Development of an abundance estimate for the eastern Bering Sea stock of beluga[1] whales (*Delphinapterus leucas*)

LLOYD F. LOWRY[2], ALEXANDRE ZERBINI[3,4], KATHRYN J. FROST[2], DOUGLAS P. DEMASTER[5] AND RODERICK C. HOBBS[3]

Contact e-mail: llowry@hawaii.rr.com

ABSTRACT

The first dedicated aerial surveys for beluga whales in the Norton Sound/Yukon Delta region of Alaska were flown during May, June and September 1992. During May 1992 surveys, all of the survey area was covered with pack ice and only a few belugas were seen. In June 1992, many whales were seen in the region of Pastol Bay and the Yukon River Delta, with a few animals seen in eastern Norton Sound. In September 1992, whales were more dispersed and occurred both off the Yukon Delta and in coastal waters of northern Norton Sound. Based on those results, subsequent surveys were flown in June 1993–95 and 1999–2000. In all years except 1999 when there was extensive sea ice in the area, belugas were common off the Yukon Delta and in southern Norton Sound. In most years they were also seen in central Norton Sound. Density and abundance were estimated from the 2000 survey as it represented the most recent data and had the most complete and systematic coverage of the area. In June 2000, belugas were rare in the northern portion of Norton Sound, so the study area was reduced to central and southern Norton Sound and the Yukon Delta, which was divided into four strata by latitude. The density that was estimated with the model that received most Akaike Information Criterion support was 0.121 belugas km^{-2} and the number of belugas at the surface in the study area was estimated to be 3,497 (CV = 0.37). A generally accepted correction factor for availability of 2.0 was applied, resulting in an abundance estimate for the eastern Bering Sea beluga stock in June 2000 of 6,994 (95% confidence interval 3,162–15,472). This estimate is likely to be conservative. There are no previous abundance estimates for this region, so a population trend cannot be determined. The available evidence suggests that the current Alaska Native subsistence harvest from this stock is sustainable. Beluga consumption of prey populations is likely significant in the regional ecosystem and may have a particular impact on some stocks of Pacific salmon.

KEYWORDS: WHITE WHALE; ARCTIC; BERING SEA; ABUNDANCE ESTIMATE; SURVEY-AERIAL; WHALING-ABORIGINAL; CONSERVATION; NORTHERN HEMISPHERE

INTRODUCTION

During the ice-free season along the western coast of Alaska, annual concentrations of beluga whales (*Delphinapterus leucas*; also called white whale) predictably occur in Bristol Bay, the Norton Sound/Yukon Delta region, Kotzebue Sound and at Kasegaluk Lagoon. This distribution pattern was used to identify three provisional management stocks (Frost and Lowry, 1990). Studies of mitochondrial DNA have confirmed the existence of three beluga stocks that occur in western Alaska during summer months (O'Corry-Crowe *et al*., 1997, 2002). These are referred to as the Bristol Bay stock, the eastern Bering Sea (EBS) stock and the eastern Chukchi Sea stock (Fig. 1). Studies of the distribution and abundance of belugas in Bristol Bay began in the 1950s (Brooks, 1955; Frost *et al*., 1984, 1985) and the eastern Chukchi Sea in the 1970s (Seaman *et al*., 1988; Frost *et al*., 1993). However, prior to 1992 there had been no dedicated surveys of beluga whales in the EBS region.

Prior to the surveys described in this paper there was little information on the distribution of EBS belugas beyond the knowledge of the traditional Alaska Native hunting areas, and places where whales were seen on an opportunistic basis. A compilation of all available observations showed that belugas occurred throughout the coastal zone of the northeastern Bering Sea, particularly from the mouth of the

