Estimated Abundance and Trend in Aerial Counts of Beluga Whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994–2012

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Introduction

In general, beluga whales, *Delphinapterus leucas*, have strong site fidelity to natal areas and very low dispersal rates (O'Corry-Crowe, 2002). In Alaska, these natal areas occur in the Beaufort Sea, Chukchi Sea, Norton Sound, Bristol Bay, and Cook Inlet. Geographically separated from beluga whale populations in western Alaska, Cook Inlet belugas are genetically distinct (O'Corry-Crowe et al., 1997) and are rarely observed in waters outside the inlet (Laidre et al., 2000). The closest beluga whale population is in Bristol Bay (Lowry et al., 2008), 1,500 km away by sea and separated by the Alaska Peninsula that extends three degrees of latitude south of the southern limit of the Bristol Bay population.

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If the Cook Inlet population goes extinct, it is highly unlikely that Cook Inlet would be repopulated with beluga whales in the foreseeable future; the result would be a permanent loss of range.

Until 1999, Cook Inlet beluga whales were subject to an unregulated subsistence hunt (Mahoney and Shelden, 2000). Following abundance estimates that indicated this stock had declined nearly 50% (from 1994 to 1998), the National Marine Fisheries Service (NMFS) designated the stock as depleted under the U.S. Marine Mammal Protection Act (NOAA, 2000a). During this period of decline, beluga whales taken during the annual hunt ranged in number from 21 to 147 per year (Mahoney and Shelden, 2000), averaging about 70 whales per year killed and struck but not recovered. In 1999, the hunt was suspended and thereafter NMFS co-managed the hunt through a series of agreements with the Native hunting community (NOAA, 2000b).

Considering how few whales (only 5) were killed in the subsistence hunt in the 13 years between 1999 and 2012, wildlife managers anticipated that the population would begin to recover. However, the population showed no signs of recovery; accordingly, NMFS determined that the Cook Inlet beluga whale distinct population segment (DPS) was endangered as defined by the U.S. Endangered Species Act (ESA) (NOAA, 2008).

The abundance estimates noted above were generated from data collected by NMFS personnel from the Alaska Fisheries Science Center's National Marine Mammal Laboratory and Alaska Regional Office. NMFS conducts annual aerial surveys to study beluga whale distribution and abundance in Cook Inlet, Alaska. These surveys typically occur in June and have been repeated each year since 1993 (Rugh et al., 2000; 2005; Shelden et al., 2013). Abundance estimates from 1994 to 2000 were published in Hobbs et al. (2000a,b). This paper revisits that time period and presents changes in methods and statistical analyses that have occurred since 2000. The objectives of this paper include a reanalysis of the abundance estimates over the 19-year aerial survey time series (1994–2012), revising the population trajectory through 2012, and estimating population trend rates for endangered Cook Inlet beluga whales.

ABSTRACT—Aerial surveys of beluga whales, Delphinapterus leucas, *have been conducted annually in Cook Inlet, Alaska, from 1993 to 2012. Beluga whales were seen near the coast and within river mouths in all years, with nearly all of the sightings in the northernmost portions of the inlet after 2000. In this paper, we revisit abundance estimates from 1994 to 2012 and present changes in methods and statistical analyses that have occurred since an earlier publication in 2000. Our objectives include a reanalysis of the abundance estimates over the 19-year aerial survey time series (1994–2012), revising the population trajectory through 2012, and estimating population trend rates for endangered Cook Inlet beluga whales. Annual surveys documented a decline of nearly 50% between 1994 and 1998 from an estimated 653 (CV = 0.24) whales to 347 (CV = 0.17) whales. With a very limited hunt (5 whales total taken between 1999 and 2012), the anticipated recovery at a rate of at least 2% per year did not materialize. Instead, from 1999 to 2012, the rate of decline has been -1.60% (SE = 0.75%) per year, with a 97% probability that the growth rate is declining (i.e., less than zero) and a 99.9% probability that the growth rate is less than +2% per year.*

Methods

Aerial Surveys

Aerial surveys were designed to take advantage of the highly aggregated population of belugas seen near river mouths and relatively good weather and visibility in June and July.[1] Dur-

[1]Only in 1995, which occurred in late July. During this survey, whales were far more dispersed throughout the inlet than in June, affecting our

ing the summers of 1994–2012, flights took place during a 1- (1994–2003) to 2-week (2004–2012) period for 40–60 flight-hours each year. Surveys were flown at 800 ft (244 m) altitude at about 100 kn (185 km/h).

Survey protocol involved systematic searches of all coastal areas (within 3 km of the waterline) around Cook Inlet (1,350 km), where virtually all belugas are found during these months, as well as flying 500 to 1,500 km of sawtooth transects across the middle of the inlet (1994–2000 and 2011–2012) or north–south mid-inlet transects (2001–2010) to search for whales beyond 3 km from shore (Rugh et al., 2000, 2005; Shelden et al., 2013; Fig. 1). Mid-inlet and sawtooth transects followed a line transect survey design with distance to sighted marine mammals measured using hand held inclinometers.

The shoreline surveys did not meet the assumptions of line transect surveys because beluga groups are generally associated with geographic features such as river mouths and shallow tidal areas and thus are not randomly distributed either along the trackline or across the survey strip. Consequently, the intent of each survey flight was to find and count all beluga whales within Cook Inlet in the nearshore strata and estimate the density of whales in offshore areas (>3 km from shore). When whales were found, multiple aerial passes were made near whale groups until each observer had at least four good counts, and at the same time a videographer collected wide-angle and zoomed-in video recordings of the group.

The twin-engine survey aircraft had high wings, bubble windows, and more than 8 h endurance (an Aero Commander[2] 680/690 in most years, or a Twin Otter in two years). Observers were positioned on the left and right side of the aircraft directly behind the pilots. An additional observer sat behind the observer on the coastal side of the aircraft where almost all sightings of beluga whales occurred. A data recorder occupied the seat behind the observer viewing the offshore waters. The data recorder used custom software on a laptop computer to enter sightings data (species, clinometer angle, and group size), environmental conditions (Beaufort Sea state, visibility, cloud cover, and glare), comments, and changes in effort (such as off-effort while circling and counting whales or during periods of poor or unacceptable visibility).

All entries were stamped with time and date (using the clock on the computer) and location (downloaded into the laptop from a portable Global Positioning System (GPS)). Visibility was assessed by observers and documented in five subjective categories

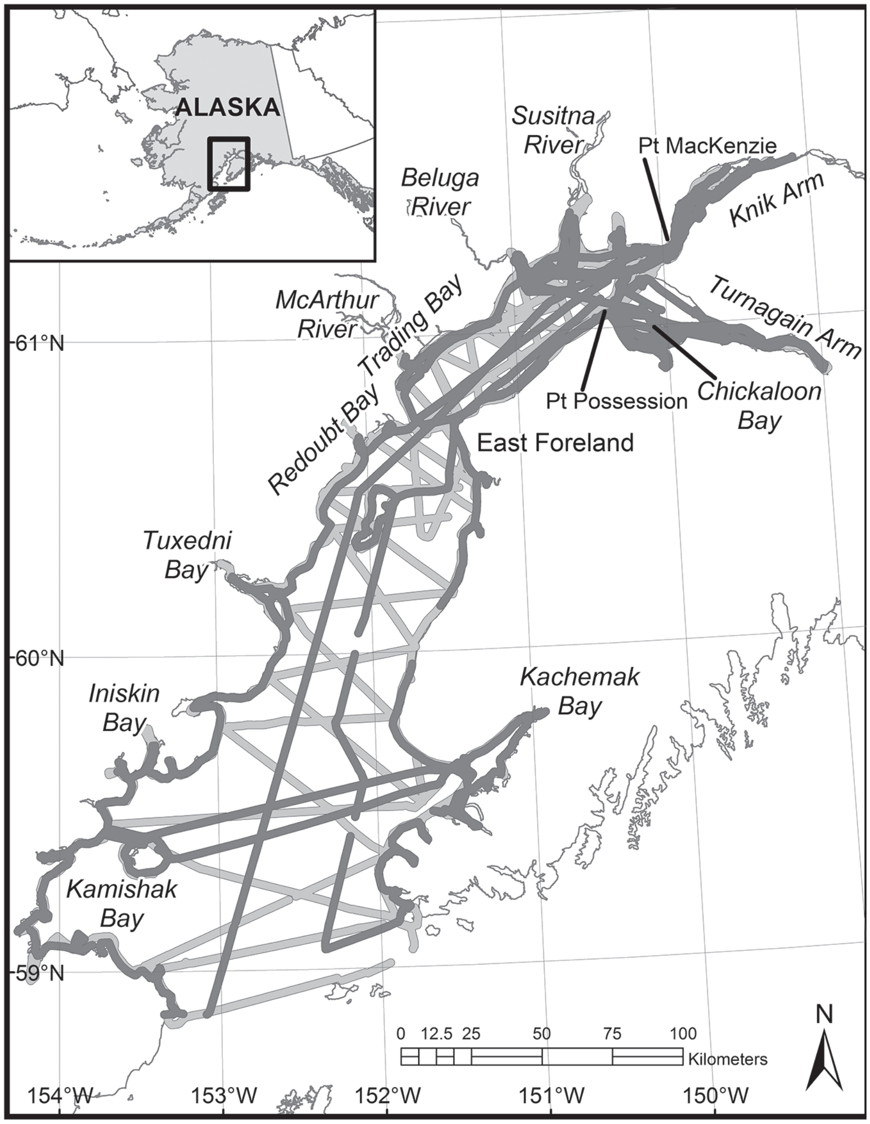

Figure 1.—Examples of survey tracklines from aerial counts of beluga whales in Cook Inlet, Alaska, 1994–2012. The light gray tracklines depict a "sawtooth transect" used to sample offshore waters 1994–2000 and 2011–2012. For 2001–2010, offshore tracklines roughly paralleled the coast (dark gray). See Rugh et al. (2000, 2005) and Shelden et al. (2013) for effort by year.

ability to find, count, and video groups. Thereafter, all abundance surveys were conducted in June.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA

from "excellent" to "useless." When visibility conditions were rated "poor" or "useless," the survey effort was not used in the analysis and the area was considered unsurveyed.

An intercom system provided communication among the observers, data recorder, and pilots, but when possible, a selective listening device was used to aurally isolate[3] the paired observer positions on the coastal side of the aircraft. This isolation setup allowed for independent search efforts, providing information on the probability of a single observer missing a whale group. Immediately upon seeing a whale group, each observer independently reported the sighting to the data recorder. After a whale group was reported, the trackline was maintained until the group was well behind the aircraft. The computer operator then turned off the isolation unit and changed effort status to "off" to end the transect leg before the plane circled back to begin counting passes.

Belugas were usually in distinct clusters, generally making it easy to define each group; however, when there were loose aggregations of whales, groups were defined for convenience of counting while circling over them. For example, whale groups within 100 m of each other were usually treated as a single group for counting purposes. Each whale group was circled using an extended oval around the group. Whale counts were made on each pass parallel to the long axis of the oval, with two observers and a videographer (the third observer) on the same side of the aircraft. The computer operator assigned a unique group identification number to each group, and recorded the start and end time of each counting pass as well as any comments made about group behavior, position of the plane, or issues with the video. The paired observers made independent counts until four to eight passes of at least good quality were obtained. Daily count records were not shared within the aerial team until the end of the survey season in order to maintain the independence of each observer's counts.

Paired video cameras were mounted side-by-side and used to record the beluga groups during the counting passes. One video camera was used for group counts, and it was set at a wide angle to view the entire group. The second video camera was used to determine correction factors for missed animals by zooming in to a narrower view to magnify individual whales in the group (Hobbs et al., 2000a). The analysis of the zoomed video recordings included the examination of color ratios, size, and proximity of white adults relative to dark juveniles and calves (Litzky, 2001; Hobbs et al., in press a).

Observer Counts

Annual aerial counts (serving as an index) represent the uncorrected tallies of whales made by observers during the aerial surveys (Rugh et al., 2000; 2005; Shelden et al., 2013). The annual index was calculated by reviewing all observer counts for a group and determining if counts should be combined or discarded based on the behavior of the beluga whale group. For example, when groups merged or split while counting passes were taking place, the changes were noted by the recorder.

During the nightly data review, the field project leader determined final group designations and checked that observer counts were assigned to the correct group or subgroup. Once a set of counts had been established for a group, a median value was calculated for each observer from counts that were given a grade of "A" or "B" (indicating that the location of the group was clearly visible to the observer and not affected by glare or whitecaps). Lower scores such as "C," "D," and "F" indicated that visibility was poor or part of the group was missed because it was too far from, close to, or under the plane, and were not used in the median calculation). A median value from all "A" or "B" observer medians was then calculated for each group. These group medians were summed by survey day and the largest of the daily sums was used as the index count for the year.

When group size could not be estimated for a beluga group from the video record, observer counts were used to estimate the group size. The estimation method, described in Hobbs et al. (2000a) and excerpted in the Appendix here, used group sizes estimated from video recordings as the dependent variable in a linear regression, with the observer counts and the observer counts multiplied by the encounter rate as the independent variables for those same groups. This method assumes that group sizes estimated from video recordings, and already corrected for availability bias (whales that were underwater and therefore not visible) and perception bias (whales are at the surface but not detected), represent the true group sizes. Therefore, the parameters fitted by the regression are an empirically derived correction factor that accounts for availability, perception, and observer differences.

We also found during the analysis for Hobbs et al. (2000a) that observers were under counting when groups were in large, dense aggregations. This required an additional correction to account for bias resulting from the time available to observers to count individual whales (Appendix; see also Video Counts section). These correction factors were then applied when video was not available (e.g., because of camera malfunction or poor quality video), to obtain group size estimates from observer counts alone.

Video Counts

Each video counting pass was reviewed for quality and rated on a scale (excellent, good, fair, poor, and unacceptable). Video passes rated excellent and good were analyzed using sequential transparencies or a computer-aided system (introduced in 2004). For the transparency method, a clear plastic transparency sheet (8 x 11 inches) was placed over the screen of a video monitor as the video tape was advanced frame by frame in a tape deck. At 0.5 second (15 frame) inter-

[3]In all years but 2011 and 2012.

vals each beluga image was marked in ink and the transparencies were compared in sequence to identify individual whale images and obtain a count of a group (Appendix).

With the introduction of digital video, a computer program was developed ("Beluga Dots") to capture and analyze the video sequences. With this program, analysts were able to catalog the individual whale images found in the survey video, track the images across the screen, and measure image size and color; all of these data were stored in a text file used by the program. The video analyst was able to review each video pass frame by frame or in slow motion and make changes to the corresponding saved data. After primary and secondary counts and zoomed analysis were completed, the program was used to export the saved data into a database format. This program increased efficiency and ease of reviewing the video, and a comparison of video counts made with plastic transparencies vs. the computer program found that the counts were equivalent.

The improvement of camera resolution over the 19 years of this project increased the likelihood that video analysts would detect small or darker whales in the counting video. The video collected from the zoomed camera each survey year made it possible to develop an appropriate correction factor (i.e., for whales missed at the surface in the counting video) for each year. While zoomed video quality has also improved with camera quality, in even the oldest zoomed video individual animal images were clear, and small, gray-colored belugas were easily distinguished from the background water color.

Abundance Estimation

The analysis methods applied to count data collected after 2000 and the resulting abundance estimates follow those presented in Hobbs et al. (2000a, b) (see Appendix), with a few notable exceptions below:

1) In the years 1994 to 2000, 4 years of data were averaged to estimate some correction factors (Hobbs et al., 2000b). Since then, only data collected during the respective survey season have been used to generate the correction factors for that specific season. The exception to this change in protocol was the continued use of data on whale surfacing intervals collected from suction cup tag data (Lerczak et al., 2000), which provided that same correction factor for the 19-year time series.

