Aerial Surveys of Bristol Bay Beluga Whales, *Delphinapterus leucas*, in 2016

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ABSTRACT—Beluga whales, (Delphinapterus leucas), *of the Bristol Bay stock were counted from 7 to 11 July 2016, during aerial surveys in Bristol Bay, Alaska. These surveys were a follow-up of surveys flown in Bristol Bay in 1993, 1994, 1999, 2000, 2004, and 2005, and used the same methods. Nine surveys were flown during 7–11 July. The total count of belugas per survey ranged from 484 to 1,024 (= 660; CV = 0.26). Correcting the average count for the number of belugas that are diving and not available to be sampled (2.62) and the proportion of calves (1.18) that cannot be seen from the aircraft suggests there are ~2,040 belugas (660 × 2.62 × 1.18) in Bristol Bay. The mean and range of counts made in 2016 is similar to those in 2004 and 2005 suggesting that the population growth observed during 1993–2005 has slowed or ceased. The greatest challenge with how belugas are surveyed within Bristol Bay is the difficulty in counting large groups. Separate counts of large groups had high variance and we suggest future surveys consider photo-documenting groups to determine if groups of belugas can be counted more consistently or using video to adjust for beluga behavior in real-time.*

Introduction and Methods

Beluga whales, *Delphinapterus leucas*, are small cetaceans (≤5.5 m), that live in seasonally ice-covered waters in Arctic and subarctic regions. The Bristol Bay stock of beluga whales is one of five known stocks that frequent Alaska waters, the other stocks being the Cook Inlet, eastern Bering Sea, eastern Chukchi Sea, and Beaufort Sea stocks (Frost and Lowry, 1990; O'Corry-Crowe et al., 1997, 2002, 2018). The Bristol Bay stock is restricted to Bristol Bay year-round (Lowry et al., 2008; Citta et al., 2016a, b) and is genetically distinct from other stocks (O'Corry-Crowe et al., 1997, 2002, 2018).

Periodic monitoring of beluga abundance in Bristol Bay is necessary for a variety of reasons. First and foremost, the population is relatively small, numbering fewer than 3,000 belugas (Lowry et al., 2008). Second, this population is important to Alaska Natives; during 2006–2016 the annual average harvest was 23 belugas (Lowry et al., 2019). Last, Bristol Bay has a number of commercial and subsistence fisheries that pose a risk of entanglement to belugas (Frost et al.[1]), including the largest commercial sockeye salmon, *Oncorhynchus nerka*, fishery in the world (Jones et al.[2]). The last aerial survey of beluga abundance in Bristol Bay was in 2005; therefore, an updated survey was necessary to assess the status of this population.

Aerial surveys were conducted during 7–11 July 2016, to count belugas of the Bristol Bay stock in Bristol Bay, Alaska. These surveys were a follow-up of surveys flown in Bristol Bay in 1993, 1994, 1999, 2000, 2004, and 2005 (Lowry et al., 2008), and used the same methods. Aerial surveys were flown using a high-wing, twin-engine *Aero Commander*[3] with oversized bubble windows. The survey crew included a pilot, a co-pilot, two observers (one seated behind the pilot and the other behind the co-pilot on the left and right sides of the aircraft), and a data recorder seated in the rear of the aircraft. The survey was designed to cover Kvichak and Nushagak bays (Fig. 1) where essentially all reported June–July sightings of belugas have occurred (see Fig. 3 in Frost and Lowry, 1990), where belugas were sighted during previous June–July aerial surveys (Lowry et al., 2008), and where all belugas with satellite data recorders were known to range in June and July (Citta et al., 2016a).

The standard survey transect followed the entire coast of both bays 0.9 km offshore, including the lower parts of major rivers. In the wider portions of the bays, east-west transects at 1.8 km intervals were flown to cover the entire area and observers counted whales in a strip 0.9 km wide on each side of the plane. Strip widths were measured by inclinometers and angles were marked on the aircraft windows with grease pencils for reference during surveys. Survey altitude was 305 m along the coast and 150 m when surveying rivers. Airspeed was approximately 222 km/h during all surveys. All surveys were flown in early July

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[1]Frost, K. J., L. F. Lowry, and R. R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. *In* B. R. Melteff, (Editor), Proceedings of the workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, p. 187–200. Alaska Sea Grant Report 84-1, Univ. Alaska, Fairbanks, AK. Alaska Sea Grant. P.O. Box 755040, 201 Elvey Building, Fairbanks, AK 99775-5040.

