaska, showing boundaries of five survey areas within the study area.

All photographs obtained on surveys.

↓

Copies of photographs archived.
Photographs that are blurry or do not contain whales are discarded.

Single photographs; may contain more than one whale.

↓

All "acceptable" quality photographs are cropped to contain only a single whale.
Multiple photographs of the same whale compiled into folders of individuals.

Each folder of an individual contains one or more photographs of a single whale.
Each photograph contains one or more cells of a single individual.

↓

Folders from a new survey are placed into folders from previous surveys where individuals can be matched based on all available photos.

Folders contain photographs from multiple surveys (if the individual has been re-sighted) or just one survey (if it was a first sighting).

↓

All photographs scored for photograph quality. Photos of only the highest quality continue on in the analysis; photographs of lower quality are archived.
For each high-quality photograph, each cell is classified as marked or unmarked.

Folders of individual whales now contain one to many photographs of marked and unmarked cells from one to many survey dates.

↓

For each cell, all encounters of marked whales are summed across 2008 surveys. (Only one sighting per individual whale per cell for each survey date.)
For each cell, all the unmarked whales are summed across 2008 surveys.

Input file to the Zero-truncated Poisson log-normal mixed-effects model (ZPNE).

Figure 2.3. Flow chart showing the processing steps for photographs to obtain the input data file for the software Program MARK. Arrows denote the steps taken and text boxes represent stages of processing.

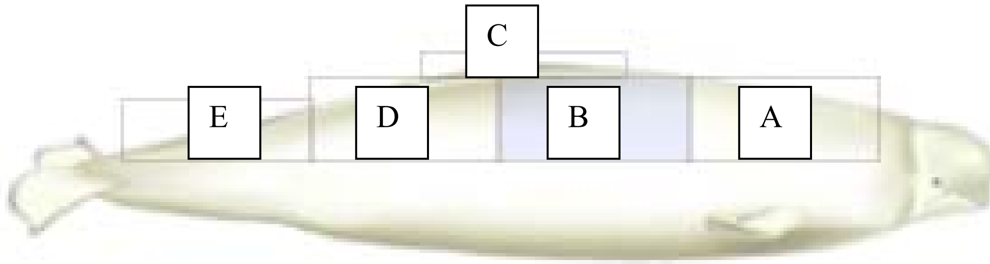

Figure 2.4. Figure showing the five portions ("cells") of a beluga whale that are used for scoring photographs for photographic quality and mark identifiability. Cell A: From the blow hole to ½ the way to the midpoint of the ridge. Cell B: Center point of the ridge to the ½ way point forward to the blow hole. Cell C: The dorsal ridge. Cell D: From the midpoint or the dorsal ridge to ½ the way to the base of the tail. Cell E: From the base of the tail to ½ the way to the midpoint of the dorsal ridge. Cells A, B, D, and E have an estimated depth of ½ the thickness of the whale. Beluga illustration courtesy of Uko Gorter.

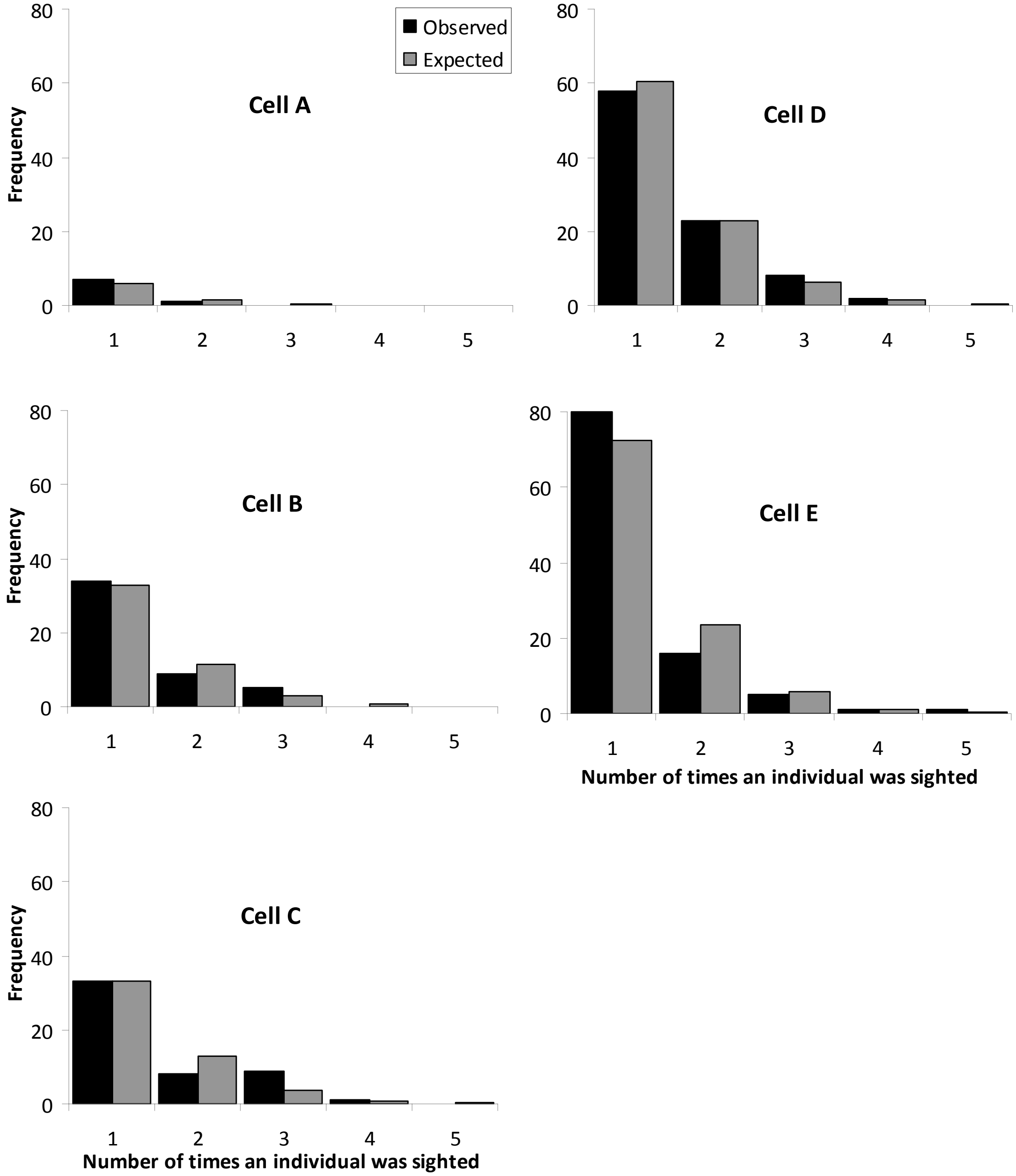

Figure 2.5. Comparison of expected versus observed frequency for the number of times an individual beluga whale was sighted. The predicted number of sightings represents the average from all six models (see Methods for model descriptions) weighted by their Akaike weights.

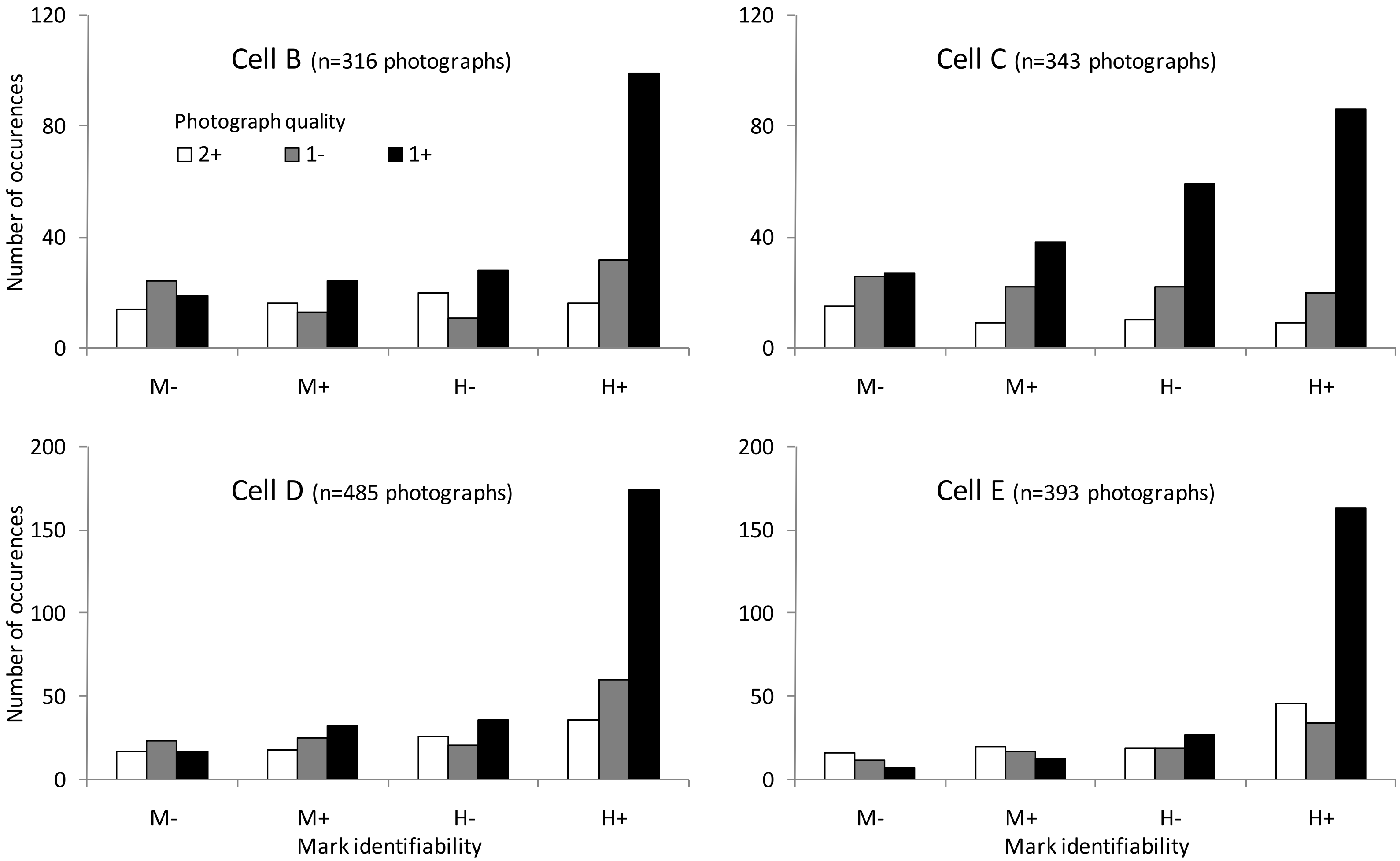

Figure 2.6. Number of photographs for all combinations of the top three photograph-quality and top four mark-identifiability scores by each body cell used in the 2008 mark-resight model for Cook Inlet beluga whales. In the final analysis, only photographs of 1+ quality and H- and H+ identifiabilities were examined to determine if cells were marked or unmarked (310 photographs).

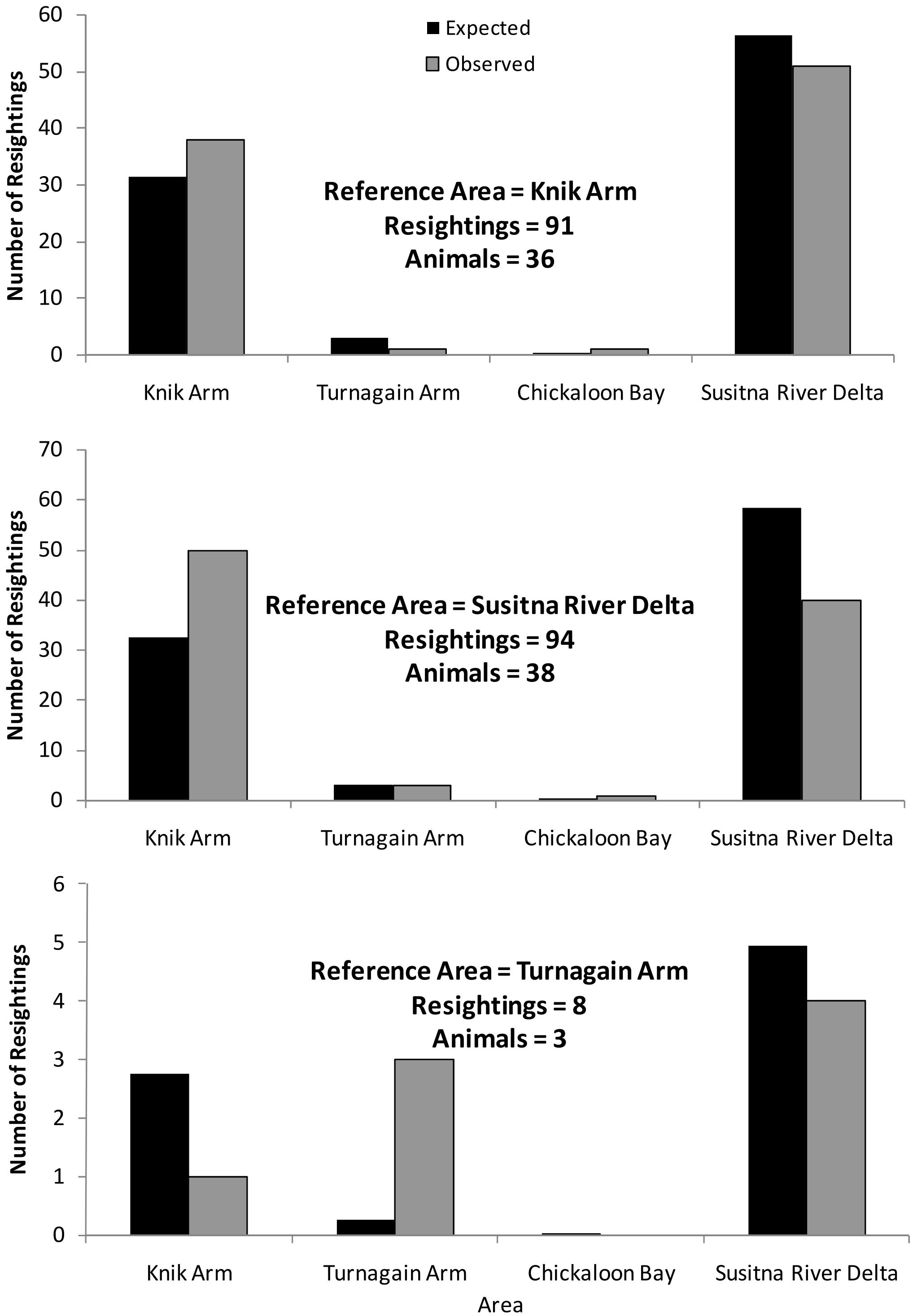

Figure 2.7. Movement analysis of beluga whales across three of the surveyed areas in Upper Cook Inlet. Observed values represent the number of resightings across areas given an animal had also been seen in the reference area indicated. Expected values represent the total resights from animals sighted in the reference area parsed across all areas based on relative effective effort (number quality photos included in the mark-resight analysis; see Table 2.6).

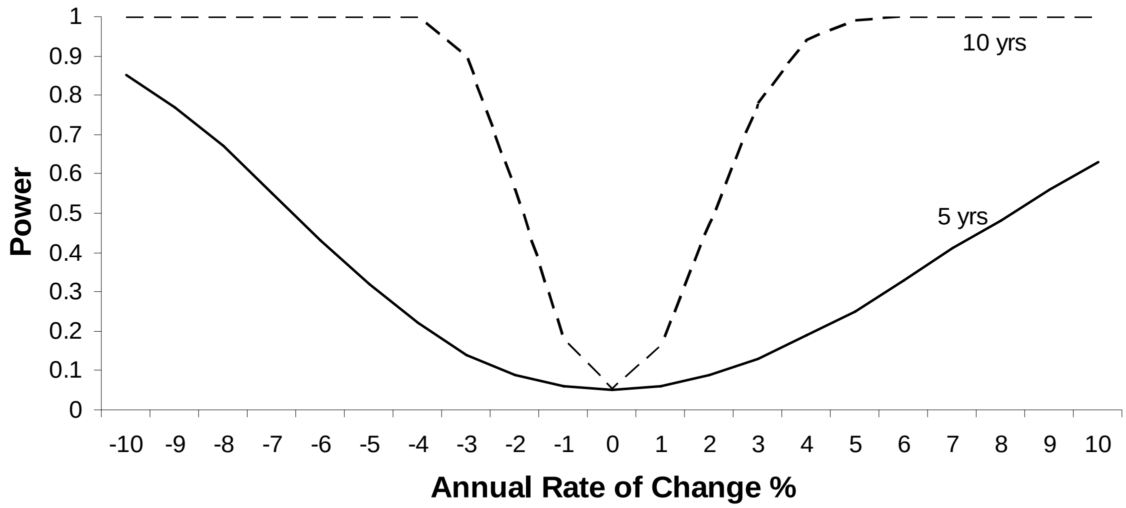

Figure 2.8. The power to detect an annual rate of change, given the coefficient of variation (CV) of the mark-resight abundance estimate is shown. The solid line is the power of five years of survey data, and the dashed line is for 10 years of data.

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APPENDIX 2-A

THE ZERO-TRUNCATED POISSON LOG-NORMAL MIXED EFFECTS (ZPNE) MODEL

John R. Brandon

The Model

This appendix outlines the details of the zero-truncated Poisson log-normal mixed effects (ZPNE) model as applied to the beluga photo-id data. The ZPNE model was adopted for these analyses because it takes into account mark-resight data where the exact number of marked individuals is unknown, and also incorporates the information to be gained from sightings of unmarked individuals. This is essentially a generalized linear mixed effects model with a log-link function and a modified Poisson likelihood that accounts for the aforementioned information. Further details and additional applications of this framework are provided by McClintock et al. (2009) and McClintock and White (2009).