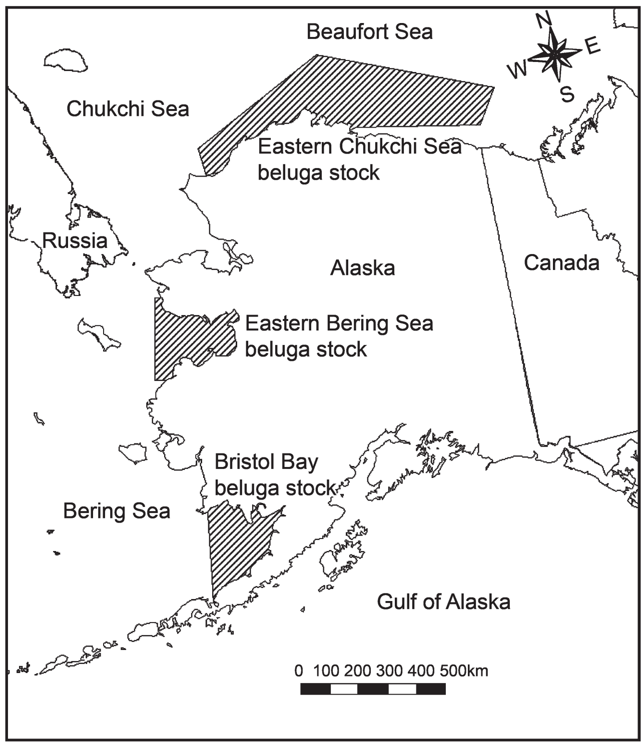

Fig. 1. Map showing the summer concentration areas of beluga whales in western Alaska (cross-hatching).

[1] The agreed common name for *Delphinapterus leucas* by the Scientific Committee of the International Whaling Commission is 'white whale.' However, 'beluga' is commonly used in several parts of the world, including Alaska, and is used in this paper.

[2] *University of Alaska, School of Fisheries and Ocean Sciences, 73-4388 Paiaha Street, Kailua Kona, HI 96740 USA.*
[3] *National Marine Mammal Laboratory, National Marine Fisheries Service, National Atmospheric and Oceanic Administration, 7600 Sand Point Way NE, Seattle, WA 98115 USA.*
[4] *Cascadia Research Collective, 218½ 4th Ave W, Olympia, WA, 98501, USA.*
[5] *Alaska Fisheries Science Center, National Marine Fisheries Service, National Atmospheric and Oceanic Administration, 17109 Pt. Lena Loop Road, Juneau, AK 99801 USA.*

Yukon River to northern Norton Sound near Nome. Relatively few sightings were reported far away from the shoreline (Frost and Lowry, 1990). Belugas were seen predominantly during ice-free months. This was from just after the breakup of the ice (usually mid-May) until freeze-up (usually November), and whales were harvested during spring, summer and autumn at villages in southern, eastern and northern Norton Sound (Lowry *et al*., 1989; Frost and Suydam, 2010). Traditional knowledge of hunters in the region indicated that the belugas arrive in the area at spring time and stay through to late autumn (Huntington, 1999).

Since 1992, the US Government has provided funds for the Alaska Beluga Whale Committee (ABWC) to conduct studies of beluga whales in Alaska. Part of the ABWC research program has consisted of aerial surveys to estimate the abundance and trends of western Alaska beluga stocks. This paper describes the results of ABWC surveys flown in the EBS over six years, 1992–95 and 1999–2000.

METHODS

Survey design and field methods

In 1992, several aerial surveys were conducted during three periods in May, June and September to assess the distribution of beluga whales during those periods (Lowry *et al*., 1999; DeMaster *et al*. 2001). The surveys found relatively few belugas in May and September, but a large number of whales in June. Based on those results, surveys in subsequent years were only conducted in June.

The survey was designed to cover coastal and offshore waters of Norton Sound and the Yukon Delta. Coastal transects were parallel to the shoreline with the centerline of the aircraft approximately 0.9km offshore. Offshore transects were flown east–west along lines of latitude, north–south along lines of longitude, or on diagonals when travelling to and from airports. An adaptive sampling design was used in 1992–95 to increase survey effort in areas where belugas had been sighted. When the whales were seen on an offshore transect, additional parallel transects were flown at a 3.6–9.3km spacing on both sides of the original line. Parallel transects were continued as long as whales were seen, and usually stopped after two transects if there were no sightings (Fig. 2). In 1999 and 2000, the survey was designed to cover all of Norton Sound and the Yukon River mouth with east–west transects regularly spaced at 9.3km intervals (Fig. 3).

The total length of survey transects flown during each survey period was limited by the aircraft time available. The completion of transects was sometimes limited by weather conditions, particularly fog or high winds, and in June 1999 ice cover was a factor.