[2]Jones, M., T. Sands, S. Morstad, P. Salomone, G. Buck, F. West, C. Brazil, and T. Krieg. 2013. 2012 Bristol Bay area annual management report. Alaska Dep. Fish Game, Fish. Manage. Rep. 13-20, Division of Commercial Fisheries, Anchorage, AK (avail. at www.adfg.alaska.gov/FedAidPDFs/FMR13-20.pdf).

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

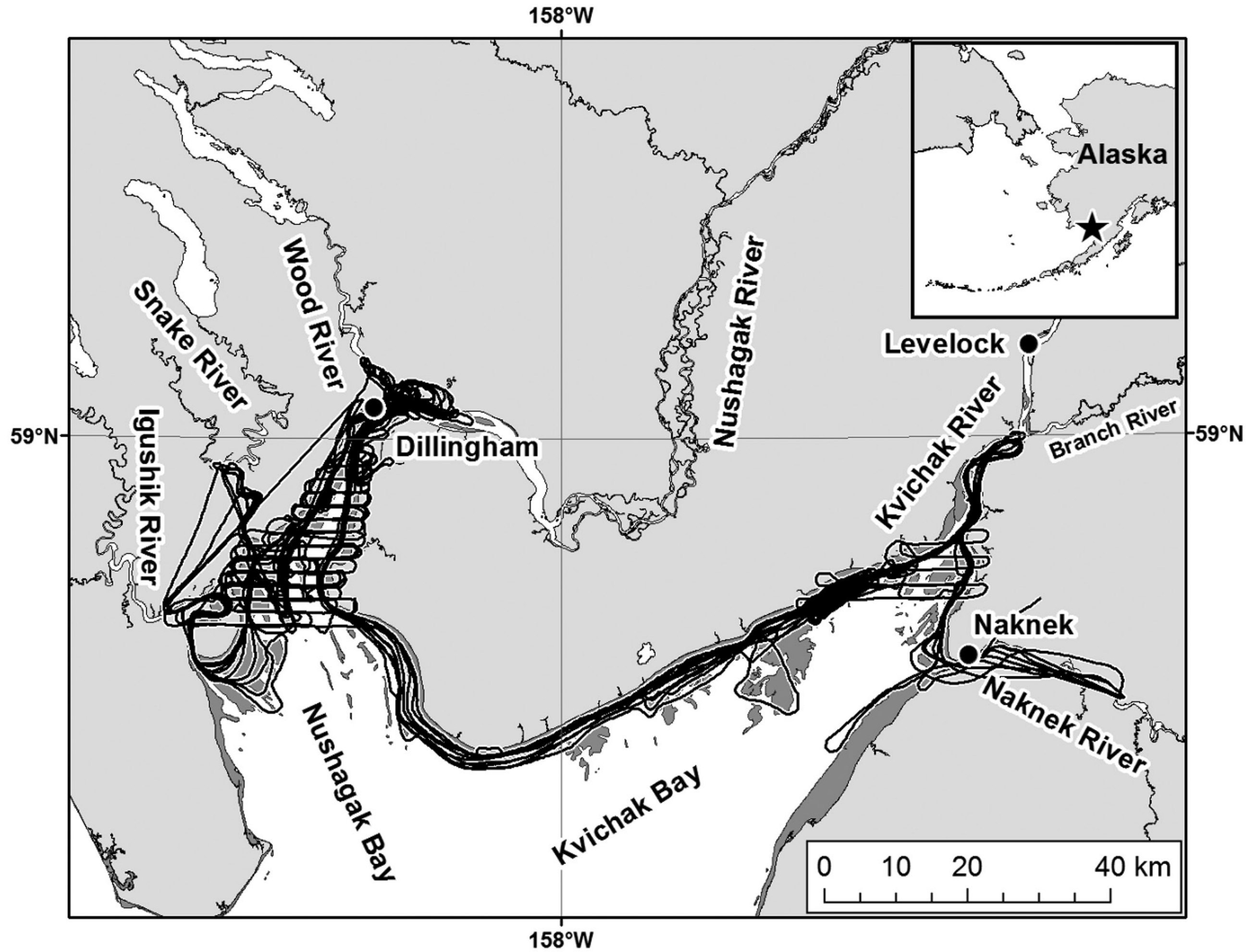

Figure 1.—Survey lines flown in Bristol Bay, Alaska, 7–11 July 2016. Dark gray areas are mudflats exposed at low tide.

when belugas aggregate near-shore and at the mouths of creeks and rivers to feed on a large sockeye salmon run.

