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ANNUAL CALF INDICES FOR BELUGA WHALES (*DELPHINAPTERUS LEUCAS*) IN COOK INLET, ALASKA 2006-2010

by

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ABSTRACT

Beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, form an isolated, depleted population that is now listed as endangered. One monitor of population health is through documenting calving rates. This study provides an index of the number of calves seen in Cook Inlet in August. Although the August survey is the focus for the calf index, given most births are thought to occur by late July, data collected during the annual June abundance survey are used for comparison. Analyses cover the period from 2006 to 2010 (a feasibility and techniques study occurred in August 2005). Systematic aerial surveys covered primary habitat for belugas in Cook Inlet, and paired video cameras provided images used in laboratory analysis. A total of 44 groups of whales from the August surveys were examined, of which most contained images of calves that were identified by color (darker than adults), small size, and proximity to adults. Among these whale groups, 688 usable images were found and examined. By rating inter-whale proximity in five categories, and estimating the ages represented, we developed criteria for recognizing young calves, an index that represents primarily young-of-the-year calves, and a second index that represents young-of-the-year, yearling calves, and some young juveniles. It appears that more calves were born in 2006 (12%) than in subsequent years (2007-2010 ranged from 0.5% to 3%). However, these calving rates have several potential biases and should be used for trend analysis only, not for absolute estimates of calf production. Overall, the 5-year average (2006-2010) birth rate was 3.6%. With mortality rates per year of roughly 3% or more (based on counts of beach-cast carcasses), this would suggest that the birth rate estimated here is probably at or below the replacement level necessary for recovery of this population.

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INTRODUCTION

Beluga whales in Alaska's Cook Inlet are genetically distinct and geographically isolated from beluga whale populations in western Alaska and the Arctic (O'Corry-Crowe et al. 1997, Laidre et al. 2000). In 1999, the Cook Inlet stock was determined to be depleted under the U.S. Marine Mammal Protection Act (65 FR 34590), and in 2008, this distinct population segment (DPS) was listed as endangered under the U.S. Endangered Species Act (ESA) (73 FR 62919). As a part of the recovery efforts, criteria defining benchmarks for extinction risk must be developed in the ESA Recovery Plan. One such indicator of recovery or decline in a population is change in calving rates. That is, a decline in calving rate will result in a shortage of replacements and an ensuing reduction in population size. The 2011 abundance for the Cook Inlet beluga population was estimated to be 284 (CV = 0.16) and the trend indicates a continued decline, thus prompting an investigation of the calving rate.

Beluga whales have a protracted calving period, and peaks in calving periods vary from region to region (Braham 1984, Kleinenberg et al. 1964). In general, calving occurs in spring and summer, usually between March and September, with peaks occurring in some locales in late June or late July. In Cook Inlet, Native hunter traditional knowledge indicates calving occurs from April through August (Huntington 2000). Hunters described calving areas in the lower inlet (the southern portion of Cook Inlet) along the northern side of Kachemak Bay in April and May, and in the northwestern portion of the upper inlet near the Beluga and Susitna Rivers in May and Chickaloon Bay and Turnagain Arm in summer (Huntington 2000:138).

To develop a calf index for Cook Inlet beluga whales, the National Marine Mammal Laboratory (NMML) conducted aerial surveys in August annually beginning in 2005 (see field reports Rugh et al. 2006, Shelden et al. 2007, 2008, 2009, 2010), supplementing abundance surveys conducted each June or July since 1993 (Rugh et al. 2000, 2005, 2010). By August, the majority of calves are thought to be born, and because traditional Native knowledge indicates that calves are born in the early summer in Cook Inlet

(Huntington 2000), calves will be typically less than 2 months postpartum at the time of the August surveys. The young-of-the-year (defined as calves) remain in close proximity to their mothers, and in August (1 or 2 months post-natal) they are nearly always in contact with their mother (Krasnova et al. 2006, Suydam 2009) and are therefore more readily identified as calves. Here, we describe techniques used to create a calving rate index and discuss the implications for the conservation and recovery of this depleted, isolated population.

METHODS

Survey Area

Cook Inlet is an arm of tidal waters north of the Gulf of Alaska. Beluga whales in Cook Inlet have been more or less isolated from other populations for as much as 10,000 years (O'Corry-Crowe et al. 1997). This population currently inhabits three primary areas denoted as the following for the purposes of this study:

- "*Susitna area*", which includes the northwestern portion of the upper inlet between Point McKenzie and Beluga River;
- "*Knik area*" which is Knik Arm, north of Anchorage, the largest city in Alaska; and,
- "*Turnagain area*", including Turnagain Arm and Chickaloon Bay, in the northeast portion of upper Cook Inlet.

Belugas in Cook Inlet tend to be found near shore; therefore, aerial surveys have emphasized searches within 1.4 km of the apparent waterline (Rugh et al. 2000, 2005, 2010). This coastal survey included searches up rivers until the water appeared to be too shallow for belugas (as indicated by Alaska Native hunters who participated on surveys in the past).

Aircraft and Data

Aerial surveys were consistently flown in twin-engine, high-wing aircraft at an altitude of 244 m (800 ft) and speed of 185 km hr $^{-1}$ (100 kt). Bubble windows were at the right and left forward observer positions, maximizing the search area. The data recorder used a laptop computer[1] connected to a handheld portable Global Positioning System (GPS) to record sighting and effort data. To each manual entry, time and location were added from the GPS as well as routine records of time and location taken directly from the GPS by the survey software. Data entries included percent cloud cover, sea state (Beaufort scale), glare (on the left and right sides), and visibility (on the left and right sides) as well as information on sightings of beluga and other marine mammals and beluga group count data.

Counting and Video Passes

When beluga groups were seen, each observer reported the sighting to the data recorder. Because of the turbid water in Cook Inlet, only the portion of the whale (i.e., head and/or back) above the surface of the water as the animal breathes is visible to the observers and cameras. As the aircraft passed abeam of the whale group, the observer(s) informed the recorder of the inclinometer angle and notable group behaviors but not group size. Whale group locations were established via GPS at the onset of the counting passes. Counts of each whale group were made by following an extended oval around the group. Whale counts were made on each pass down the long axis of the oval following procedures used during spring abundance surveys (Rugh et al. 2000). Daily aerial counts of beluga groups are represented by medians of each observer's median counts on multiple passes (typically 4 to 8 passes) over each whale group.