2) For estimations of abundance derived before 2001, the inlet was divided into three sectors: two for the upper inlet (northeast and northwest) and one for the lower inlet (all waters south of the Forelands)):

$$\hat{N}_{s,y} = \frac{\hat{K}_y}{J_{s,y}} \sum_{s=1}^{J_{s,y}} \sum_{i=1}^{G_{j,s,y}} \hat{n}_{i,j}$$

Where,

- $\hat{N}_{s,y}$ is the estimated average abundance in sector s during year y,
- $\hat{K}_y$ is the correction factor for belugas in groups that were missed in year y,
- $J_{s,y}$ is the number of surveys conducted in sector s during year y,
- $G_{j,s,y}$ is the number of groups seen in sector s during survey j in year y, and
- $\hat{n}_{i,j}$ is the estimated number of whales in group i of survey j.

An average abundance was estimated for each sector (see Table 1 in Hobbs et al. (2000b)), and these estimates were summed for the overall abundance estimate (Hobbs et al., 2000b). Sectors on some survey days were excluded if estimates were unreliable (e.g., because of poor surveying conditions or incomplete coverage, or if estimates were below 60% of the highest estimate for the sector during the survey period).

From 2001 to 2003, the method of Hobbs et al. (2000b) was continued. Beginning in 2004, the number of survey days was increased and the northeast and northwest sectors in the upper inlet were combined so that the inlet was divided into two sectors (upper and lower). In years that belugas were not observed in the lower inlet, the formula could be further simplified, as each survey of the upper inlet captured the entire population:

$$\hat{N}_{j,y} = \sum_{i=1}^{G_{j,y}} \hat{n}_{i,j}, Var(\hat{N}_{j,y}) = \sum_{i=1}^{G_{j,y}} Var(\hat{n}_{i,j})$$

$$\hat{N}_y = \frac{\hat{K}_y}{J_y} \sum_{j=1}^{J_y} \hat{N}_{j,y},$$

$$Var(\hat{N}_y) = \frac{1}{J_y - 1} \sum_{j=1}^{J_y} (\hat{N}_y - \hat{K}_y \hat{N}_{j,y})^2 +$$

$$\frac{\hat{K}_y^2}{J_y^2} \sum_{j=1}^{J_y} Var(\hat{N}_{j,y}) + CV^2(\hat{K}_y)\hat{N}_y^2$$

Where,

- $\hat{N}_{j,y}$ = the estimated number of beluga in groups found in survey j of year y,
- $G_{j,y}$ = the number of groups found in survey j of year y,
- $\hat{n}_{i,j}$ = the estimated number of beluga in the ith group found in survey j,
- $\hat{N}_y$ = the estimated number of belugas in year y,
- $\hat{K}_y$ = the multiplicative correction for belugas in groups that were missed, and
- J_y = the number of usable surveys in year y.

Estimates from each survey day were summed, and only survey days with complete surveys of the upper inlet were used to estimate abundance in the upper inlet. This addressed the concern that groups of whales might move from one sector to another in the upper inlet between days during the two-week period of the surveys, but it required more survey days and flight hours to complete.

As previously, for survey days with unusually low estimates (e.g., less than about 60% of the highest daily estimate), the flight paths were reviewed to determine if a group seen on other survey days could have been missed either because the area was unavailable due to weather or air traffic or if the group could have moved to an adjacent area that was not surveyed. If this was the case, these survey days were not included in the abundance estimate to reduce the possibility of biasing the estimate downward.

3) The estimate of the variance of the abundance in each sector equation in Hobbs et al. (2000b) under the heading Abundance Estimate was revised to use the squared standard error of the average for the sector in place of the variance of the abundance estimate and the measurement error. In Hobbs et al. (2000b), both measurement error and the standard deviation were included to avoid underestimation of the variance; at that time it was thought that there were significant variations in behavior from year to year that could not be corrected for with existing methods.

With the recent trend results, it is clear that the variance is overestimated by the method of Hobbs et al. (2000b). Examining the standard deviation of the residuals of abundance estimates from 1999 to 2012 around the trend line, we have an upper bound for the average *CV* of 11%. The residuals include both the variation resulting from the estimation (*CV*), and any variation in the dynamics of the population from year to year. Using the equation in Hobbs et al. (2000b), the average *CV* (square root of the mean of CV^2) for 1999–2012 was 17%, indicating that *CV* had been overestimated by this equation. The revised estimate of variance (shown below) accounts for the variation in behavior explicitly and uses the standard error which takes advantage of the increased sampling effort of the recent surveys.

Using the notation of Hobbs et al. (2000b), the variance is now:

$$Var(\hat{N}_{s,y})$$
$$= \frac{1}{(J_{s,y}-1)J_{s,y}} \sum_{j=1}^{J_{s,y}} \left(\hat{N}_{s,y} - \hat{K}_y \sum_{i=1}^{G_{j,s,y}} \hat{n}_{i,j} \right)^2$$
$$+ \left(CV^2(T_{I,y}) + CV^2(\hat{K}_y) \right) \hat{N}_{s,y}^2$$

Where,

$\hat{N}_{s,y}$ = the estimated number of beluga whales in groups found in sector *s* (northwest, northeast, or south 1994–2003, and upper or lower 2004–2012) of year *y*,

$J_{s,y}$ = the number of surveys of sector *s* during year *y*.

$\hat{K}_y$ = the multiplicative correction for beluga whales in groups that are missed,

$G_{j,s,y}$ = the number of groups found in survey *j* of sector *s* of year *y*,

$\hat{n}_{i,j}$ = the estimated number of beluga whales in the *i*th group found in survey *j*,

CV = the coefficient of variation (standard error/mean) of an estimate (c.f. Hobbs et al., 2000b), and

$T_{I,y}$ = the annual mean of the average dive interval (time from the end of one dive to the end of the next) resulting from variation in average behavior of groups from year to year.

Revised Variance Estimates

For each year (1994–2012), the variance estimate for each sector was revised per the equation above, and the variance of the abundance by sectors was summed to estimate the variance of the totaled abundance as in Hobbs et al. (2000b). For areas with a single survey, typically the lower inlet, the measurement error was used. The value for $CV(T_{I,y})$ had not been estimated in the past. While considerable anecdotal data occur in the field reports (cf. Rugh et al., 2005; Shelden et al., 2013) regarding different beluga behaviors observed during the survey, no study has been conducted to relate these observations to variation in the average dive interval. As a proxy, we used time at surface data for a beluga captured and tagged in May 1999 with a satellite-linked time/depth recorder (SLTDR).

The SLTDR provided summaries of the amount of time that it was “dry” (when the dorsal ridge was above the water surface), summarized by 6-h intervals. Using the notation of Hobbs et al. (2000a) (see Appendix), the proportion of time that the transmitter was dry, P_{dry}, was proportional to T_s/T_I , where T_s was the average time at the surface per surfacing, and T_I was the average dive interval. In Cook Inlet, the whales were only visible when at the surface, thus T_s remained fairly constant and the variation in P_{dry} resulted largely from variation in T_I. Consequently, T_I was proportional to T_s/P_{dry}, and via the delta method (c.f. Seber, 1973), an estimate of $CV(T_I)$ was $CV(P_{dry})$.

To estimate the $CV(T_{I,y})$ for a survey period, we considered each set of 8 consecutive days (the average length of an aerial survey) for the twelve day period between the earliest start date of a survey (31 May) and the latest start date (11 June), such that 31 May–7 June was one sample, 1–8 June was the next sample, etc., with the final sample as 11–18 June. For each of these periods, the 8-day average of P_{dry} for the hours between 0900 and 2100 was calculated. The estimate of $CV(T_{I,y})$ was obtained by dividing the standard deviation of the averages by the mean of the 8-day averages.

Trend Estimation

Trends were estimated using weighted linear regression of the natural logarithms of the abundance estimates with the weights being the squared inverse of the coefficients of variation of the estimates. We considered the end of the unregulated subsistence hunt in 1999 to be the point in the time series where change in Cook Inlet beluga whale population dynamics may have occurred. To examine the impact of a trend in $T_{I,y}$ with survey dates, we regressed the residuals of the trend analysis against the median date for each survey.

To assess whether the increase in the survey days and change in analysis from two sectors to one had affected the estimated trend, we divided each survey from 2004 to 2012 into two 1-week surveys and then analyzed each week as a separate sample using the northeast/northwest sector methodology of Hobbs et al. (2000b). The resulting two abundance estimates for each year were considered replicates equivalent to the survey results for 1994–2003. We evaluated the trend resulting from the two weeks, averaged by year.

We also created a distribution of all potential trend results by analyzing all possible combinations of 1-week samples from each annual pair of estimates and then applying the trend analysis as described above. We then compared the distribution of possible trends that were calculated using the 1-week survey sample size and analysis to the confidence interval of the trend that was calculated using current survey effort and analysis.

Results and Discussion

The timing of the abundance surveys takes advantage of the changes in beluga behavior that occur by late May–early June (Shelden et al., in press). At that time, most whales gather into large groups near river mouths to feed on anadromous prey returning to spawn in natal rivers. In the past, these large groups began to disperse to other areas within the inlet by July and August (Rugh et al., 2000; Shelden et al., in press). Throughout each abundance survey, beluga whales were seen near the coast and within river mouths in all years (Fig. 2), and after 2000, nearly all of the sightings occurred in the northernmost portions of the inlet. Belugas were found in the Susitna delta region (defined as the area between Point MacKenzie and the Beluga River) throughout the survey time series (Fig. 3).

Whales were also seen in large numbers in Knik Arm from 1997 to 2003, with a few observations continuing until 2007, after which none were found in this region during the June surveys (Fig. 3). From 2004 to 2007, more whales were observed in the Chickaloon Bay–Turnagain Arm region, coincident with the lower numbers seen in Knik Arm (Fig. 3). Smaller numbers of belugas (group sizes ranging from 1 to 27 whales) have been observed in areas south of North Foreland and Point Possession (Fig. 4), but not consistently.

All observer and video counts of beluga whale groups collected during the abundance surveys from 1994 to 2012

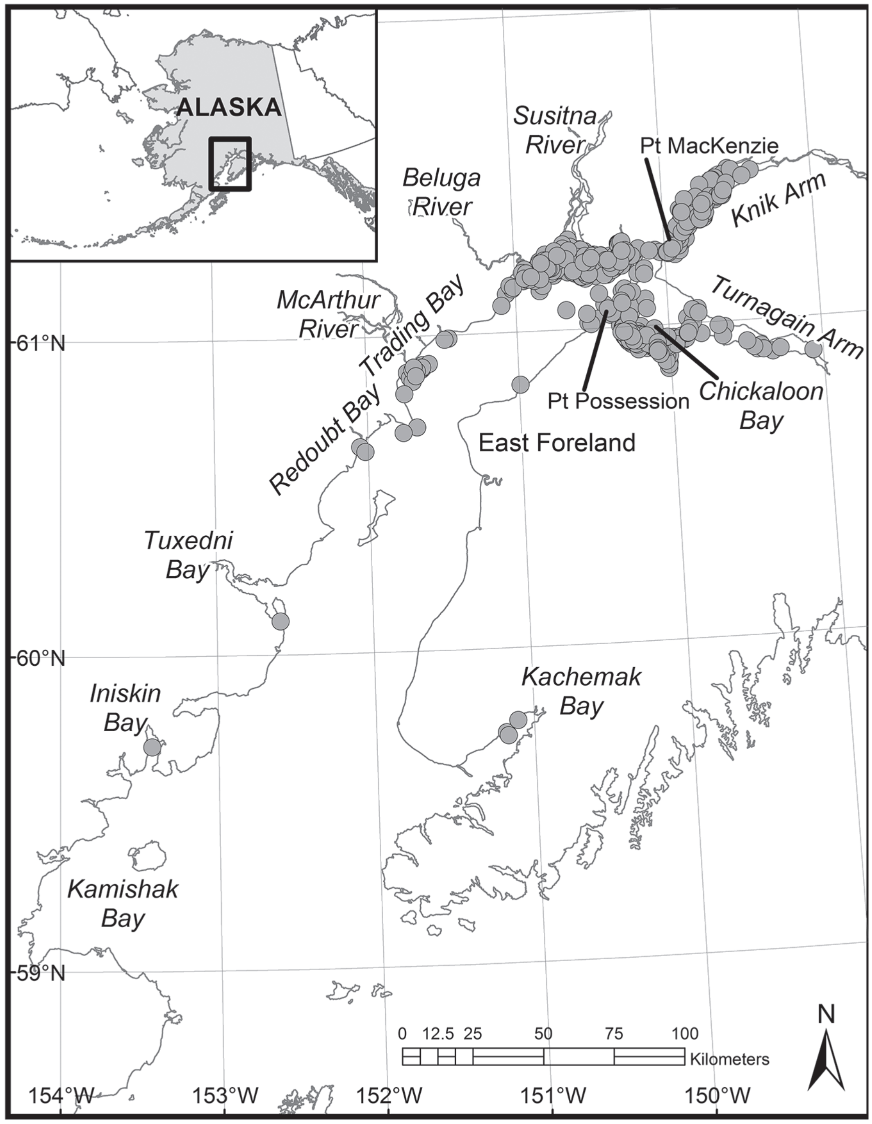

Figure 2.—Sightings of beluga whale groups in Cook Inlet, Alaska, made during aerial surveys, 1994–2012.

are presented in Table 1. Rounding errors were discovered for a few groups presented in the tables in Hobbs et al. (2000a, b) and have been corrected here. Index counts and abundance estimates for the 19-year time series are presented in Table 2.

For the 2001 to 2012 dataset, the average correction for whales missed below the surface (i.e., availability bias) in the video is 1.95 (SD = 0.42), while the average correction for whales missed at the surface (i.e., undetectable due to resolution of the video) is 1.31. This is similar to calculations from the 1994 to 2000 dataset where the average for these corrections was 2.03 and 1.17, respectively (Hobbs et al., 2000a). While improvements in video camera resolution did make a noticeable difference in the success rate of the video data collection from the period 1994–1998 (46% of estimates made from video) to the period 1999–2000 (84%, see Hobbs et al., 2000a), this was not as evident in the

Table 1.—Beluga whale groups reported during surveys of Cook Inlet, Alaska, 1994–2012, used to estimate abundance and/or corrections for missed groups. "Source" indicates whether group size was estimated from video analysis or by correction of counts from observers. "Estimated group size" is the corrected estimate for the respective group (from Hobbs et al., 2000a, b). CV = coefficient of variation. The last three columns indicate sighting records used in the logistic regression to estimate the probability that a beluga group might have been missed by the aerial observers: "Obs" is the ID number assigned to each observer (commas separate the first (i.e., front position) and second of the paired observers), "Vis" is the visibility (E = excellent, G = good, F = fair, P = poor, and U = useless) at the time of the sighting, and "Seen" indicates if the group was observed (1 = yes, 0 = no) and by which observer (first, second).