All belugas visible at the surface along the survey track were counted. When large groups were encountered, multiple counts were made of the same group. In those situations the aircraft circled after passing by the group and flew past again on a line oriented to provide one observer the best view of the entire group. Multiple counts, usually by both observers, were recorded individually, and observers identified which counting pass was best based upon viewing conditions, such as minimum glare or position of the group relative to the aircraft (i.e., no whales in the blind spot directly under the plane). The best count for each group was used in analysis of the data. Beluga counts, weather, sea state, glare, overall sighting conditions, and other observations were entered into a computer database that also recorded the aircraft's position every 60 s. Database software was provided by the National Marine Fisheries Service (NMFS), Marine Mammal Laboratory (MML) and is also used during beluga surveys in Cook Inlet.

Results and Discussion

Nine surveys were flown during 7–11 July. The total count of belugas per survey ranged from 484 to 1,024 ($\bar{X}$ = 660; CV = 0.26) on days with good or excellent viewing conditions (eight of nine survey flights; Fig. 2; Table 1). Counts from aerial surveys are typically corrected for availability bias, defined as the bias in the count due to belugas that were diving and not available to be sampled. Frost et al. (1985) used VHF transmitters to estimate an availability correction factor of 2.75, which was later revised to 2.62 by Frost and Lowry[4]. Because beluga calves are small and gray colored and are typically not spotted in the silty (i.e., gray-colored) water, a sepa-

[4]Frost, K. J., and L. F. Lowry. 1995. Radio tag based correction factors for use in beluga whale population estimates. Working paper for Alaska Beluga Whale Comm. Sci. Workshop, Anchorage, AK, 5–7 April 1995, 12 p. Avail. from North Slope Borough, Dep. Wildlife Manage., Box 69, Barrow, AK 99723.