The survey aircraft was a high-wing, twin-engine Aero Commander equipped with bubble windows, based in Nome. The crew included the pilot, a data recorder in the right front

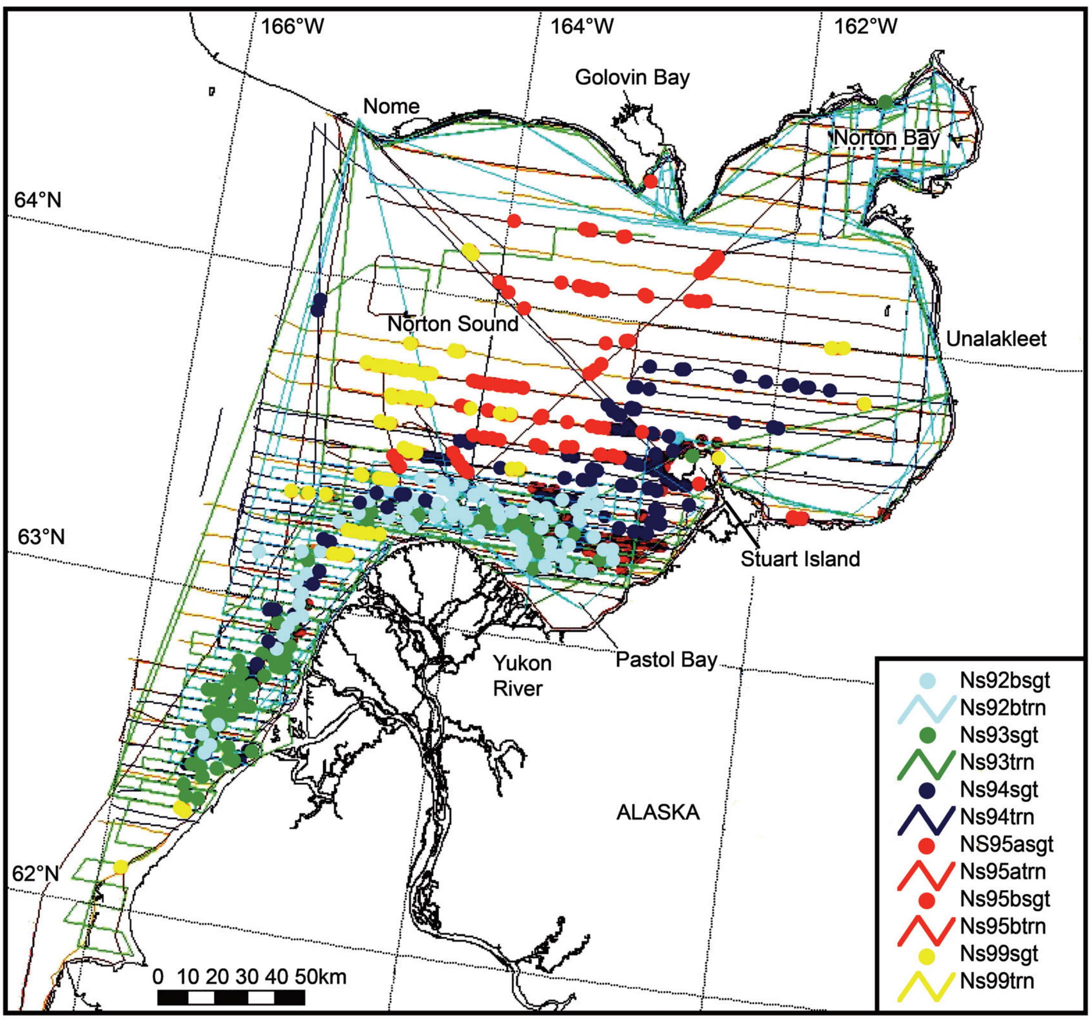

Fig. 2. Transects flown and beluga sightings made during ABWC beluga whale surveys in the eastern Bering Sea, June 1992–99.