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
01 Jun 1994	1	4	Susitna R	1.12	1.22	209	17%	video	No			
01 Jun 1994	2	1	Susitna R	1.24	1.46	263	31%	video	No			
02 Jun 1994	1	4	W of Susitna R			394	60%	observer	Yes	3,2	G	1,1
02 Jun 1994	2	4	Turnagain Arm			18	47%	observer	Yes	3,2	G	1,1
02 Jun 1994	3	4	Chickaloon Bay			47	43%	observer	Yes	3,2	F	1,0
03 Jun 1994	1	5	Pt Possession			27	39%	observer	No	4,3	G	0,1
03 Jun 1994	2	5	Kachemak Bay			8	31%	observer	Yes	4,3	E	0,1
03 Jun 1994	3	3	Kachemak Bay			13	29%	observer	Yes			
04 Jun 1994	1	4	Iniskin Bay			4	30%	observer	Yes			
04 Jun 1994	2	4	W of Susitna R			144	31%	observer	Yes	3,1	G	0,1
04 Jun 1994	3	2	Susitna R	1.17	1.38	252	22%	video	Yes	3,1	G	1,1
04 Jun 1994	4	1	W of Little Susitna	1.14	3.39	475	24%	video	Yes	3,1	G	1,1
05 Jun 1994	1	3	Pt Possession/E Foreland			2	93%	observer	Yes	2,3	F	0,1
05 Jun 1994	2	1	Beluga R	1.16	2.21	41	51%	video	Yes	2,3	G	1,0
05 Jun 1994	3	1	W of Susitna R	1.16	1.08	20	96%	video	Yes	4,1	G	0,1
05 Jun 1994	4	6	W of Susitna R			21	34%	observer	Yes	4,1	G	0,1
05 Jun 1994	5	1	W of Susitna R	1.19	1.59	55	51%	video	Yes	4,1	G	1,1
05 Jun 1994	6	6	Little Susitna R			337	19%	observer	Yes	4,1	G	1,1
05 Jun 1994	7	1	Chickaloon Bay	1.16	1.52	11	110%	video	Yes	3,2	G	1,1
18 Jul 1995	1	5	Chickaloon Bay	1.26	1.36	29	36%	video	Yes	4,1	G	0,1
18 Jul 1995	2	8	McArthur R			1	115%	observer	Yes			
18 Jul 1995	3	7	Susitna R			731	36%	observer	Yes	1,3	G	1,1
19 Jul 1995	1	6	Chickaloon	1.16	1.42	20	41%	video	Yes	5,4	G	1,1
19 Jul 1995	2	5	McArthur R			8	58%	observer	Yes			
19 Jul 1995	3	1	Shirleyville			4	42%	observer	Yes			
19 Jul 1995	4	2	Susitna R	1.35	1.72	348	22%	video	Yes	4,5	E	1,1
20 Jul 1995	1	4	Chickaloon Bay	1.16	2.11	16	40%	video	No	1,5	E	1,1
20 Jul 1995	2	1	Susitna R	1.23	1	73	50%	video	Yes	1,5	E	1,1
20 Jul 1995	3	5	Susitna R			309	41%	observer	Yes			
21 Jul 1995	1	1	Susitna R (E)	1.16	1.55	32	65%	video	Yes	3,2	G	1,0
21 Jul 1995	2	5	Susitna R (W)			278	77%	observer	Yes	3,2	G	1,0
21 Jul 1995	3	1	Knik Arm			2	42%	observer	Yes			
21 Jul 1995	4	8	Chickaloon Bay			43	26%	observer	Yes	5,3	G	1,1
22 Jul 1995	1	4	Big R	1.16	1.75	17	42%	video	Yes			
24 Jul 1995	1	5	Drift R			5	105%	observer	No	3,4	F	1,0
24 Jul 1995	2	12	McArthur R			4	68%	observer	Yes	1,5	P	0,1
24 Jul 1995	3	1	Susitna R (W)	1.25	2.54	272	27%	video	Yes	1,5	G	1,1
24 Jul 1995	4	7	Susitna R (E)			94	45%	observer	Yes			
11 Jun 1996	1	1	S of Beluga R			2	42%	observer	No			
11 Jun 1996	2	6	Lewis R			13	69%	observer	No	1,4	G	1,0
11 Jun 1996	3	1	Ivan R			2	42%	observer	No			
11 Jun 1996	4	3	Theodore R			9	49%	observer	No			
11 Jun 1996	5	13	Lewis R			256	25%	observer	No			
12 Jun 1996	1	5	Knik Arm			12	39%	observer	No			
12 Jun 1996	2	1	Knik Arm			4	42%	observer	No			
12 Jun 1996	3	2	Susitna R (after stranding)	1.16	1.64	69	34%	video	No			
12 Jun 1996	4	1	Pt Possession			48	58%	observer	Yes	5,6	F	1,0
12 Jun 1996	5	12	Lewis R			304	29%	observer	No			
12 Jun 1996	6	9	Theodore R			12	39%	observer	No	6,4	G	1,1
12 Jun 1996	7	2	Lewis R	1.16	0.88	33	60%	video	No	6,4	G	1,1
12 Jun 1996	8	2	Susitna R			199	19%	observer	No	6,4	F	1,1
12 Jun 1996	9	5	Susitna R			47	29%	observer	No			
13 Jun 1996	1	7	Knik Arm			17	26%	observer	Yes	5,4	E	1,1
13 Jun 1996	2	7	Knik Arm			18	45%	observer	Yes	5,4	E	1,1
13 Jun 1996	3	3	Pt Possession	1.16	2.13	69	26%	video	Yes			
13 Jun 1996	4	8	Ivan R			168	20%	observer	Yes	6,1	G	1,1
13 Jun 1996	5	3	Susitna R	1.16	2.6	229	17%	video	Yes			
14 Jun 1996	1	6	Pt MacKenzie			39	39%	observer	No			
16 Jun 1996	1	6	Knik Arm			37	15%	observer	Yes			
16 Jun 1996	2	10	Knik Arm			28	32%	observer	Yes			
16 Jun 1996	3	2	Pt Possession	1.16	2.32	40	36%	video	Yes	1,4	E	1,1
16 Jun 1996	4	8	Lewis/Ivan R	1.12	3.08	365	9%	video	Yes	6,5	G	1,1
16 Jun 1996	5	4	Susitna R	1.16	1.75	69	23%	video	Yes	4,1	E	1,1
16 Jun 1996	6	8	Susitna/Little Susitna R			132	39%	observer	Yes	5,6	E	1,1
16 Jun 1996	7	2	Little Susitna	1.16	1.02	22	74%	video	Yes			
17 Jun 1996	1	2	Ivan/Susitna R	1.11	3.25	446	17%	video	No			
17 Jun 1996	3	3	Little Susitna R	1.15	1.19	30	44%	video	No			
17 Jun 1996	4	1	Ivan/Susitna R	1.16	3.06	230	28%	video	No			
08 Jun 1997	1	3	Knik Arm	1.1	2.14	30	34%	video	Yes			
08 Jun 1997	2	5	Knik Arm	1.29	1.41	63	23%	video	Yes	5,6	G	1,1
08 Jun 1997	3	5	Knik Arm	1.17	1.8	76	20%	video	Yes	1,7	E	1,1
08 Jun 1997	4	1	Knik Arm			2	42%	observer	Yes			
08 Jun 1997	5	5	Knik Arm	1.18	2.18	96	40%	video	Yes			
08 Jun 1997	7	1	Knik Arm			4	42%	observer	Yes			

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
08 Jun 1997	8	6	Chickaloon Bay	1.19	2.02	20	32%	video	Yes	6,5	G	0,1
08 Jun 1997	9	4	Chickaloon Bay	1.19	1.73	19	43%	video	Yes	6,5	G	1,1
08 Jun 1997	10	3	Susitna R	1.21	2.1	127	21%	video	Yes	7,1	G	1,1
09 Jun 1997	1	1	Tuxedni Bay			2	42%	observer	Yes			
09 Jun 1997	2	9	Susitna R			103	36%	observer	Yes	7,5	P	0,1
10 Jun 1997	1	4	Chickaloon Bay	1.14	3.3	113	16%	video	Yes	5,1	P	0,1
10 Jun 1997	2	15	Susitna R			140	35%	observer	Yes	6,7	G	1,1
10 Jun 1997	3	7	Knik Arm	1.14	2.15	153	12%	video	Yes			
10 Jun 1997	4	5	Knik Arm	1.18	2.03	60	21%	video	Yes			
10 Jun 1997	5	1	Knik Arm			2	42%	observer	Yes			
10 Jun 1997	6	2	Knik Arm			9	42%	observer	Yes			
09 Jun 1998	1	1	Little Susitna R	1.13	1.18	78	50%	video	No			
10 Jun 1998	1	8	Fire Island			21	52%	observer	Yes			
10 Jun 1998	2	5	Chickaloon Bay	1.16	1.62	27	33%	video	Yes	4,7	G	1,1
10 Jun 1998	3	3	Susitna R	1.23	1.45	139	23%	video	Yes	5,8	F	1,0
10 Jun 1998	4	1	Knik Arm			4	42%	observer	Yes			
10 Jun 1998	5	4	Knik Arm			21	39%	observer	Yes			
10 Jun 1998	6	4	Knik Arm			7	48%	observer	Yes			
10 Jun 1998	7	5	Knik Arm			8	41%	observer	Yes	7,4	G	1,1
10 Jun 1998	8	3	Knik Arm			64	42%	observer	Yes	8,5	F	1,1
10 Jun 1998	9	2	Knik Arm			9	50%	observer	Yes			
10 Jun 1998	10	5	Knik Arm			49	33%	observer	Yes			
12 Jun 1998	1	4	Little Susitna R	1.21	1.8	53	28%	video	Yes			
12 Jun 1998	2	5	Knik Arm			9	89%	observer	Yes	8,5	G	0,1
12 Jun 1998	3	2	Knik Arm	1.16	1.89	26	46%	video	Yes			
12 Jun 1998	4	3	Knik Arm	1.16	1.93	18	53%	video	Yes			
12 Jun 1998	5	3	Knik Arm	1.16	2.54	21	37%	video	Yes	4,8	G	0,1
12 Jun 1998	6	4	Knik Arm			19	66%	observer	Yes			
12 Jun 1998	7	1	Knik Arm	1.16	2.04	45	51%	video	Yes			
12 Jun 1998	8	3	Chickaloon Bay	1.16	1.74	31	40%	video	Yes	4,8	F	1,1
12 Jun 1998	9	2	Chickaloon Bay	1.15	1.16	19	68%	video	Yes	4,8	F	1,1
15 Jun 1998	1	3	Chickaloon Bay	1.18	2.34	89	22%	video	Yes	4,8	G	1,1
15 Jun 1998	2	1	Little Susitna R			2	42%	observer	Yes			
15 Jun 1998	3	4	Little Susitna R	1.21	1.79	285	14%	video	Yes	5,1	E	1,0
15 Jun 1998	4	3	Knik Arm			21	42%	observer	Yes			
15 Jun 1998	5	7	Knik Arm	1.16	2.13	40	21%	video	Yes	8,4	G	1,1
15 Jun 1998	6	2	Knik Arm	1.16	2.29	4	108%	video	Yes			
15 Jun 1998	7	5	Knik Arm	1.16	2.05	11	66%	video	Yes			
09 Jun 1999	1	6	Little Susitna R	1.08	2.62	314	17%	video	Yes	5,8	E	1,1
09 Jun 1999	2	3	Knik Arm			55	11%	observer	Yes			
09 Jun 1999	3	1	Chickaloon Bay	1.06	1.71	29	46%	video	Yes	4,1	E	
11 Jun 1999	1	1	Little Susitna R	1.06	3.21	245	41%	video	No	1,5;8,4	F,P	1,1;1,1
12 Jun 1999	1	4	Chickaloon Bay	1.19	2.62	3	44%	video	Yes	8,1	E	1,1
12 Jun 1999	2	6	Chickaloon Bay	1.14	1.63	30	19%	video	Yes	8,1	E	
12 Jun 1999	4	1	Beluga R	1.24	1.46	13	52%	video	Yes	4,5	E	0,1
12 Jun 1999	5	4	Susitna R	1.06	2.73	92	21%	video	Yes	4,5	E	0,1
12 Jun 1999	6	1	Little Susitna R	1.06	2.45	179	41%	video	Yes	1,8	E	1,1
12 Jun 1999	7	3	Knik Arm	1.20	1.69	39	26%	video	Yes	5,4	E	1,1
13 Jun 1999	1	2	Susitna R	1.15	1.42	25	33%	video	Yes	8,4	G	0,1
13 Jun 1999	2	4	Little Susitna R	1.13	1.46	258	21%	video	Yes	8,4	E	1,1
13 Jun 1999	4	5	Knik Arm	1.15	1.35	18	23%	video	Yes	4,8	G	
07 Jun 2000	1	3	Knik Arm	1.34	1.87	44	30%	video	No	1,8	E	1,0
07 Jun 2000	2	5	Knik Arm	1.18	2.28	25	22%	video	No			
08 Jun 2000	1	8	Little Susitna R	1.25	2.37	317	16%	video	Yes	1,4	E	1,1
08 Jun 2000	2	3	Little Susitna R	1.24	1.17	33	27%	video	Yes			
08 Jun 2000	3	2	Chickaloon Bay	1.11	3.32	11	38%	video	Yes	4,1	E	1,1
11 Jun 2000	1	9	Little Susitna R	1.15	2.37	231	15%	video	No	5,1	E	1,1
11 Jun 2000	2	5	Beluga R	1.27	1.77	2	41%	video	No	4,8	E	1,0
12 Jun 2000	1	8	Chickaloon Bay	1.26	2.28	31	20%	video	Yes			
12 Jun 2000	2	5	Chickaloon Bay	1.13	2.86	11	25%	video	Yes			
12 Jun 2000	3	8	Little Susitna R	1.11	2.52	357	15%	video	Yes	5,4	E	1,1
12 Jun 2000	4	1	Little Susitna R	1.08	3.61	27	47%	video	Yes			
12 Jun 2000	5	2	Knik Arm			13	79%	observer	Yes	5,4	G	1,1
12 Jun 2000	6	1	Knik Arm	1.16	3.00	3	74%	video	Yes	5,4	G	1,1
12 Jun 2000	7	5	Knik Arm	1.26	2.00	49	21%	video	Yes			
13 Jun 2000	1	2	Chickaloon Bay			9	51%	observer	No	1,4	G	1,1
13 Jun 2000	2	6	Susitna R	1.31	2.40	156	18%	video	No	1,4	E	1,1
13 Jun 2000	3	2	Knik Arm			18	32%	observer	No	5,8	E	1,1
13 Jun 2000	4	1	Knik Arm			9	68%	observer	No	5,8	E	1,1
13 Jun 2000	5	5	Knik Arm	1.14	2.88	28	22%	video	No			
05 Jun 2001	1	5	Little Susitna R	1.53	1.66	68	15%	video	Yes	5,1	F	1,0
05 Jun 2001	2	1	Knik Arm			6	130%	observer	Yes	5,1	G	0,1
05 Jun 2001	3	1	Knik Arm			5	130%	observer	Yes	5,1	G	0,1
05 Jun 2001	4	6	Knik Arm	1.54	2.01	115	13%	video	Yes	5,1	G	0,1
05 Jun 2001	5	4	Knik Arm, Eagle R	1.45	2.04	166	16%	video	Yes	4,8	E	1,0
05 Jun 2001	6	5	Turnagain Arm			16	35%	observer	Yes	4,1	E	0,1
05 Jun 2001	7	4	Chickaloon Bay	1.87	1.91	23	20%	video	Yes	1,4	F	1,1
06 Jun 2001	1	15	Susitna R			113	20%	observer	Yes	4,8	F	1,1