Video Procedures

Paired video cameras were used to document beluga whale groups; one camera had a lens set at wide angle to view the entire beluga group (referred to hereafter as "standard" video), and the second camera lens was zoomed to approximately 10× to 15× to magnify

[1] Starting in 2006, survey data were entered using a new software program specifically developed for the Cook Inlet beluga aerial survey by Niel Goetz and Kimberly Goetz, Dept of Ecology and Evolutionary Biology, University of California, Long Marine Lab, 100 Shaffer Rd, Santa Cruz, CA 95064-1077, USA.

a subsample of individual whales in the group. The zoomed video was used to determine correction factors for missed animals (see Hobbs et al. 2000) and to examine color ratios of white adults relative to dark juveniles (Litzky 2001, Sims et al. 2003, 2006). During 2005, a high-speed digital single-lens reflex (SLR) camera (Nikon D1X) was used for the zoomed data collection paired alongside a mini-digital video camera (Sony DVCAM, DSR-PDX10 Model L10A). The August 2005 survey was an experimental survey to determine the level of camera resolution required and to see if still photography would be adequate. Although calves were seen clearly in the still images, the camera was not able to fire fast enough (approximately 3 frames per second) and would pause after several frames to clear its memory. Consequently the still camera was less than ideal and could not reliably capture enough frames of a surfacing event to determine the image size at the mid-time of a whale's surfacing (i.e., the maximum image size). In 2006, both the counting video camera and the zoomed still camera were replaced with high-definition (HD) video cameras (JVC GR-HD1, 1290 × 720 pixels) to collect both standard and zoom video (Table 1). While the resolution of the JVC HD cameras (1290 × 720) was lower than the resolution of the Nikon still camera (3008 × 1960), it was an improvement over the Sony DVCAM video resolution (720 × 480). A test run in May 2006 demonstrated that the continuous HD video gave a better sampling of beluga groups than the Nikon still camera could, and the HD video still provided sufficient resolution and captured enough frames to maximize image size during the surfacing for calf detection and size comparisons. Therefore, the data collected with the Nikon still camera during the 2005 survey are not used in subsequent analysis.

Video Analysis

Post-survey video was digitally streamed into the computer and edited and exported so that each counting pass was created as an individual video file. Video passes were then reviewed to ensure sufficient quality of the video for counting whales. Ratings were excellent, good, fair, poor, or unacceptable (defined in Hobbs et al. 2000); only aerial passes with excellent or good ratings were used in the analysis. After each video clip was assessed for viewing quality, the clip was analyzed using the "Beluga Dots" program, software designed specifically to analyze video collected during these surveys[2]. The Beluga Dots program, used on Macintosh computers, allowed an analyst to view video passes, mark and number each individual whale image, track the images across the screen, and use tools to measure whale image size and color. The computer program electronically records all relevant information of the analysis process for data export at a later time. One of the advantages of the video analysis program is that it allows analysts to review the video frame by frame or in slow motion an unlimited number of times. Changes to the corresponding saved data can be made whenever necessary. Each video sequence was examined by a primary analyst who catalogued individual whales, noted surfacing and diving times, and measured whale images for size and color. A second analyst used the same video and corresponding data file to review the primary analyst's whale count and provide second measurements of each whale image size and color.

The computerized video analysis program allows for slower, more methodical counting of groups compared to counting real time during the aerial survey. This advantage in counting is especially important when belugas form large dense groups.

A calf index was derived from the zoomed video. Zoomed video of each counting pass was synchronized with the standard video. Analysis of zoomed whale images often yielded small gray whales that were undetected in standard video due to size (much smaller than adults), dark color (blending with the muddy water), or surfacing behavior (only a small portion of the whale broke the water surface).

Calf Proximity Analysis

We identify calves by their size and coloration plus proximity to an adult whale. Small whales that met size and coloration criteria to be calves (the majority of which were only found in zoomed video) were analyzed to determine proximity to an adult. For this analysis, "adult" is defined as a large white or light gray whale. Calves are identified by their dark color and relatively small size in relation to adults. Whales that were gray but not as dark as a calf or were too large to be a calf were likely juveniles or adults. Whales

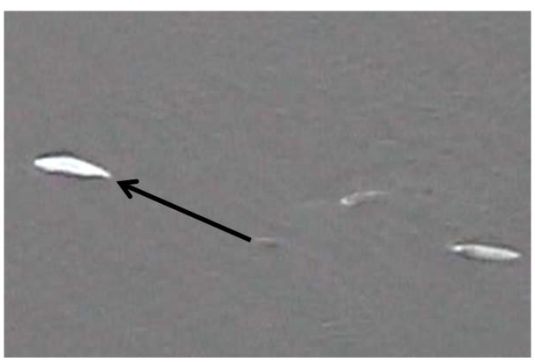
[2] Starting in 2004, video data were analyzed using a new software program specifically developed for the Cook Inlet beluga aerial survey by Steven Hentel, 6170 NE 187th Pl Kenmore, WA 98028.

that appeared to be calves were given proximity codes based on distance to the nearest adult in the field of view. The Proximity Codes (1 through 5) (Fig.1) are as follows:

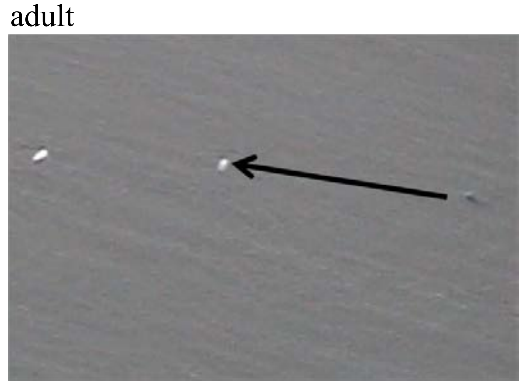
1. Touching adult whale.
2. One whale length from adult whale.
3. Two to three whale lengths apart from adult whale.
4. In same field of view (>3 whale lengths apart).
5. Alone in field of view.

Code 1: Touching adult

Code 2: One whale length away from adult



Code 3: 2-3whale lengths away from adult



Code 4: In same frame (>3 whale lengths) as adult

Code 5: Alone in field of view

Figure 1. -- Still images captured from video show codes used to estimate proximity (Code 1-5) to nearest adult.

To estimate the average ages of whales in each proximity category, image sizes were averaged and compared to the average size of adults from each survey season (June and August). A ratio to adult length (f = fraction of adult size) was found by dividing the average image size in number of pixels of potential calves with the average image size of adult whales (June: 37.5 pixels, August: 41.1 pixels). Next, the approximate length was estimated by multiplying the ratio to the average length of an adult female Cook Inlet beluga whale (361 cm) (Suydam 2009). This gave estimated average lengths for calves in each proximity type for both June and August. Approximate average ages for calves by proximity type are estimated using the Gompertz growth curve (see Suydam 2009) for Cook Inlet females. The growth curve equation is solved for the age at length to yield as follows:

$$age = ln[ln(estimated\ average\ length/361)/-0.84]/-0.35,$$

where *ln* is the natural logarithm.

The ratio of calves to non-calves is estimated from groups sampled in zoomed video. The narrow scope in the zoomed video means a point on the water passes through the field of view in about 1 to 2 seconds. The surfacing time for calves is on-half to one-third of that of the accompanying adult which is visible at the surface for 3-5 seconds. To remove the bias that would result from the longer surfacing time of adults, we only used non-calf images that were near their maximum size (i.e., backs fully exposed at the surface), and we included all potential calves. The following criteria were applied to complete the data set for the calf ratio analysis:

1. Whales sampled in zoomed video that included a point within 20 or fewer frames away from the estimated midpoint of surfacing as determined in the standard video (i.e., +/- 0.66 seconds).
2. Whales that were only found in zoomed video and not visible in standard video but that met the size and coloration criteria for calves.

Removed from the data were as follows:

1. Whales that were only found in zoomed video and were not visible in standard video for which the color was judged to be white or off-white.
2. Whales measured in zoomed video with additional comments that stated “at beginning” or “at end” of a surfacing.
3. Partial surfacing of a whale that was visible in zoomed video but not visible in standard video.