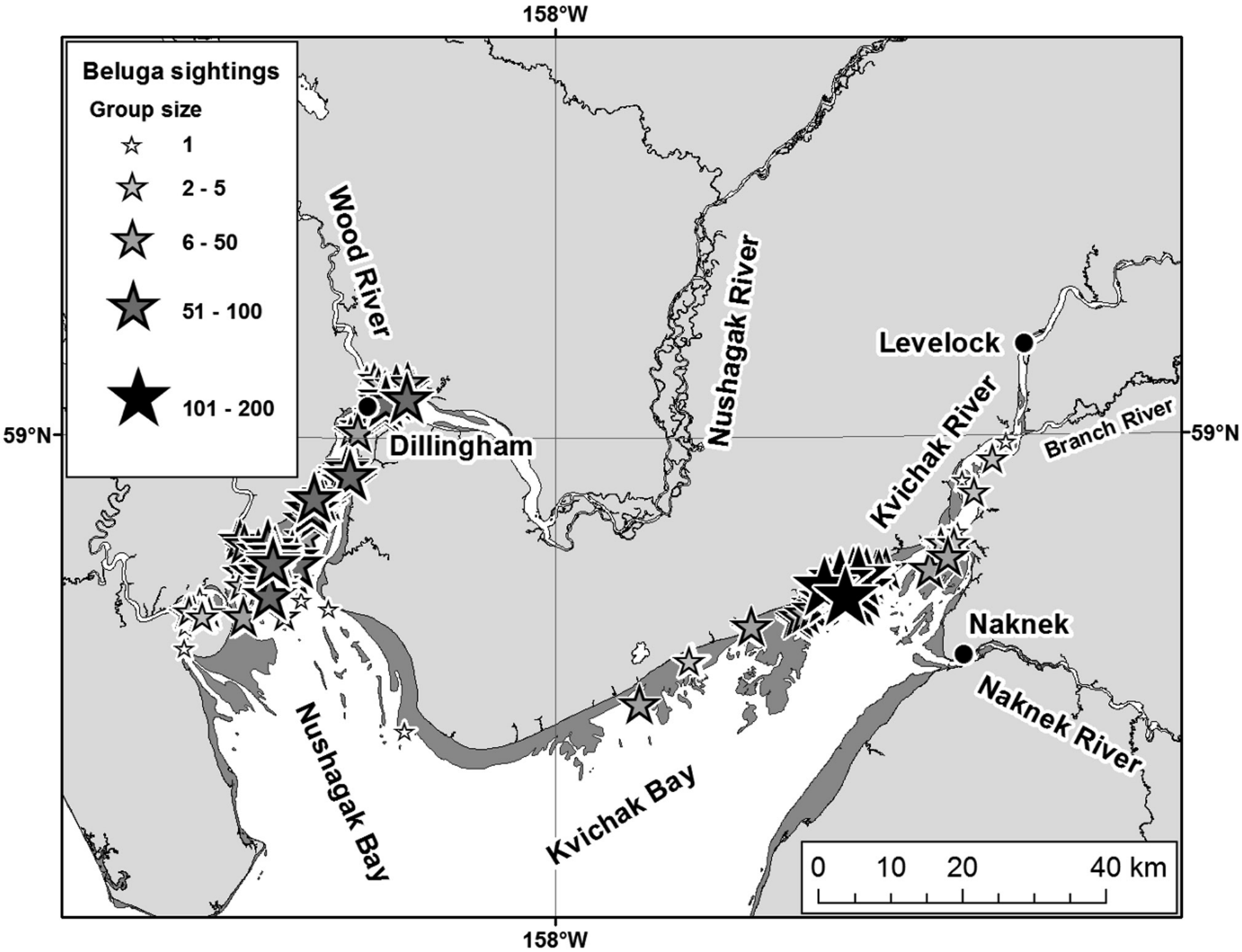

Figure 2.—Location of beluga sightings by group size in Bristol Bay, Alaska, 7–11 July 2016. Dark gray areas are mudflats exposed at low tide.

rate correction is sometimes used for calves (1.18; Brodie, 1971). Applying these corrections to the average count of belugas suggests there are 2,040 belugas (660 × 2.75 × 1.18) in Bristol Bay. Lowry et al. (2008) showed that the mean count of Bristol Bay belugas increased 4.8% per year (95% confidence interval (CI) = 2.1–7.5%) over the 12-year period, 1993–2005. After including the 2016 data in the regression analysis, increasing linear trends received the same statistical support as trends that allowed the growth in counts to lessen over time. For example, when using Akaike Information Criteria (AIC; Burnham and Anderson, 2002) to judge model support, we found that an increasing linear trend is 0.1 AIC units better than a curvilinear trend (i.e., count = year + year^2) that would allow counts to plateau or decline over time. Models within 2 AIC units of one another are considered plausible and two models within 0.1 AIC units have more-or-less equivalent support (Burnham and Anderson, 2002). Regardless, the mean and range of counts made in 2016 are similar to those in 2004 and 2005 (Fig. 3), suggesting that the population growth observed during 1993–2005 has slowed or ceased.

One goal of the survey effort in 2016 was to assess limitations of the current design and to determine if future surveys would benefit from the use of other sampling methods, such as distance sampling (e.g., Buckland et al., 1993; Thomas et al., 2010), double-observer (e.g., Buckland and Turnock, 1992; Chen, 1999), or photo/video methods (e.g., Lydersen et al., 2008; Hobbs et al., 2000a, b). We found that counts can vary considerably, even for surveys conducted on the same day and covering the same area. In 2016, the largest range of counts from replicate surveys (484 to 1,024) occurred on the same day, within a few hours of each other and with good or excellent viewing conditions (Table 1). Assuming that true population size was 2,000 belugas, then the availability correc-

Table 1.—Summary of aerial surveys for counting beluga whales in Bristol Bay, Alaska. Visibility rating scores are subjectively based upon the Beaufort wind scale and levels of glare (not shown). Because of glare, the view out one side of the aircraft is typically better than the other and large groups of belugas are typically counted from the side of the airplane that has the best visibility. Hence, when calculating proportions, we only used the better of the two visibility scores. The first survey (#1 below) was conducted as a practice run and visibility conditions were not as good as other surveys; hence, we did not use this survey when computing statistics.