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
06 Jun 2001	2	3	Knik Arm	1.82	1.59	24	22%	video	Yes	4,8	G	1,1
06 Jun 2001	3	7	Knik Arm	1.70	1.87	19	15%	video	Yes	4,8	G	1,0
06 Jun 2001	4	7	Knik Arm	1.64	1.99	64	13%	video	Yes	4,8	G	1,1
06 Jun 2001	5	5	Knik Arm	2.09	2.08	131	14%	video	Yes	4,8	G	1,1
06 Jun 2001	6	16	Chickaloon Bay			32	43%	observer	Yes		G	
07 Jun 2001	1+2	4	Little Susitna R	1.39	2.00	128	16%	video	Yes	8,5:8,5	E	1,1:0,0
07 Jun 2001	3	8	Little Susitna R	1.94	1.92	80	12%	video	Yes	8,1	E	1,1
07 Jun 2001	4	1	Knik Arm			4	130%	observer	Yes	5,4	E	1,1
07 Jun 2001	5	5	Knik Arm	1.50	1.92	112	15%	video	Yes	5,4	G	1,1
07 Jun 2001	6	7	Knik Arm	1.49	2.11	37	14%	video	Yes	5,8	E	1,1
07 Jun 2001	7	6	Chickaloon Bay			7	36%	observer	No	1,4	F	1,1
08 Jun 2001	1	1	Kachemak Bay			2	0%	observer	No		F	
10 Jun 2001	1	6	Chickaloon Bay	1.85	1.74	45	14%	video	Yes	1,8	E	1,1
10 Jun 2001	2	6	Little Susitna R	1.57	1.75	263	13%	video	Yes	5,4	E	1,1
10 Jun 2001	3	6	Little Susitna R	1.71	1.40	18	17%	video	Yes		E	
10 Jun 2001	4	6	Knik Arm, Eagle R	1.86	1.82	50	14%	video	Yes	1,5	G	1,1
10 Jun 2001	5	6	Knik Arm, Eagle R	1.31	1.84	53	14%	video	Yes	1,5	G	1,1
10 Jun 2001	6	2	Knik Arm	6.25	1.52	4	48%	video	Yes		G	
11 Jun 2001	1	1	Potters Marsh	1.49	2.75	22	39%	video	Yes	5,4:4,5	G	1,0:1,1
11 Jun 2001	2	6	Chickaloon Bay	1.93	1.64	27	16%	video	Yes	5,4:1,8	F	1,1:1,0
11 Jun 2001	3	4	Susitna R	1.91	2.04	135	16%	video	No	8,1:1,8	G	1,1:1,1
11 Jun 2001	4	6	Pt MacKenzie			21	30%	observer	No		E	
11 Jun 2001	5	3	Knik Arm			8	58%	observer	No	1,8	E	1,1
11 Jun 2001	6	3	Knik Arm, Eagle R	1.63	1.99	8	30%	video	No	1,8	E	1,1
11 Jun 2001	7	2	Knik Arm, E side			4	8%	observer	No	1,5	E	1,1
12 Jun 2001	1a	9	Susitna R			25	40%	observer	Yes	5,8	F	1,1
12 Jun 2001	1b	25	Susitna R			131	23%	observer	Yes		F	
12 Jun 2001	2	6	Susitna R			11	35%	observer	Yes		F	
12 Jun 2001	4	1	Pt MacKenzie			11	130%	observer	Yes		F	
12 Jun 2001	5	10	Pt MacKenzie			14	71%	observer	Yes	5,8	G	1,1
12 Jun 2001	6	12	Knik Arm, Eagle R			3	96%	observer	Yes	5,8	E	1,1
12 Jun 2001	7	16	Knik Arm, Eagle R			34	53%	observer	Yes	1,5	E	1,1
05 Jun 2002	1	1	Pt Possession			3	0%	observer	No	8,9	G	1,1
06 Jun 2002	1	3	Knik Arm, Eagle R	1.19	2.48	159	17%	video	No	8,4	G	1,1
06 Jun 2002	2	2	Chickaloon Bay	1.16	1.63	26	25%	video	Yes	8,4	F	1,1
07 Jun 2002	1	1	Chickaloon Bay			16	5%	observer	Yes	1,4	E	1,1
07 Jun 2002	2	12	Knik Arm			105	21%	observer	Yes	8,9	E	1,1
07 Jun 2002	3	10	Knik Arm	1.09	2.25	13	40%	observer	Yes		E	
07 Jun 2002	4	8	Knik Arm	1.19	1.79	30	53%	observer	Yes		E	
07 Jun 2002	5	9	Knik Arm	1.14	2.05	18	59%	observer	Yes		E	
07 Jun 2002	6	1	Knik Arm			4	6%	observer	Yes	8,9	E	1,1
07 Jun 2002	7	6	Knik Arm			43	47%	observer	Yes		E	
07 Jun 2002	8	3	Knik Arm	1.25	1.92	17	23%	video	Yes		E	
07 Jun 2002	9	8	Chickaloon Bay	1.24	1.22	7	19%	video	Yes	1,4	G	1,1
07 Jun 2002	10	1	Chickaloon Bay			4	6%	observer	Yes	1,4	F	1,0
08 Jun 2002	1a+1b	2	Pt MacKenzie			10	23%	observer	No	8,9:8,9	E	1,0:0,1
08 Jun 2002	2	4	Pt MacKenzie			16	109%	observer	No	8,9	E	1,1
08 Jun 2002	3	12	Knik Arm, Eagle Bay			60	47%	observer	No	8,9	E	1,1
08 Jun 2002	4	9	Knik Arm, Eagle Bay			28	32%	observer	No	8,9	E	1,1
08 Jun 2002	5	7	Knik Arm			10	51%	observer	No	8,4	E	1,1
09 Jun 2002	1	16	Knik Arm			48	34%	observer	No	1,4	E	1,1
09 Jun 2002	2	6	Knik Arm			30	46%	observer	No	1,4	E	1,1
09 Jun 2002	3	6	Knik Arm			22	45%	observer	No	1,4	E	1,1
09 Jun 2002	4	17	Knik Arm			23	45%	observer	No	1,4	E	1,1
10 Jun 2002	1	6	Beluga R	1.17	1.65	7	22%	video	No	1,9	E	1,1
10 Jun 2002	2	2	Susitna R	1.29	1.71	30	25%	video	No	8,9	E	1,1
10 Jun 2002	4	7	Knik Arm, Goose Bay	1.16	1.64	12	17%	video	No	1,4	E	1,0
10 Jun 2002	5	4	Knik Arm, Eklutna	1.31	1.95	12	22%	video	No	8,9	E	1,1
10 Jun 2002	6	9	Knik Arm, Eklutna	1.18	1.84	5	107%	observer	No	1,4	E	1,1
10 Jun 2002	7	3	Knik Arm	1.18	1.85	45	19%	video	No	1,4	E	1,1
10 Jun 2002	8	15	Knik Arm, Eagle Bay			7	76%	observer	No		E	
11 Jun 2002	1	1	Chickaloon Bay			3	6%	observer	No	8,9	F	1,1
11 Jun 2002	2	11	Susitna R	1.25	1.33	135	38%	observer	Yes	8,9	F	1,1
11 Jun 2002	3	2	Knik Arm			2	20%	observer	Yes	1,4	E	1,1
11 Jun 2002	4	5	Knik Arm	1.16	1.68	130	13%	video	Yes	1,4	G	1,1
03 Jun 2003	1	6	Chickaloon Bay	1.06	1.97	112	14%	video	Yes	1,4	G	1,1
03 Jun 2003	2	8	Little Susitna R	1.05	3.06	33	14%	video	Yes	1,4	E	1,0
03 Jun 2003	3+4	6	Knik Arm, Eagle Bay	1.06	2.15	246	14%	video	Yes	1,4:1,4	G	1,0:1,1
04 Jun 2003	1	2	Chickaloon Bay			9	19%	observer	Yes	9,10	F	1,1
04 Jun 2003	2	3	Chickaloon R	1.08	2.69	59	21%	video	Yes		F	
04 Jun 2003	3	6	Knik Arm, Eagle R	1.06	2.29	13	52%	video	No	10,9	G	1,1
04 Jun 2003	4	1	Knik Arm, Eagle Bay	1.07	3.49	198	35%	video	No	10,9	G	1,1
05 Jun 2003	1	5	Potter Marsh	1.06	2.36	50	17%	video	No	1,4	E	1,0
05 Jun 2003	2	2	Chickaloon Bay			1	156%	observer	No	1,4	G	1,0
05 Jun 2003	3	2	Knik Arm, Eagle R	1.10	2.34	5	43%	video	No	1,4	G	1,1
06 Jun 2003	1	2	Chickaloon R, mouth	1.04	1.80	25	29%	video	Yes	1,10	G	1,1
06 Jun 2003	2	1	Chickaloon R, W of mouth	1.06	2.39	25	41%	video	Yes		G	
06 Jun 2003	3	8	Chickaloon R, bend			4	129%	observer	Yes		G	

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
06 Jun 2003	4	2	Beluga R			1	228%	observer	No	4,10	E	0,1
06 Jun 2003	5	3	Susitna R			2	227%	observer	No	4,10	G	0,1
06 Jun 2003	6	2	Little Susitna R	1.01	2.81	3	53%	video	No	4,10	G	1,0
06 Jun 2003	7	15	Knik Arm, Fish Creek			134	29%	observer	No	9,4	E	1,1
06 Jun 2003	8	7	Knik Arm, Palmer Slough	1.09	2.74	11	19%	video	No		E	
08 Jun 2003	1	3	Theodore R	1.06	2.59	11	28%	video	No	10,1	E	1,1
08 Jun 2003	2	8	Little Susitna R	1.07	3.21	65	13%	video	No	10,1	E	1,1
08 Jun 2003	3	2	Knik Arm, Goose Bay	1.04	3.09	6	40%	video	No	10,1	E	0,1
08 Jun 2003	4	6	Knik Arm	1.09	2.37	107	16%	video	No	10,1	E	1,1
08 Jun 2003	5	8	Chickaloon Bay	1.07	2.10	70	13%	video	Yes	1,10	G	1,1
10 Jun 2003	2	24	Beluga R			6	35%	observer	Yes	10,4	G	1,1
10 Jun 2003	3 (orig. 1)	6	S of Little Susitna R	1.08	3.08	28	16%	video	Yes	9,1(10,4)	E	1,0(1,1)
10 Jun 2003	4	8	Little Susitna R	1.02	3.55	36	14%	video	Yes	9,1	G	1,0
10 Jun 2003	5	10	Knik Arm			9	83%	observer	No	9,1	E	1,1
10 Jun 2003	6	4	Knik Arm	1.13	1.75	24	21%	video	No		G	
10 Jun 2003	7	2	Knik Arm	1.07	2.19	38	27%	video	No		G	
10 Jun 2003	8	2	Knik Arm, Birchwood	1.07	2.59	19	30%	video	No		G	
10 Jun 2003	9	2	Knik Arm, Eagle Bay	1.08	2.91	14	33%	video	No		G	
11 Jun 2003	1	2	Chickaloon Bay, E side	1.12	2.26	10	35%	video	Yes	9,1	G	
11 Jun 2003	2	3	Chickaloon Bay, W side	1.08	2.27	45	22%	video	Yes	9,1	E	
11 Jun 2003	3	2	Chickaloon Bay, W side	1.06	2.53	15	32%	video	Yes		E	
11 Jun 2003	4	3	Chickaloon Bay, W side	1.07	2.70	8	31%	video	Yes		E	
11 Jun 2003	5+6+7		Beluga R to Little Susitna R			not counted		observer	No	1,9	E	1,0:1,1:1,1
11 Jun 2003	8	1	Knik Arm, mid-arm	1.09	2.34	150	35%	video	Yes	1,9	E	1,1
11 Jun 2003	9	6	Knik Arm, south			20	58%	observer	Yes		G	
11 Jun 2003	10	1	Knik Arm, south			12	5%	observer	Yes		G	
02 Jun 2004	1		Little Susitna R			not counted		observer	No	1,4	G	1,1
03 Jun 2004	1	7	Little Susitna R			19	28%	observer	Yes	5,1	F	0,0
03 Jun 2004	2	1	Little Susitna R	1.17	2.39	424	47%	video	Yes	5,1	F	1,1
04 Jun 2004	1	6	Chickaloon Bay	1.27	2.45	22	36%	video	No	9,4	E	1,1
04 Jun 2004	2	7	Little Susitna R	1.33	2.04	123	29%	video	No	1,10	F	1,1
07 Jun 2004	1	4	Chickaloon Bay	1.41	2.35	253	33%	video	Yes	10,1	E	1,1
07 Jun 2004	2	7	Chickaloon Bay	1.23	2.09	73	30%	video	Yes		G	
07 Jun 2004	3	1	Susitna R	1.47	1.69	25	55%	video	Yes	1,4	G	1,0
08 Jun 2004	1	7	Little Susitna R	1.21	2.28	15	37%	video	Yes	9,5	G	0,1
08 Jun 2004	3	5	Turnagain Arm	1.26	2.74	88	33%	video	Yes	1,10	E	1,1
08 Jun 2004	4	2	Chickaloon Bay	1.37	2.05	104	40%	video	Yes	1,10	G	1,1
08 Jun 2004	5	3	Chickaloon Bay			19	20%	observer	Yes		G	
08 Jun 2004	6	7	Chickaloon Bay			39	11%	observer	Yes		G	
08 Jun 2004	7 (orig. 2)	1	Chickaloon Bay	1.36	2.22	106	45%	video	Yes	5,9(1,10)	E	1,1(1,1)
09 Jun 2004	1	3	Little Susitna R	1.31	2.18	31	41%	video	Yes	10,1	G	0,1
09 Jun 2004	2	2	Little Susitna R	1.34	2.21	16	53%	video	Yes		G	1,1
09 Jun 2004	3	6	Turnagain Arm	1.26	2.82	99	36%	video	Yes		E	0,1
09 Jun 2004	4a+5	1	Chickaloon Bay	1.49	2.25	100	43%	video	Yes	10,1	E	1,1
09 Jun 2004	4b	10	Chickaloon R			15	21%	observer	Yes	10,1	E	1,1
31 May 2005	2	2	Chickaloon Bay	1.06	1.65	37	48%	video	Yes	4,9	E	1,1
31 May 2005	3	3	Ivan R	1.08	2.16	229	40%	video	Yes	11,1	G	1,1
31 May 2005	4+5	2	Little Susitna R	1.05	1.36	7	61%	video	Yes	9,11:9,11	E	1,1:1,0
01 Jun 2005	1	5	Chickaloon Bay	1.05	2.13	45	38%	video	Yes	11,4	E	1,1
01 Jun 2005	2	2	Ivan R	1.07	2.28	46	47%	video	Yes	9,1	G	1,0
01 Jun 2005	3	7	Ivan R	1.07	2.19	79	33%	video	Yes	9,1	G	1,0
01 Jun 2005	4	4	Susitna R			156	32%	observer	Yes	11,4	E	1,1
02 Jun 2005	1	1	N of Pt Possession			2	0%	observer	Yes	12,1	G	0,1
02 Jun 2005	2	3	Susitna R	1.07	1.94	211	40%	video	Yes	12,1	G	1,1
02 Jun 2005	3	1	Knik Arm, Goose Bay	1.08	1.64	7	71%	video	Yes	11,4	E	0,1
02 Jun 2005	4	2	Chickaloon Bay	1.05	1.91	20	51%	video	Yes	11,4	G	1,0
05 Jun 2005	1	4	Chickaloon Bay	1.06	1.87	33	41%	video	Yes	11,1	G	0,1
05 Jun 2005	2	5	Susitna R	1.10	1.71	205	35%	video	Yes	12,9	E	1,1
08 Jun 2005	1	1	Chickaloon Bay	1.09	1.90	66	55%	video	Yes	4,12	P	1,0
08 Jun 2005	2	1	Chickaloon R			3	0%	observer	Yes	4,12	P	0,1
08 Jun 2005	3	4	Chickaloon Bay			29	30%	observer	Yes	1,11	P	1,1
08 Jun 2005	4	2	Chickaloon Bay	1.05	2.23	26	49%	video	Yes	1,11	F	1,1
08 Jun 2005	5	1	Chickaloon Bay			3	0%	observer	Yes	1,11	F	1,1
08 Jun 2005	6	1	Fire Island, SW tip			9	69%	observer	Yes	4,12	E	1,1
08 Jun 2005	7	3	Fire Island, SW tip	1.07	2.68	43	43%	video	Yes		E	
08 Jun 2005	8	1	Fire Island, SW tip			5	0%	observer	Yes		E	
08 Jun 2005	9	5	Susitna R	1.08	1.94	29	39%	video	Yes	4,12	E	1,1
08 Jun 2005	10	3	Knik Arm, Goose Bay	1.06	2.06	20	46%	video	Yes	4,12	E	1,0
09 Jun 2005	1	4	Turnagain Arm	1.06	1.52	31	41%	video	Yes	11,4	F	1,1
09 Jun 2005	2	3	Chickaloon R	1.05	1.98	78	41%	video	Yes	11,4	F	1,1
09 Jun 2005	3	1	Chickaloon Bay	1.08	2.23	17	62%	video	Yes	11,4	F	1,1
09 Jun 2005	4	1	Fire Island, SW tip	1.04	2.10	55	55%	video	Yes	11,4	G	1,1
09 Jun 2005	5	1	Susitna R			1	0%	observer	Yes	11,4	G	1,1
09 Jun 2005	6	6	Susitna R	1.07	1.96	34	37%	video	Yes	11,4	G	1,1
09 Jun 2005	7	2	Susitna R			10	36%	observer	Yes		G	
09 Jun 2005	8	1	Susitna R			1	0%	observer	Yes		G	
09 Jun 2005	9	1	Susitna R			6	0%	observer	Yes		G	
09 Jun 2005	10	1	Susitna R			1	0%	observer	Yes		G	