The underlying model was based on the assumption that the expected sighting rate λ_{sj} for individual *s* in cell *j* was a log-linear function:

$$\lambda_{sj} = \exp(\alpha_j + \sigma_j Z_{sj}) \tag{A.1}$$

where:

α_j is a fixed effect and represents the expected sighting rate (in log-space) for cell *j*;

σ_j is the standard deviation of the random effects (in log-space) for cell *j*;

Z_{sj} is an individual random effect, representing individual heterogeneity in the sighting rates in cell *j*, where $Z_{sj} \sim N(0,1^2)$.

Integrating over the individual random effects yielded the expected sighting rate for a random unobserved individual for each cell:

$$\lambda_j = \int \exp\left(\alpha_j + \sigma_j z_{sj}\right)\phi\left(z_{sj}\right) dz_{sj} = \exp\left(\frac{\sigma_j^2}{2} + \alpha_j\right) \tag{A.2}$$

where: $\int = \int_{-\infty}^{\infty}$ and $\phi(.)$ is the standard normal probability density function.

Note that this sighting rate was assumed equal for marked and unmarked animals. In this case, the sighting rate was in units of sightings per survey season and hence the expected number of sightings is equal to the expected sighting rate.

Abundance of Marked and Unmarked Animals

Because the total number of marked individuals was unknown, it was necessary to scale the observed number of marked individuals by the probability of being sighted at least once in order to calculate the total number of marked individuals in each cell:

$$n_j = n_j^* \Big/ \left\{1 - \exp\left(-\lambda_j\right)\right\} \tag{A.3}$$

where:

n_j is the actual number of marked animals for cell *j*;

n_j^* is the observed number of marked animals for cell *j*, and;

$1-\exp\left(-\lambda_j\right)$ is probability of an individual being sighted at least once in cell *j*, given that the number of sightings follows a Poisson process.

Because the sighting rate was assumed equal for marked and unmarked animals, the expected number of unmarked sightings was the product of the total number of unmarked animals and the sighting rate:

$$T_{u_j} = \left(N_j - n_j\right)\lambda_j \tag{A.4}$$

where:

T_{u_j} is the expected number of unmarked sightings for cell *j*, and;

N_j is the total abundance for cell *j*, noting that the total number of unmarked animals $U_j = N_j - n_j$.

Substituting Eqns. A.2 and A.3 into Eqn. A.4, yielded the expected number of unmarked sightings as a function of the estimated parameters and the total abundance:

$$E\left(T_{u_j}\right) = \left[N_j - n_j^* \big/ \left\{1-\exp\left(-\lambda_j\right)\right\}\right]\exp\left(\frac{\sigma_j^2}{2} + \alpha_j\right) \tag{A.5}$$

The variance of the number of unmarked sightings is:

$$\mathrm{var}\left(T_{u_j}\right) = \left[N_j - n_j^* \big/ \left\{1-\exp\left(-\lambda_j\right)\right\}\right]\mathrm{var}\left(\lambda_j\right) \tag{A.6}$$

where[2]:

$$\mathrm{var}\left(\lambda_j\right) = \exp\left(\frac{\sigma_j^2}{2} + \alpha_j\right) + \exp\left(2\alpha_j\right)\left\{\exp\left(2\sigma_j^2\right) - \exp\left(\sigma_j^2\right)\right\} \tag{A.7}$$

It was assumed that there were no marked individuals that were identified as marked, but not identified to individual identity. So, there was no need to apply a correction factor to Eqns. A.5 and A.6 to take this into account (i.e., in the notation of McClintock et al. [2009], $\varepsilon_j = 0$).

[2] McClintock et al. (2009) provide the derivation using variance decomposition in their Web Appendix.

The Data and Likelihood Function

The observed number of sightings y_{sj} for individual s in cell j were assumed to be independent Poisson random variables. However, the familiar Poisson likelihood must be modified to take into account the fact that the number of marked individuals was unknown. That is, when the number of marked individuals is unknown it is not possible to differentiate between the events that a marked animal is not observed or that it does not exist (i.e., y_{sj} = 0 is unobservable). Additionally, the individual random effects were treated as nuisance parameters and integrated out of the likelihood to reduce the dimensionality of the problem. Hence, the zero-truncated Poisson likelihood of observing the marked sightings data is:

$$L\left(y_{sj}, n_j^* \mid \sigma_j, \alpha_j\right) = \prod_{s=1}^{n_j^*} \int \frac{\lambda_{sj}^{\,y_{sj}} \exp\left(-\lambda_{sj}\right)}{y_{sj}!\left\{1-\exp\left(-\lambda_{sj}\right)\right\}} \phi\left(z_{sj}\right) dz_{sj} \qquad \text{(A.8)}$$

where:

n_j^* is the number of marked individuals in cell j which have been sighted at least once, and;

$1-\exp\left(-\lambda_{sj}\right)$ is the probability of being sighted at least once, given that the sightings are generated by a Poisson process.

The integral in Eqn. A.8 was calculated numerically using Gaussian-Hermite quadrature (McClintock et al. 2009).

Given the sightings data for marked animals (y_{sj} and n_j^*), and values for σ_j and α_j, it is possible to derive the likelihood of observing the unmarked sightings (T_{u_j}) as a function of the total number of individuals for each cell N_j. The residuals between the observed and expected number of unmarked sightings are assumed to be normally distributed with expectation and variance given by Eqns. A.5 and A.6, such that the underlying distribution is left truncated at zero (because it is not possible to have negative sightings):

$$L\left(T_{u_j}, n_j^* \mid \sigma_j^2, \alpha_j, N_j\right) = \frac{f\left(T_{u_j}\right)}{\int_0^\infty f\left(T_{u_j}\right) dT_{u_j}} \qquad \text{(A.9)}$$

where:

$f\left(T_{u_j}\right)$ is the normal probability density function with expectation and variance given by Eqns. A.5 and A.6, evaluated at T_{u_j}.

The integral in the denominator accounts for the left truncation of the normal distribution (i.e., this renormalizes the distribution so that it integrates to 1.0).

Note that in the program MARK, the total number of unmarked individuals for each cell U_j is estimated, rather than the total number of individuals N_j. However, this distinction is trivial because by definition, $U_j = N_j - n_j$. So, (given a value for n_j) it is possible to derive U_j given a value for N_j and vice-versa.

The total likelihood is the likelihood of observing the marked animals and the likelihood of observing the unmarked animals, which is simply the product of these individual likelihoods under the assumption of independence:

$$L\left(\underline{T_u}, \underline{n^*}, \underline{y} \mid \underline{\sigma}, \underline{\alpha}, \underline{N}\right) = \prod_j \left\{ \prod_{s=1}^{n_j^*} \int \frac{\lambda_{sj}^{\,y_{sj}} \exp\left(-\lambda_{sj}\right)}{y_{sj}!\left\{1 - \exp\left(-\lambda_{sj}\right)\right\}} \phi\left(z_{sj}\right) dz_{sj} \right\} \frac{f\left(T_{u_j}\right)}{\int_0^\infty f\left(T_{u_j}\right) dT_{u_j}} \tag{A.10}$$

Where the underlined quantities represent vectors for the *j* cells. Parameter values were then calculated by maximizing this joint likelihood.

Chapter 3:

Color Analysis of Cook Inlet Beluga Whales in the 2008 Photo-id Catalog

Final Report

By

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INTRODUCTION

Beluga whales are generally dark gray when they are born and gradually become white with age (Hazard 1988). Hence, it has been commonly assumed that larger animals that appear white are adults, and smaller animals that appear gray are subadults or calves. In Cook Inlet, Alaska, the color and relative body size of beluga whales have been used to estimate age-class composition of groups encountered during aerial (Sims et al. 2007) and photo-identification (photo-id) surveys (McGuire et al. 2008). The potential to extend those efforts, and derive demographic indices for the population by using color as a proxy for age-class, represents a tool for monitoring the status of this population through changes in age structure (Litzky 2001). Ultimately such information may help to explain observed population dynamics and trends in abundance, and therefore provide important guidance for management decisions.

The process of categorizing an individual whale as white or gray (or characterizing some shade thereof) is complicated by several factors including: (i) lighting conditions, (ii) camera exposure settings when images are captured, and (iii) inter-analyst differences in characterizing color. In previous years (2005-2007) of the Cook Inlet beluga whale (CIBW) photo-id study, color classification was subjective (i.e., whales were classified as gray or white depending on how their photographs appeared to a photo-analyst), and variation in color assignment among analysts was high. Variability in lighting conditions during and among photo-id surveys was also high, and often resulted in a known whale appearing gray in one photograph and white in another (sometimes on the same day). A previous study (Litzky 2001) and a more recent workshop (Appendix F in McGuire et al. 2008) were conducted with the goal of improving previous attempts at color assignment through the creation of a standard scale. This report extends those efforts, and presents progress on a research method for color categorization and standardization that is based on information collected through digital photography of individual whales and a known color object. Our objective is to move from a subjective categorization of color to a quantitative method of measuring color.

In addition to assignment errors in color classification of photographs due to lighting conditions or inter-analyst variability, there is evidence that some gray whales may be sexually mature in the CIBW population. Data from the 2005-2008 CIBW photo-id catalog suggested that color may be an imprecise indicator of age-class (Blees et al. 2008, McGuire et al. 2009). Large gray beluga whales have been photographed accompanied by small dark-gray calves, suggesting a mother-calf relationship. Local hunters have also observed gray CIBW cows with calves (Huntington 2000). Documentation of gray mothers challenges the assumption that sexually mature adult beluga whales are always white and subadults always gray.

To achieve our goal of gaining a better understanding of the relationship between age-class and color, we investigated data on annual color classifications for several individually identified whales to see if there were any detectable changes in individual color through time. This, along with documentation of the relationship between color and reproductive status, will add to our knowledge of population composition, population dynamics, and ultimately conservation status of the endangered CIBW population.

Hence, this chapter addresses part of the third CIBW photo-id 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".

METHODS

Since the project began in 2005, methods to characterize whale color have been continually refined to attempt to minimize the variation caused by changing lighting conditions and multiple analysts. In 2005 and 2006, whales were subjectively classified as "adults" if they appeared white in photographs and as "subadults" if they appeared gray. Beginning in 2007, assignment of age-class based on whale color was abandoned in favor of a more refined assessment of color, and more color categories were added in 2008 (e.g., white, light gray, gray, dark gray). Below, we summarize techniques and analyses developed during the CIBW photo-id study in 2008 to quantitatively determine whale color from photographs.

Field Photographs

2008 Photographs

All photographs in 2008 were taken with a Nikon D70, 6.1 megapixel digital SLR camera, with Nikkor 70-300 mm or 80-400 mm zoom telephoto auto focus lenses. Typical camera settings used during the study included shutter speed priority (shutter speed of 1/1,000 sec or faster), dynamic auto-focus, and 800 ISO. In order to increase contrast to show faint marks on white belugas, all images were underexposed to a setting of -1 or lower exposure bias value (Robert Michaud, personal communication). RAW format photographs were taken during most of the photo-id surveys, however for simplicity, JPEG format was used for these analyses.

Use of a gray card

The use of gray-card photographs was added to the survey methods in 2008 as a means of providing a standard gray-scale measurement that could be used by any research group studying CIBWs (McGuire et al. 2008). A standard photographic gray card (18% gray) was photographed at least once per survey to document color variability of whale images given the daily (and often hourly) variation in lighting conditions resulting from changing environmental conditions.

Analysis

In digital photography, the color intensity or brightness values of the individual pixels (the units in a digital display that produce an image) can be represented in histograms that are often referred to as tonal range. Each pixel displays a color that is comprised of the three primary colors: red, blue, and green (RGB). Each primary color has a brightness value ranging from 0-255, where black is 0 and white is 255 (McHugh

2009, Obermeier and Padova 2009). This range of tones is the number of shades of gray it takes to fool the eye into thinking it is seeing a continuous-tone (black and white) image (Kingston 2009).

RGB histograms show a composite of the three primary color channels. The tonal range of an image is displayed in a histogram of the frequency of different pixel brightness levels. Peaks in these histograms represent a large number of pixels with the same brightness (Figure 3.1). The analysis of whale color in this study was based on statistics calculated from these histograms using the Photoshop® Elements software. For example, the mean brightness (hereafter simply referred to as *brightness*) was calculated as the average intensity value of all pixels selected for a given histogram (Obermeier and Padova 2009).

2008 Photo analysis

Thirty individual whales were photographed in all four years of the study (2005-2008; McGuire et al. 2009). This sample of 30 whales (hereafter referred to as *the sample*) was evaluated to compare variability in color (brightness) throughout 2008. Using Photoshop® Elements 7.0, the histograms generated with each photograph in the sample were used to determine the brightness. The photographs processed for each whale included all of the encounters (e.g., days) an individual was photographed in 2008. In each photograph, the image of the whale was outlined and selected for color analysis, eliminating the effect of anything else (e.g., water or sky) on the histogram. Details of the procedure in Photoshop® are in Appendix 3-A.

The brightness values of the photographs in the sample were calculated for each day each whale was encountered, and were also calculated as an average across the 2008 field season. The minimum, maximum, range (maximum less minimum) and mean brightness values for each whale were compared to examine variability in brightness values over a single day of observations as well as over the entire 2008 field season.

The annual mean brightness values were compared with color classifications based on the more traditional system of having an analyst look at the photo and assign a color category. Throughout this photo-id study, three methods were used to assign color classifications to individual whales:

- Method 1 was used during the early stages of this study (2005-2006). Whales were classified as adult if they appeared white in photographs and subadult of they appeared gray. Colors were assigned by more than one analyst.
- Method 2 was used in 2008. Color classifications were expanded to account for the different shades of gray and included dark gray, gray, light gray, and white. Color was assigned by only one analyst to minimize variability, and a color classification was assigned to all whales in the 2005-2008 catalog.
- Method 3 was similar to method 2 but included only photos from within each of the field seasons. For example in the 2008 analysis, photos from 2005-2007 were excluded in order to eliminate the possibility that whale color assigned in 2008 was conditional on whale color assigned in previous years.

Four-year subset analysis

To better understand the range of color in photographs, a subset of three whales (hereafter referred to as *the subset*) was selected from the sample of 30 whales based on their 2008 brightness values. This subset was chosen to be representative of the color scale, containing a whale at the darkest end (lowest annual mean), the middle (median annual mean) and the lightest end (highest annual mean) of the brightness scale. The annual mean brightness value was calculated as an average of the brightness of all photographs of each of the three individuals in the subset. The subset was compared over the four years each whale was photographed in order to examine inter-annual color variation and possible changes in color through time (i.e., individuals becoming lighter).

The mean brightness value and brightness range for each of these three whales were calculated daily, annually and inter-annually across the four years (2005-2008) of the study. Color classifications were compared across years for each of the three whales according to the same methods used for the 30 whales sampled for 2008. Method 3 isolated photos from each of the four years the whales were photographed.

Gray-card analysis

The gray-card photographs from 2008 were also examined for brightness variability over the 2008 field season. One to three photos were selected from each day the gray card was photographed based on: (1) the number of photos of the gray card; (2) the variability in the angles and lighting among the gray card photos; and (3) if the gray card photos were taken at different times during the survey (Figure 3.2). Mean brightness values and brightness range of gray cards were calculated daily and for the 2008 season. A trial analysis was conducted in an attempt to correct color in whale photographs based on the gray-card photographs taken on the same day.

RESULTS

Analysis

2008 Photo analysis

In total, 692 photographs of the 30 "sample" whales were taken during 12 days from 15 July through 28 October 2008. Each whale was photographed more than once. The number of photos taken daily for the 2008 selection of whales ranged from 2 to 87, with an average of 8.1 photos per day.

The sample from 2008 had a brightness value range from 34 to 249, with an overall mean brightness value of 145 (Figure 3.3). The mean brightness value for each whale was calculated for each day the whale was encountered and then summarized for the 2008 field season (Appendix 3-B).

The daily and annual brightness value for each whale in the 2008 sample is shown graphically in Appendix 3-B. As shown in Figure 3.3 the overall range from all 30 whales was 215.2. The average daily brightness range for each whale in the 2008 sample varied between 2.5 and 89.3 (Table 3.1). The range varied from 3 to 198 (Table 3.1).

Whale RA025 had the highest daily range (156) on 6 August 2008 (Table 3.1). Figure 3.4 shows the brightest and the dimmest photos of whale RA025 taken on 6 August 2008. Whale RA155 had the highest brightness range (189) of all whales in the 2008 sample (Table 3.1). Whale RA155 was photographed on seven days in 2008, however on 15 July the whale was only photographed one time and therefore the range from that day was zero. Figure 3.5 shows the two most extreme (i.e., with the greatest range between them) photos of whale RA155 taken in 2008.

Figure 3.6 compares the brightness range in 2008 to the number of days each whale was photographed. The data were sorted according to frequency of encounters, showing an increase in range of brightness with increasing encounters.

Color classifications were assigned to whales in the sample using methods 1, 2, and 3, and are summarized in Table 3.2. Slight differences in color classifications of the same whales occurred for 50% of the whales observed during all four years of the study. No whales were classified as both *white* and *gray*, however *light gray* was associated with both *white* and *gray*. A whale classified as *light gray* (as described in the Methods section) with methods 2 and 3, could have been classified as either *gray* or *white* using method 1.