					Proportion of visibility rating scores				
Survey no.	Date	Start time	End time	Average Beaufort scale	Excellent	Good	Fair	Count of belugas	Comments
1	7 July 16	15:54	18:00	2.2	0.00	0.79	0.21	200	Not used to compute statistics
2	8 July 16	10:19	13:09	1.0	0.25	0.75	0.00	484	
3	8 July 16	14:03	16:23	1.0	0.40	0.60	0.00	1,024	
4	9 July 16	10:34	13:03	1.0	0.67	0.33	0.00	756	
5	9 July 16	14:06	16:14	1.6	0.40	0.60	0.00	716	
6	10 July 16	10:31	13:35	1.8	0.29	0.71	0.00	521	
7	10 July 16	14:27	16:46	2.0	0.25	0.75	0.00	640	
8	11 July 16	10:12	13:02	1.8	0.65	0.35	0.00	595	
9	11 July 16	13:52	16:08	2.2	0.80	0.20	0.00	544	
								660	Average count
								174.53	SD
								0.26	CV

tion factor would have to range from approximately 4.13 to 1.95 on the same day to account for changes in beluga behavior and variability in the count (i.e., 484 × 4.132 ~ 2,000 and 1,024 × 1.953 ~ 2,000). Sampling designs aimed at reducing this variability will help in identifying the status of the stock and population trends.

We quickly concluded that distance sampling, a method that accounts for the fact that the probability of observation declines with distance, is not appropriate for surveying Bristol Bay belugas. To assess the applicability of distance sampling during the 2016 surveys, the data collector recorded sighting distances to each group of belugas. After the first two replicate surveys, we realized that virtually all belugas are observed in close proximity to shore (i.e., within about 100 m). Because there is so little variation in detection distance, there is not enough information (nor any need) to fit detection curves. The aircraft is positioned to provide the best view of shore and observers only need to scan the shoreline. Furthermore, belugas at this time of year are typically aggregated in large groups which are relatively easy to detect.

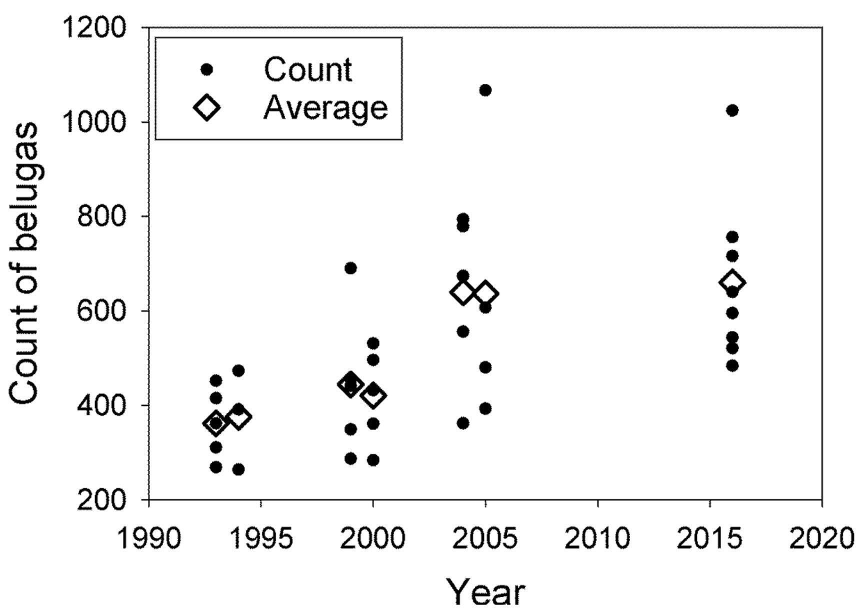

Figure 3.—Bristol Bay beluga counts and averages, 1993–2016.

We also conducted an informal experiment to assess if a correction factor is necessary for detection bias, also known as perception bias, which is defined as the bias due to observers not detecting belugas that are available to be counted. These corrections are typically estimated using multiple observers that record observations independently from one another, allowing the estimation of the probability that a group that is available to be detected is actually detected.

Because the sampling unit is a group of belugas, not individual belugas, we also wanted to know how detection varied by group size. For this informal experiment, the data recorder acted as the secondary observer and recorded the number and size of beluga groups that were missed by the primary observer on the same side of the aircraft. We found that all groups that were missed by the primary observer, but sighted by the secondary observer, had group sizes of one (n = 6) or two belugas (n = 2). No groups larger than two belugas were missed by the primary observer. Although groups of two or fewer belugas were the most common group size encountered (Fig. 4) and accounted for approximately 44% of all groups observed in 2011, these groups contributed little to the total count. Only 1.1% of the 5,480 belugas counted across all surveys occurred in group sizes of 1; likewise, only 1.1% occurred in group sizes of 2. Hence, even if the primary observer missed small groups quite often, which they