By only using images of whales that were near their maximum size and midpoint when they were at the surface of the water, we removed the bias resulting from longer surfacing times of large whales and ensured that the measurements were consistent in representing the relative size of the animal. The turbid water in Cook Inlet precludes measurements of full body lengths of whales, so we assumed that the maximum size of an image is proportional to the standard length of the whale.

Calculation of the Calf Index

The probability that a surfacing beluga was a calf was estimated for each year of the August surveys from 2006 to 2010 and for each area with all years combined. The probabilities are estimated using logistic regression in a generalized linear model (glm) (McCullagh and Nelder 1989). The calculation was done using the glm routine in the software package R. Each individual was treated as a sample drawn at random from the population with a sample weighting of the estimated group size divided by the number of samples from the group. This prevented a single group that was sampled heavily from dominating the analysis. Each sample was scored as a “1” if it was a calf and a “0” if it was not a calf. The logistic regression estimates a probability that a surfacing animal is a calf, $p(x)$, as

$$p(x) = \frac{e^{B(x)}}{1+e^{B(x)}},$$

where *B(x)* is a normally distributed parameter with standard error, SE(*B(x)*), estimated iteratively during the logistic regression, and *x* is either year or area. A 95% confidence interval for *B(x)* is *B(x)*±1.96SE*(B(x))* which is transformed to an interval for *p(x)* as

$$\frac{e^{B(x)-1.96SE(B(x))}}{1+e^{B(x)-1.96SE(B(x))}}, \frac{e^{B(x)+1.96SE(B(x))}}{1+e^{B(x)+1.96SE(B(x))}}.$$

In cases where the number of calves was zero, logistic regression cannot estimate the probability. Instead, we used the empirical logistic transform (Cox and Snell 1989) to estimate the probability and an upper bound, so that

$$B(x) = ln\left(\frac{1/2}{m+1/2}\right) \text{ and } (B(x)) = \sqrt{\frac{(m+2)}{m}},$$

where *m* is the number of non-calves found, and *ln* is the natural logarithm. In this case we calculated an upper bound using a one-sided 95% interval because the lower bound was clearly zero

$$\frac{e^{B(x)+1.65SE(B(x))}}{1+e^{B(x)+1.65SE(B(x))}}$$

The resulting estimate was the probability that an animal drawn at random from the population in a given year or area was a calf. This became the calf index for that survey period or area. Indices were developed to assess the relative number of calves in the population. To convert the index to a calving rate for adult females, we will need to know the number of adult females in the population, a factor which is not available at this time.

Results

Aerial Surveys

Calf index surveys were conducted each August from 2005 through 2010 (Fig. 2). Beluga whale groups were observed primarily in the Susitna area, in Knik Arm, and in Turnagain

Arm (Fig. 3). The daily median counts in August ranged from 109 to 277 whales and compared favorably to daily medians obtained during the June surveys (Fig. 4).

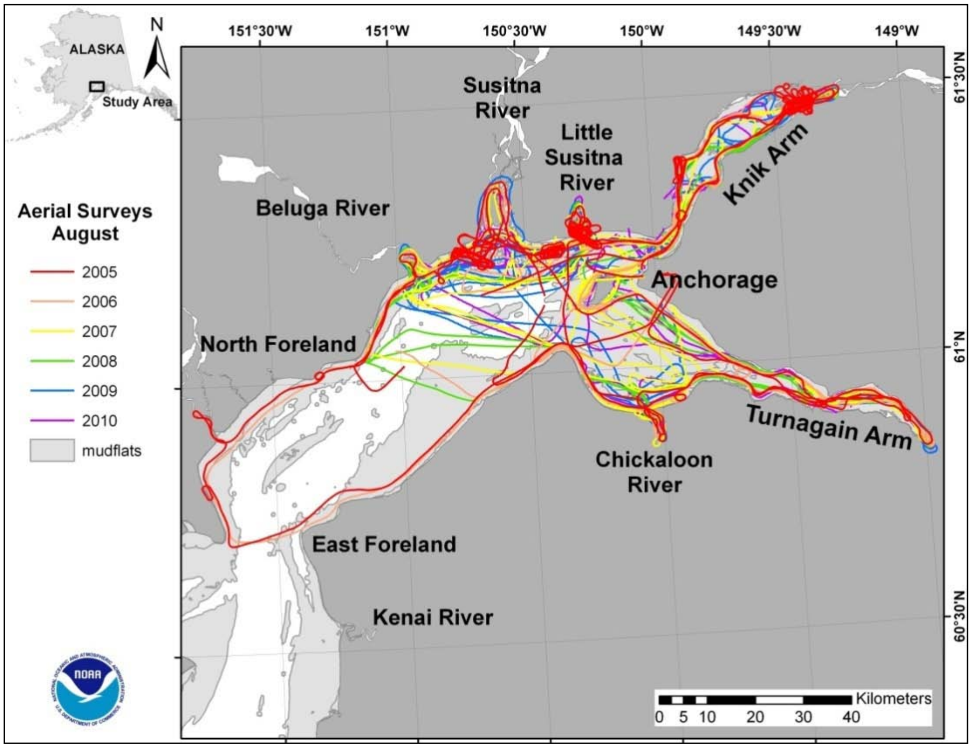


Figure 2. -- Aerial survey effort in Cook Inlet, Alaska, documenting beluga whale occurrence during calf index surveys each August 2005-2010.

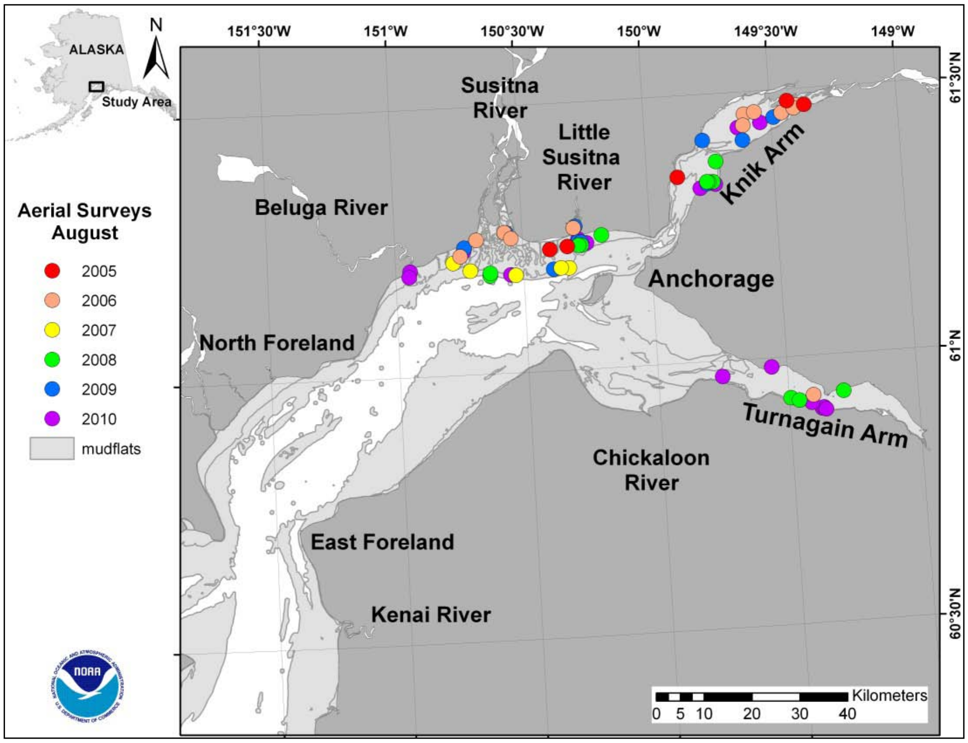


Figure 3. -- Locations of beluga whale groups observed in Cook Inlet, Alaska, during calf index aerial surveys each August 2005-2010.