Four-year subset analysis

The three-whale subset consisted of the identified whales RS139, RS001, and RA154. Of this subset, whale RS139 represented the darkest (lowest mean brightness) whale in the 2008 sample, with an annual mean brightness of 56. Whale RS001 had an annual brightness mean at the midpoint of 149, and whale RA154 represented the lightest (highest mean brightness) whale with an annual brightness mean of 197 (Figure 3.7).

In total, 235 photographs were taken of the subset on 43 days during the four study years. The number of photographs taken per whale ranged from 59-99, with an average of 5.5 photos per day.

The inter-annual mean brightness values for the subset ranged from 25 to 239, with an overall mean brightness value of 136. The mean brightness and brightness range for each of the three whales are summarized in Appendix 3-C. The mean brightness value for all three whales during all four years combined was consistent with the trends of the sample data, where whale RS139 had the lowest inter-annual mean brightness (73) and whale RA154 had the highest value (170). Whale RA001 had an inter-annual mean brightness value of 147.

Figure 3.8 compares the annual mean brightness value for each of the three subset whales over all four years of the study. The mean brightness for whale RA154 was 145 (SD = 28) in 2005, 121 (SD = 35) in 2006, 181 (SD = 26) in 2007 and 197 (SD = 20) in 2008. The mean brightness for whale RA001 was 127 (SD = 15) in 2005, 133 (SD = 48) in 2006, 170 (SD = 15) in 2007 and 149 (SD = 46) in 2008. The mean brightness for whale RS139 was 49 (SD = 16) in 2005, 84 (SD = 36) in 2006, 135 (SD = 0) in 2007 and

56 (SD = 31) in 2008. The mean brightness for RS139 in 2007 was calculated from a sample of one photograph.

The daily and inter-annual (2005-2008) brightness range (the maximum brightness value minus the minimum brightness value) for each whale in the subset was calculated and shown graphically in Appendix 3-C. As shown in Figure 3.9, the overall range from the three whales from 2005 to 2008 was 214. The average annual range of mean brightness for each whale varied between 0 (0 because whale RS139 was photographed only once in 2007) and 147, and the inter-annual brightness ranged from 131 to 150 (Table 3.3). Figure 3.10 compares the annual brightness value ranges of each whale for each year the whale was cataloged.

Color associations for whales RA154, RA001, and RS139 for the four years of the study are summarized in Table 3.4. Inconsistencies in color assignment occurred in every year for whale RS139 and during one year for whale RA001. Whale RA154 had no inconsistencies in color classification among years. No whales were categorized as both *white* and *gray*, however *light gray* was associated with *white* during the color assignment of whale RA001 based on 2006 photos. Some photos of whale RA001 during 2006 appeared to be *light gray*, while in most photos the whale was classified as *white*.

2008 Gray-card analysis

The gray card was photographed on 15 days from 19 June 2008 to 28 October 2008. In this analysis, one to three photographs were processed for each day, depending on the number and quality of the photos of the gray card that were taken each day. Twenty photographs were analyzed.

The daily mean brightness of the gray card is displayed in Figure 3.11. The daily mean brightness of the gray card ranged from 14 to 145, with a mean of 76 (Figure 3.11). The color of the gray card appeared to fluctuate from day to day, appearing from blue-gray to very light gray (Figure 3.2). This is shown by the range of mean brightness values in Figure 3.11.

DISCUSSION

Previous color classification of CIBW had been subjective and qualitative. Photo-analysts tried to account for the variation in environmental lighting and camera exposure when making a determination of true whale color. This proved to be difficult because the perceived color of a whale could fluctuate greatly under different lighting/exposure conditions and among different analysts. This study has demonstrated that it is possible to quantify whale color by using the brightness values of digital photographs. Use of this brightness value should eliminate subjective bias in color assignment. CIBWs in photos can now be classified as white or dark gray based on their brightness values and where these values fall on a numerical scale of 0 (black) to 255 (white). We were able to assign whale colors to ranges of brightness values (i.e., dark gray <91 and white >197; Figure 3.12) by comparing the brightness values of individual whales in photographs to their qualitative color classifications. The area between 91 and 197 is referred to as the mixed-color zone because it includes the brightness values for both gray and light gray.

When colors were assigned qualitatively, whales in the sample were classified from dark gray to white. Using the quantitative brightness value method, the darkest whale had a brightness value of 34 and the lightest whale had a value of 249. The range in brightness values was broad, indicating that there was a large difference in color between the darkest and lightest whales. This difference was likely due to several factors. The most obvious explanation is that the whales actually were different colors. However, the less obvious and more difficult factors to account for were lighting and exposure. Environmental conditions, such as cloud cover, time of day, and glare, can affect the light, which in turn affects the exposure settings on the camera. For example, the photos of whale RA 155 (Figure 3.5) were taken approximately two weeks apart under different environmental conditions. Some photographs appeared overexposed and others appeared underexposed, resulting in a broad range in brightness values and this made it difficult to confidently assign a color. The use of color correction tools (explained below) in future work should help to reduce or eliminate the variability in brightness values of individual whales that was caused by different photographic conditions that could confound the detection of an actual change in color of the whale.

We found that the range of brightness values for any given whale increased with the number of days it was photographed, although not in a gradually-increasing way that would indicate we were documenting a whale changing color with age (e.g., we did not document individual gray animals with low brightness values who gradually lightened with time). Each encounter increased the variability in environmental conditions and exposure settings because the conditions were constantly fluctuating, especially with the seasonal changes in daylight during the May through October field season. It would be worthwhile to compare photographs to daily environmental data in the future to determine if there are any associations between photographic brightness values and environmental conditions.

As explained above, lighting and exposure can affect how a whale appears in a photograph and it often varies among encounters. If an analyst takes into account all the available photographs in the photographic record of an individual whale, a general color assignment can be made that would potentially account for the outlier photos that are a bad representation of whale color. However, color classification could be affected if an analyst only looks at one photo or one day or a single year of photos. For example, the mean brightness value of whale RS139 was much higher in 2007 than it was in the other three years; this was most likely because only one photo was taken in 2007.

Color classifications, in association with whale size, have been used as an indication of age-class in beluga whales (Litzky 2001, Sims et al. 2007, Markowitz et al. 2005, Kirillova et al. 2004). Our color analysis of photos in the CIBW photo-id catalog has documented that there were several factors that contributed to color classifications and therefore we remain cautious about assigning age-class based on color (McGuire et al. 2008). Color classifications are subjective and can vary from day to day with a single analyst and more significantly if there is more than one analyst. Several whales were classified as gray under Method 1 and dark gray or light gray under Methods 2 and 3. Similarly, some whales labeled as white using Method 1 were classified as light gray under Methods 2 and 3. These differences in color assignment based on method were due mostly to the limited categories used in Method 1 (gray and white) compared to the newer methods (2 and 3) which included dark gray, gray, light gray, and white. At no time was the same whale classified as both white and gray or dark gray. Gray belugas were never classified as white but white whales were classified as light gray under certain lighting conditions. More whales were classified consistently as gray than white, which further suggested that there was less variation when classifying gray animals under variable lighting conditions. Because gray animals were never misclassified as white, an over-estimate of white animals was not possible. However, gray animals could have been over-estimated, and any age-class assignments made solely on qualitative color classifications will have over-estimated the subadults (gray whales) in the catalog because white whales can be classified as light gray. Furthermore, the age at which belugas become white is unknown, or if this occurs at different rates for different individuals and/or sexes.

We had hoped to combine color classification with size estimates from photogrammetry to determine relative age-class of individual whales. Similar to Durban and Parsons (2006), we attempted to measure morphometrics on beluga whales using lasers mounted a known distance apart on top of the camera lens. The two resulting points of light projected onto the bodies of photographed beluga whales allowed for measurement of marks on photographed whales and for estimation of body length. 2008 was the first field season in which the lasers were used and the resulting sample size was small (n = two whales) due to problems with calibration of the laser mount (McGuire et al. 2009). Currently, laser measurements are not feasible for this study until improvements are made in mounting hardware and calibration equipment.

Although we were able to quantify whale color with the brightness values, problems remain with this method of determining whale color because of the effect of variable lighting conditions. The gray card proved useful as a color constant to compare to whale photographs taken under conditions of varying lighting and camera exposure. Photographs of the same gray card demonstrated the effects that variability in lighting and exposure can have on a single, known color. Many photographs of the gray card appeared underexposed or overexposed even though all photographs were taken with the same camera settings (i.e., -1 exposure bias). In 2008, the gray card brightness values ranged from 14 to 145, with a mean of 76 on the brightness scale indicating darker images. This was expected, considering our subject was a known gray color. However, the range in brightness in photographs of this constant demonstrated the extreme variability in the lighting conditions and exposures. Likewise, the brightness values of the photographs were affected by the lighting conditions, occasionally causing the under/overexposure of the images. This further demonstrated the necessity of learning how to control and/or correct for this environmental variability.

Gray cards are often used by photographers to account for lighting and to adjust the white-balance camera settings when photographing an object. During 2008, we used the gray card in the field, with the intent of it being a constant that would later be used in the lab to correct for color variability. This proved to be much more difficult than anticipated using the available software and after discussions with professional photographers Flip Nicklin and Jonathan Kingston, we decided that a white constant would be more precise and accurate than a gray constant. We plan on experimenting with different white constants during the 2010 field work. Adobe® Photoshop®

Lightroom® will be used for color analysis of photographs taken in 2009 and 2010 because it has the capacity to help perform color correction based on a photo of the white constant, and to then apply the correction to many photographs. To apply the color correction based on the white constant to a day of photos, the photographs will be imported into Lightroom® and the photo of the white constant will be selected. Using the eyedropper tool in the develop module, a neutral white will be selected and modified using the tint and temperature sliders. Once the photograph appears to be corrected (i.e., where the white constant appeared white), the correlating whale photographs will be selected and "synced". Syncing applies the same settings used for correcting the white constant photograph to all selected photos, and therefore color will be more accurately represented in the photographs. These photographs will be processed as above to obtain more accurate brightness values using the histograms, and ideally the analyst will have less visual "filtering" to do when assigning a color assignment.

In addition to using the white constant for color correction, we plan to use an incident light meter while on the survey boat to determine the proper exposure of photographs based on ambient lighting conditions. To maximize photographic data, we will no longer underexpose photographs and we plan to change format of the digital photographs. During analysis of the 2008 photographs, JPEG format was used rather than RAW format because JPEG format has a much smaller file size and can be processed more quickly than RAW format. RAW format photos will be used in future analyses because they contain more information than compressed JPEG photos. Photo-information (e.g., color saturation and contrast) is lost during the conversion from RAW to JPEG and this information loss cannot be reversed (McHugh 2009; Flip Nicklin, personal communication). It will be necessary to retain all photo-information in order to use the white constant to correct for color.

Although whales in digital photographs can now be classified as white or dark gray depending on where their brightness value falls on a gray scale, the mixed color zone contains whales with color classifications of both gray and light gray. This could be caused by either inconsistent lighting or actual whale color variation. We plan to reduce or eliminate this area of mixed colors by applying a white constant color correction method that will reduce the effect of the controllable variables (primarily exposure and lighting conditions) and thus narrow the mixed-color zone to include only variation caused by the actual whale color. The goal of the color correction method is to assign a quantitative color score (i.e., color-corrected brightness value) to each photograph of each whale in the database.

With the color-corrected brightness values, statistical models can be used to explore consistency in brightness scores of individuals within a season, and to test for lightening of individuals over time for those seen in multiple years. Ultimately, with a more standardized application and more years of data with which to detect trends, we will be able to track changes in actual color of individually identified whales through time to better understand the relationship between whale color and age. Using photo-id, we are able to document reproductive maturity of female belugas through monitoring their associations with calves, and we plan to photographically track calves as they mature and lighten in color. We will also investigate associations among geographic areas and whale color (e.g., are there differences in the percentages of white versus gray belugas in Knik and Turnagain Arms?). Finally, we hope the color assessment techniques summarized in this chapter will be useful to other researchers studying beluga whales in Cook Inlet and elsewhere.

Table 3.1. Encounter date, daily range, average daily range, and annual range of brightness values for whales in the sample photographed in 2008. Range = difference between the minimum and maximum brightness values for a given time period.

Whale Name	2008 Encounter Date	Daily Range	Average Daily Range	Annual Range
RA001	22-Jul	8	34	147
	6-Aug	101		
	2-Sep	2		
	12-Sep	26		
RA002	18-Aug	24	24	30
	22-Aug	25		
RA009	22-Jul	11	12	144
	6-Aug	19		
	2-Sep	7		
RA013	22-Jul	8	28	144
	12-Sep	17		
	18-Aug	57		
	29-Jul	29		
RA025	6-Aug	156	89	158
	29-Jul	23		
RA029	18-Aug	2	8	58
	29-Jul	14		
RA036	24-Jul	13	13	13
RA054	29-Jul	33	33	33
RA063	18-Aug	66	36	66
	15-Jul	6		
RA066	2-Sep	3	3	3
RA100	24-Jul	21	14	41
	15-Jul	6		
RA102	6-Aug	6	31	90
	18-Aug	86		
	22-Aug	0		
RA123	2-Sep	23	16	24
	29-Jul	8		
RA132	27-Aug	3	3	3
RA145	29-Jul	28	25	125
	24-Jul	24		
	15-Jul	21		
RA147	2-Sep	36	36	36
RA148	22-Jul	5	20	128
	18-Aug	46		
	22-Aug	5		
	29-Jul	5		
	15-Jul	5		

Table 3.1. Continued.

Whale Name	2008 Encounter Date	Daily Range	Average Daily Range	Annual Range
	27-Sep	54		
RA154	6-Aug	64	52	78
	29-Jul	40		
RA155	22-Jul	10	12	189
	6-Aug	12		
	2-Sep	1		
	12-Sep	25		
	29-Jul	6		
	24-Jul	30		
	15-Jul	0		
RA160	6-Aug	92	39	155
	22-Aug	70		
	29-Jul	0		
	24-Jul	5		
	27-Aug	28		
RS002	22-Jul	10	17	161
	29-Jul	35		
	24-Jul	20		
	27-Aug	4		
RS044	22-Jul	11	46	198
	6-Aug	35		
	2-Sep	39		
	12-Sep	16		
	29-Jul	26		
	28-Oct	152		
RS110	22-Jul	19	35	137
	6-Aug	16		
	29-Jul	43		
	24-Jul	64		
RS118	6-Aug	12	12	12
RS124	24-Jul	10	10	10
RS134	22-Jul	1	6	133
	6-Aug	0		
	22-Aug	16		
	29-Jul	6		
RS139	24-Jul	94	57	122
	28-Oct	21		
RS140	6-Aug	117	36	117
	29-Jul	0		
	24-Jul	19		
	15-Jul	8		

Table 3.1. Continued.

Whale Name	2008 Encounter Date	Daily Range	Average Daily Range	Annual Range
RS221	22-Jul	50	36	161
	2-Sep	46		
	15-Jul	5		
	27-Aug	42		
RS222	2-Sep	3	3	3

Table 3.2. Color classifications and mean brightness values for whales photographed in 2008. Individual whales are listed according to their 2008 annual mean brightness values. Three methods were used to assign color to whales. Method 1 was used 2005-2006, and one or two analysts classified whales as gray or white. Method 2 was used in 2008, and one person classified all whales photographed 2005-2008 as gray, light gray, dark gray, and white. Method 3 included the same methods as in method 2, but only took into account the photographs of the sample from 2008. Shaded areas indicate inconsistencies in color assigned to the same whale.

Whale Name	Annual Mean Brightness Values for 2008	Color Assigned by Method 1	Color Assigned by Method 2	Color Assigned by Method 3
RS139	56	Gray	Dark	Dark
RS221	78	Gray	Gray	Gray
RS124	91	Gray	Light	Gray
RA132	94	White	Light	Light
RS222	94	Gray	Gray	Gray
RA155	99	White	White	White
RS140	100	Gray	Gray	Gray
RA036	107	White	Light	Light
RA100	107	White	White	White
RA063	125	White	Light	Light
RA145	130	White	White	Light
RS044	136	Gray	Light	Gray
RA160	137	White	Light	Light
RS002	144	Gray	Light	Light
RA001	149	White	White	White
RS118	158	Gray	Gray	Gray
RA147	158	White	White	White
RA102	160	White	Light	Light
RA013	160	White	Light	Light
RS134	163	Gray	Gray	Gray
RA123	164	White	Light	Light
RA066	165	White	White	White
RA029	169	White	White	White
RA148	170	White	White	White
RA002	175	White	White	White
RA025	175	White	Light	White
RA054	182	White	Light	Light
RA009	187	White	Light	White
RA154	197	White	White	White
RS110	200	Gray	Gray	Gray

Table 3.3. Encounter date, daily range (difference between maximum and minimum daily brightness values), average daily range, annual range within a given year, and the inter-annual range (difference between the highest and lowest brightness values across all years 2005-2008) for the three whales of the subset of whales.

Whale Name	Year	Encounter Date	Daily Range	Average Daily Range (Per Year)	Maximum Range Per Year	Inter-Annual Range 2005-2008
RA154	2005	18-Aug-2005	4			
		7-Sep-2005	39			
		8-Sep-2005	6			
		9-Sep-2005	16	19	90	
		14-Sep-2005	55			
		15-Sep-2005	0			
		19-Sep-2005	10			150
	2006	16-Sep-2006	31	65	99	
		23-Sep-2006	99			
	2007	27-Jul-2007	117	83	119	
		15-Aug-2007	49			
	2008	29-Jul-2008	40	52	78	
		6-Aug-2008	64			
RA001	2005	8-Sep-2005	1			
		9-Sep-2005	26	15	50	
		14-Sep-2005	18			
	2006	17-Jun-2006	11			
		7-Aug-2006	13			
		21-Aug-2006	33			
		16-Sep-2006	10	37	147	
		23-Sep-2006	98			
		25-Sep-2006	88			186
		27-Sep-2006	6			
	2007	27-Jul-2007	10	28	53	
		27-Sep-2007	46			
	2008	22-Jul-2008	8			
		6-Aug-2008	101	34	147	
		2-Sep-2008	2			
		12-Sep-2008	26			
RS139	2005	14-Sep-2005	0			
		21-Sep-2005	0	5	57	131
		22-Sep-2005	8			
		21-Oct-2005	11			

Table 3.3. Continued.