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
09 Jun 2005	11	3	Knik Arm, Eagle Bay	1.06	2.27	69	41%	video	Yes	1,11	E	1,1
06 Jun 2006	1	5	Pt Possession			16	59%	observer	Yes	1,10	F	1,1
06 Jun 2006	2	3	Susitna R			6	173%	observer	Yes	1,10	E	1,0
06 Jun 2006	3	4	Little Susitna R			15	85%	observer	Yes	1,10	E	0,1
06 Jun 2006	4	4	Little Susitna R			36	22%	observer	Yes		E	
06 Jun 2006	5	5	Little Susitna R			155	33%	observer	Yes		G	
06 Jun 2006	6	4	Chickaloon Bay			16	57%	observer	Yes	10,4	G	1,1
06 Jun 2006	7	4	Chickaloon Bay			21	52%	observer	Yes	10,4	G	1,1
06 Jun 2006	8	4	Chickaloon Bay			7	72%	observer	Yes	10,4	F	1,1
06 Jun 2006	9	4	Chickaloon Bay			9	90%	observer	Yes		U	
06 Jun 2006	10	4	Chickaloon Bay			13	116%	observer	Yes		U	
06 Jun 2006	11	1	Pt Possession			2	0%	observer	Yes	10,4	F	1,0
07 Jun 2006	1	2	Chickaloon Bay	1.27	2.10	17	30%	video	No	11,13	E	1,1
07 Jun 2006	2	3	Chickaloon Bay	1.37	1.89	22	23%	video	No		E	
07 Jun 2006	3	3	Susitna R	1.44	2.03	22	28%	video	No	11,13	E	1,1
07 Jun 2006	4	5	Susitna R	1.33	1.73	26	20%	video	No		E	
07 Jun 2006	5	2	Susitna R	1.46	1.85	43	30%	video	No		E	
07 Jun 2006	6	3	Little Susitna R	1.33	1.83	12	35%	video	No	13,11	F	1,1
08 Jun 2006	1	5	Chickaloon Bay			5	53%	observer	No	9,1	G	1,1
08 Jun 2006	2	4	Chickaloon Bay			8	68%	observer	No	9,1	E	1,0
08 Jun 2006	3	4	Beluga R	1.28	2.02	43	20%	video	No	9,11	G	1,1
08 Jun 2006	4	3	Susitna R	1.32	2.07	29	27%	video	No		E	
08 Jun 2006	5	8	Susitna R			55	27%	observer	No	9,11	E	0,1
08 Jun 2006	6	4	Little Susitna R	1.27	2.10	13	25%	video	No	9,13	E	1,0
08 Jun 2006	7	1	Knik Arm	1.33	2.62	14	50%	video	No	9,13	G	1,1
10 Jun 2006	1	1	Pt Possession			1	0%	observer	Yes		F	
10 Jun 2006	2	1	Pt Possession			15	0%	observer	Yes		E	
11 Jun 2006	1	6	Chickaloon R	1.44	1.75	7	38%	video	Yes	13,1	G	1,1
11 Jun 2006	2	2	Chickaloon R	1.44	2.32	17	44%	video	Yes	13,1	E	0,1
11 Jun 2006	3	2	Pt Possession	1.14	2.05	12	35%	video	Yes	13,1	E	0,1
11 Jun 2006	4	7	Pt Possession	1.08	1.79	14	19%	video	Yes	13,1	E	1,1
11 Jun 2006	5	4	Beluga R	1.28	2.09	8	30%	video	Yes		G	
11 Jun 2006	6	4	Susitna R	1.16	2.29	181	20%	video	Yes	13,1	G	1,1
11 Jun 2006	7	3	Knik Arm	1.24	2.17	15	28%	video	Yes	11,1	E	0,1
12 Jun 2006	1	1	Susitna R	1.33	1.86	188	36%	video	Yes		G	
12 Jun 2006	2	4	Chickaloon Bay	1.28	1.91	36	21%	video	Yes	13,11	E	1,1
12 Jun 2006	3	1	Chickaloon Bay	1.25	1.69	34	41%	video	Yes	13,1	E	1,1
12 Jun 2006	4	2	Chickaloon Bay	1.42	1.67	50	26%	video	Yes		P	
14 Jun 2006	1	1	Chickaloon R			1	0%	observer	No	11,1	E	1,0
14 Jun 2006	2	3	Chickaloon Bay	1.29	2.15	21	26%	video	No	11,1	E	1,1
14 Jun 2006	3	1	Chickaloon Bay			1	0%	observer	No		E	
14 Jun 2006	4	3	Chickaloon Bay	1.25	2.04	6	36%	video	No		E	
14 Jun 2006	5	1	Chickaloon Bay	1.29	2.06	53	26%	video	No		E	
14 Jun 2006	6	1	Pt Possession			6	0%	observer	No	11,1	E	0,1
14 Jun 2006	7	4	Beluga R	1.30	1.92	163	18%	video	No	11,1	E	1,1
14 Jun 2006	8	5	Susitna R	1.16	2.17	43	17%	video	No	11,1	E	0,1
14 Jun 2006	9	3	Little Susitna R	1.35	1.86	31	22%	video	No	11,1	E	0,1
15 Jun 2006	1	5	Chickaloon R	1.12	2.16	12	21%	video	No	5,13	E	1,1
15 Jun 2006	2	3	Chickaloon Bay	1.26	2.15	15	28%	video	No		E	
15 Jun 2006	3	4	Beluga R	1.28	2.01	33	22%	video	No	5,13	G	1,1
15 Jun 2006	4	2	Susitna R	1.14	2.08	51	27%	video	No		E	
15 Jun 2006	5	5	Susitna R	1.06	1.55	74	18%	video	No		E	
09 Jun 2007	1	4	Knik Arm, Goose Bay	1.25	2.35	6	80%	video	Yes	4,14	G	0,1
09 Jun 2007	2	9	Knik Arm, Eagle Bay	1.23	2.17	35	64%	video	Yes	4,14	E	1,1
09 Jun 2007	3	16	Susitna R			94	35%	observer	Yes	11,1	E	1,1
09 Jun 2007	4	5	Susitna/Little Susitna R			3	132%	observer	Yes	11,1	G	1,1
09 Jun 2007	5	8	Little Susitna R			58	16%	observer	Yes	11,1	G	1,1
09 Jun 2007	6	3	Turnagain Arm	1.39	2.53	24	85%	video	Yes	11,14	E	1,1
09 Jun 2007	7	4	Turnagain Arm			97	18%	observer	Yes	11,1	G	1,1
09 Jun 2007	8	2	Chickaloon Bay	1.55	1.55	2	102%	video	Yes	14,1	E	1,1
09 Jun 2007	9	8	Chickaloon Bay			6	24%	observer	Yes	14,1	E	1,1
09 Jun 2007	10	8	Pt Possession			63	15%	observer	Yes		E	
10 Jun 2007	1	4	Fire Island	1.43	1.35	14	79%	video	Yes		E	
10 Jun 2007	2	3	Susitna R	1.51	1.46	84	84%	video	Yes	11,4	E	1,1
10 Jun 2007	3	1	Susitna/Little Susitna R	1.37	1.75	55	110%	video	Yes	14,1	E	1,1
10 Jun 2007	4	1	Little Susitna R	1.37	1.60	9	113%	video	Yes		E	
10 Jun 2007	5	4	Little Susitna R	1.45	1.95	54	78%	video	Yes	11,4	E	1,0
10 Jun 2007	6	2	Little Susitna R			1	0%	observer	Yes	11,4	E	1,1
10 Jun 2007	7	5	Knik Arm, Windy Pt	1.41	1.54	31	74%	video	Yes		G	
10 Jun 2007	8	1	Burnt Island			1	0%	observer	Yes	11,4	G	0,1
10 Jun 2007	9	1	Burnt Island			1	0%	observer	Yes		E	
10 Jun 2007	10	1	Chickaloon Bay	1.61	1.31	21	112%	video	Yes	11,4	G	0,1
10 Jun 2007	11	3	Chickaloon Bay	1.34	1.78	42	84%	video	Yes	11,4	E	0,1
11 Jun 2007	1	4	Turnagain Arm			1	8%	observer	Yes	4,14	E	0,1
11 Jun 2007	2	1	Chickaloon Bay	1.54	1.64	18	112%	video	Yes	4,14	E	1,1
11 Jun 2007	3	2	Chickaloon Bay			3	0%	observer	Yes	4,14	E	0,1
11 Jun 2007	4	3	Chickaloon Bay	1.41	1.91	35	84%	video	Yes	4,14	G	1,1
11 Jun 2007	5	6	Little Susitna R	1.51	1.48	54	71%	video	Yes	1,11	G	0,0

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
11 Jun 2007	6	5	Little Susitna R	1.50	1.53	223	74%	video	Yes	14,4	E	1,1
11 Jun 2007	7	6	Knik Arm, Windy Pt	1.40	1.82	40	71%	video	Yes	1,11	F	1,1
14 Jun 2007	1	12	Chickaloon Bay			6	33%	observer	Yes	14,9	G	1,1
14 Jun 2007	2	8	Chickaloon Bay			3	99%	observer	Yes		G	
14 Jun 2007	3	2	Chickaloon Bay bluffs	1.31	1.56	42	93%	video	Yes	14,9	E	1,1
14 Jun 2007	4	1	Beluga R	1.48	1.66	12	112%	video	Yes	14,9	G	1,1
14 Jun 2007	5	2	Susitna R, W tributary	1.47	1.79	57	93%	video	Yes	14,9	G	1,1
14 Jun 2007	6	3	Susitna R, E tributary	1.42	1.69	177	84%	video	Yes	11,1	G	1,1
14 Jun 2007	7	2	Little Susitna R	1.54	1.91	48	93%	video	Yes	11,1	E	1,1
14 Jun 2007	8	4	Little Susitna R	1.33	1.77	39	78%	video	Yes	14,9	G	1,1
14 Jun 2007	9	3	Little Susitna R			1	0%	observer	Yes	14,9	G	1,1
14 Jun 2007	10	9	Knik Arm, Fire Creek			1	153%	observer	Yes		E	
14 Jun 2007	11	2	Fire Island, NE tip			2	0%	observer	Yes		G	
15 Jun 2007	1	1	Turnagain Arm			1	0%	observer	No		G	
15 Jun 2007	2	3	Chickaloon R	1.39	1.70	9	86%	video	No	9,1	E	0,1
15 Jun 2007	3	5	Chickaloon Bluff	1.40	1.13	5	77%	video	No	9,1	E	1,1
15 Jun 2007	4	3	Chickaloon Bluff	1.45	1.54	15	85%	video	No		E	
15 Jun 2007	5	3	Beluga R	1.41	1.27	178	84%	video	No	9,1	E	1,1
15 Jun 2007	6	3	Susitna R, E tributary	1.42	1.57	17	85%	video	No	9,1	E	0,1
03 Jun 2008	1	4	Beluga R			41	21%	observer	No	11,5	G	1,1
03 Jun 2008	2	16	Little Susitna R			137	56%	observer	No	11,1:1:15	E	0,1:0,1
04 Jun 2008	1	6	Susitna R	1.38	1.78	383	33%	video	Yes	1,4	G	1,1
05 Jun 2008	1	5	Chickaloon R	1.34	1.21	40	38%	video	No	15,1	G	1,0
05 Jun 2008	2	3	Susitna R	1.29	1.48	77	41%	video	No		G	
06 Jun 2008	1	4	Chickaloon R	1.27	1.80	7	52%	video	Yes	1,15	G	1,1
06 Jun 2008	2	4	Lewis R			2	0%	observer	Yes	1,15	E	1,0
06 Jun 2008	3	3	Little Susitna R	1.28	1.64	387	39%	video	Yes		E	
07 Jun 2008	1	10	Chickaloon R (morning)			50	37%	observer	Yes	1,15:1,5	G	1,1:1,1
07 Jun 2008	2	2	Susitna R (morning)	1.20	2.06	313	43%	video	Yes		P	
07 Jun 2008	3	3	Chickaloon R (afternoon)	1.25	1.93	120	40%	video	Yes		F	
11 Jun 2008	1 4	10	Beluga R			24	19%	observer	No	1,15	G,G,E,G	1,1:1,0:0,1
12 Jun 2008	1	9	Beluga R	1.20	2.28	220	30%	video	Yes		F	
12 Jun 2008	2	5	Little Susitna R	1.28	1.87	64	36%	video	Yes	1,15	F	1,1
02 Jun 2009	1	5	Susitna R, W tributary	1.23	1.90	183	10%	video	Yes	1,10	G	1,0
02 Jun 2009	2	5	Susitna R, E tributary	1.19	1.93	90	10%	video	Yes	1,10	E	1,1
02 Jun 2009	3	2	Chickaloon Bay	1.13	1.90	10	30%	video	Yes	1,10	F	1,1
03 Jun 2009	1	7	Little Susitna R	1.23	1.61	248	8%	video	Yes	1,10	G	1,1
03 Jun 2009	2	4	Chickaloon R	1.16	1.81	19	17%	video	Yes		G	
03 Jun 2009	3	3	Chickaloon Bay bluffs	1.20	1.91	30	17%	video	Yes	5,1	G	1,1
04 Jun 2009	1	5	Susitna/Little Susitna R	1.25	1.52	87	10%	video	Yes		E	
04 Jun 2009	2	5	Little Susitna R, mouth	1.23	1.65	146	10%	video	Yes	10,5	E	1,1
04 Jun 2009	3	1	Chickaloon R			2	0%	observer	Yes	10,1	P	0,0
04 Jun 2009	4	2	Chickaloon Bay bluffs	1.16	1.79	39	19%	video	Yes	10,1	G	1,1
05 Jun 2009	1	4	Chickaloon R	1.16	1.73	30	14%	video	Yes	1,10	G	1,1
05 Jun 2009	2	3	Chickaloon Bay bluffs	1.13	1.90	11	23%	video	Yes	1,10	E	1,1
05 Jun 2009	3	18	Susitna R			99	6%	observer	Yes	5,10	F	1,1
05 Jun 2009	4	5	Little Susitna R	1.19	1.55	181	10%	video	Yes	5,10	G	1,1
09 Jun 2009	5	6	Little Susitna R	1.17	2.15	118	9%	video	Yes		F	
09 Jun 2009	6	4	Susitna R	1.26	1.55	14	19%	video	Yes		F	
09 Jun 2009	7	2	Theodore R	1.21	1.61	252	15%	video	Yes		F	
09 Jun 2009	8	9	Pt Possession			29	22%	observer	Yes		E	
01 Jun 2010	1	4	Fire Island, SW tip			9	52%	observer	No	15,10	G	1,1
01 Jun 2010	2	10	E of Chickaloon R			21	29%	observer	No	15,10	G	1,0
01 Jun 2010	3	4	Chickaloon R	1.05	1.99	51	16%	video	No		G	
01 Jun 2010	4	5	Chickaloon Bay bluffs			14	33%	observer	No	15,10	F	0,0
01 Jun 2010	5	14	E of Little Susitna R			129	36%	observer	No	15,10	F	1,1
02 Jun 2010	1	3	Chickaloon Bay	1.06	1.52	126	20%	video	Yes	15,10	G	1,1
02 Jun 2010	2	5	Susitna/Little Susitna R	1.02	2.41	200	22%	video	Yes	15,10	E	1,1
04 Jun 2010	1	1	Turnagain Arm			1	166%	observer	No	10,11	G	1,0
04 Jun 2010	2	3	Chickaloon R, mouth			21	23%	observer	No	10,11	G	1,1
04 Jun 2010	3	12	Chickaloon Bay bluffs			8	86%	observer	No	10,11	G	1,1
04 Jun 2010	4	1	Susitna R, E tributary			4	166%	observer	No		G	
04 Jun 2010	5	7	Susitna R, E tributary			99	29%	observer	No	15,11	E	1,1
08 Jun 2010	1	10	Turnagain Arm, Six Mile			5	66%	observer	Yes	15,1	F	1,1
08 Jun 2010	2	2	Chickaloon R to bluffs	1.05	1.98	32	15%	video	Yes		G	
08 Jun 2010	3	4	Beluga/Ivan R	1.09	2.15	74	13%	video	Yes	15,1	G	1,1
08 Jun 2010	4	2	Susitna R	1.02	2.50	171	14%	video	Yes	15,1	G	0,1
08 Jun 2010	5	1	Susitna R, E tributary	1.09	1.24	69	16%	video	Yes	15,1	G	1,1
09 Jun 2010	1	2	W. of Chickaloon R	1.05	1.63	16	12%	video	Yes	5,11	G	1,1
09 Jun 2010	2	1	Chickaloon Bay bluffs	1.07	1.21	5	15%	video	Yes	5,11	G	1,1
09 Jun 2010	3	3	Theodore/Lewis R	1.08	1.85	88	14%	video	Yes	5,11	E	1,1
09 Jun 2010	4	10	Susitna R, W tributary			5	100%	observer	Yes		E	
09 Jun 2010	5	14	Susitna R, E tributary			144	27%	observer	Yes	5,11	G	1,1
09 Jun 2010	6	12	Little Susitna R, mouth			22	24%	observer	Yes	5,11	G	1,1
09 Jun 2010	7	11	Little Susitna R, first bend			7	47%	observer	Yes		G	
10 Jun 2010	1	5	Fire Island, SW tip	1.05	2.27	20	14%	video	Yes	1,11	G	1,1
10 Jun 2010	2	3	Turnagain Arm, Gull Rock	1.04	1.78	3	13%	video	Yes	1,11	G	0,1
10 Jun 2010	3	1	Burnt Island, offshore			2	133%	observer	Yes		G	