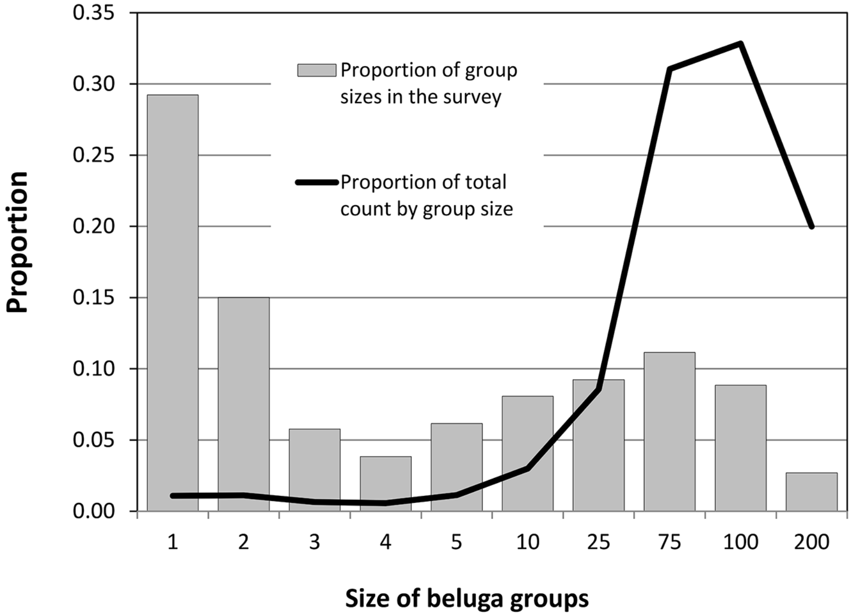

Figure 4.—Proportion of beluga group sizes (bars) observed and the proportion of the total count (line) contributed by each group size during aerial surveys in Bristol Bay, Alaska, 7–11 July 2016. Approximately 44% of all groups were composed of one or two belugas; however, only 2.2% of the total count occurred in groups of one or two belugas.

apparently do not, small groups probably do not contribute much to the overall count.

This is also the case for aerial surveys of belugas in Cook Inlet, Alaska, where double observers are used to estimate the probability of missing a group. Cook Inlet is a similar estuarine system as Bristol Bay and aerial surveys also follow the coastline (but also make more offshore flights; see Fig. 1 in Hobbs et al., 2015). During 2009–2016, the correction factor for missed groups ranged from 1.001 (in 2009) to 1.036 (in 2011; Shelden et al.[5]). Hence, in Cook Inlet, counts of belugas are typically corrected by less than 4% to account for groups that observers miss.

A more worrisome issue is how to count all the belugas in large groups. We conducted multiple counts of large groups and let observers identify which count was best, based upon observation conditions. If we look at multiple passes (i.e., counts) of the same group of belugas, we find that counts of group size sometimes varied by large amounts (Table 2). Although Table 2 includes counts that observers stated were not usable due to visibility concerns, this illustrates the uncertainty involved in counting large groups.

The fact that multiple passes are necessary to yield a count that observers think is valid also underscores the difficulty in counting large groups. We do not think that most of the variability in the count is due to our inability to count, but rather is due to beluga behavior. For example, if the diving behavior of individuals is correlated in such a way that many belugas dive or surface at the same time, then replicate counts of groups may exhibit large variation. Unfortunately, this cannot be assessed with the data available.

Because of the high variability in counts, both within and between surveys, we suggest that future surveys investigate how photo- (e.g., Lydersen et al., 2008; Terletzky and Ramsey, 2016) or video-based (e.g., Hobbs et al., 2000a, b) methods may be used to yield more precise counts or estimate real-time correction factors that account for beluga behavior at that moment, at least when counting large groups. Photos may allow for more precise counts and video may allow for the estimation of availability correction factors in real-time. For example, a commonly used correction factor (*CF*) is that of McLaren (1961):