Whale Name	Year	Encounter Date	Daily Range	Average Daily Range (Per Year)	Maximum Range Per Year	Inter-Annual Range 2005-2008
	2006	27-May-2006	10			
		7-Aug-2006	23			
		9-Sep-2006	0			
		16-Sep-2006	30	23	114	
		23-Sep-2006	30			
		25-Sep-2006	57			
		27-Sep-2006	9			
	2007	27-Jul-2007	0	0	0	
	2008	24-Jul-2008	94	57	122	
		28-Oct-2008	21			

Table 3.4. Color classifications and annual mean brightness values for the subset of whales photographed in all four years of the study. Three methods were used to assign color to whales. Method 1 was used 2005-2006, and one or two people classified whales as gray or white. Method 2 was used in 2008, and one person classified all whales photographed 2005-2008 as gray, light gray, dark gray, and white. Method 3 included the same methods as in method 2, but only took into account the photographs of the sample from each field season sampled. Shaded areas indicate inconsistencies in color assigned to the same whale.

Whale Name	Year	Annual Mean	Color Assigned by Method 1	Color Assigned by Method 2	Color Assigned by Method 3
RA154	2005	147	White	White	White
RA154	2006	122	White	White	White
RA154	2007	181	White	White	White
RA154	2008	194	White	White	White
RA001	2005	124	White	White	White
RA001	2006	135	White	White	White/Light
RA001	2007	165	White	White	White
RA001	2008	158	White	White	White
RS139	2005	56	Gray	Dark	Dark
RS139	2006	79	Gray	Dark	Dark
RS139	2007	135	Gray	Dark	Dark
RS139	2008	71	Gray	Dark	Dark

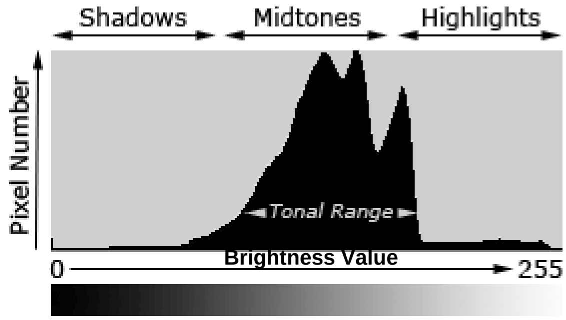

Figure 3.1. Example of an RGB (red-green-blue) histogram with the brightness values ranging from 0 (black) – 255 (white) (Image: (http://www.cambridgeincolour.com/tutorials/histograms1.htm).

Figure 3.2. Two photographs of the 18% gray card held at different angles and photographed with different lighting conditions and exposures. Photos taken 6 August 2008 (top) and 22 July 2008 (bottom).

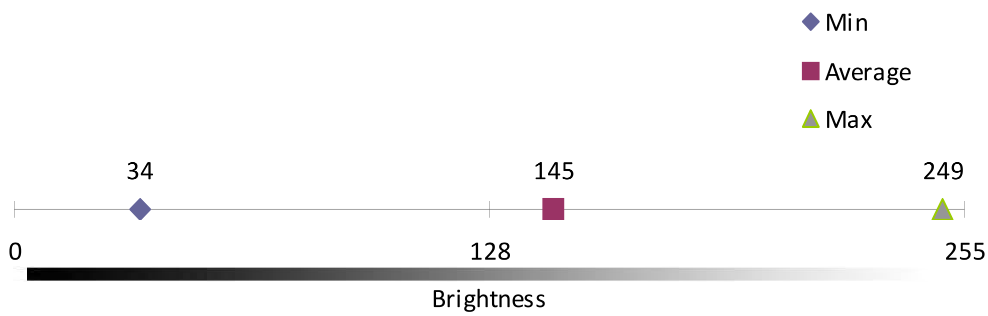

Figure 3.3. Minimum, mean, and maximum brightness for all 30 whales combined during the 2008 field season.

Figure 3.4. Two photos of whale RA025 on 6 August 2008 demonstrating the daily variability in color due to fluctuating light and exposure. The top is the brightest photo taken on 6 August 2008 (brightness value = 211) and the bottom photo is the darkest photo taken on the same day (brightness value = 55).

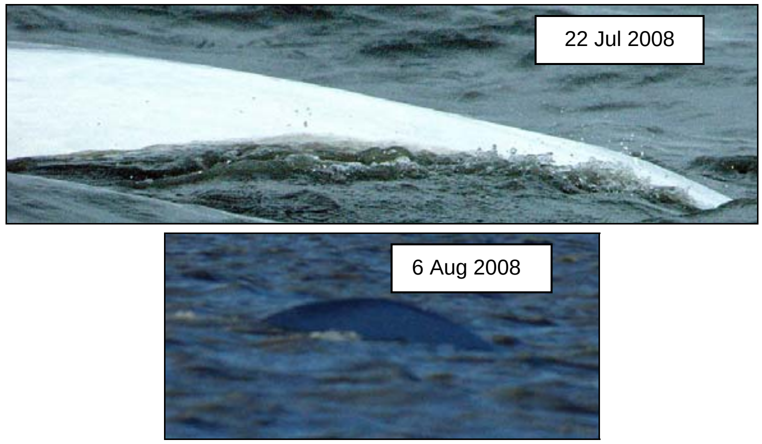

Figure 3.5. Two photos taken in 2008 of whale RA155 that illustrate the intra-annual variability in color due to fluctuating light and exposure. The top is the brightest photo taken on 22 July 2008 (brightness value = 243) and the bottom photo is the darkest photo taken 6 August 2008 (brightness value = 54).

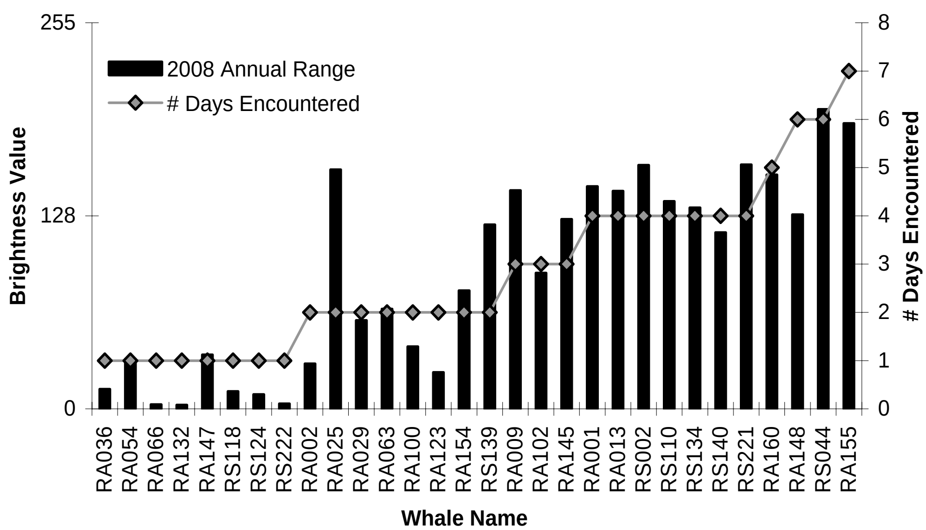

Figure 3.6. Range of brightness values compared to the number of days encountered in sample (n = 30) of whales photographed in 2008.

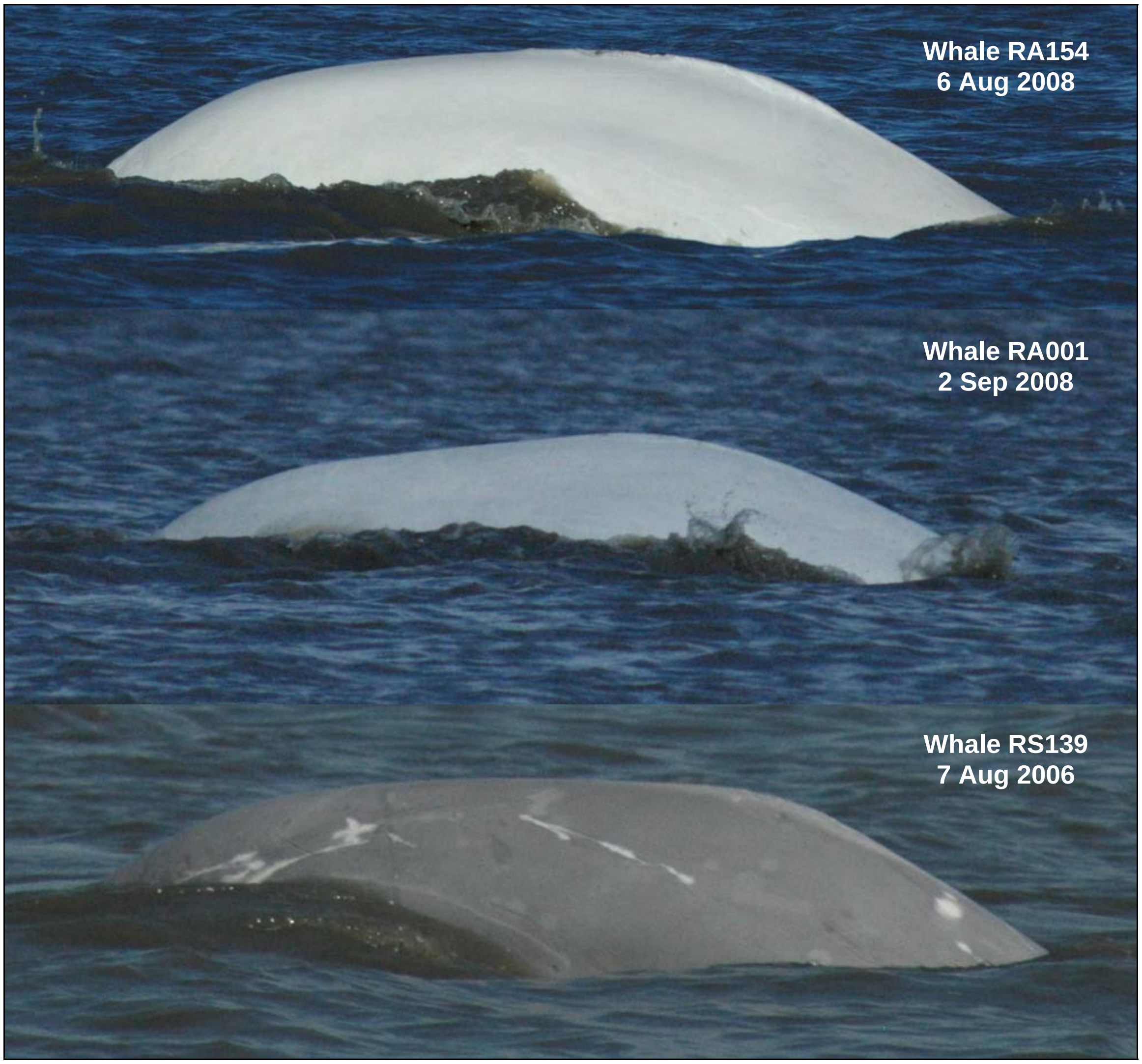

Figure 3.7. Photographs of each of the three whales in the subset that were selected based on their 2008 mean brightness values. Whale RA154 had the highest brightness value, whale RS 139 had the lowest brightness value, and whale RA001 was at the midpoint.

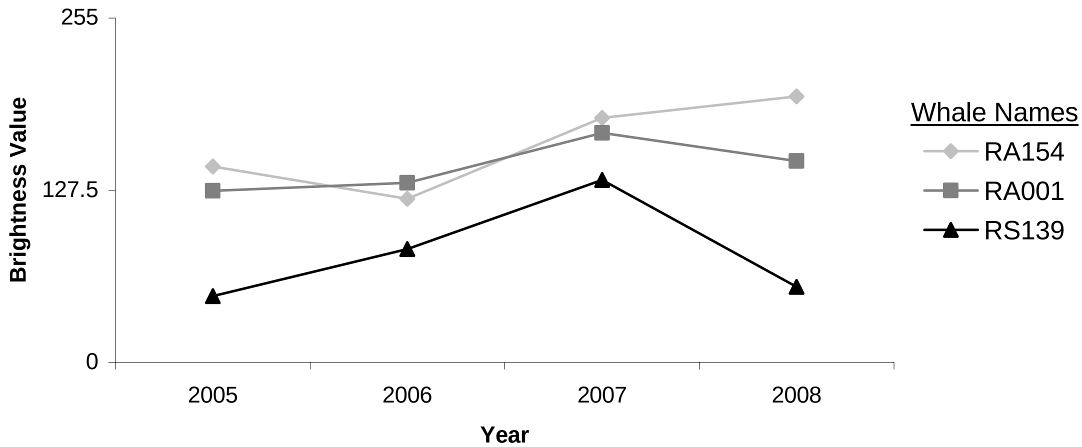

Figure 3.8. Annual mean brightness values of the subset (n = 3) of whales for all four years of the study.

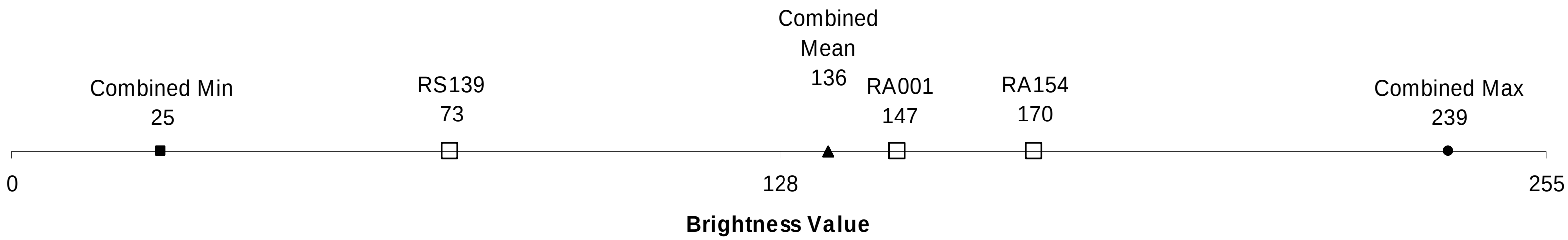

Figure 3.9. The combined minimum, mean, and maximum brightness values for whales RS139, RA001, and RA154, as well as the individual inter-annual mean brightness values for each of the three whales.

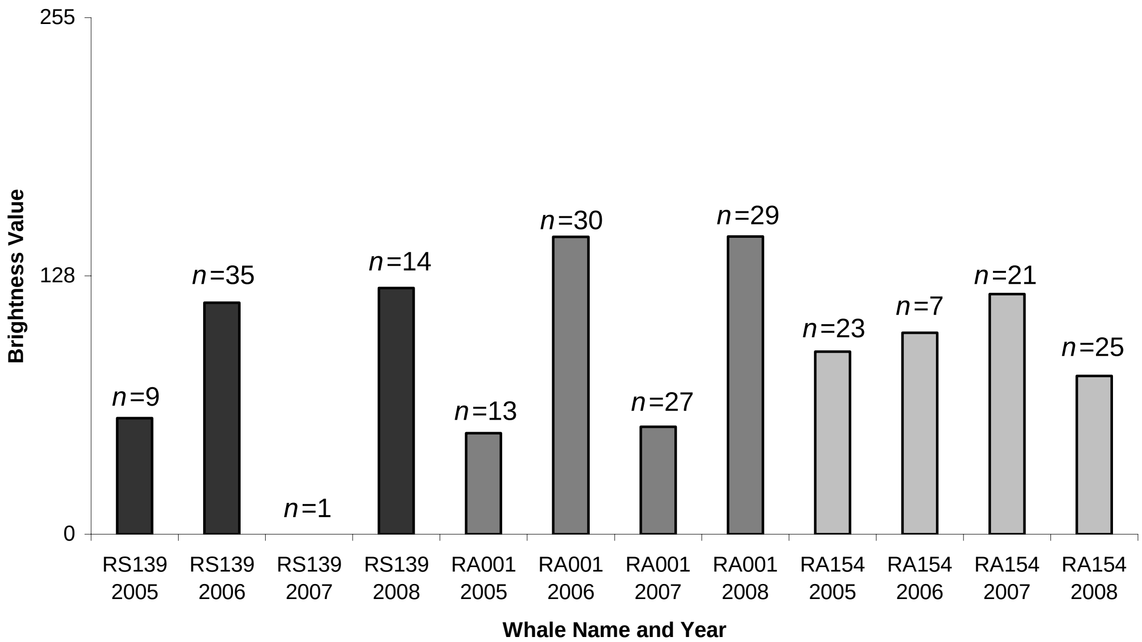

Figure 3.10. The annual range of brightness values for the subset (*n* = 3 whales), according to whale name and year observed. The number of photos analyzed is listed above each bar. Note that whale RS139 was photographed only one time in 2007 and therefore did not have a range.