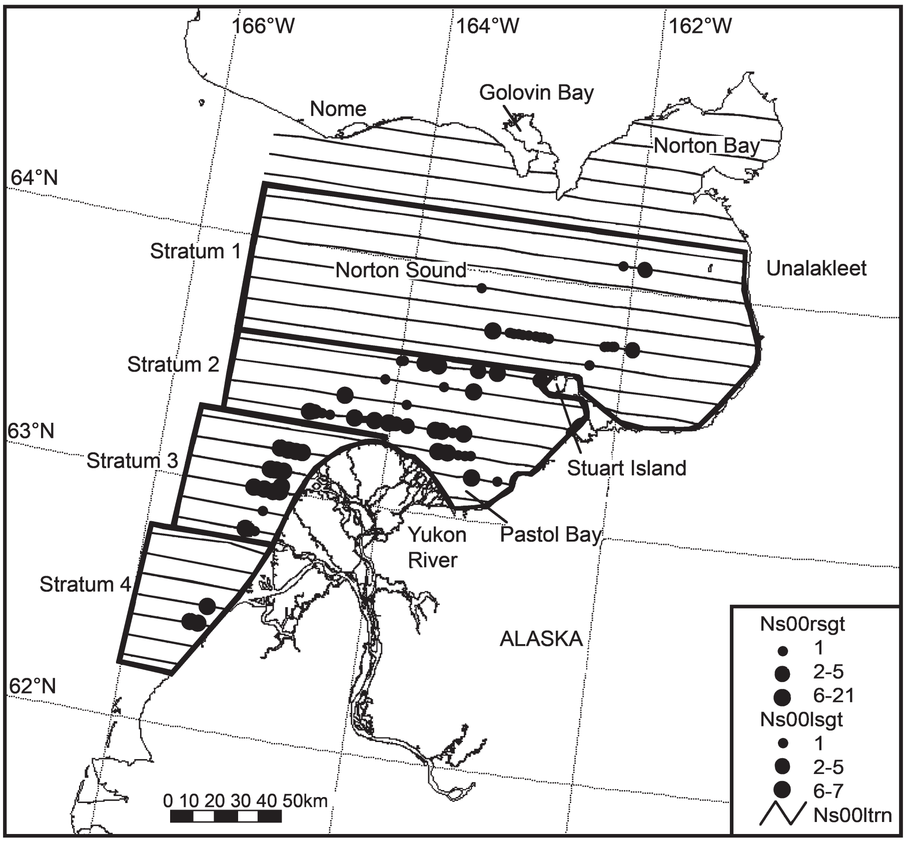

Fig. 3. Transects flown, strata used in the analysis, and beluga sightings made during ABWC beluga whale surveys in the eastern Bering Sea, June 2000.

seat and two observers seated behind the pilot on the left and right sides of the aircraft. Survey altitude was usually 305m, and ground speed was 274km/hr in 1992 and 220km/hr in all other years. Navigation was done by reference to landmarks and with a Global Positioning System. The survey was done in a passing mode, where whales were counted while staying on effort on the trackline. On the coastal transects, all beluga whales visible along the survey track were counted. For the 1992 offshore transects, observers counted whales within 915m wide strips on each side of the aircraft. The strips were offset 305m from the centerline to eliminate the blind spot under the plane. In 1993–95 and 1999–2000, the offshore transects on each side of the aircraft were divided into seven zones and each whale sighting was recorded in one of the zones. Inclinometers were used to delineate the inner and outer bounds of zones as follows: zone 1, 45°–51°; zone 2, 40°–45°; zone 3, 33°–40°; zone 4, 27°–33°; zone 5, 21°–27°; zone 6, 14°–21°; and zone 7, < 14°. In 1992 and 1993, sightings and other data were recorded on datasheets by observers in one-minute intervals and were then entered into a computer database. In 1994–95 and 1999–2000, a computer-based data entry program was used, logging the locations and times for the beginning and end of transects, the position on transect every 1 minute, and the exact time and position of each sighting. Wind speed (from the aircraft navigation system), cloud cover (%), ice coverage (%) when present, sea state (using the Beaufort scale), glare (present or absent) and overall sighting conditions (excellent, good, fair, poor) were reported by observers and any changes were recorded. The overall sighting conditions were characterised as follows:

- Excellent-ocean conditions, calm or very small waves; ability of observers to discriminate objects on the water not impeded by waves, whitecaps, fog, haze, low ceiling, glare, or precipitation;
- Good-ocean conditions, small waves with few or no whitecaps; ability of observers to discriminate objects on the water only slightly impeded by waves, whitecaps, fog, haze, low ceiling, glare, or precipitation;
- Fair-ocean conditions, small to medium waves with frequent whitecaps; ability of observers to discriminate objects on the water moderately impeded by waves, whitecaps, fog, haze, low ceiling, glare, or precipitation; and
- Poor-ocean conditions, medium to large waves with constant whitecaps; ability of observers to discriminate objects on the water substantially impeded by waves, whitecaps, fog, haze, low ceiling, glare, or precipitation.

Data analyses for the 2000 survey

Uncorrected density and abundance estimates were only obtained from the 2000 dataset because it was the most recent and included the most complete and systematic coverage of the EBS study area (see Table 1 and Fig. 3). Beluga sightings and transect data were entered into a geographic information system (ArcView), they were then plotted and visually inspected. During the surveys, there were no belugas seen on the seven northernmost transect lines, indicating extremely low densities within that area. That part of northern Norton Sound was excluded from

Table 1

Survey lengths and areas, counts and encounter rates for beluga whales in the eastern Bering Sea region, based on aerial surveys conducted in June 1992–95 and 1999–2000.