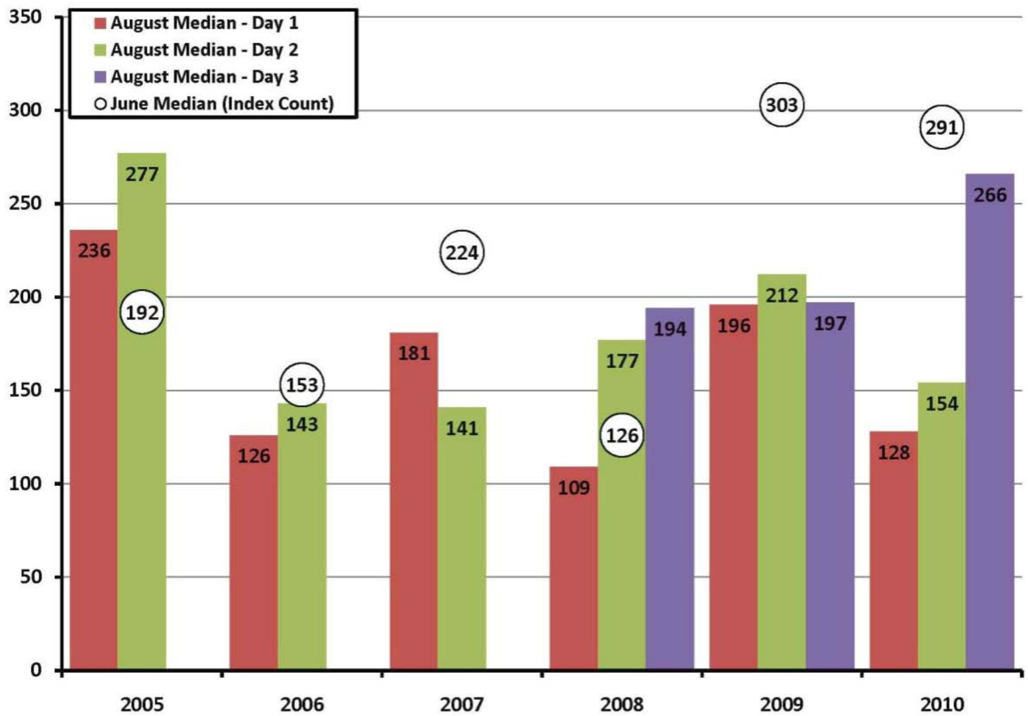


Figure 4. -- Daily median counts of beluga whales obtained during aerial surveys of Cook Inlet in August compared to June (highest daily median count circled) 2005-2010.

Video Analysis

Multiple zoomed video samples of beluga whale groups were collected each August from 2006 to 2010 (only still photos were collected in zoomed mode in 2005) (Table 1). For 2006-2009, zoomed video images were obtained of 6 whale groups (in 2006 and in 2007), 8 whale groups (in 2008), and 9 whale groups (in 2009) for a total of 29 sampled groups. In 2010, although 92 whales were found in 11 groups in the zoomed video, none were considered to be calves based on size and color. Two or three complete surveys of the upper inlet were conducted each June and August, with beluga whale groups being resampled over multiple days; therefore, totals represent the number of groups sampled rather than total number of groups in the inlet. A total of 688 images were useable for August (Table 2), and 842 images for June (Table 3).

Table 1. -- Survey dates, total groups with useable data, and camera systems used during beluga calf surveys of Cook Inlet each August 2005-2010.

Year	Survey days	Number of beluga groups with video data	Standard camera	Zoomed camera
2005	August 11	4	Sony DVCAM (video)	Nikon D1X (still)
2006	August 16-17	6	JVC HD 720p (video)	JVC HD 720p (video)
2007	August 1-2	6	JVC HD 720p (video)	JVC HD 720p (video)
2008	August 12-14	8	JVC HD 720p (video)	JVC HD 720p (video)
2009	August 11-13	9	JVC HD 720p (video)	JVC HD 720p (video)
2010	August 17-19	11	JVC HD 720p (video)	JVC HD 720p (video)
Totals	14 days	44 groups		

Table 2. -- Beluga whale groups in Cook Inlet, Alaska, in August with usable zoomed video data. numbers reflect data collected on multiple passes on each group. Data on non-calves includes both adults and larger gray animals that were considered older juveniles. Proximity codes were 1) touching adult whale; 2) one whale length from an adult whale; 3) two or three whale lengths from an adult whale; 4) in same field of view (>3 whale lengths apart); and 5) alone in the field of view.

		Proximity					
Date	Area	1	2	3	4	5	Non-Calf
16-Aug-06	Knik						3
16-Aug-06	Susitna	1		1		1	29
17-Aug-06	Turnagain						4
17-Aug-06	Susitna						7
17-Aug-06	Knik	1					5
17-Aug-06	Knik	1					1
1-Aug-07	Susitna	1					9
1-Aug-07	Susitna						21
1-Aug-07	Susitna	1					55
1-Aug-07	Susitna						12
2-Aug-07	Susitna	1	2		1		23
2-Aug-07	Susitna	2	1	2	6		26
12-Aug-08	Turnagain						4
12-Aug-08	Susitna					1	4
12-Aug-08	Knik						1
13-Aug-08	Turnagain						9
13-Aug-08	Susitna	5	5	1	1		44
13-Aug-08	Susitna					1	3
13-Aug-08	Knik						15
14-Aug-08	Turnagain			1			31
11-Aug-09	Susitna			1			58
11-Aug-09	Susitna						49
11-Aug-09	Knik					1	5
12-Aug-09	Susitna		1		1	1	18
12-Aug-09	Knik				1		20
13-Aug-09	Knik						8
13-Aug-09	Susitna	1		1	1		21
13-Aug-09	Susitna						9
13-Aug-09	Susitna	2	2	1	2	1	53
17-Aug-10	Turnagain						4
17-Aug-10	Susitna						5
18-Aug-10	Knik						4
18-Aug-10	Susitna						1
18-Aug-10	Turnagain						4
18-Aug-10	Turnagain						7
19-Aug-10	Knik						18
19-Aug-10	Susitna						32
19-Aug-10	Susitna						6
19-Aug-10	Turnagain						4
19-Aug-10	Turnagain						5
	Totals	16	11	8	13	6	634

Table 3. -- Beluga whale groups in Cook Inlet, Alaska, in June with usable zoomed video data. Numbers reflect data collected on multiple passes on each group. Data on non-calves includes both adults and larger gray animals that were considered older juveniles. Proximity codes are as listed in Table 2.