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
10 Jun 2010	4	14	W of Chickaloon R			26	27%	observer	Yes	1,11	G	1,1
10 Jun 2010	5	1	W of Chickaloon R			13	133%	observer	Yes		E	
10 Jun 2010	6	3	Pt Possession	1.03	2.41	11	17%	video	Yes	1,11	E	1,1
10 Jun 2010	7	5	Susitna R, W tributary	1.04	1.79	17	14%	video	Yes	1,11	E	1,0
10 Jun 2010	8	4	Susitna R, W tributary			6	86%	observer	Yes		E	
10 Jun 2010	9	8	Susitna R, E tributary			8	37%	observer	Yes	1,11	G	1,0
10 Jun 2010	10	4	Susitna/Little Susitna R	1.02	2.26	233	14%	video	Yes	1,11	E	1,1
10 Jun 2010	11	3	Susitna/Little Susitna R	1.02	2.42	8	48%	video	Yes	1,11	E	1,1
10 Jun 2010	12	8	Little Susitna R, first bend			8	32%	observer	Yes	1,11	E	1,0
31 May 2011	1	12	Chickaloon Bay bluffs			57	16%	observer	Yes	no isolation unit, used 2010		
31 May 2011	2	15	Little Susitna R, mouth			200	7%	observer	Yes	correction for 2011 data.		
01 Jun 2011	1	3	Chickaloon R, mouth	1.97	1.62	13	22%	video	Yes			
01 Jun 2011	2	3	Chickaloon Bay bluffs	1.98	1.17	4	36%	video	Yes			
01 Jun 2011	3	5	Susitna/Little Susitna R	1.89	1.33	271	10%	video	Yes			
02 Jun 2011	1	4	Chickaloon Bay bluffs	1.96	1.23	22	17%	video	Yes			
02 Jun 2011	2	1	Lewis R	1.85	1.66	49	27%	video	Yes			
02 Jun 2011	3	5	Susitna/Little Susitna R	1.90	1.43	155	11%	video	Yes			
03 Jun 2011	1a	8	Chickaloon Bay bluffs			4	14%	observer	Yes			
03 Jun 2011	1b	3	Chickaloon R, mouth	2.11	1.11	77	15%	video	Yes			
03 Jun 2011	2	1	Susitna R, E tributary	1.92	1.22	187	24%	video	Yes			
04 Jun 2011	1	1	Fire Island, SW tip			3	70%	observer	No			
04 Jun 2011	2	2	Chickaloon R, mouth	1.87	1.44	18	25%	video	No			
04 Jun 2011	3	11	Chickaloon Bay bluffs			4	14%	observer	No			
04 Jun 2011	4	18	Theodore R			68	6%	observer	No			
04 Jun 2011	5a	2	Little Susitna R			5	19%	observer	No			
04 Jun 2011	5b	1	Little Susitna R	1.80	1.29	76	26%	video	No			
05 Jun 2011	1	2	Chickaloon R, mouth	1.97	1.52	21	24%	video	Yes			
05 Jun 2011	2	2	Chickaloon Bay bluffs	1.85	1.37	23	23%	video	Yes			
05 Jun 2011	3	3	Susitna/Little Susitna R	1.92	1.61	295	13%	video	Yes			
08 Jun 2011	1	2	Chickaloon Bay, Burnt Island	1.39	1.84	6	36%	video	Yes			
08 Jun 2011	2	12	E of Chickaloon R			11	20%	observer	Yes			
08 Jun 2011	3	2	Chickaloon R, mouth			4	3%	observer	Yes			
08 Jun 2011	4	12	W of Chickaloon R			18	11%	observer	Yes			
08 Jun 2011	5	8	Chickaloon Bay bluffs			17	9%	observer	Yes			
08 Jun 2011	6	15	Beluga R to Susitna R			223	10%	observer	Yes			
09 Jun 2011	1		Chickaloon Bay			not counted		observer	No			
09 Jun 2011	2	1	Beluga R, mouth	1.81	2.09	60	27%	video	No			
09 Jun 2011	3	1	Theodore R			11	42%	observer	No			
09 Jun 2011	4		Ivan R to Susitna R			not counted		observer	No			
09 Jun 2011	5	1	Little Susitna R, mouth			4	3%	observer	No			
01 Jun 2012	1	1	Chickaloon Bay bluffs			1	0%	observer	No	15,14	E	1,1
01 Jun 2012	2	1	Pt Possession			1	0%	observer	No	2,10	E	1,1
01 Jun 2012	3	1	Susitna R			8	0%	observer	No	15,14	E	0,1
01 Jun 2012	4	5	Little Susitna R mouth	1.26	1.43	129	4%	video	No	15,14	E	1,1
01 Jun 2012	5	3	McArthur R	1.16	1.95	25	8%	video	No	14,2	G	1,1
02 Jun 2012	1	1	Potter Marsh			1	0%	observer	Yes	10,15	G	1,1
02 Jun 2012	2	1	Beluga Pt			1	0%	observer	Yes	10,15	G	1,1
02 Jun 2012	3	2	Chickaloon Bay bluffs	1.09	1.88	26	8%	video	Yes	10,15	G	1,1
02 Jun 2012	4	2	Granite Pt	1.07	2.07	29	7%	video	Yes	15.1	E	1,1
02 Jun 2012	5	7	Susitna R, E tributary	1.15	1.83	119	3%	video	Yes	10,15	G	1,1
02 Jun 2012	6	4	Little Susitna R mouth	1.25	1.89	143	4%	video	Yes	10,15	G	1,1
03 Jun 2012	1	3	McArthur R	1.16	1.77	23	9%	video	No	14,15	E	1,1
03 Jun 2012	2	1	Susitna R, E tributary			3	0%	observer	No	14,15	F	1,0
03 Jun 2012	3	3	Little Susitna R	1.22	1.95	209	4%	video	No	14,15	F	1,1
04 Jun 2012	1	8	Mid-Chickaloon Bay			22	9%	observer	Yes	14.2	G	1,1
04 Jun 2012	2	3	McArthur R	1.21	1.7	17	7%	video	Yes	2,14	G	1,1
04 Jun 2012	3	4	Susitna R	1.13	2.06	128	5%	video	Yes	10,14	G	1,1
04 Jun 2012	4	3	Little Susitna R	1.21	1.95	173	5%	video	Yes		G	
04 Jun 2012	5	1	W of Little Susitna R	1.17	1.96	67	13%	video	Yes		G	
05 Jun 2012	1	7	Chickaloon Bay bluffs			4	12%	observer	Yes	2,15	E	1,1
05 Jun 2012	2	2	McArthur R	1.22	1.48	14	13%	video	Yes	15,2	G	1,1
05 Jun 2012	3	7	W of Little Susitna R	1.21	1.5	263	3%	video	Yes	15,2	G	1,1
06 Jun 2012	1	6	Chickaloon Bay bluffs			14	6%	observer	No	2,15	G	1,1
06 Jun 2012	2	5	McArthur R			14	6%	observer	No	14,2	G	1,1
06 Jun 2012	3	1	Susitna R			84	5%	observer	No		F	
07 Jun 2012	1	3	Chickaloon R			1	47%	observer	Yes	14,2	G	1,0
07 Jun 2012	2	4	Chickaloon Bay bluffs			7	12%	observer	Yes		G	
07 Jun 2012	3	2	McArthur R	1.13	1.5	25	23%	video	Yes	14,2	E	1,1
07 Jun 2012	4	4	Lewis R	1.1	2.43	54	14%	video	Yes		G	
07 Jun 2012	5	3	W of Little Susitna R	1.15	2.25	154	14%	video	Yes	14,2	G	1,1

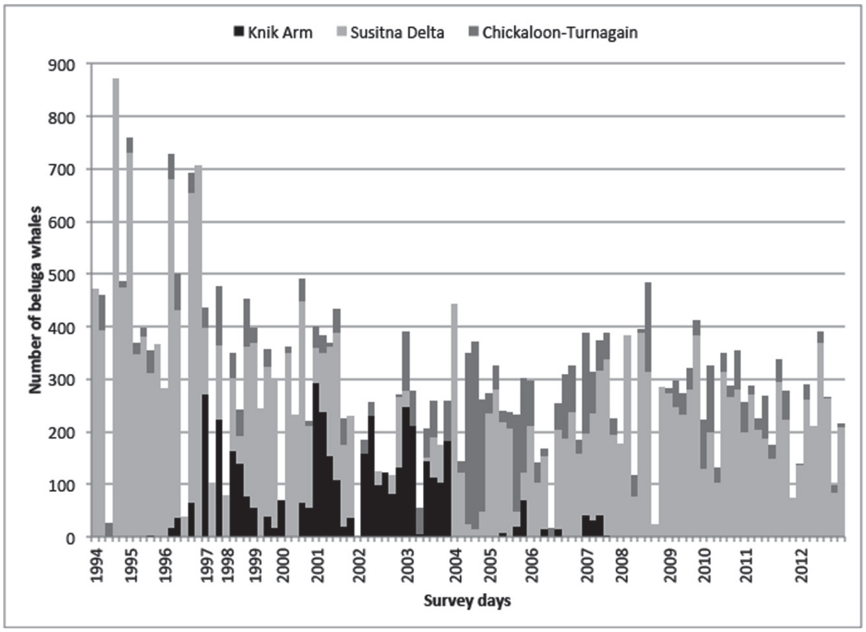

Figure 3.—Regions occupied by beluga whales in upper Cook Inlet, Alaska, north of North Foreland and Point Possession: Knik Arm, Chickaloon Bay–Turnagain Arm, and the Susitna delta (defined as the area between Beluga River and Point MacKenzie) from 1994 to 2012. Each survey day is represented as a single bar above and following the year indicated on the x-axis.

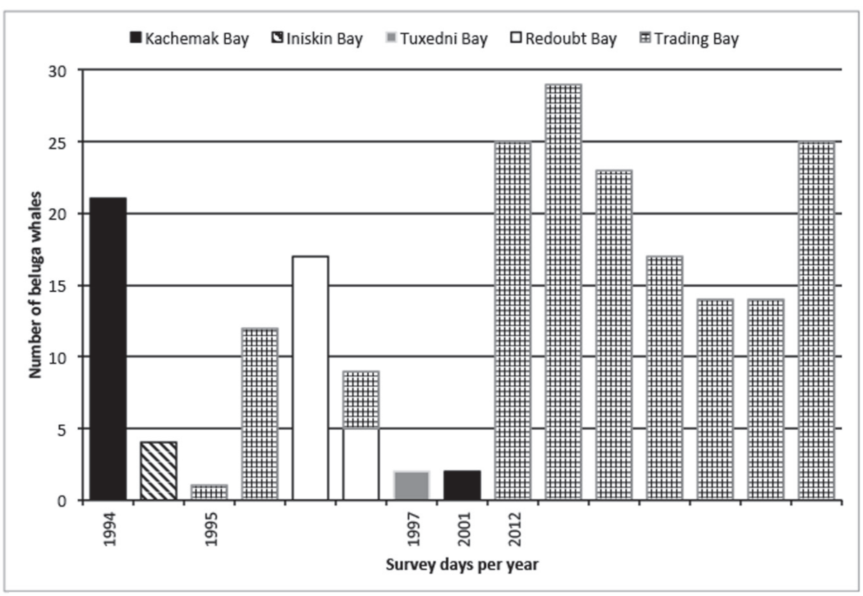

Figure 4.—Regions occupied by beluga whales in Cook Inlet, Alaska, south of North Foreland and Point Possession: Kachemak Bay, Iniskin Bay, Tuxedni Bay, Trading Bay, and Redoubt Bay, from 1994 to 2012. Each survey day is represented as a single bar above and following the year indicated on the x-axis.

2001–2012 dataset where 60% (range: 44–89%) of group size estimates were derived using video data (Table 1).

Analysis of the 6-h summarized time at surface data for the one whale tagged in 1999 indicated that the values for P_{dry} ranged from a low of 0.290 to a high of 0.350 with a mean of 0.306 (SD = 0.0193). Each field season represented a single draw from this distribution so that $CV(T_{I,y})$ is estimated to be 0.063. Regression of P_{dry} values against survey start date showed a significant relationship, with P_{dry} increasing by 0.0036 (SE 0.0013) per day, representing 36% of the variability in P_{dry}. This translates to a change in $T_{I,y}$ of 1.17% per day, suggesting that the progression from a 31 May to a 11 June survey start date corresponds with a change in beluga diving behavior, possibly related to prey switching from small smelt (eulachon, *Thaleichthys pacificus*) to adult salmonids (Chinook salmon, *Oncorhynchus tshawytscha*). While this trend does not affect the estimate of *CV*, it may have implications for the timing of the survey from year to year.

The revised estimates of variance yielded *CV* values that, in all cases, were less than those calculated by the equation of Hobbs et al. (2000b), and in some cases, were reduced nearly by half (Table 2). By explicitly accounting for the variation in beluga diving behavior (albeit from limited data, i.e., one tagged whale), it was possible to quantify an effect of behavior on abundance estimates that has been a point of speculation among observers. Regression of the residuals from the trend estimate against the median survey date of each survey resulted in a trend of 1.5% per day (SE = 1.4%), but it was not a significant relationship and explained less than 10% of the variability in the abundance estimates. While the trend over the survey period was a small part of the variability of $T_{I,y}$ from year to year, this highlights the need to consider variation in animal behavior when considering alternative survey start dates.

Estimates of abundance documented a decline of nearly 50% between 1994

Table 2.—Cook Inlet beluga whale aerial survey original and revised analysis results, June/July 1993–2012. The revised index counts use the highest daily count vs. the old index count that treated Turnagain Arm/Chickaloon Bay separately from the rest of upper Cook Inlet prior to 2003 (see Rugh et al. 2005:36). Abundance estimates based on sector analysis (the upper inlet divided into a northeast and northwest sector) for the years 2004 to 2012 include estimates for Week 1, Week 2, and an Average of the two weeks for comparison to previous survey years (1994–2003). The Old CV (coefficient of variation) was estimated using the method of Hobbs et al. (2000b). The revised CV is based on the standard error of the daily abundance estimates and an estimate of the variance based on diving behavior of a tagged whale. The trend estimates are for the years 1999 to 2012. The trend under Week 1 and Week 2 columns was the average of all possible combinations of the Week 1 and Week 2 estimates by year. The trends under Average and Abundance estimate (without sectors) included Week 1 estimates for the years 1999 to 2003.