Survey dates	Trackline flown (km)	No. belugas counted	Encounter rate, belugas per km	Study area (km^2)
17–21 June 1992	7,278	1,625	0.223	6,145
14–18 June 1993	5,539	374	0.068	10,975
11–16 June 1994	5,746	370	0.064	13,965
5–8 June 1995	4,450	750	0.169	19,983
20–22 June 1995	1,776	456	0.257	3,352
15–17 June 1999	3,366	589	0.175	15,794
17–20 June 2000	4,226	428	0.101	38,104

further analysis, and the study area used for density calculations was limited to the area in central and southern Norton Sound and off the Yukon River Delta. The study area was post-stratified into four strata by latitude. Stratifying by latitude places similar survey tracklines together and reduces the considerable variability of habitat coverage among the survey lines.

Sightings data were truncated by subtracting 305m from the perpendicular distances of all sightings (equivalent to the blind spot under the plane). Truncation was also applied by excluding all sightings at distances greater than 1,000m from the centerline (the inner bound of the last zone). Detection probability was estimated with Conventional (CDS) and Multiple Covariate Distance Sampling (MCDS) methods. CDS and MCDS analyses included the half normal and the hazard rate functions with no series expansions. MCDS models also included covariates individually (Table 2). Model selection was performed according to the Akaike Information Criterion (AIC, see Burnham and Anderson, 2002).

Encounter rates and group sizes were computed separately for each stratum. An exploratory analysis indicated that cluster size did not correlate with the detection distance and therefore expected group sizes were calculated as simple means (Buckland *et al*., 2001). Model parameter estimates were computed with program DISTANCE 6, Release 2 (Thomas *et al*., 2010). Variances for all model parameters, density and abundance were empirically estimated as specified by Buckland *et al*. (2001). Uncorrected density and abundance were computed for the model most supported according to AIC (see results below).

Correction factor for availability bias

The DISTANCE program used in the analysis estimated the density and abundance of belugas visible at the surface from the plane. When available, data on dive behaviour are generally used to estimate the number of additional whales that would have been submerged when the survey aircraft passed. Telemetry data on beluga diving behaviour were not available for the EBS region, but in other regions where belugas have been tagged with satellite-linked dive recorders, it has been found that they spend half or less of their time at or near the surface (Heide-Jorgensen *et al*., 1998; Lerczak *et al*., 2000; Kingsley *et al*., 2001; Citta *et al*., 2013). Several studies have concluded that aerial counts should be multiplied by two or more to account for animals diving (Sergeant, 1973; Frost *et al*., 1985; Kingsley *et al*., 2001). In this study the uncorrected abundance was multiplied by 2.0 to estimate the total abundance.

Table 2

Covariates included in conventional and multiple covariate distance sampling analyses for eastern Bering Sea beluga survey data.

Covariate	Type	Range or levels
Glare	Factor	Present or absent
Group size	Numerical	1–21
Observer	Factor	LL and RA
Sea state (Beaufort scale)	Factor and numerical	1–3
Sighting conditions	Factor	Excellent, good, fair, poor

RESULTS

Beluga surveys and sightings

Transect lines and beluga sightings for surveys conducted in June 1992–95 and 1999 are shown in Fig. 2 and summarised in Table 1. During May 1992 surveys, all of the survey area was covered with pack ice and only a few belugas were seen. In June 1992, many whales were seen in the region of Pastol Bay and the Yukon River Delta, with only a few animals seen in eastern Norton Sound. In September 1992, whales were more dispersed and occurred both off the Yukon Delta and in coastal waters of northern Norton Sound. Based on these results, in subsequent years the surveys were only conducted in June and our efforts focused on the region off the mouths of the Yukon River and Pastol Bay. Belugas were commonly sighted within the region in every subsequent survey. The overall size of the study area expanded over the years as the area of beluga occurrence increased with coverage added by our adaptive sampling and sightings of belugas in other regions during transit lines. In 1995, a more comprehensive coverage was attempted of the entire Norton Sound-Yukon Delta region but persistent fog prevented us from surveying off the Yukon River. We returned later in June and were able to survey the Yukon mouth, but without a better understanding of beluga behaviour and movements we were not comfortable with combining the data for the surveys, as they were conducted about two weeks apart (Lowry *et al*., 1999). June 1999 was unlike previous years when the survey area had been virtually ice free and pack ice covered much of Norton Sound. Beluga distribution was also unusual with relatively few whales seen in open water off the Yukon Delta and most sightings in pack ice in the southwestern Sound. Nearly all sightings were in ice coverage of 10%–50% and very few belugas were seen in 60% or greater ice coverage. Because of the anomalous conditions, the 1999 survey was terminated earlier than planned. During 17–20 June 2000, the survey covered the entire study area with east–west transects spaced at 9.3km intervals; 428 belugas were counted in 297 sightings, on 4,226km of surveys (Fig. 3). Most of the beluga whales were seen off the Yukon Delta and in Pastol Bay, but a number of sightings were made in central Norton Sound west and north of Stuart Island.