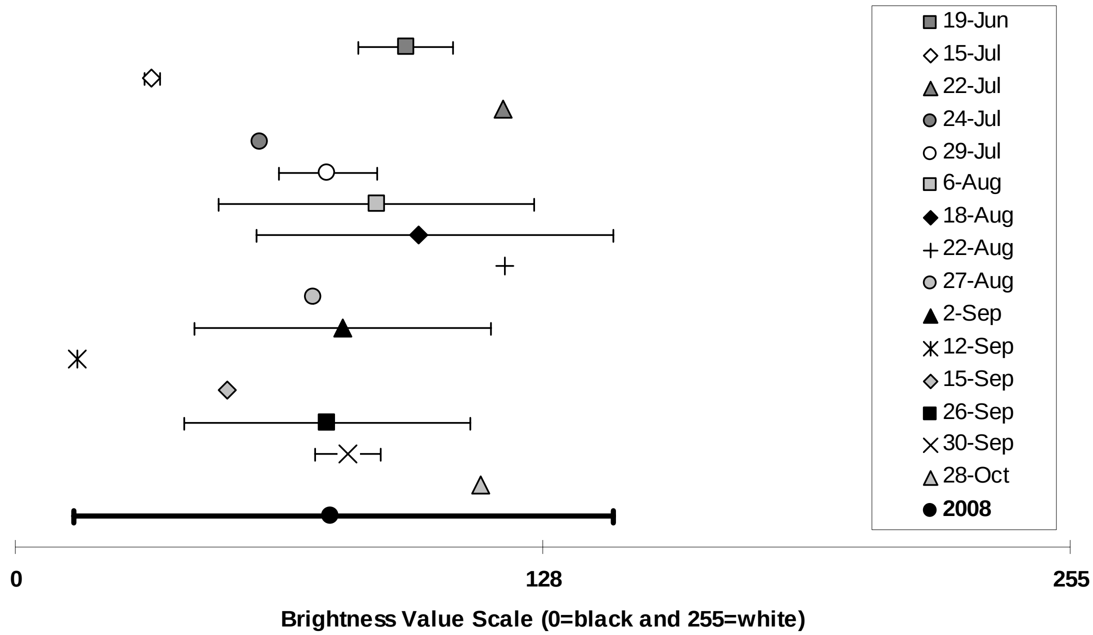

Figure 3.11. The mean brightness values (points) and range (bars) of the gray card as it was photographed during the 2008 field season (n = 15 days). Daily brightness values are shown above the annual brightness value for 2008.

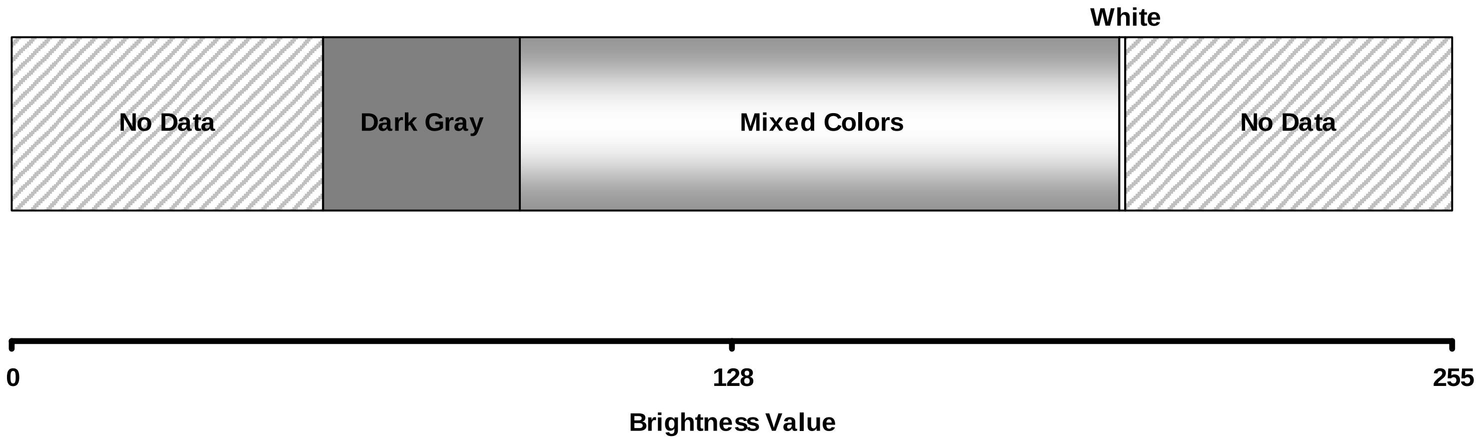

Figure 3.12. The gradient of color based on the 2008 mean of the sample of whales. The area labeled as dark gray encompasses the range of brightness values where whales were consistently classified as gray or dark gray. The area labeled white encompasses the range of brightness values where whales were consistently classified as white. There were no data for the ends of the gradient. Whales have been classified as either gray, light gray or white in the mixed colors area.

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APPENDIX 3-A

PHOTO PROCESSING USING PHOTOSHOP® ELEMENTS 7.0

INITIAL PHOTO PROCESSING

Photo processing and color analyses were performed with Adobe® Photoshop® Elements. The Editor module was used and is referred to within this Appendix. All photos that were analyzed were in JPEG format.

Gray Card Photos

The gray card photos were opened in Editor. The “quick selection” tool was used to select only the gray card (Figure A1). Care was taken to not select anything that was not part of the gray card (i.e., lasers) and to remove the black border surrounding the gray of the card.

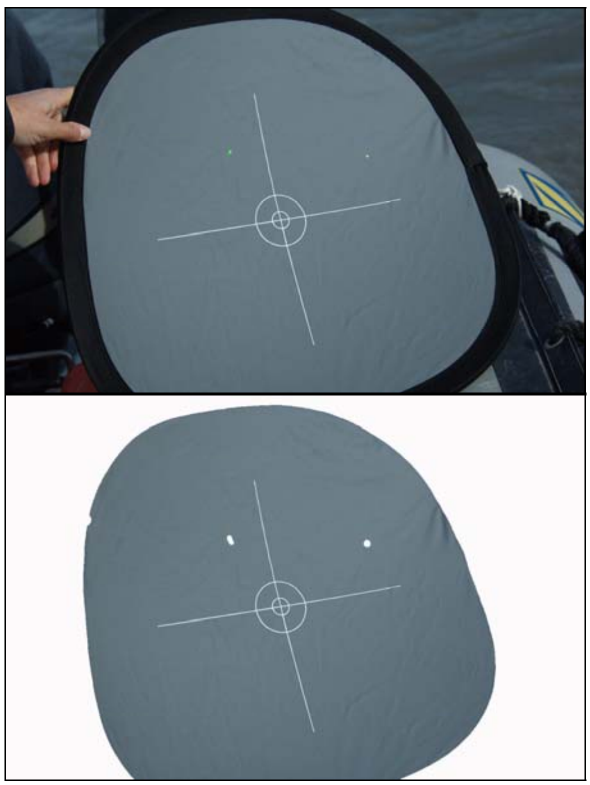

Figure A1. An original photo of the gray card during a survey (top) and the same photo after it was processed with the quick selection tool (bottom).

Whale Photos

The same method used for the gray card photos was applied to the whale photos, and only the images of the whales were selected. Care was taken to avoid selecting splash on the whales, but occasionally splash was unavoidable and included in the selected photos (Figure A2).

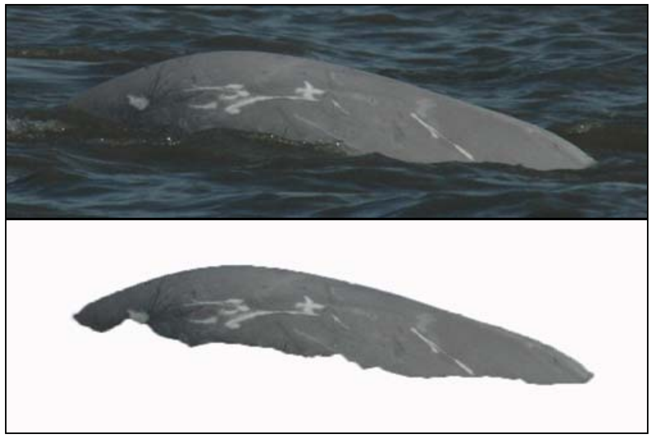

Figure A2. An original photo of whale RS139 during a survey (top) and the same photo after it was processed with the quick selection tool (bottom).

HISTOGRAM

A RGB (red-green-blue) histogram was created for each of the gray card and whale photos to calculate the mean brightness value of each photo (Figure A3).

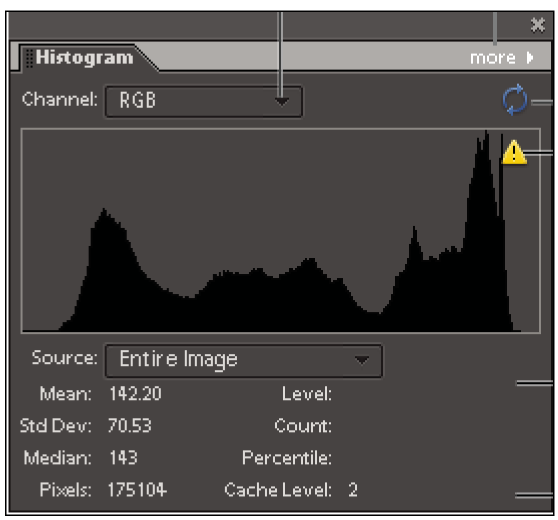

Figure A3. An example of an RGB histogram as it appears in Adobe® Photoshop® Elements 7. Note the statistics in the bottom half of the image, specifically the mean (brightness value).

APPENDIX 3-B

MEAN BRIGHTNESS VALUE RANGES FOR EACH OF THE 30 WHALES SEEN IN ALL FOUR YEARS OF THE STUDY

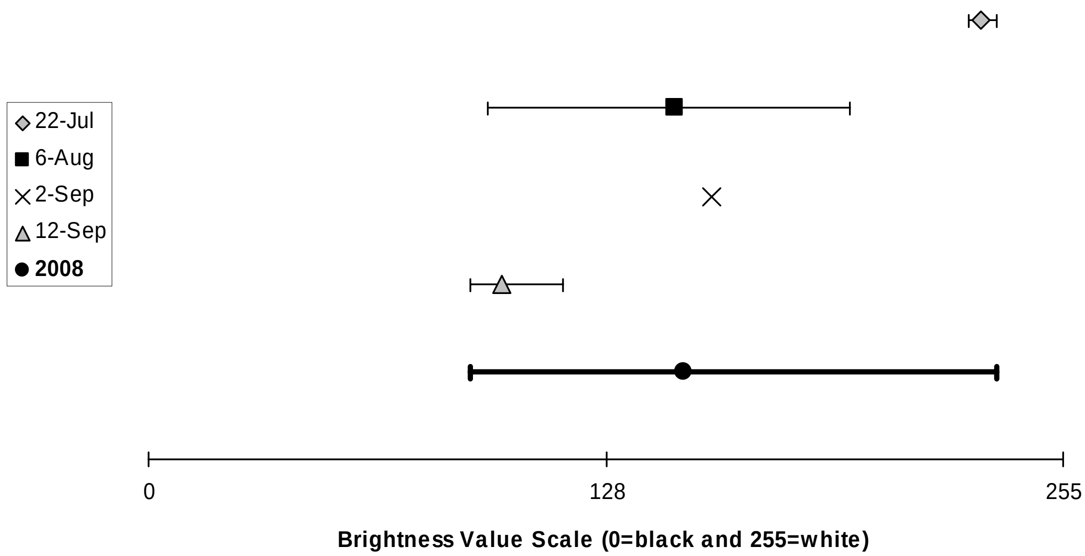

Figure B1. Mean brightness values (points) and ranges (bars) for whale RA001 on each day photographed in 2008 (*n* = 4) and over the 2008 season. Daily values are shown above the annual values for 2008.

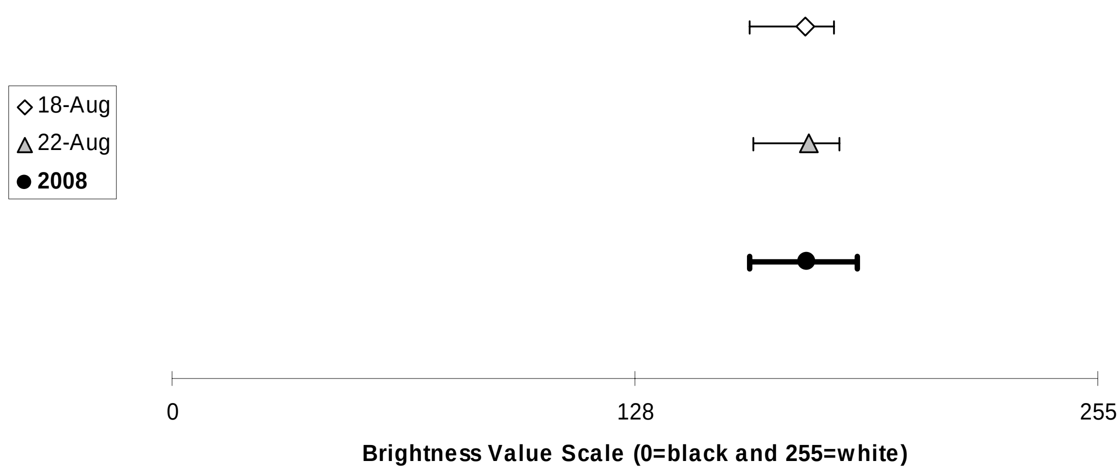

Figure B2. Mean brightness values (points) and ranges (bars) for whale RA002 on each day photographed in 2008 (*n* = 2) and over the 2008 season. Daily values are shown above the annual values for 2008.

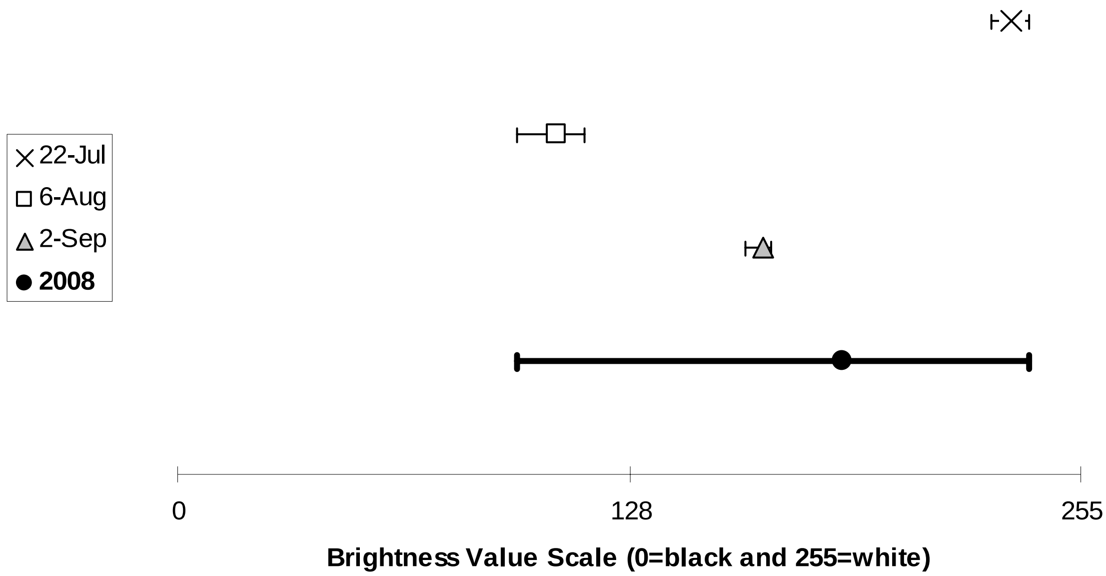

Figure B3. Mean brightness values (points) and ranges (bars) for whale RA009 on each day photographed in 2008 (*n* = 3) and over the 2008 season. Daily values are shown above the annual values for 2008.

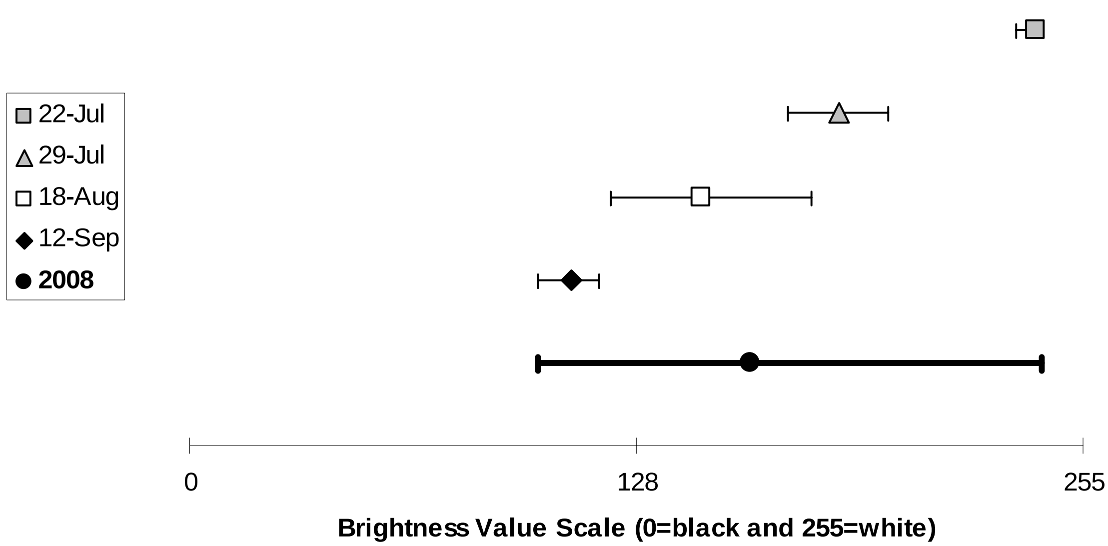

Figure B4. Mean brightness values (points) and ranges (bars) for whale RA013 on each day photographed in 2008 (*n* = 4) and over the 2008. Daily values are shown above the annual values for 2008.