		Proximity					
Date	Area	1	2	3	4	5	Non-Calf
7-Jun-06	Turnagain						1
7-Jun-06	Turnagain						1
7-Jun-06	Susitna						1
8-Jun-06	Susitna		1				9
8-Jun-06	Susitna						2
11-Jun-06	Turnagain						2
11-Jun-06	Susitna						2
11-Jun-06	Susitna						6
11-Jun-06	Knik						1
12-Jun-06	Susitna		1				6
12-Jun-06	Turnagain				1		5
12-Jun-06	Turnagain						3
14-Jun-06	Turnagain						2
14-Jun-06	Turnagain						5
14-Jun-06	Susitna						23
14-Jun-06	Susitna	1					2
14-Jun-06	Susitna						2
15-Jun-06	Turnagain						1
15-Jun-06	Susitna						4
15-Jun-06	Susitna						4
15-Jun-06	Susitna						4
9-Jun-07	Knik		1				11
9-Jun-07	Susitna						4
9-Jun-07	Turnagain						1
9-Jun-07	Turnagain						1
10-Jun-07	Turnagain						6
10-Jun-07	Susitna						15
10-Jun-07	Susitna						2
10-Jun-07	Susitna						2
10-Jun-07	Knik			1			2
10-Jun-07	Turnagain	1					2
10-Jun-07	Turnagain						9
11-Jun-07	Turnagain	1					8
11-Jun-07	Susitna			1		1	19
11-Jun-07	Susitna				1		69
11-Jun-07	Knik			1			5
14-Jun-07	Susitna						4
14-Jun-07	Susitna						33
14-Jun-07	Susitna						8
14-Jun-07	Susitna	1					6
15-Jun-07	Turnagain		1				5
15-Jun-07	Turnagain						3
15-Jun-07	Susitna						22
15-Jun-07	Susitna						1
15-Jun-07	Turnagain						1

Table 3. -- Continued.

Date	Area	Proximity 1	2	3	4	5	Non-Calf
4-Jun-08	Susitna		1	3			62
5-Jun-08	Turnagain						18
5-Jun-08	Susitna				1		9
6-Jun-08	Susitna	1					1
7-Jun-08	Turnagain				1		4
7-Jun-08	Susitna	1					26
12-Jun-08	Susitna	1					24
12-Jun-08	Susitna						12
2-Jun-09	Susitna	2		2			45
2-Jun-09	Susitna					3	19
3-Jun-09	Susitna						73
3-Jun-09	Turnagain						1
3-Jun-09	Turnagain						3
4-Jun-09	Susitna			1			17
4-Jun-09	Susitna				1	1	26
4-Jun-09	Turnagain						1
5-Jun-09	Turnagain						2
5-Jun-09	Turnagain						1
5-Jun-09	Susitna	2					29
1-Jun-10	Turnagain					1	4
2-Jun-10	Turnagain						7
2-Jun-10	Susitna	1					49
8-Jun-10	Turnagain						1
8-Jun-10	Susitna						1
8-Jun-10	Susitna						6
8-Jun-10	Susitna						2
10-Jun-10	Turnagain						1
10-Jun-10	Susitna						37
	Totals	12	5	9	5	6	805

In general, groups were found in greater numbers (n = 21 of the 40 sampled) in the Susitna area, and these yielded the greatest number of Proximity 1 samples (n = 14) but also the largest number of non-calves (Table 2). Fewer groups were seen in Knik area (n = 10) with only two Proximity 1 animals. Of the 9 groups seen in the Turnagain area, there were no Proximity 1 samples and only one Proximity 3 sample.

We analyzed the video data from the June surveys in the years 2006-2010 following the same methods used for the August data. The video camera systems were the same ones used in August. Because more survey days were conducted in June, these surveys yielded more groups and a larger sample (Table 3). The majority of groups were seen in the

Susitna area with most of the other groups in the Turnagain area, and very few groups were seen in the Knik area.

Average size and age of apparent calves is estimated for June and August (Table 4). The images in June all have estimated average ages greater than one year, with “alone in field of view” resulting in an estimated age (i.e., 5.1 years old: Table 4) similar to that for the lighter gray animals that are determined not to be calves by the video analysts. These results are consistent with the analysis in Suydam (2009) which showed that animals of a size that indicated that they were approximately 1 year old began to spend less time in close proximity to the mother. Because young-of-the-year whales were not observed in the June sample, subsequent analyses focus on the August sample where Proximity codes 1 and 5 indicate very young animals and probably represent primarily young-of-the-year (Table 4).

Table 4. -- Estimated beluga whale ages by category for zoomed video data from June and August in Cook Inlet, Alaska. Average image sizes for each proximity category and all gray individuals are compared to the average image sizes for adults (white whales). Estimated average “calf” size is calculated by multiplying the image size ratio to an average length for Cook Inlet adult females of 361 cm, and age was obtained using the Gompertz growth curve from Suydam (2009). Sample sizes for each proximity code are presented in Table 2 (for August) and Table 3 (for June).

	Size based on 361 cm adult		Age from Gompertz growth curve	
Proximity codes	June	August	June	August
1: Calf touching an adult	215	199	1.4	1.0
2: Calf within one body length of an adult	209	256	1.2	2.6
3: Calf 2 or 3 body lengths from an adult	239	246	2.0	2.2
4: Calf in same frame as an adult	224	235	1.6	1.9
5: Calf alone in field of view	313	182	5.1	0.6
*Gray belugas considered not to be calves	286	296	3.7	4.1

Calf Indices

Using the proximity data and the interpretation of age groups, we developed two indices which are applied to the August data:

1) The touching adult or Proximity 1. This index accounts for the young-of-the-year calves and some of the 1 year old calves.
2) The sum of the Proximity 1 through 4. This index includes all of the animals that the video analysts had considered to be calves near adults. Based on ages estimated from relative size, this index includes calves, yearlings, and some smaller juveniles.

The proximity 5 category (alone in the field of view) is problematic and is not included in these indices because, based on estimated age, it represents young-of-the-year calves that are being brought to the surface by an unseen adult. Young-of-the-year calves are known to surface more frequently than the accompanying adult. Including the observations of young calves without an adult visible with the observations of young calves surfacing beside the mother when she breathes would add a bias to the calf index. The indices are presented in Figure 5 for the years 2006 to 2010. Note that there is no apparent trend for each index.