Density and abundance estimates for the 2000 survey

As described in the methods section, the northernmost part of Norton Sound (where no belugas were sighted) was excluded from the analysis. This reduced the survey effort to 3,052km of trackline and the study area to 28,936km^2. Truncation of the inner and outer boundaries of the survey strip reduced the number of groups in the dataset to 232, and the number of individuals counted to 366.

Detection probability models considered in the study are listed in Table 3. Models with group size were not included because their results were inconsistent with the hypothesis that detection probability increases with group size. The model that received most support from the data was a half normal without covariates (AIC = 746.17). The estimated average detection probability ranged from 0.48 to 0.56, which translates into effective strip half-widths (ESW) of 493–576m.

Estimates of encounter rate, group sizes, density and abundance for each stratum for the most supported model are presented in Table 4. All proposed models provided similar estimates irrespective of their AIC score. Overall, uncorrected density and abundance were estimated at 0.121 whales/km^{-2} and 3,497 individuals (CV = 0.37, 95% CI = 1,581–7,736). Estimates corrected for availability bias were 0.242 whales/km^{-2} and 6,994 individuals.

Table 4

Encounter rate, group size, density, and abundance estimates for eastern Bering Sea belugas in 2000. (*N* = number of sightings; *CV* = coefficient of variation) computed with the most-supported detection probability mode1 (model 1).

	Estimate	*CV*
Stratum 1 (16,128km^2)		
N	23	
Encounter rate	0.014	0.79
Mean group size	1.04	0.04
Uncorrected density (individuals/km^2)	0.015	0.79
Uncorrected abundance	233	0.79
Corrected abundance	466	
Stratum 2 (6,894km^2)		
N	133	
Encounter rate	0.181	0.58
Mean group size	1.52	0.11
Uncorrected density (individuals/km^2)	0.280	0.60
Uncorrected abundance	1,933	0.60
Corrected abundance	3,866	
Stratum 3 (3,171km^2)		
N	65	
Encounter rate	0.191	0.38
Mean group size	1.95	0.09
Uncorrected density (individuals/km^2)	0.380	0.40
Uncorrected abundance	1,206	0.40
Corrected abundance	2,412	
Stratum 4 (2,743km^2)		
N	11	
Encounter rate	0.038	1.03
Mean group size	1.18	0.10
Uncorrected density (individuals/km^2)	0.045	1.03
Uncorrected abundance	124	1.03
Corrected abundance	248	
TOTAL (28,936km^2)		
Uncorrected density (individuals/km^2)	0.121	0.37
Uncorrected abundance	3,497	0.37
Corrected abundance	6,994	

DISCUSSION

Beluga distribution in the Eastern Bering Sea region

Based on the information available prior to our surveys belugas were expected to be found mostly near the coast during May–June. Contrary to this, with the exception of around Stuart Island, very few whales were sighted on transects that covered the strip within 1.8km of the coast, or in areas such as Golovin Bay or Norton Bay (Figs 2 and 3). Instead, the most predictable region in which to find belugas was from the south mouth of the Yukon River to Stuart Island. West of the Yukon Delta whales were seen every year in a narrow band approximately 10km wide located 9–18km offshore. North and east of the Yukon Delta belugas were more broadly distributed in Pastol Bay. In essence, each year belugas were distributed in a continuous band around the Yukon Delta that was approximately 200km long. This band was centered around the 5m isobath and largely corresponded to the sediment plume discharged by the Yukon River (Fig. 4). In several years whales were seen in central Norton Sound and in 1995 the distribution of belugas extended well into the northern half of Norton Sound.

The distribution of belugas observed during the surveys was consistent with observations made more than 100 years ago. Zagoskin (1967) described the occurrence of belugas in Norton Sound in the 1840s, and noted that beginning in July

Table 3

Conventional and multiple covariate distance sampling detection probability models for eastern Bering Sea beluga survey data. (hr = hazard rate; hn half normal; f() = covariate included in the model as a factor; ESW = effective strip width, *N* = total estimated number of belugas; *CV* = coefficient of variation).