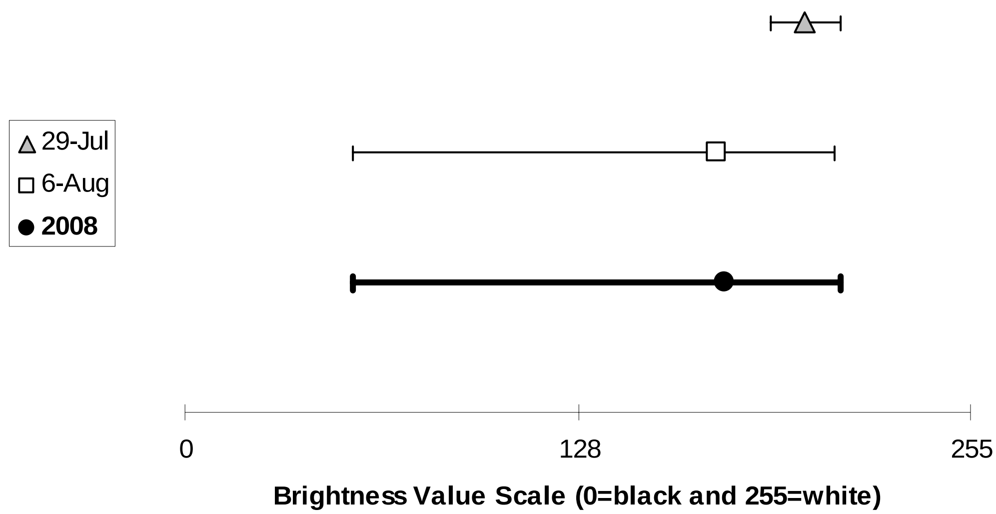

Figure B5. Mean brightness values (points) and ranges (bars) for whale RA025 on each day photographed in 2008 (n = 2) and over the 2008 season. Daily values are shown above the annual values for 2008.

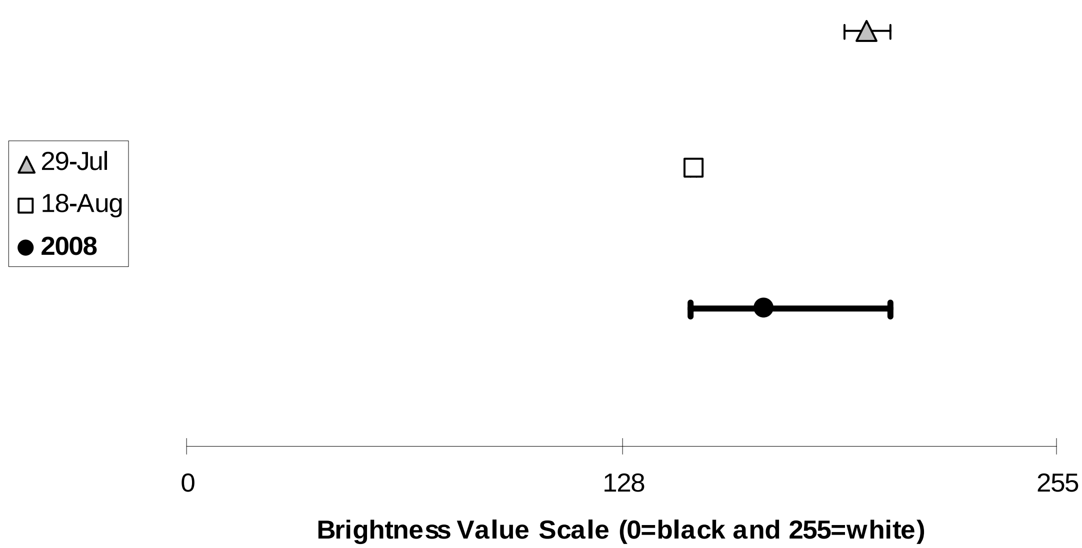

Figure B6. Mean brightness values (points) and ranges (bars) for whale RA029 on each day photographed in 2008 (n = 2) and over the 2008 season. Daily values are shown above the annual values for 2008.

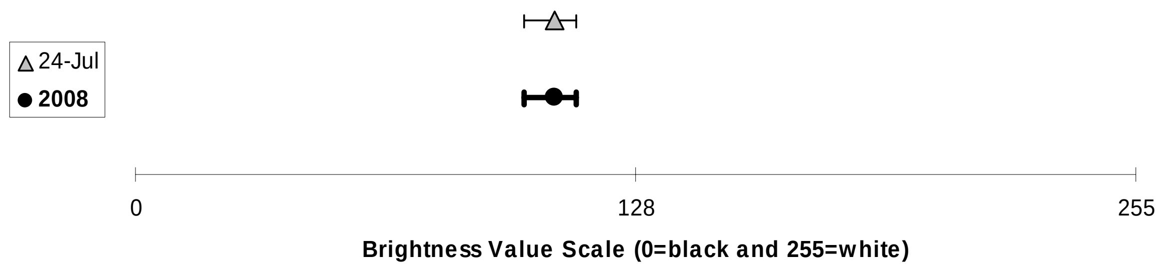

Figure B7. Mean brightness values (points) and ranges (bars) for whale RA036 on each day photographed in 2008 (n = 1) and over the 2008 season. Daily values are shown above the annual values for 2008.

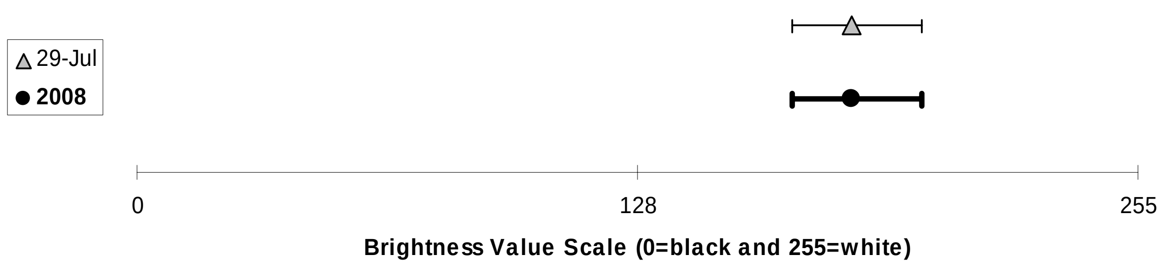

Figure B8. Mean brightness values (points) and ranges (bars) for whale RA054 on each day photographed in 2008 (n = 1) and over the 2008 season. Daily values are shown above the annual values for 2008.

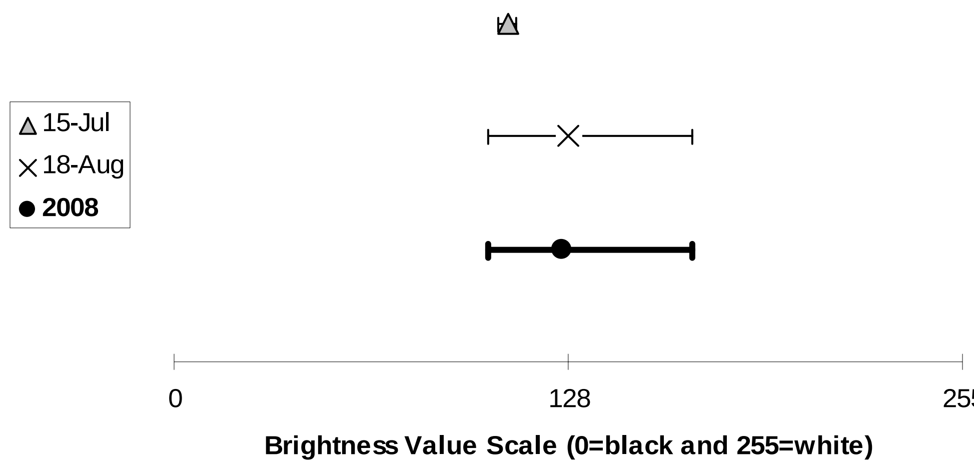

Figure B9. Mean brightness values (points) and ranges (bars) for whale RA063 on each day photographed in 2008 (n = 2) and over the 2008 season. Daily values are shown above the annual values for 2008.

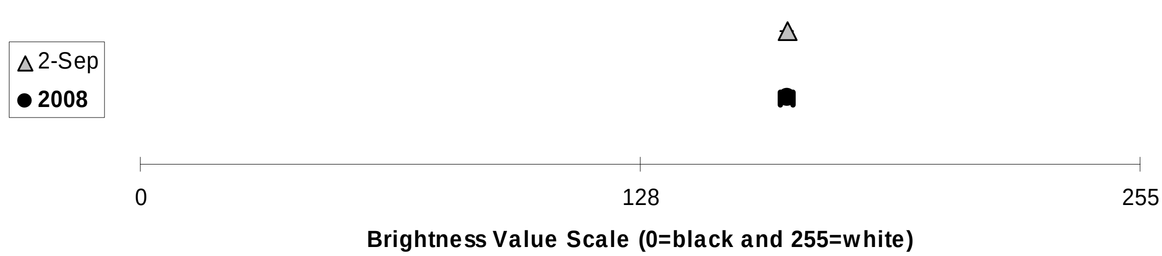

Figure B10. Mean brightness values (points) and ranges (bars) for whale RA066 on each day photographed in 2008 (n = 1) and over the 2008 season. Daily values are shown above the annual values for 2008.

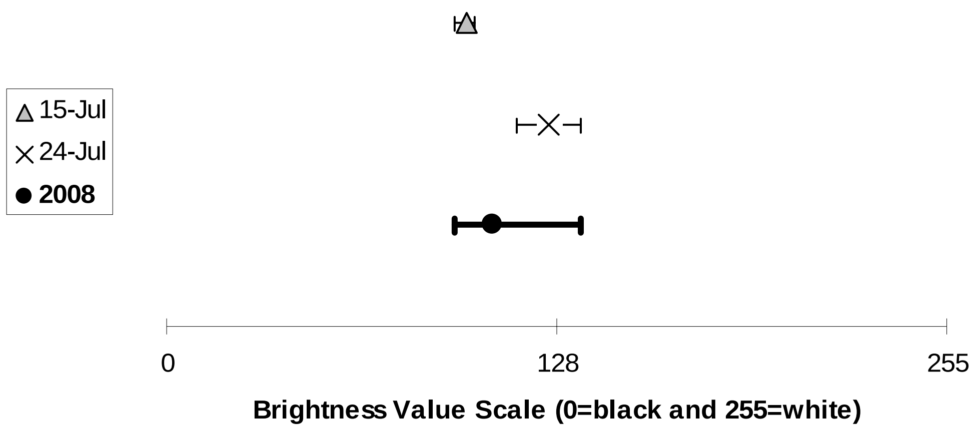

Figure B11. Mean brightness values (points) and ranges (bars) for whale RA100 on each day photographed in 2008 (n = 2) and over the 2008 season. Daily values are shown above the annual values for 2008.

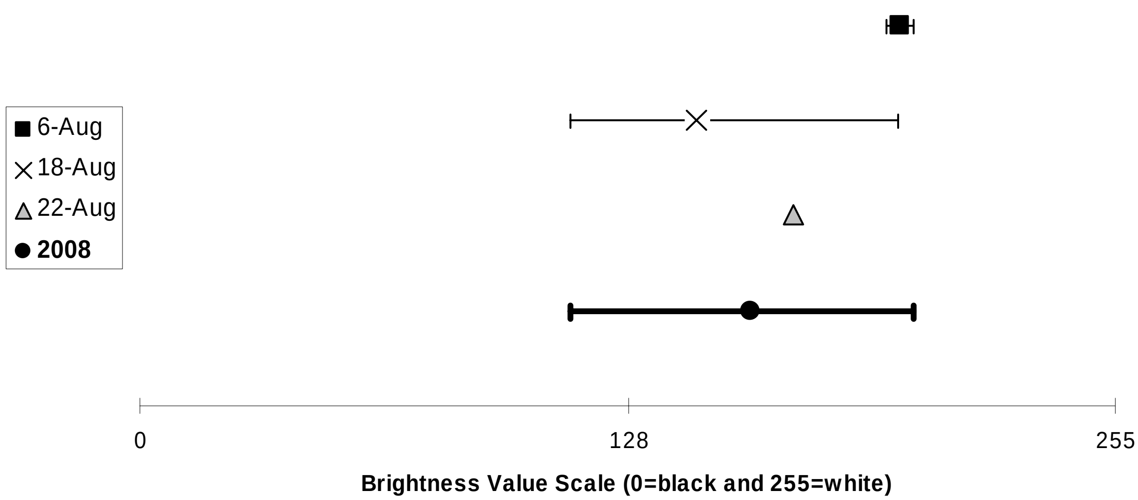

Figure B12. Mean brightness values (points) and ranges (bars) for whale RA102 on each day photographed in 2008 (n = 3) and over the 2008 season. Daily values are shown above the annual values for 2008.

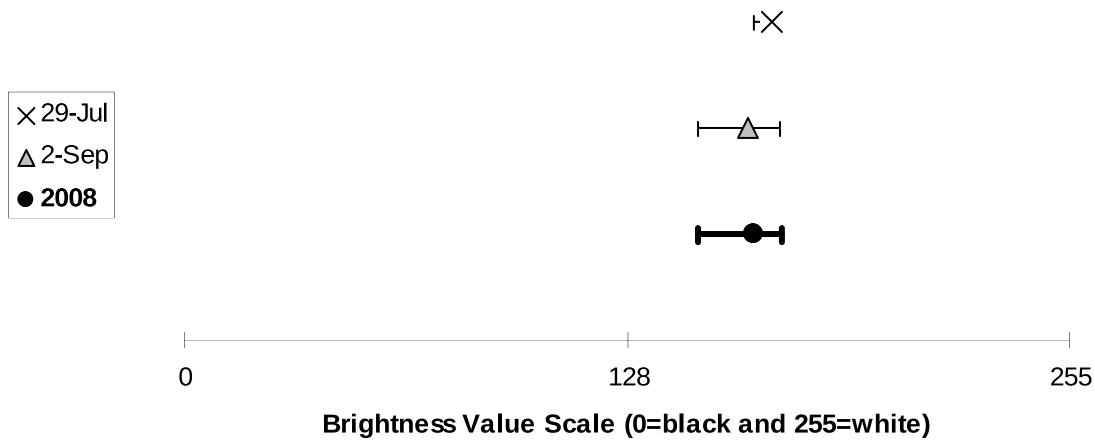

Figure B13. Mean brightness values (points) and ranges (bars) for whale RA123 on each day photographed in 2008 (*n* = 2) and over the 2008 season. Daily values are shown above the annual values for 2008.

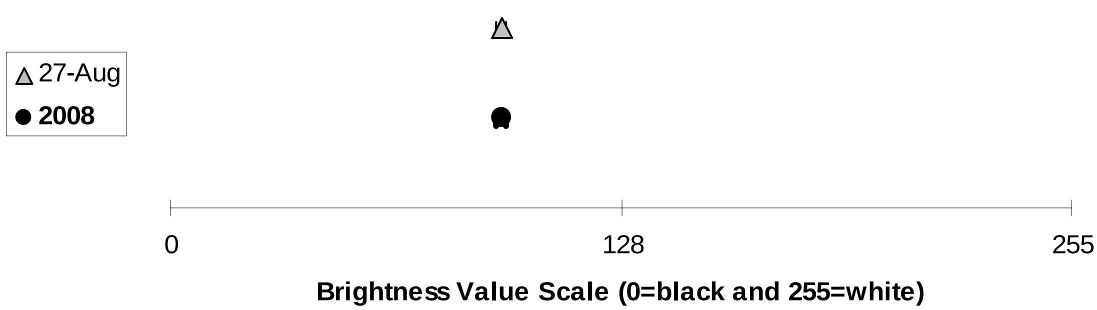

Figure B14. Mean brightness values (points) and ranges (bars) for whale RA132 on each day photographed in 2008 (*n* = 1) and over the 2008 season. Daily values are shown above the annual values for 2008.

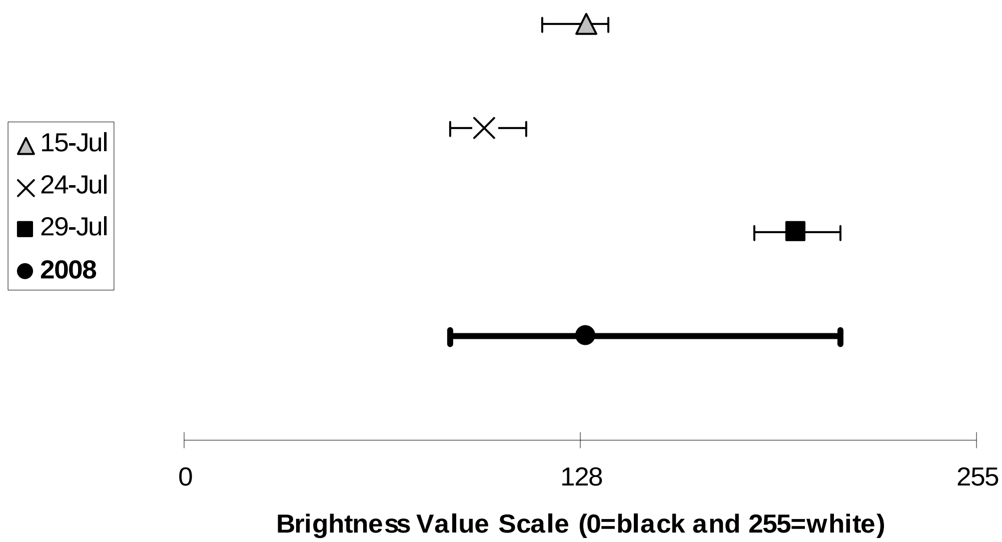

Figure B15. Mean brightness values (points) and ranges (bars) for whale RA145 on each day photographed in 2008 (*n* = 3) and over the 2008 season. Daily values are shown above the annual values for 2008.