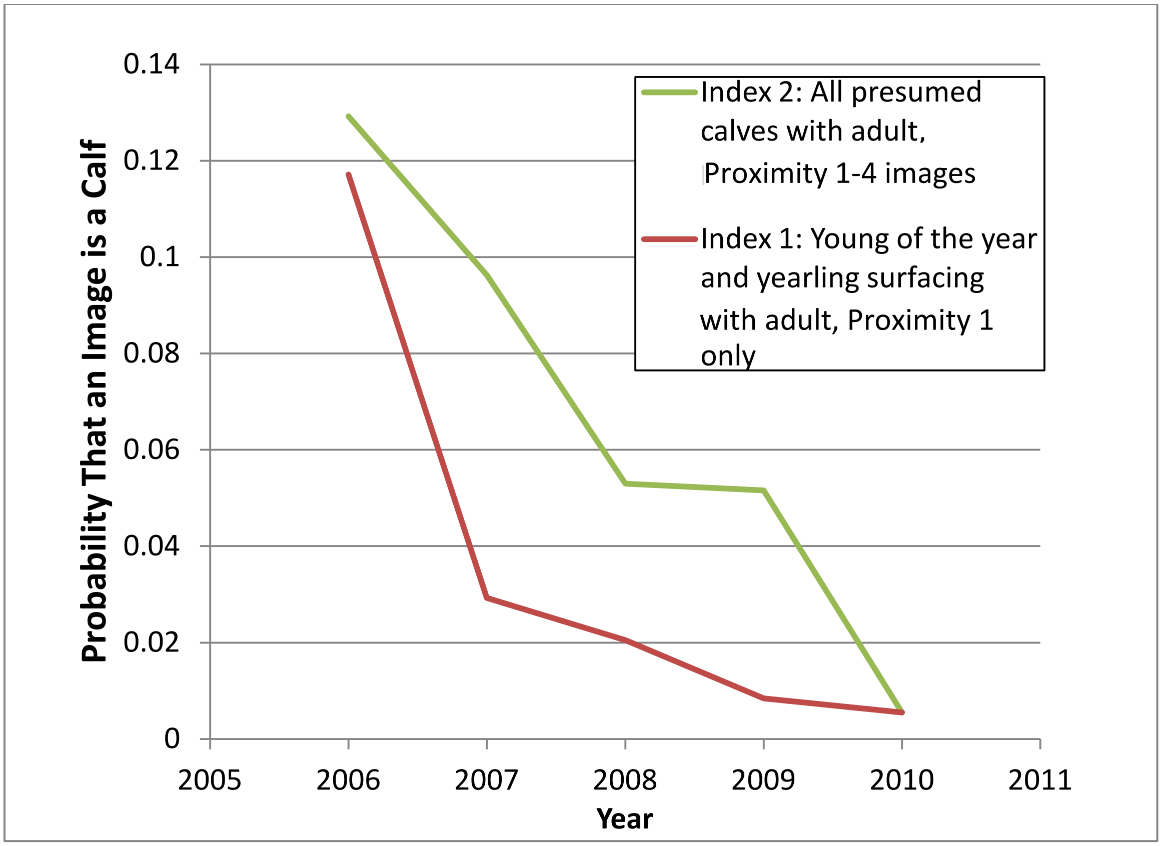


Figure 5. -- Calf indices by year for beluga whales in Cook Inlet. Index 1 (red) is based on Proximity 1 animals only and probably represents calves born earlier the same summer. Index 2 (green) includes the Proximity 1 animals with the Proximity 2, 3, and 4 animals and probably represents 1-year old and some 2-year old animals as well as the young-of-the-year.

Taken together, the two indices are nested, and index 2 encompasses all of the young calves in index 1 (Fig. 5). In 2006, the two indices are fairly close suggesting that it was a relatively good year for new calves, and that the previous year (2005) may have been poor so that the 2006 cohort is the majority of the young age classes. With 12% of the population as calves and yearlings, this would be encouraging for the health of the population and could be a highly sustainable level if it occurred in all years. However, rates from 2007 to 2010 were between 0.5% and 3%, with a 4-year average of 1.6%. The 5-year (2006-2010) average rate is 3.6%. Index 2 represents young-of-the-year and older calves and continues to include young-of-the-year cohort from 2006 through 2009. Consequently, the probability of occurrence of index 2 does not drop off as quickly as index 1 (Fig. 6A, B).

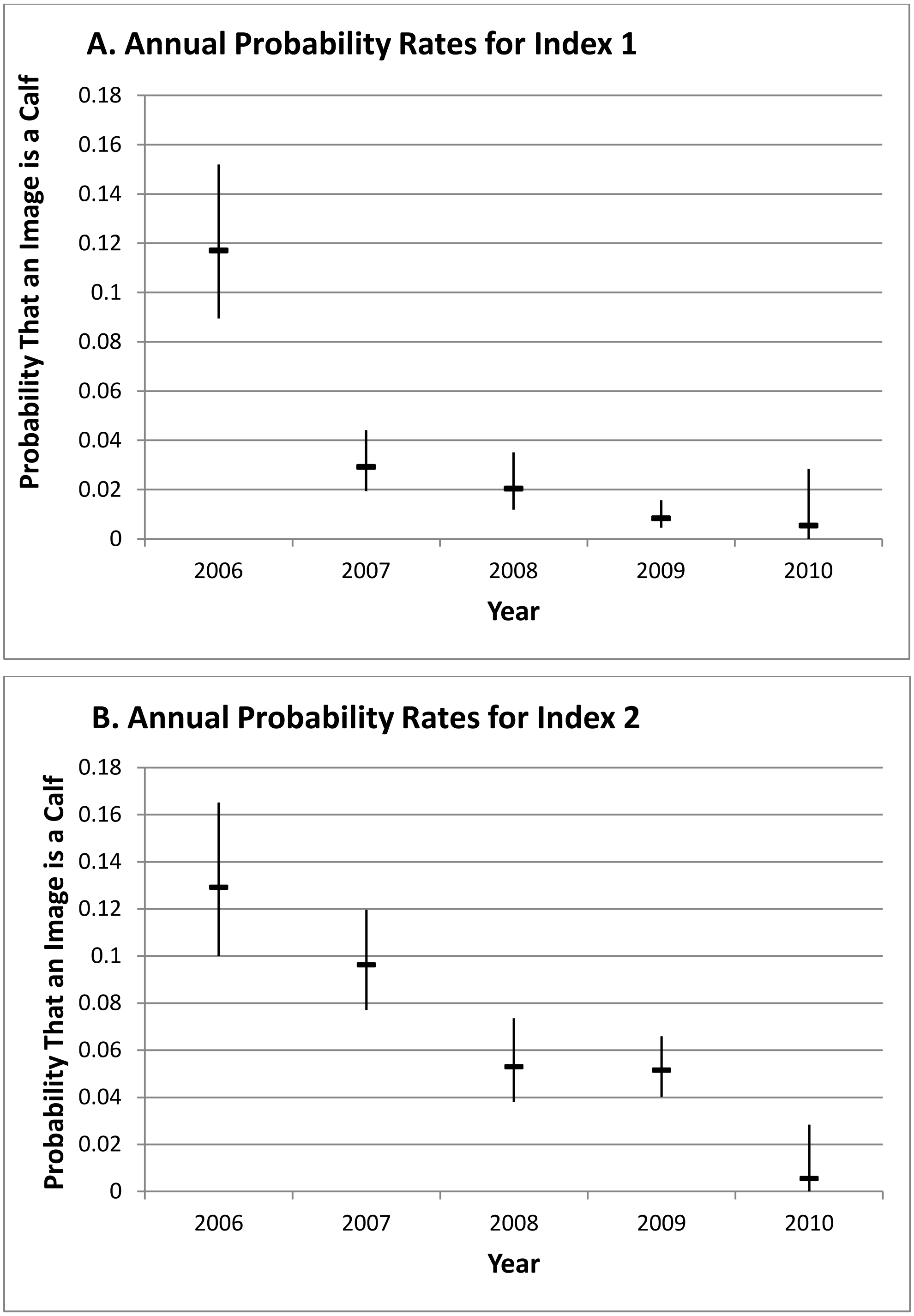


Figure 6. -- Annual calf indices for Cook Inlet beluga whales. Horizontal bars indicate averages and vertical bars show 95% confidence intervals. Index 1(A) is based on Proximity 1 animals only and probably represents calves born earlier the same summer. Index 2 (B) includes Proximity 1 animals with the Proximity 2, 3, and 4 animals and probably represents 1-year old and some 2-year old animals as well as young-of-the-year.