Model no.	Model name	No. of parameters	Delta AIC	*P*	*CV(P)*	ESW	*N*	*CV(N)*
1	hn	1	0.00	0.49	0.06	498	3,497	0.37
2	hr	2	0.56	0.49	0.08	500	3,484	0.37
3	hn + f(sighting conditions)	4	1.46	0.48	0.05	493	3,535	0.36
4	hn + f(sea state)	2	1.72	0.49	0.05	498	3,501	0.36
5	hn + f(glare)	2	1.80	0.49	0.05	498	3,499	0.36
6	hn + f(observer)	2	1.85	0.49	0.05	498	3,499	0.36
7	hn + f(sea state)	3	2.64	0.49	0.05	497	3,508	0.36
8	hr + f(sea state)	4	4.46	0.49	0.05	498	3,498	0.36
9	hr + f(sighting conditions)	5	5.02	0.51	0.05	519	3,360	0.36
10	hr + f(sea state)	3	5.87	0.56	0.04	576	3,028	0.36
11	hr + f(glare)	3	5.87	0.56	0.04	576	3,027	0.36
12	hr + f(observer)	3	5.90	0.56	0.04	576	3,025	0.36

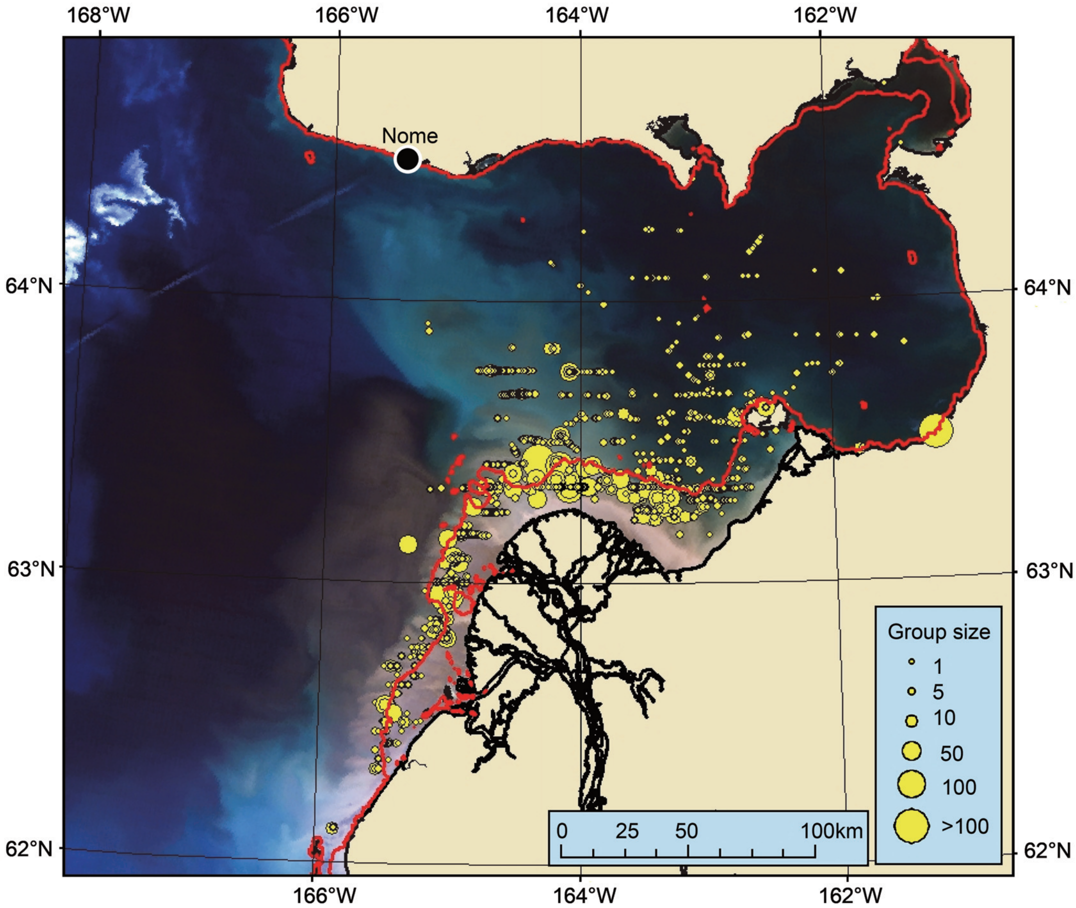

Fig. 4. MODIS image of Norton Sound and the Yukon River Delta taken from the Terra satellite on 17 June 2002. Yellow dots are sightings of beluga whales made during aerial surveys 1995–2000. Red line indicates the 5m isobath. The discharge plume of the Yukon River shows as gray/brown.