$$CF = \frac{Dive\ interval}{Surface\ time + Observation\ time},$$

where the *dive interval* is the duration of time between surfacing events, *surface time* is the duration of surfacing events, and *observation time* is duration of time that a group is visible to observers. Laake et al. (1997) was able to estimate both surface intervals and dive intervals for groups of harbor porpoises, *Phocoena phocoena*, but only because they dove and surfaced as a group. Hobbs et al. (2000a) used video to estimate surface intervals for belugas in Cook Inlet, Alaska. Because belugas in Cook Inlet did not appear to dive and surface at the same time within groups and because individual belugas cannot be identified from the air, Hobbs et al. (2000b) could not estimate dive durations for individual belugas and had to use values from elsewhere. As in Cook Inlet, groups of belugas in Bristol Bay also do not dive and surface at the same time, so estimating dive intervals would be similarly difficult from an aircraft. We question the utility of using video to estimate surface intervals for beluga groups while assuming that the duration of dives is constant. Clearly, more research is needed to better estimate correction factors that account for changes in beluga behavior that occur during the aerial surveys.

A larger issue is whether it is better to improve aerial survey methods, including the development of improved correction factors, or to pursue completely different approaches for estimating abundance, such as genetic

[5]Shelden, K. E. W., R. C. Hobbs, C. L. Sims, L. Vate Brattström, J. A. Mocklin, C. Boyd, and B. A. Mahoney. 2017. Aerial surveys, abundance, and distribution of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2016. AFSC Proc. Rep. 2017-09, 62 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle, WA 98115.

Table 2.—Counted group size by replicate count (aircraft pass) for 11 large groups of belugas.

	Group number										
Pass	1	2	3	4	5	6	7	8	9	10	11
1	111	283	271	210	192	236	67	65	69	433	270
2	60	552	390	262	202	279	62	47	54	341	285
3	43	302	295	247	246	226	76	52	74	403	289
4		332	230	300	244	289	96		90	360	
5			260	269	278	268	80			364	
6				271			96				
Range	68	269	160	90	86	63	34	18	36	92	19

mark-recapture. During 2004–11, the Alaska Department of Fish and Game (ADFG), working with the Alaska Beluga Whale Committee and Alaska Native beluga hunters, collected skin samples from the Bristol Bay stock using biopsy tips mounted on jab-sticks. Genetic markers from the skin biopsies were used to identify individual belugas and these data were analyzed in a mark-recapture framework. Using a POPAN Jolly-Seber model, abundance was estimated at 1,928 belugas (95% CI = 1,611–2,337; Citta et al., 2018). Most belugas were sampled in Kvichak Bay at a time when belugas are also known to occur in Nushagak Bay (Fig. 1). The pattern of genetic recaptures between bays and data from belugas with satellite transmitters (Citta et al., 2016a) indicated that belugas in the two bays regularly mix, suggesting the estimate of abundance likely applies to all Bristol Bay belugas. However, because it is likely that some belugas did not enter the sampling area during sampling, this estimate of abundance is best considered a minimum population size.

Results from the genetic mark-recapture study (*N* = 1,928 belugas) are consistent with the estimate from the 2016 aerial surveys, after commonly used correction factors were applied (*N* = 2,040 belugas). The mark-recapture approach has the advantage of not requiring correction factors, has valid confidence intervals, and allows the estimation of other parameters, such as survival. However, as it was implemented, the mark-recapture estimate required 10 years of data collection and survival rates were indistinguishable from a value of 1 (Citta et al., 2018). Although the mark-recapture approach could be implemented with just a few years of data collection, a much higher sampling intensity would be necessary, which would add additional disturbance to a method that already causes more disturbance than aerial surveys. Furthermore, the mark-recapture estimate was likely biased low (Citta et al., 2018), so the close correspondence in abundance between the mark-recapture study and aerial surveys was at least partially due to chance.

One last consideration is cost; the multi-year genetic-mark recapture project cost ~$260,000, while the aerial surveys in 2016 cost ~$53,000 and yielded a similar estimate of abundance. Although aerial survey costs would be higher if photos or video methods were implemented, it would still likely cost much less than a genetic mark-recapture project. That all the surveys flown in 2016 could be repeated four or five times in lieu of a single mark-recapture study is significant. We are not stating that another mark-recapture study in Bristol Bay is unwarranted because genetic approaches are constantly improving. In particular, the 'close-kin' mark-recapture technique of Bravington et al. (2016), which allows use of closely related animals to act as recaptures, may allow estimating abundance from a single sample year. However, until improved methods can be successfully implemented, we conclude that relatively simple aerial surveys are cost-effective for assessing the status of Bristol Bay belugas.

Acknowledgments

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