Index 1, with its 95% confidence interval, demonstrates that the sampling effort has been sufficient to show a difference between a good calving year (2006) and poor years (2007-2010) (Fig. 6A). Index 2 shows significant differences between years, except 2008 and 2009 (Fig. 6B), but it is less certain what fraction of young animals this represents. Also, interpretation of index 2 may be confused to some extent when whale groups are very dense because unassociated calves and young juveniles are more likely to appear in the same video frame with an adult, even though they are not a calf/mother pair.

Examining the indices as a function of area within Cook Inlet, it appears that Knik Arm is the preferred location for young calves with four times the likelihood that an animal is a calf than the sample from the Susitna area and very low probability of finding a calf in the Turnagain area (Fig. 7A, B). Index 2 indicates that many of the older calves are in the Susitna area, but there is still a higher percentage in the Knik area (Fig. 7B). The Turnagain area had a very low probability of index 2 sightings, but the sample was sufficient to show that it was significantly less than either of the other two areas (Fig. 7B).

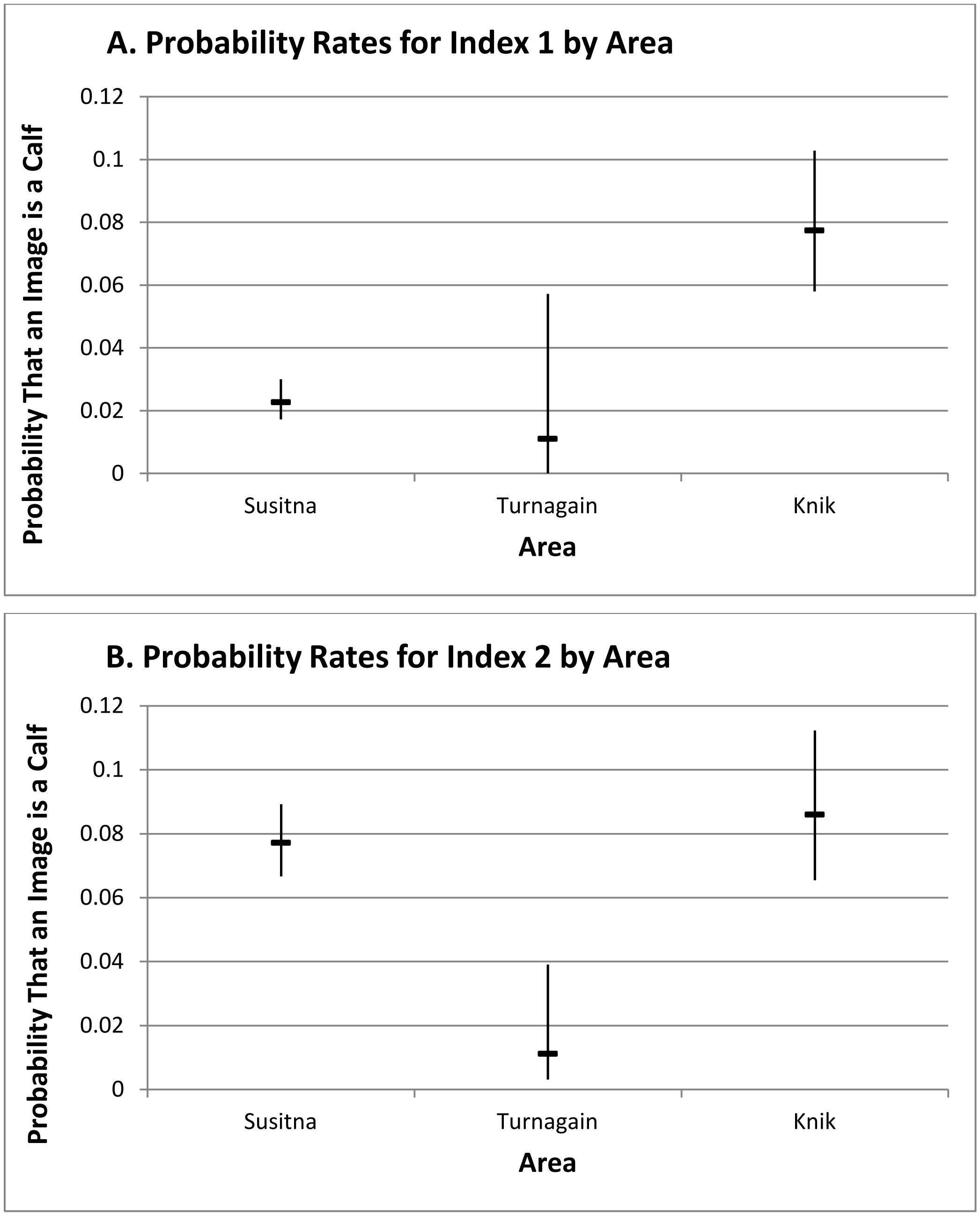


Figure 7. -- Calf indices for beluga whales sorted by area within Cook Inlet. Horizontal bars show averages; vertical bars indicate 95% confidence intervals. Index 1 (A) is based on Proximity 1 animals only and probably reflects calves born earlier the same summer. Index 2 (B) includes the Proximity 1 animals with the Proximity 2, 3, and animals and probably represents 1-year old and some 2-year old animals as well as the young-of-the-year.

Discussion

It is well documented that beluga calves remain in close proximity to their mothers and in direct contact with their mother at least 90% of the time (Krasnova et al. 2006, Suydam 2009). After the first year, juveniles break from this close contact but remain near the mother. This change in behavior allows us to conclude that index 1 (calves in immediate proximity to an adult) corresponds closely to how many calves were born in the respective year, although there is the caveat that sometimes very young calves may have surfaced with the support of an unseen mother and therefore appear to be alone. Index 2 is less well defined and probably represents both calves and yearlings and possibly some young juveniles. However, Proximity codes 2, 3, and 4 are probably affected by group density because there is increased likelihood that random adult whales will happen to be near young whales when groups are compact than when whales are dispersed.

Our data from August surveys are consistent with an early summer birthing period. The average ages of whales in close proximity to adults in August are 1 year old and younger than those in this same category for June. The average age of 1 year suggests that the August sample includes both young-of-the-year and some yearlings born the previous summer. The category "alone in field of view" has an average age of less than a year in the August sample, which may be interpreted as very young calves that were brought to the surface by the mother to breathe but the mother didn't surface herself and remained hidden in the opaque water.

Treating index 1 as a reliable indication of calving rates, we conclude that more calves were produced in 2006 than in subsequent years. The high calving rate in 2006 may be reflected in lower rates in 2007 and 2008 if we assume many mature females had dependent calves and were not ready to begin a new pregnancy. However, this does not explain continued low calving rates in subsequent years (i.e., 2009 and 2010).