Year	Survey date	Old index count	Revised index count	Abundance estimate (with sectors) Week 1	Week 2	Average	Abundance estimate (without sectors)	Old CV	Revised CV
1993	June 2–5	305	302						
1994	June 1–5	281	276	653				0.43	0.24
1995	July 18–24	324	322	491				0.44	0.21
1996	June 11–17	307	287	594				0.28	0.20
1997	June 8–10	264	261	440				0.14	0.13
1998	June 9–15	193	192	347				0.29	0.17
1999	June 8–14	217	217	367				0.14	0.09
2000	June 6–13	184	184	435				0.23	0.14
2001	June 5–12	211	210	386				0.17	0.10
2002	June 4–11	192	181	313				0.12	0.10
2003	June 3–12		274	357				0.11	0.08
2004	June 2–9		187	477	356	417	366	0.20	0.13
2005	May 31–June 9		192	283	316	300	278	0.18	0.10
2006	June 5–15		153	276	311	294	305	0.15	0.10
2007	June 7–15		224	452	397	425	375	0.14	0.08
2008	June 3–12		126	459	292	376	375	0.23	0.11
2009	June 2–9		303	306	418	362	321	0.18	0.11
2010	June 1–9		291	284	347	316	340	0.11	0.08
2011	May 31–June 9		208	285	309	297	284	0.16	0.09
2012	May 29–June 7		319	317	301	310	312		0.13
Trend (1999–2012) as percent per year				-1.57%		-1.50%	-1.60%		
	(Standard error)			(0.42%)		(0.86%)	(0.75%)		

and 1998, from an estimate of 653 (CV = 0.24) whales to 347 (CV = 0.17) whales, respectively. This is a period during which subsistence whale hunts were unrestricted. The annual rate of decline during this time period was -13.7% (SE = 0.045). Abundance estimates since 1998 vary from as high as 435 (CV = 0.14) in 2000 to as low as 278 (CV = 0.10) in 2005 (Table 2, Fig. 5). With the very limited hunt between 1999 and 2012 (5 whales killed), it was anticipated that the population would begin to recover. However, the population continued to decline at a rate of -1.60% (SE = 0.75%) per year since 1999 (Fig. 5 trend line), with a 97% probability that the growth rate is declining (i.e., less than zero) and a 99.9% probability that the growth rate is less than +2% per year.

Changes in survey methodology introduced in 2004 (i.e., increasing the number of survey days and no longer splitting the upper inlet into separate sectors) removed the concern that beluga groups moving between sectors (e.g., Fig. 3) could bias the estimate while not significantly affecting the trend results. Abundance estimates from each 1-week period (Table 2) were not significantly different from the estimate that included both weeks and did not split the upper inlet (n = 9 (2004–2012), T-$test$ = 2.12; p = 0.52 (Week 1 vs. Abundance without sectors), p = 0.61 (Week 2 vs. Abundance without sectors), p = 0.48 (Weeks averaged vs. Abundance without sectors)).

Trend analysis using the “weeks averaged” estimates yielded an average annual rate of decline of -1.50% (SE

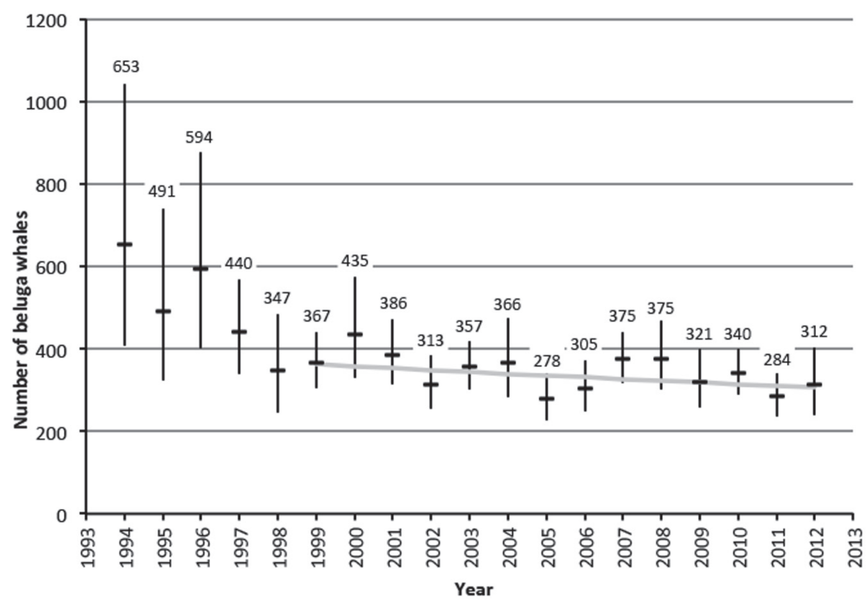

Figure 5.—Abundance estimates for beluga whales in Cook Inlet with 95% confidence intervals for revised coefficients of variation (CV’s) (vertical bars). From 1994 to 1998, when the harvest was unrestricted, the annual rate of decline was -13.7% (SE = 0.045). In the years since a hunting quota has been in place (1999–2012), the rate of decline (trend line) was -1.6% (SE = 0.75%) per year.

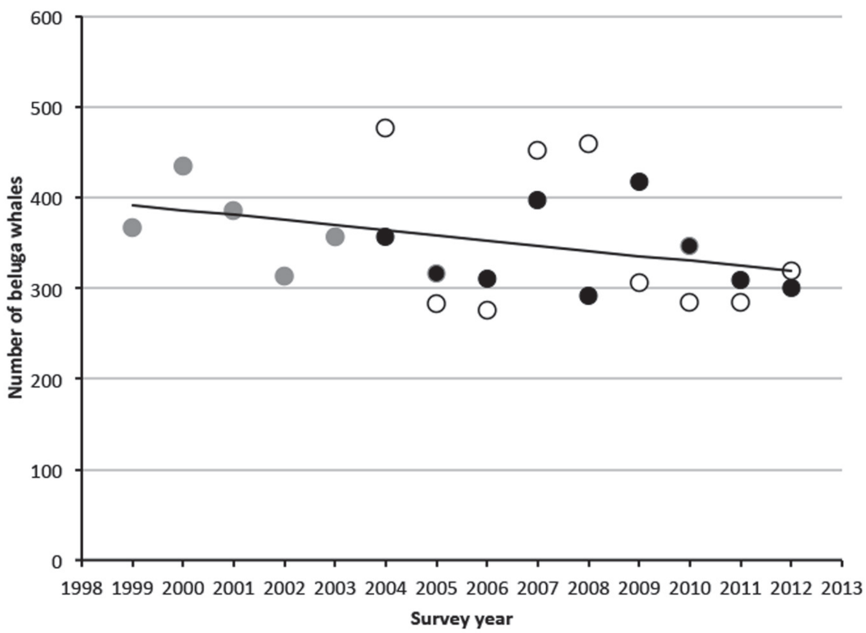

Figure 6. —Abundance estimates and trend for beluga whales in Cook Inlet during the hunting quota years (1999–2012) using analysis by week and sector. For 1999 to 2003, the existing estimates based on one-week surveys and sector analysis (c.f. Hobbs et al., 2000b) are presented as gray circles. For 2004 to 2012, the two-week surveys were divided into one-week surveys and sector analysis was applied to each week to obtain independent abundance estimates (shown as pairs of estimates for each year: week 1 = white circles, week 2 = black circles). The trend line was calculated from 1999 to 2012 (using the averaged abundance estimates for the years 2004 to 2012) and shows a growth rate of –1.50% per year.

= 0.86%) (Fig. 6). The possible trends when week 1 and week 2 were analyzed in all 512 possible combinations by year ranged from -2.56% to -0.56% with an average annual growth rate of -1.57% (Fig. 7). All of these trends fell within the 95% confidence interval of the current trend (-3.24%, +0.01%). Overall, the trend in growth remained negative regardless of the choice of weeks, averaging the weeks, or applying sector analysis.

Conclusions

With the distinctive geography of Cook Inlet and the affinity of beluga whales for specific locations, the survey design applied here covered all known prime beluga whale habitat several times as well as sampling areas where beluga whales are rarely seen. Relative to line transect survey techniques, these surveys of Cook Inlet are positively biased towards finding whales and, therefore, are not treated as random samples. The consistency of whale counts from day to day and year to year is a clear indication of the resolution of the sampling protocol; that is, these aerial surveys have a proven ability to find a high proportion of the beluga whale groups in Cook Inlet during each sampling period. Furthermore, counts have been remarkably repeatable between years with relatively small coefficients of variation, notable considering that this is a whale population being surveyed from an aircraft.

Collecting additional behavioral data will be key to further improvements in the precision of the abundance estimates, as the variability in the surfacing interval accounts for over half of the variation in the new *CV* estimates. With data from only one tagged beluga, without corresponding aerial observation, it is not possible to revise the abundance estimation procedure, only the estimate of variation. Results from tagging several animals in several years with corresponding aerial observations will be necessary to develop these correction methods.

Beluga whales in Cook Inlet have not shown appreciable signs of recovery since 1999 when hunting restrictions began. Although a significant decline in abundance was documented during the first 5 years of systematic abundance estimates conducted by NMFS from 1994 to 1998 (Hobbs et al., 2000b), there are few empirical data prior to this period except for a credible estimate of 1,300 beluga whales in Cook Inlet in 1979 (Calkins[4]). Between 1979 and 1994, there is insufficient information to model the apparent loss of half of this population from 1,300 to 650 beluga whales, which represents an average annual decline of around 5% (see Hobbs et al., in press b). However it suggests that the population was depleted in 1994 and is now at a depletion level of less than 25% of carrying capacity.

An Alaskan Native subsistence hunt (quantified through hunter interviews) was significant during the 1970's and 1980's and may have been at levels similar to the hunts reported in the mid-1990's (Huntington, 2000; Mahoney and Shelden, 2000). Also, commercial and sport hunts occurred during the 1960's and 1970's (Mahoney and Shelden, 2000). Therefore, the highest available abundance estimate of 1,300 may already represent a partially depleted population.

Compared to other cetacean species in U.S. waters, the Cook Inlet beluga is unique in the level of survey effort. A review of monitoring of marine mammal stocks in U.S. waters found only one other stock that was monitored on an annual basis (via a photo identification catalog) and no other

[4]Calkins, D. G. 1989. Status of belukha whales in Cook Inlet, *In* L. E. Jarvela and L. K. Thorsteinson (Editors), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information update meeting, 7-8 Feb. 1989, Anchorage , Alaska, p. 109–112. U.S. Dep. Inter., Minerals Manage. Serv., OCS Study, MMS 89-0041.

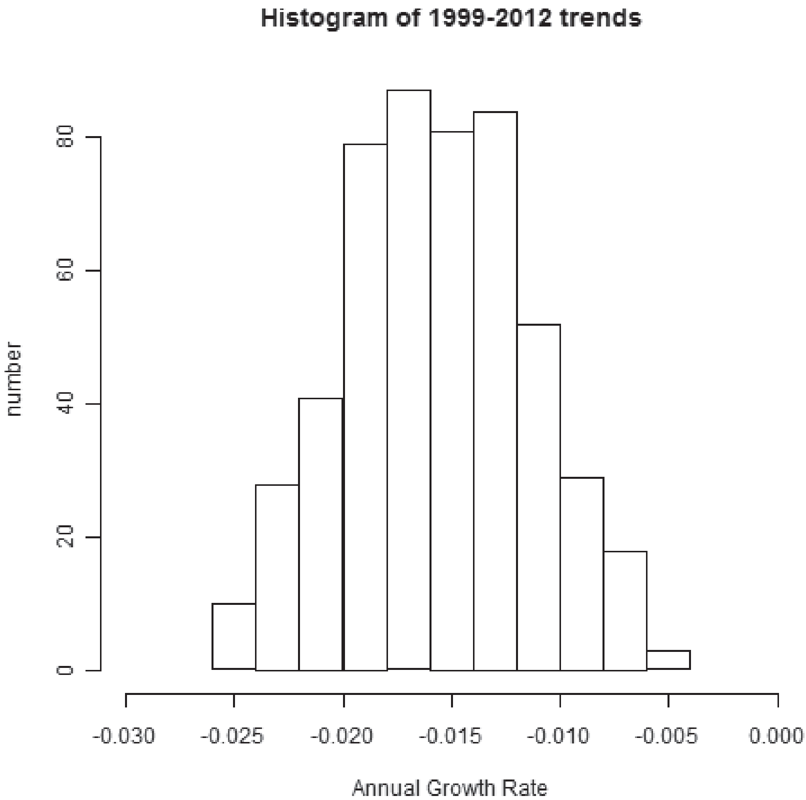

Figure 7. —Growth rate trends for Cook Inlet beluga whales based on abundance estimates from 1999 to 2012. For 1999 to 2003, the existing estimates based on one-week surveys and sector analysis (c.f. Hobbs et al., 2000b) were used. For 2004 to 2012, the two-week survey was divided into one-week surveys and sector analysis was applied to each week to obtain independent abundance estimates. All possible combinations (512) of one-week estimates were used to calculate a growth rate for each time series. These growth rate trends were rounded to the nearest 0.1%. The distribution of trends resulted in an average growth rate of –1.57% per year.

cetacean population with abundance estimates with *CV*'s consistently below 15% (Taylor et al., 2007). Thus, this 19-year time series of aerial surveys represents an outlier among the monitoring efforts of endangered cetaceans, but it has allowed us to demonstrate convincingly that the Cook Inlet stock continues to decline. The decline appears to be continuous and gradual suggesting that the population mechanisms involved are chronic decreases in fecundity and/or survival rather than a few unfortunate events of unusual mortality.

By 1999, there were sufficient data to indicate a clear decline in abundance of beluga whales in Cook Inlet, and in response, hunters instituted a moratorium on the hunt while NMFS and Congress moved to regulate the hunt. Although the rate of decline diminished from about 14% per year during 1994–1998 to <2% per year after the cessation of unregulated hunting in 1999, no satisfactory explanation is yet available for the continued decline. A similar lack of recovery has been noted in eastern tropical Pacific dolphins, *Stenella* sp. (Gerrodette and Forcada, 2005; Wade et al., 2007) as well as other odontocetes, leading to speculation that odontocetes in general may have difficulty recovering from over exploitation (Wade et al., 2012). However we must contrast this with the Bristol Bay population of belugas which is growing at an average rate of 4% per year after a period of depletion (Lowry et al., 2008). Further monitoring and research to investigate the mechanisms of decline will be required to determine the reason for the current decline of the Cook Inlet beluga and are critical to the management and recovery of this small, isolated population.

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Literature Cited

Gerrodette, T., and J. Forcada. 2005. Non-recovery of two spotted and spinner dolphin populations in the eastern tropical Pacific Ocean. Mar. Ecol. Prog. Ser. 291:1–21. http://dx.doi.org/ 10.3354/meps291001.

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

_____________, D. J. Rugh, and D. P. DeMaster. 2000b. Abundance of beluga whales, *Delphinapterus leucas,* in Cook Inlet, Alaska, 1994–2000. Mar. Fish. Rev. 62(3):37–45.

_____________, C. L. Sims, K. E. W. Shelden, L. Vate Brattstrom, and D. J. Rugh. In press a. Annual calf indices for beluga whales, *Delphinapterus leucas,* in Cook Inlet, Alaska, 2006-12. Mar. Fish. Rev. 77.

_____________, P. R. Wade, and K. E. W. Shelden. In press b . Viability of a small, geographically-isolated population of beluga whales, *Delphinapterus leucas:* Effects of hunting, predation, and mortality events in Cook Inlet, Alaska. Mar. Fish. Rev. 77.

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

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.

Lerczak, J. A., K. E. W. Shelden, and R. C. Hobbs. 2000. Application of suction-cup attached VHF transmitters to the study of beluga, *Delphinapterus leucas*, surfacing behavior in Cook Inlet, Alaska. Mar. Fish. Rev. 62 (3):99–111.