Figure B16. Mean brightness values (points) and ranges (bars) for whale RA147 on each day photographed in 2008 (*n* = 1) and over the 2008 season. Daily values are shown above the annual values for 2008.

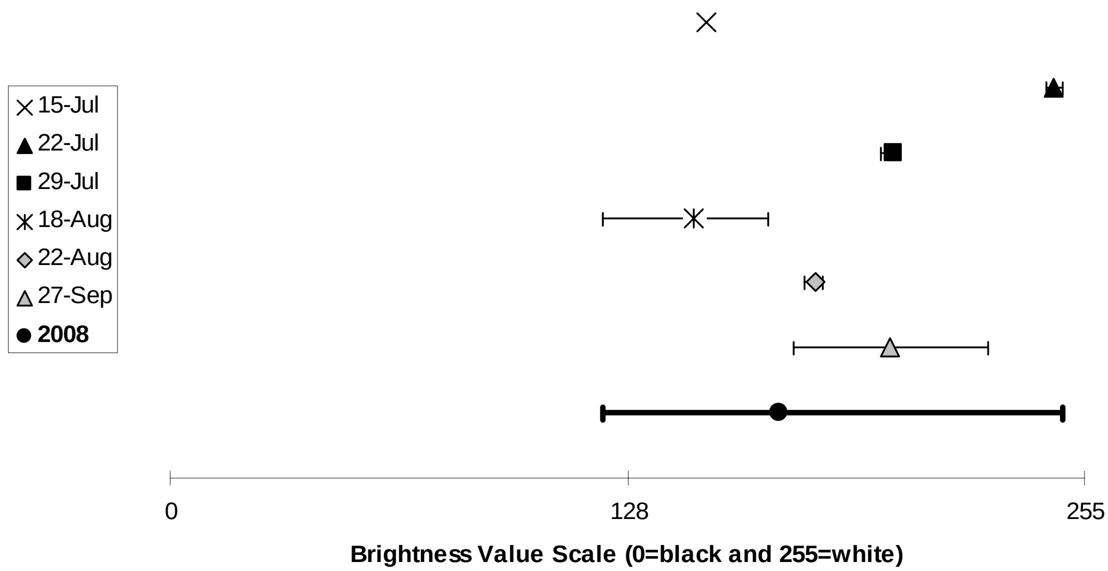

Figure B17. Mean brightness values (points) and ranges (bars) for whale RA148 on each day photographed in 2008 (n = 6) and over the 2008 season. Daily values are shown above the annual values for 2008.

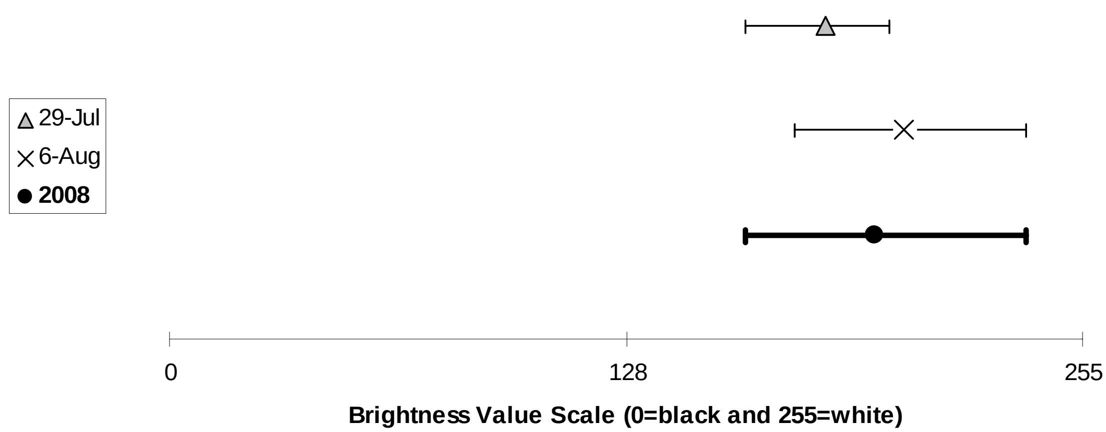

Figure B18. Mean brightness values (points) and ranges (bars) for whale RA154 on each day photographed in 2008 (n = 2) and over the 2008 season. Daily values are shown above the annual values for 2008.

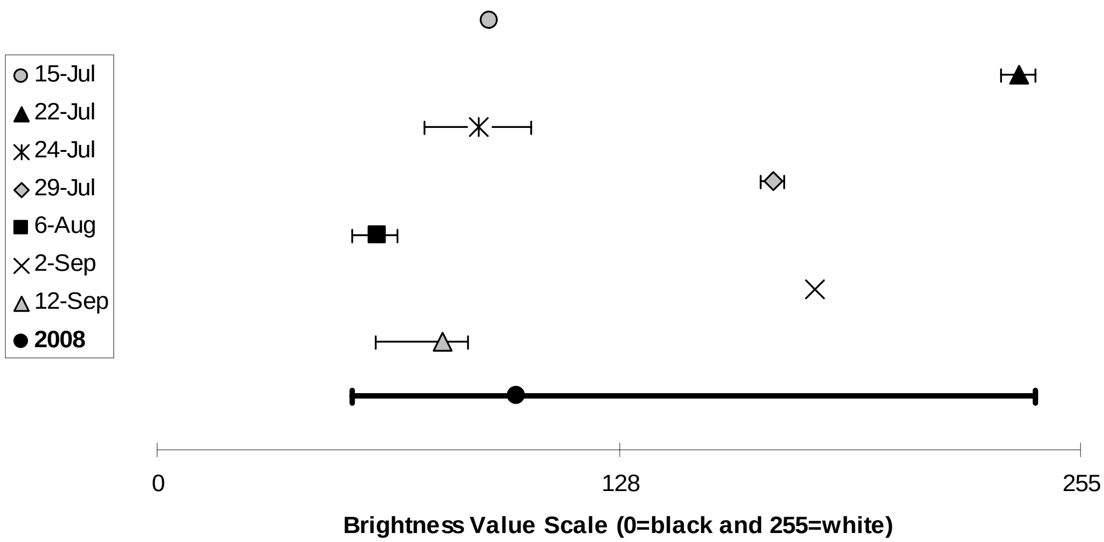

Figure B19. Mean brightness values (points) and ranges (bars) for whale RA155 on each day photographed in 2008 (n = 7) and over the 2008 season. Daily values are shown above the annual values for 2008.

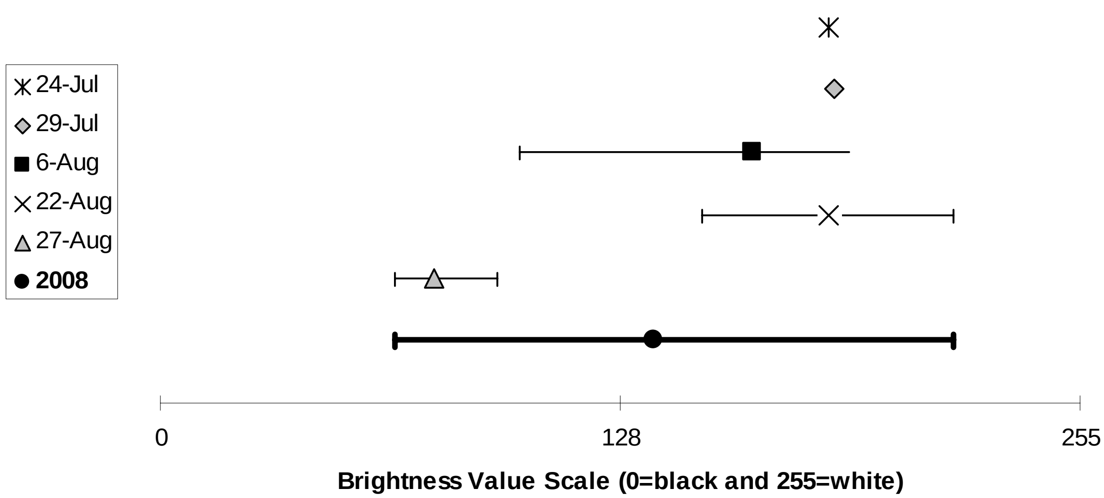

Figure B20. Mean brightness values (points) and ranges (bars) for whale RA160 on each day photographed in 2008 (n = 5) and over the 2008 season. Daily values are shown above the annual values for 2008.

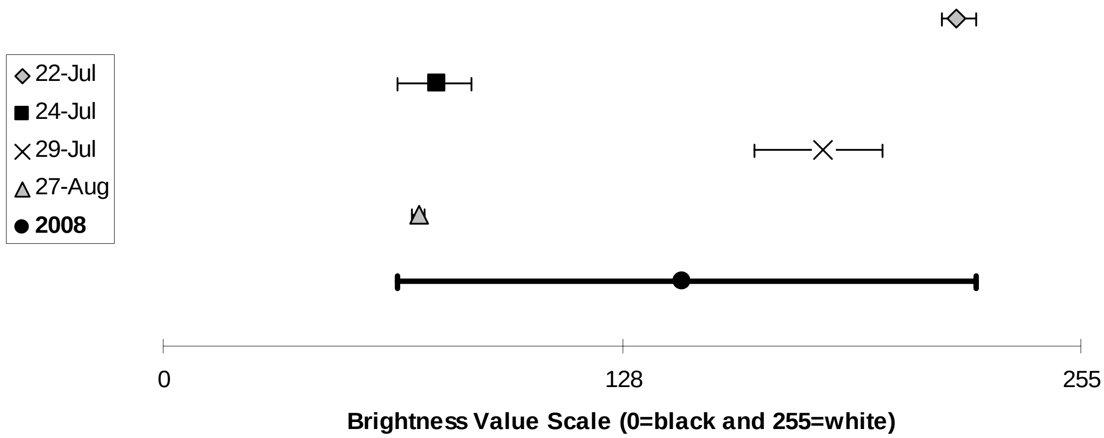

Figure B21. Mean brightness values (points) and ranges (bars) for whale RS002 on each day photographed in 2008 (n = 4) and over the 2008 season. Daily values are shown above the annual values for 2008.

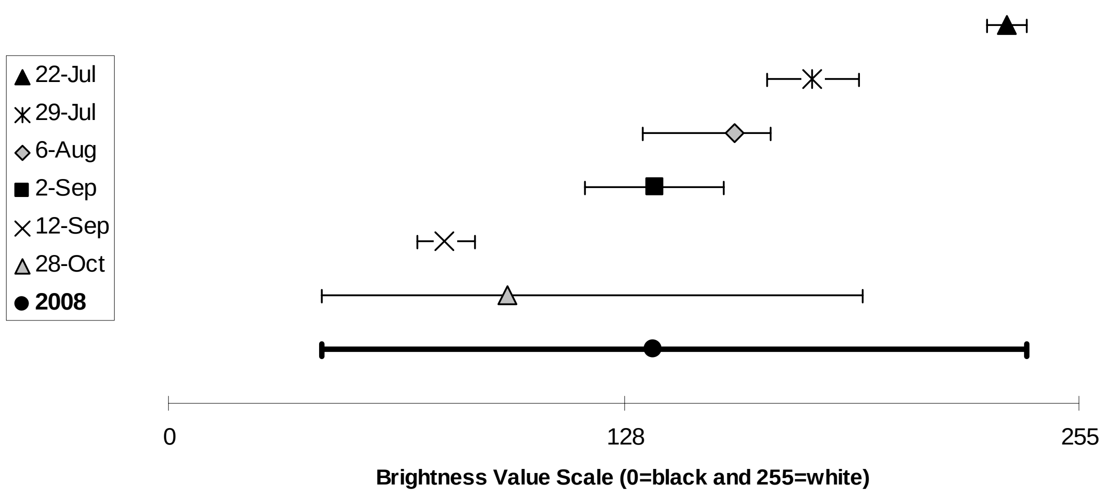

Figure B22. Mean brightness values (points) and ranges (bars) for whale RS044 on each day photographed in 2008 (n = 6) and over the 2008 season. Daily values are shown above the annual values for 2008.

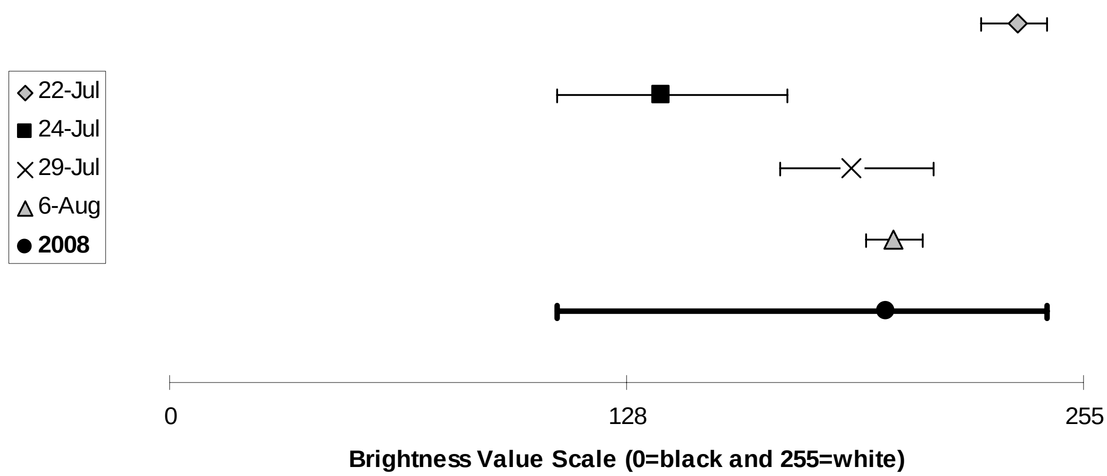

Figure B23. Mean brightness values (points) and ranges (bars) for whale RS110 on each day photographed in 2008 (*n* = 4) and over the 2008 season. Daily values are shown above the annual values for 2008.

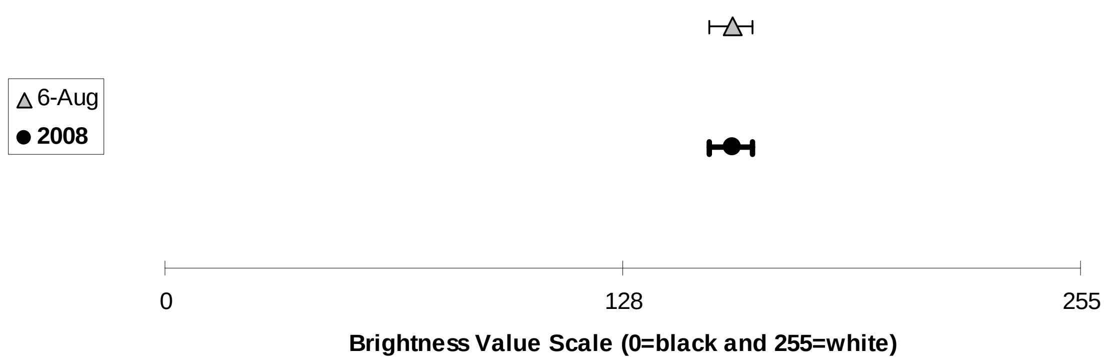

Figure B24. Mean brightness values (points) and ranges (bars) for whale RS118 on each day photographed in 2008 (*n* = 1) and over the 2008 season. Daily values are shown above the annual values for 2008.

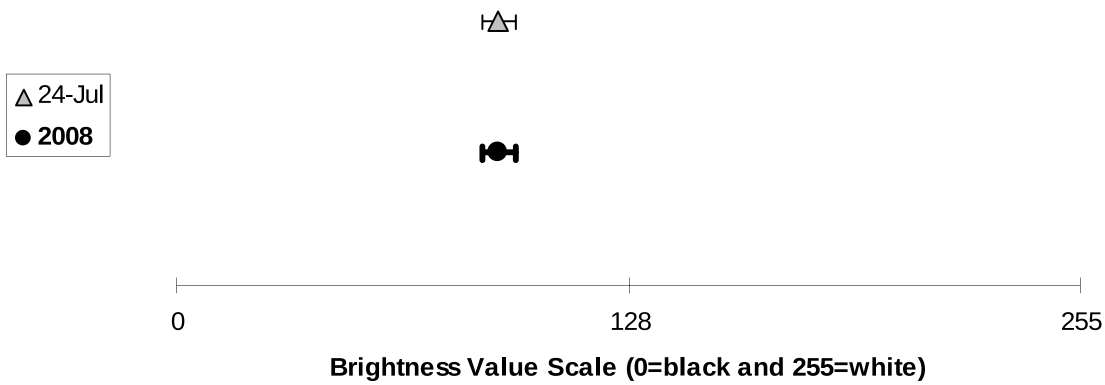

Figure B25. Mean brightness values (points) and ranges (bars) for whale RS124 on each day photographed in 2008 (n = 1) and over the 2008 season. Daily values are shown above the annual values for 2008.