While these two indices (index 1 and 2) can be used to monitor the relative number of calves, there are several key issues remaining to be resolved before an estimate of the calving rate of mature females in the population can occur:

1) The surfacing frequency of calves: Young calves are inefficient swimmers compared to adults and will surface much more frequently than an adult. Young-of-the-year calves are nearly always accompanied by an adult (Suydam 2009). A calf in echelon position with an adult will surface and breathe when the adult surfaces. However, adults accompanying a calf have been observed to bring the calf to the surface without surfacing themselves (Krasnova et al. 2006). Both the increased frequency of surfacing, and the appearance of calves surfacing on their own, confounds the possibility of an unbiased estimate of calves in the population.
2) Verification of relative image size assumption: We have assumed that the measure of size of the visible portion of the beluga is a constant fraction of the total length and the relative image sizes represent proportional sizes of belugas. The high particulate loads in the waters of Cook Inlet preclude the collection of images of the entire length of each animal and the current practice of collecting video at an oblique angle further increases the variability in relative size.
3) Unknown fraction of the population that represents mature females: These indices are proportional to the entire population. As the population changes in size and the age structure recovers from effects of high levels of removals, we expect that the fraction of mature females will change.

Until these issues are resolved, the results presented here represent an index proportional to the per capita calving rate that is suitable for trend analysis only. It is not possible to distinguish males and females from the air, consequently, the calf indices are a measure of population level relative to reproductive success from year to year but not an actual measure of the reproductive success of mature females. At the population level, the number of births per capita can be compared to the number of mortalities per capita to estimate the growth rate. With an average birth rate over the 5-year period of this study of 3.6%, we need to have a mortality rate less than 3.6% to see any growth in the population. While we do not have a good measure of mortality rate, we have a minimum value of 3% based on the number of carcasses discovered each year (Hobbs et al. 2008) which suggests that the birth rate estimated here is probably at or below the replacement level.

While the survey effort presented here is sufficient to determine the relative success of calving from year to year, we propose that further work be done to resolve the uncertainties listed above. Addressing issue 1 could be done by attaching time-depth recorders to mothers and their calves for short periods of a few hours each to collect surfacing data. To address issue 2, we propose surveying a similar population of beluga whales, such as those in Bristol Bay, that occupy waters somewhat less turbid that Cook Inlet. To address issue 3, we propose annual biopsy surveys to determine the fraction of pregnant females and identify mature females in coordination with a photo-identification database for recognizing individual whales.

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Citations

Braham, H. W. 1984. Review of reproduction in the white whale, *Delphinapterus leucas*, narwhal, *Monodon monoceros*, and Irrawaddy dolphin, *Orcaella brevirostris*, with comments on stock assessment. Rep. Int. Whal. Comm. (Spec. Issue 6):81-89.

Cox, D. R., and E. J. Snell. 1989. Analysis of Binary Data. London: Chapman and Hall.

Hobbs, R.C., J.M. Waite, and D.J. Rugh. 2000. Beluga, *Delphinapterus leucas*, group sizes in Cook Inlet, Alaska, based on observer counts and aerial video. Mar. Fish. Rev. 62(3):46-59.

Hobbs, R. C., K. E. W. Shelden, D. J. Rugh, and S.A. Norman. 2008. Status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Processed Rep. 2008-02, 116 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE., Seattle, WA 98115-6349.

Huntington, H.P. 2000. Traditional knowledge of the ecology of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):134-140.

Kleinenberg, S. E., A. V. Yablokov, B. M. Bel'kovich, and M. N. Tarasevich. 1964. Beluga (*Delphinapterus leucas*). Investigations of the species. Izdatel'stvo Nauka, Moscow. [Translated from Russian by the Israel Program for Scientific Translation, Jerusalem, 1969]. 376 p.

Krasnova, V. V., V. M. Bel'kovich, and A. D. Chernetsky. 2006. Mother-infant spatial relations in wild beluga (*Delphinapterus leucas*) during postnatal development under natural conditions. Biol. Bull. 33(1):53-58.

Laidre, K. L., K. E. W. Shelden, D. J. Rugh, and B. A. Mahoney. 2000. Beluga, *Delphinapterus leucas*, distribution and survey effort in the Gulf of Alaska. Mar. Fish. Rev. 62(3): 27-36.

Litzky, L.K. 2001. Monitoring recovery status and age structure of Cook Inlet, Alaska belugas by skin color determination. Thesis (M.S.) Univ. Wash. 76 p.

McCullagh P. and J. A. Nelder. 1989. Generalized Linear Models. London: Chapman and Hall.

O'Corry-Crowe, G. M., R. S. Suydam, A. Rosenberg, K. J. Frost, and A. E. Dizon. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. Mol. Ecol. 6:955-970.

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

Rugh, D.J., K.E.W. Shelden, C.L. Sims, B.A. Mahoney, B.K. Smith ,L.K. Litzky, and R.C. Hobbs. 2005. Aerial surveys of belugas in Cook Inlet, Alaska, June 2001, 2002, 2003, and 2004. U. S. Dep. Commer., NOAA Tech Memo. NMFS-AFSC-149, 71 p.

Rugh, D. J., K. T. Goetz, C. L. Sims, and B. K. Smith. 2006. Aerial surveys of belugas in Cook Inlet, Alaska, August 2006. Unpubl. field rep. 9 p. (Available at: http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2006.pdf accessed July 19, 2011).

Rugh, D.J., K.E.W. Shelden, and R.C. Hobbs. 2010. Range contraction in a beluga whale population. End. Species Res. 12:69-75.

Shelden, K. E. W., K. T. Goetz, and J. A. Mocklin. 2007. Aerial surveys of belugas in Cook Inlet, Alaska, August 2007. Unpubl. field rep. 11 p. (Available at: http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2007.pdf accessed July 19, 2011).

Shelden K. E. W., K. T. Goetz, L. Vate Brattström, B. A. Mahoney, M. Migura-Krajzynski, and B. S. Stewart. 2008. Aerial surveys of belugas in Cook Inlet, Alaska, August 2008. Unpubl. field rep. 11 p. (Available at: http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2008.pdf accessed July 19, 2011).

Shelden K. E. W., K. T. Goetz, L. Vate Brattström, and B. A. Mahoney. 2009. Aerial surveys of belugas in Cook Inlet, Alaska, August 2009. Unpubl. field rep. 11 p. (Available at: http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august09.pdf accessed July 19, 2011).

Shelden K. E. W., L. Vate Brattström, and C. L. Sims. 2010. Aerial surveys of belugas in Cook Inlet, Alaska, August 2010. Unpubl. field rep. 12 p. (Available at: http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august2010.pdf accessed July 19, 2011).

Sims, C.L, R.C. Hobbs, and D.J. Rugh. 2003. Developing a calving rate index for beluga in Cook Inlet, Alaska using aerial videography and photography. Abstract (poster) in the Fifteenth Biennial Conference on the Biology of Marine Mammals. Greensboro, North Carolina. 14-19 Dec. 2003.

Sims, C.L., R.C. Hobbs, K.T. Goetz, and D.J. Rugh. 2006. Using advanced techniques to determine age categories of belugas. Abstract presented at the First International Workshop on Beluga Whale Research, Husbandry and Management in Wild and Captive Environments. 9-11 March 2007. Valencia, Spain.

Suydam, R. S. 2009. Age, growth, reproduction, and movements of beluga whales (*Delphinapterus leucas*) from the eastern Chukchi Sea. Dissertation. University of Washington School of Aquatic and Fishery Sciences.