Litzky, L. K. 2001. Monitoring recovery status and age structure of Cook Inlet, Alaska beluga whale by skin color determination. M.S. thesis, Univ. Wash., Seattle, 76 p.

Lowry, L. F., K. J. Frost, A. Zerbini, D. DeMaster, and R. R. Reeves. 2008. Trend in aerial counts of beluga or white whales (*Delphinapterus leucas*) in Bristol Bay, Alaska, 1993–2005. J. Cetacean Res. Manage. 10(3):201–207.

Mahoney, B. A., and K. E. W. Shelden. 2000. Harvest history of beluga whale, *Delphinapterus leucas*, in Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):124–133.

McLaren, I. A. 1961. Methods of determining the numbers and availability of ringed seals in the eastern Canadian Arctic. Arctic 14(3):162–175.

NOAA. 2000a. Designating the Cook Inlet, Alaska, stock of beluga whale as depleted under the Marine Mammal Protection Act (MMPA). 65 Fed. Regist. 34590 (31 May 2000), p. 34,590–34,597 (avail. online at: https://federalregister.gov/a/00-13371).

__________. 2000b. Taking of the Cook Inlet (CI), Alaska, stock of beluga whales by Alaska Natives. 65 Fed. Regist. 59164 (04 Oct. 2000), p. 59,164–59,170 (avail. online at: https://federalregister.gov/a/00-25481).

__________. 2008. Endangered and threatened species; endangered status for the Cook Inlet beluga whale. 73 Fed. Regist. 62919 (22 Oct. 2008), p. 62,919–62,930 (avail. online at: https://federalregister.gov/a/E8-25100).

O'Corry-Crowe, G. M. 2002. Beluga whale (*Delphinapterus leucas*). *In* W. F. Perrin, B. Wursig, and J. G. M. Thewissen (Editors), Encyclopedia of marine mammals, p. 94–99. Acad. Press, N.Y.

___________. 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. http://dx.doi.org/10.1046/j.1365-294x.1997.00267.x.

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.

___________, _________. 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.

Seber, G. A. F. 1973. The estimation of animal abundance and related parameters. Hafner Press, N.Y., 506 p.

Shelden, K. E. W., D. J. Rugh, K. T. Goetz, C. L. Sims, L. Vate Brattström, J. A. Mocklin, B. A. Mahoney, B. K. Smith, and R. C. Hobbs. 2013. Aerial surveys of beluga whales, *Delphinapterus leucas*, in Cook Inlet Alaska, June 2005–2012. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-263, 122 p.

_____________, K. T. Goetz, D. J. Rugh, D. G. Calkins, B. A. Mahoney, and R. C. Hobbs. In press. Spatio-temporal changes in beluga whale, *Delphinapterus leucas*, distribution: results from aerial surveys (1977–2012), opportunistic sightings (1975–2012), and satellite tagging (1999–2003), in Cook Inlet, Alaska. Mar. Fish. Rev. 77.

Taylor, B. L., M. Martinez, T. Gerrodette, J. Barlow, and Y. N. Hrovat. 2007. Lessons from monitoring trends in abundance of marine mammals. Mar. Mammal Sci. 23(1):157–175. http://dx.doi.org/10.1111/j.1748-7692.2006.00092.x.

Wade, P. R., G. M. Watters, T. Gerrodette, and S. B. Reilly. 2007. Depletion of spotted and spinner dolphins in the eastern tropical Pacific: modeling hypotheses for their lack of recovery. Mar. Ecol. Prog. Ser. 343:1–14. http://dx.doi.org/10.3354/meps07069.

__________, R. R. Reeves, and S. L. Mesnick. 2012. Social and behavioural factors in cetacean responses to overexploitation: are odontocetes less "resilient" than mysticetes? J. Mar. Biol. 2012(Article ID567276), 15 p. (http://dx.doi.org/10.1155/2012/567276).

Appendix.—Correction factors applied to video and observer data to estimate group sizes during aerial abundance estimate surveys of Cook Inlet, Alaska, beluga whales (excerpted from Hobbs et al. (2000a:50–52).

Correction for Perception Bias

Detecting whales in video recordings is limited by the resolution of the video system. Probability of detection was measured by comparing the whales seen in the zoomed video to those seen in the corresponding region on the counting video. The whale images in the zoomed video were each assigned to one of three categories: 1) whales that were seen in both the zoomed and counting video; 2) whales in the zoomed video that were missed in the counting video due to proximity—two whales surfacing close to each other appear as one large image on the counting video; or 3) image size—a whale seen in the zoomed is too small or gray so that it falls below a threshold and does not form a visible image on the counting video. The two mechanisms (proximity and image size) that affect whale detection in the counting video require different approaches for correction.

Proximity Correction

When two whales were close enough together to appear as a single whale on the counting video, the space between them was much narrower than the width of an average whale. Consequently, these two images would be merged throughout the typical range of magnifications used in the counting video, regardless of their relative size. Thus, a constant ratio could be used to correct for whales missed due to proximity:

$$\frac{J_z}{J_z - J_p},$$

where J_z is the number of whales seen in the zoomed video and J_p is the number of whales missed due to proximity.

Image Size Correction

The resolution of a video system is limited by the density of scan lines in the video recording system and the density of pixels on the display monitor. This process of scanning and pixelation has the effect of smearing images and edges by averaging the gray scale and hue across each pixel. If a pixel is half water and half beluga, then it will appear to have a gray scale and hue halfway between that of the water and the beluga. A large, white beluga will appear as a bright white ellipse with a fuzzy edge that fades to the gray scale of the water. A gray beluga will appear as a gray ellipse with a less distinct fading to the water color. Small, gray belugas or distant belugas of any hue may not have a sufficiently large image to completely fill any pixels so that the image is entirely made up of these averaged pixels. Because the edge of the image has been blurred, it is necessary to interpret by eye the margin of the image from the surrounding background. Experience has shown that with a limited amount of training, consistent and repeatable measurements of beluga images can be made. However, the measurement method is partially subjective, so it is necessary to estimate the bias in the interpreted image size. The smearing occurs only at the edges, so the bias should be independent of size. The gradient that is interpreted is dependent on the difference in hue between the object and the background. The subjectivity involves a determination of the point along this gradient that is the edge of the image.

The lengths of the images at the midtimes of beluga surfacings matched between the counting and zoomed videos can be related by the following formula:

$$\frac{L_z}{m} = \frac{l_z - b}{m} = l_c - b = L_c,$$

where L_z and L_c are the unbiased sizes of the whale images on the zoomed and counting videos, respectively; l_z and l_c are the measured sizes of the whale images on the zoomed and counting videos, respectively; m, is the relative magnification between the zoomed and counting video frames (obtained as the ratio of the distance between centers of two whale images seen on both the counting and zoomed video); and b is the bias resulting from smearing of the edge. An average value for the bias can be estimated from several image pairs as,

$$\hat{b} = \frac{\sum_{j=1}^{J_n}(l_{zj} - m_j l_{cj})}{\sum_{j=1}^{J_n}(1 - m_j)},$$

where J_n is the number of whales seen in both the zoomed and counting video, and j is the index of the jth pair. If b was not significantly different from zero, it was not necessary to correct for bias.

The following equation was then used to estimate the image size in the counting video for the whales that were visible in the zoomed video but, because of their size, were not detected in the counting video. The estimated image size for these whales in the counting video was:

$$\hat{l}_c = \frac{l_z - \hat{b}}{m} + \hat{b}.$$

A binomial logistic regression was applied to the resulting combined distribution of measured and estimated standard image sizes to estimate the probability that a whale with a given image size would be seen in the counting video.

For a given group, g, and pass, p, m is not known. Instead, the average of image sizes, $\mu_{g,p}$, and the fractions of whales that would be detected, $F(\mu_{g,p})$, in a counting video are related. To determine this relationship, arbitrary values for magnification, m' , (e.g., magnification increasing at 0.01 intervals) are chosen to span the range of possible magnifications. The combined distribution of observed (whales seen in both the zoomed and counting video) and estimated (whales seen in the zoomed but missed in the counting because of small size) counting video sizes are then re-scaled by

$$\hat{l}_{m'j} = (l_{cj} - \hat{b})m' + \hat{b}$$

to simulate the distribution of image sizes under these arbitrary magnifications. For this re-scaled distribution, the average of image sizes, $\mu(m')$, and the fractions of whales, $F(\mu(m'))$, that would be detected in a counting video are

$$\mu(m') = \frac{\sum_{J_n+J_w} P(\hat{l}_{m'j})\hat{l}_{m'j}}{\sum_{J_n+J_w} P(\hat{l}_{m'j})}$$

$$F(\mu(m')) = \frac{\sum_{J_n+J_w} P(\hat{l}_{m'j})}{J_n + J_w}$$

where $P(l)$ is the probability that an image of size l will be seen in the counting video. A lookup table relating average image size for a group counted from video, $\mu_{g,p}$, to the correction for the fraction that were missed because of image size, $1/F(\mu_{g,p})$, was created from this analysis. For passes with a sample of measured images, the fraction missed was found in the table. Passes of small groups where images were not measured were given the average fraction missed from other passes of the same group, or if no other passes on the group had measured images, the pass was given the average fraction missed of all measured passes from all groups.

Combined Correction Factor

The correction for perception bias was the product of the proximity correction and the image size correction. For a video count with an estimated average image size, $\hat{\mu}_{gp}$, the correction factor, $D_{g,p}$ is then,

$$D_{gp} = \left[\frac{J_z}{J_z - J_p}\right]\frac{1}{F(\mu(m'))}.$$

Correction for Availability

The formula of McLaren (1961) for the correction for availability bias is the inverse of the probability that a typical beluga is at or will appear at the surface during the videotaping. The correction factor, $A_{g,p}$, for a group and pass depending on the time spent counting, $t_{g,p}$, is calculated as,

$$A_{g,p} = \frac{T_I}{T_s + t_{g,p}},$$

where T_I is the average dive interval (24.1 sec., Lerczak et al., 2000), and T_s is the average time at the surface from the video analysis described above.

Estimation of Group Size

The group size, $\hat{n}_g$, was estimated by averaging the corrected video counts for a group:

$$\hat{n}_g = \frac{1}{P_g}\sum_{P_g} c_{g,p} D_{g,p} A_{g,p},$$

where, $c_{g,p}$ is the count for group g from pass p, and P_g is the number of passes for group g that were counted. When a video pass contained two or more distinctly different segments (e.g., it began using the point method, then switched to the scan method when the first portion of the group came abeam of the plane), the counts were corrected separately to create a group size estimate for each subgroup. These subgroup estimates were then summed to estimate the total group size.

The coefficient of variation (CV) for $\hat{n}_g$ was estimated as:

$$CV(\hat{n}_g) = \sqrt{\frac{\overline{CV}^2(n)}{P_g} + \overline{CV}^2(D_g) + \overline{CV}^2(A_g)}$$

An average CV for a group size estimate made from a single count was estimated by averaging the variation of the group size estimates of all groups where more than one pass from the group was counted from video(G_2),

$$\overline{CV}^2(n) = \frac{\sum_{G_2} \frac{1}{P_g - 1} \sum_{P_g} (n_{g,p} - \overline{n}_g)^2}{\sum_{G_2} \overline{n}_g^2}.$$

Where more than one count is used to estimate group size, this average CV is scaled appropriately. The value $CV(n)$ includes an empirical measure of stochastic variation between counts that is not corrected by the two correction factors, but it does not account for the variation of the correction factors themselves which must be accounted for separately.

The component of the CV resulting from the correction for perception, $CV(D_g)$, is estimated by the delta method as,

$$\overline{CV}^2(D_g) = \frac{\sum_{P_g} \left[\left. \frac{\partial D}{\partial \mu} \right|_{\mu_{g,p}} \right]^2 SE^2(\mu_{g,p})}{\left[\sum_{P_g} D_{g,p} \right]^2}.$$

For cases where $\mu_{g,p}$ was not estimated, the correction factor $D_{g,p}$ was derived from an average of $\mu_{g,p}$ from other passes of the same group or an average of other groups. In these cases $SE(\mu_{g,p})$ was the standard deviation of the set of the estimated average image sizes of the averaged groups.

The component of the CV resulting from the correction for availability, $CV(D_g)$, is dominated by the variation of T_I. The variation of T_I has a component related to the variability between individuals and the variation of a typical individual. Following the delta method yields,

$$\overline{CV}^2(A_g) = \frac{\sum_{P_g} \left[\frac{1}{T_S + t_{g,p}} SE_g(T_I) \right]^2}{\left[\sum_{P_g} A_{g,p} \right]^2} = \frac{\frac{\sigma_A^2 + \sigma_I^2}{\hat{n}_g} \sum_{P_g} \left[\frac{1}{T_S + t_{g,p}} \right]^2}{\left[\sum_{P_g} A_{g,p} \right]^2}$$

where σ^2_A (= 41 sec^2 , σ_A = 6.4 sec) and σ^2_I (= 707 sec^2 , σ_I = 26.6 sec) are the variance of the average dive interval among individuals and the average variance of the dive interval of individuals, respectively (values taken from Lerczak et al., 2000). Note that in this formulation, $CV(A)$ was not independent of group size because of the assumption that the dive behavior of individuals in the group is uncorrelated so that the variation in the average of dive intervals during the counting interval decreases as group size increases.

Group Size Estimates from Observer Counts

Good quality video was not available for all groups, so a method for estimating group size from observer counts was devised. Aerial counts of beluga whales were corrected for observer differences and the effect of encounter rate (group density in whales per second). Data from observers who had participated in the equivalent of one or more complete survey seasons (three surveys of the upper inlet and one survey of the lower inlet) were included in the analysis. Only counts made during passes considered by the observers to be excellent or good in quality (A or B) were used. Group sizes, estimated from video recordings, were used to represent the true group size.

This method provided a correction for availability and perception as well as the uncertainty in the time available to observers to count individual whales. The correction formula was derived by regression of the video-derived group sizes against the observer counts for those groups and an interaction term between the counts and the observed encounter rate with the intercept fixed at zero:

$$\hat{n}_{g,p,o} = \hat{b}_{1,o} c_{g,p,o} + \hat{b}_{2,o} \frac{c_{g,p,o}^2}{t_{g,p}}$$

$$Var(\hat{n}_{g,p,o}) = SE^2(\hat{b}_{1,o}) c_{g,p,o}^2 + 2Cov(\hat{b}_{1,o}, \hat{b}_{2,o}) \frac{c_{g,p,o}^3}{t_{g,p}} + SE^2(\hat{b}_{2,o}) \frac{c_{g,p,o}^4}{t_{g,p}^2},$$

Where $\hat{n}_{g,p,o}$ is the size estimate for group g from a count by observer o during pass p, $\hat{b}_{1,o}$, $\hat{b}_{2,o}$ are the parameters estimated for each observer by linear regression, $c_{g,p,o}$ is the count by observer o of group g during pass p, $t_{g,p}$ is the time spent counting group g during pass p, $SE^2(\ )$ is the squared standard error of the regression coefficients, and $Cov(\ )$ is the estimated covariance of the regression coefficients.

This approach weights the correction formula to be most accurate for large groups where a bias would have the greatest impact on the abundance estimate. The first summand estimates a multiplicative correction for counts to group size; the second summand estimates an additive bias proportional to the count multiplied by the density of the group. For aerial counts without recorded time, a single multiplicative correction was also estimated. The correction formula was applied to counts from groups where no group size estimate was available through the video analysis. These corrected counts were then averaged to estimate the group size:

$$\hat{n}_g = \frac{\sum_{J_g} \hat{n}_{g,p,o}}{J_g}$$

$$Var(\hat{n}_g) = \frac{\sum_{J_g} (\hat{n}_g - \hat{n}_{g,p,o})^2}{J_g - 1} + \frac{\sum_{J_g} Var(\hat{n}_{g,p,o})}{J_g^2}$$

where $\hat{n}_g$ is the estimated size of group g, and J_g is the set of corrected observer counts for group g.