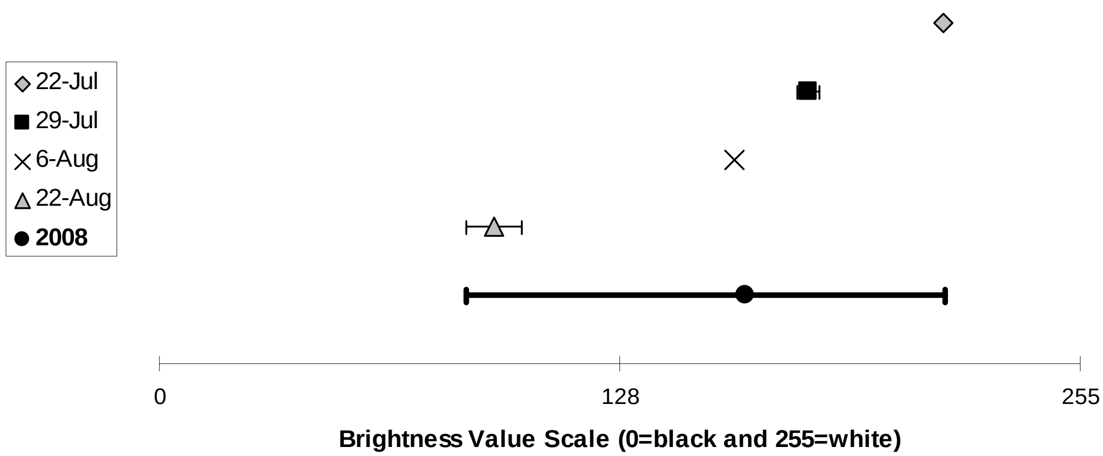

Figure B26. Mean brightness values (points) and ranges (bars) for whale RS134 on each day photographed in 2008 (n = 4) and over the 2008 season. Daily values are shown above the annual values for 2008.

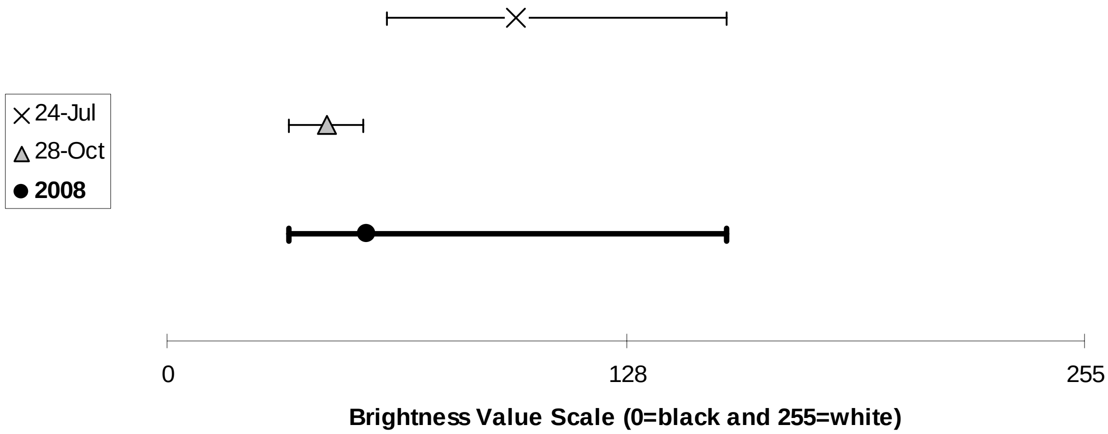

Figure B27. Mean brightness values (points) and ranges (bars) for whale RS139 on each day photographed in 2008 (*n* = 2) and over the 2008 season. Daily values are shown above the annual values for 2008.

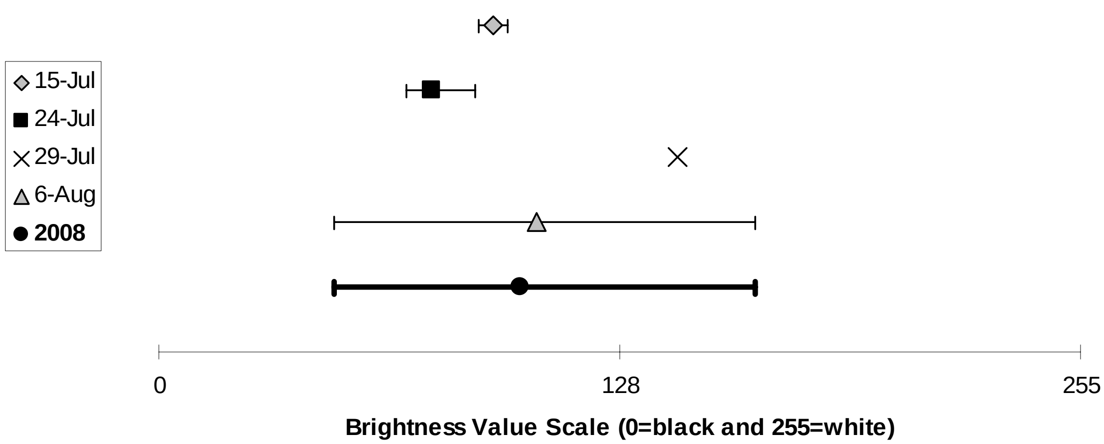

Figure B28. Mean brightness values (points) and ranges (bars) for whale RS140 on each day photographed in 2008 (*n* = 4) and over the 2008 season. Daily values are shown above the annual values for 2008.

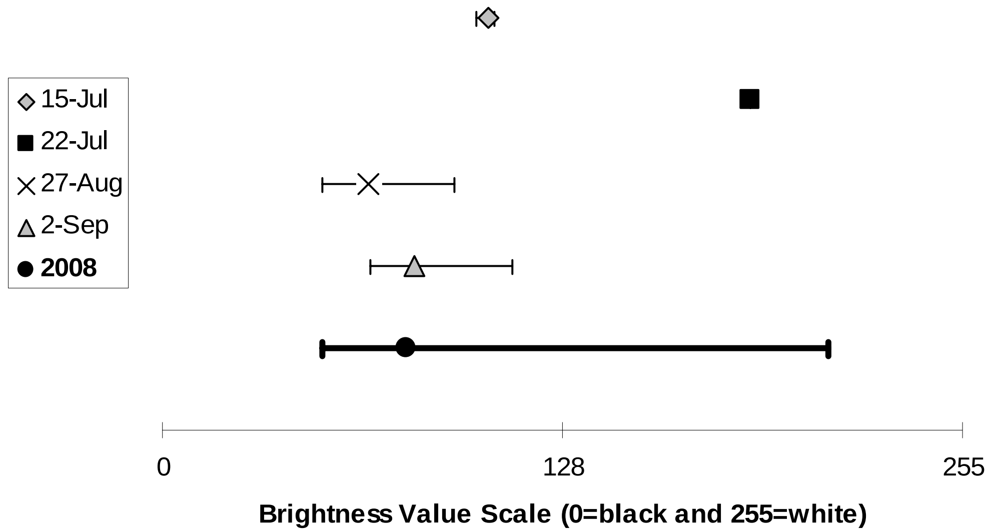

Figure B29. Mean brightness values (points) and ranges (bars) for whale RS221 on each day photographed in 2008 (n = 4) and over the 2008 season. Daily values are shown above the annual values for 2008.

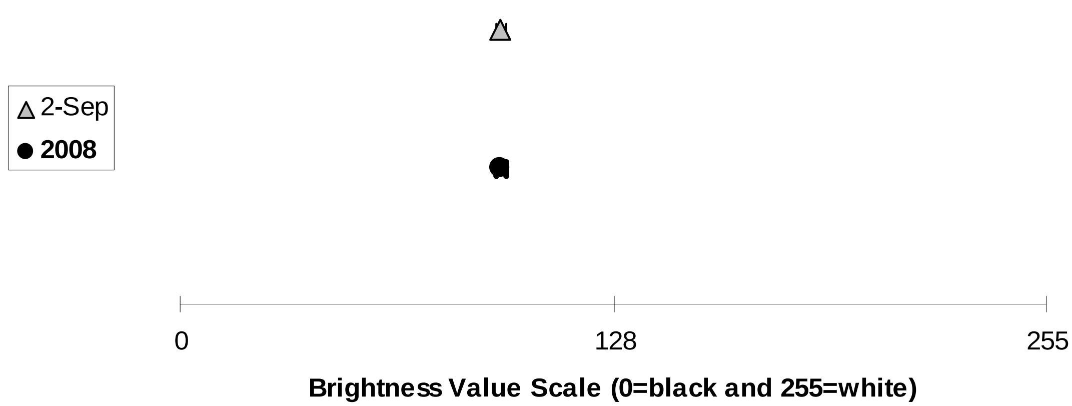

Figure B30. Mean brightness values (points) and ranges (bars) for whale RS222 on each day photographed in 2008 (n = 1) and over the 2008 season. Daily values are shown above the annual values for 2008.

APPENDIX 3-C

MEAN BRIGHTNESS VALUE RANGES FOR THE THREE WHALES SEEN IN ALL FOUR YEARS OF THE STUDY AND SELECTED FOR THE INTER-ANNUAL ANALYSIS

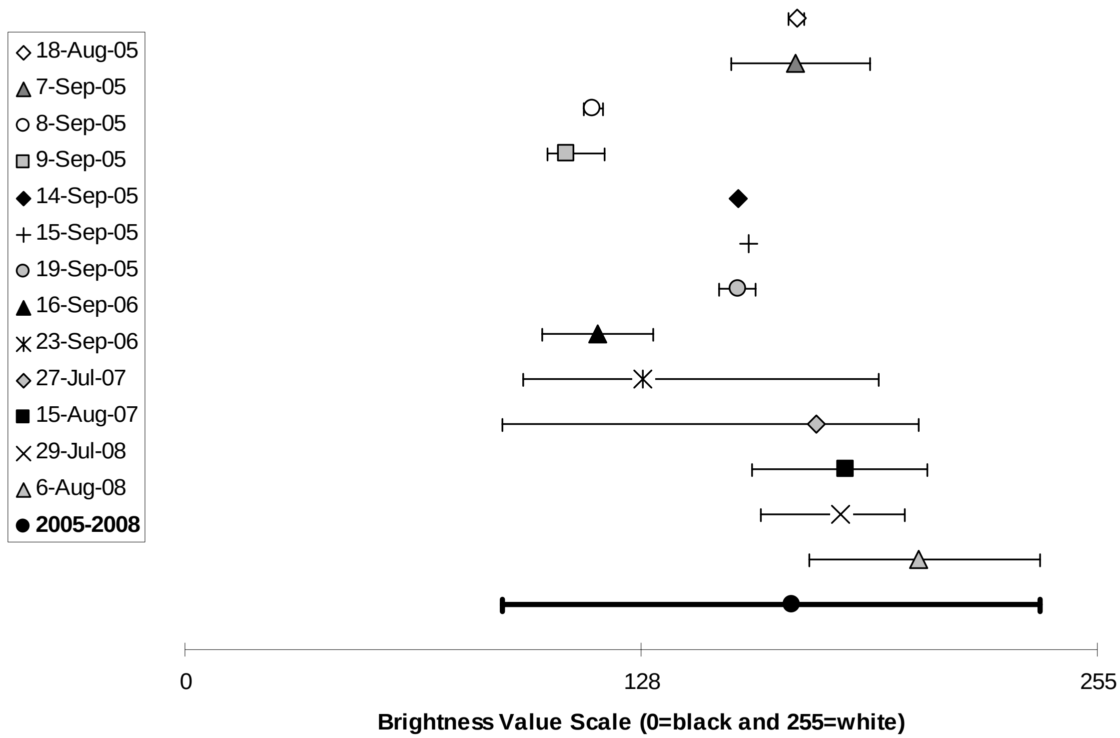

Figure C1. Mean brightness values (points) and ranges (bars) for whale RA154 on each day photographed from 2005-2008 (n = 13) and over the 2005-2008 seasons. Daily values are shown above the inter-annual values for 2005-2008.

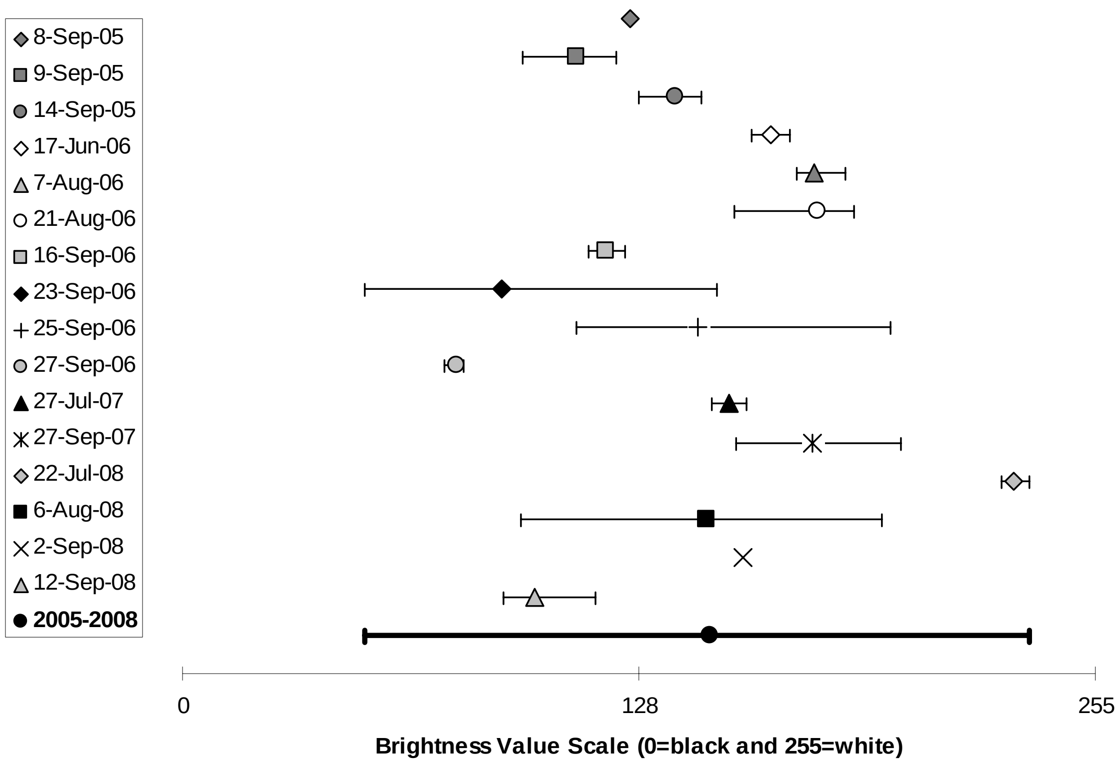

Figure C2. Mean brightness values (points) and ranges (bars) for whale RA001 on each day photographed from 2005-2008 (*n* = 16) and over the 2005-2008 seasons. Daily values are shown above the inter-annual values for 2005-2008.

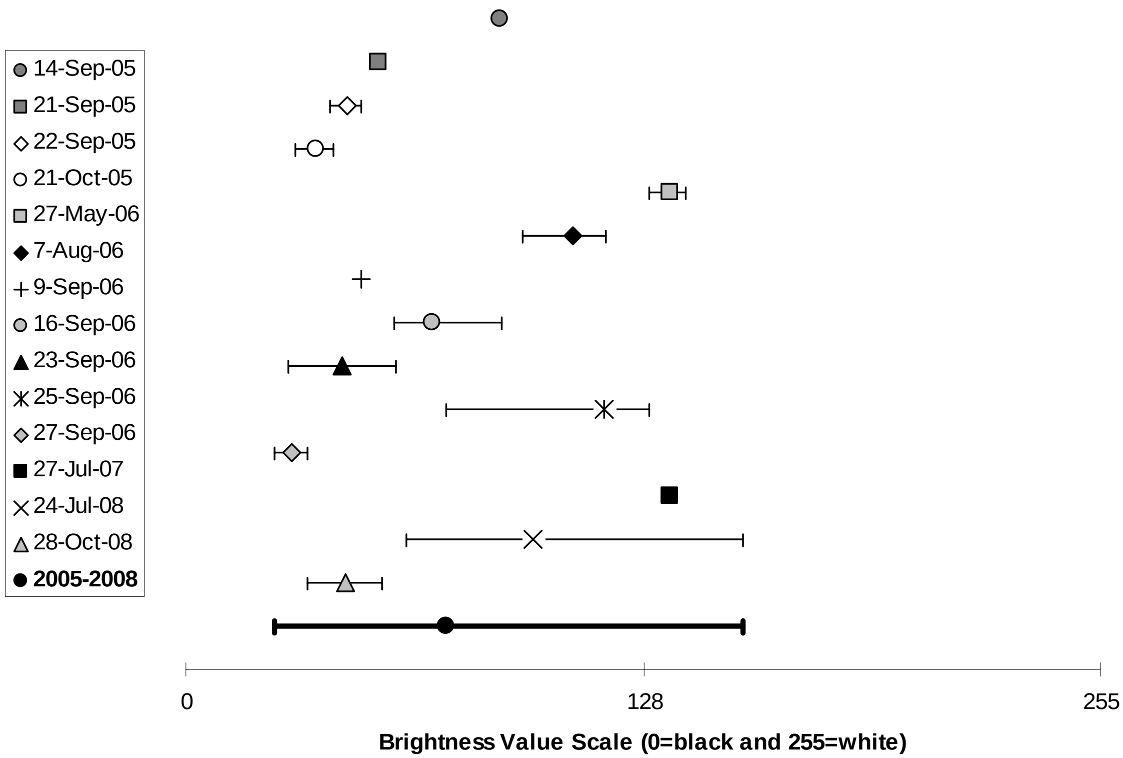

Figure C3. Mean brightness values (points) and ranges (bars) for whale RS139 on each day photographed from 2005-2008 (*n* = 14) and over the 2005-2008 seasons. Daily values are shown above the inter-annual values for 2005-2008.