'the beluga appear in great numbers with their young as they follow the fish outside the mouths of the Yukon.' He described large organised hunts that occurred in mid–July in Pastol Bay, where as many as 100 animals were taken in a single drive. According to Nelson (1887), belugas usually appeared at Stuart Island between 5 June and 10 June and schools of 20 to over 100 animals were frequently seen in the bay nearby. He documented the summer occurrence of belugas at the mouth of the Yukon River, and as much as 800km upstream.

Limited observations from aerial surveys in the 1970s and 1980s also indicated that belugas frequented the waters off the Yukon Delta. Harrison and Hall (1978) flew bird and mammal surveys in this region and made five sightings of belugas in southern and eastern Norton Sound in late August 1976. During 1981, Ljungblad *et al*. (1982) flew whale surveys in the northern Bering Sea and saw belugas in Norton Sound on 22 June (12 animals), 6 July (10 animals) and 12 July (137 animals). Sightings made by Ljungblad *et al*. (1982) were all in southern Norton Sound in the region between Stuart Island and the north mouth of the Yukon River. They noted that on 12 July a sonobuoy recorded a variety of calls from more than 100 belugas 'vigorously feeding in shallow, muddy water near the Yukon River delta.' Each year during 1976–88, Alaska Department of Fish and Game biologists flew aerial surveys to assess herring (*Clupea pallasii*) stocks in Norton Sound shortly after ice breakup (late May and early June). Those surveys provided numerous sightings of beluga whales throughout Norton Sound and off the Yukon River delta (Frost and Lowry, 1990).

As survey effort was concentrated in June, little information on seasonal distribution patterns was obtained. However, results of the surveys in May and September 1992 confirm observations of local residents (Huntington, 1999) that belugas arrive in the Sound in the spring while it is still covered with ice and they are more common in the northeast part of the Sound in the autumn than in the summer.

Population abundance

The surveys conducted for the ABWC in 1992–95 and 1999–2000 have provided the first systematic information on the distribution and abundance of beluga whales in the Norton Sound/Yukon Delta region. In June 2000, systematic survey lines were flown over the entire region. Using distance sampling models an uncorrected estimate of 3,497 belugas at the surface in the study area was calculated. To estimate the true abundance it is necessary to account for any whales that were diving and not available to count when the survey aircraft passed (availability bias) and whales that were at the surface in the study area but were not recorded by observers (perception bias). Off the mouth of the Yukon River water is shallow and beluga dives must have been also, but the water was very turbid and whales could only be seen when part of their back was above the surface. Further offshore water was clearer and deeper, and while whales were easier to see they also could make deeper and longer dives. Because there are no data available on beluga diving behaviour in the EBS region, a commonly accepted correction factor of 2.0 was used to correct for this availability bias (e.g. Reeves *et al*., 2011) and the estimate of the total population size was then 6,994. This estimate is likely to be conservative for two reasons. Firstly, the analysis did not account for perception bias. By comparing observer counts of belugas in Cook Inlet, Alaska with videotapes, Hobbs *et al*. (2000) concluded that observers missed a significant number of animals. Photographic studies using models have shown that turbidity and rough water affect beluga visibility, especially for the younger animals that are grey (Kingsley and Gauthier, 2002). Secondly, the survey area focused on the main concentration of belugas in the EBS during June, however it is possible that some whales were elsewhere. For example, during the summer months some belugas move into and up the Yukon River (Nelson, 1887; Lensink, 1961; Frost and Lowry, 1990), and the surveys presented here did not include the river system itself.

There are no historical data available that can be used for comparison with this studies' abundance estimate. Results from this study indicate that the estimate of 1,000–2,000 whales for the EBS stock suggested by Seaman *et al*. (1988) based on local reports was too low by a substantial amount.

Survey methods and adequacy

This survey effort demonstrates that an adequate population assessment of EBS belugas can be done using line-transect surveys flown in June provided that: (1) surveys of the Yukon Delta and Norton Sound areas can be done during the same range of dates; and (2) survey transects cover all of Norton Sound and the Yukon Delta. However, it should be noted that that future survey efforts may well be complicated by sea ice that sometimes persists into the survey period, heavy fog that often develops off the Yukon Delta and simply the size of the area that must be surveyed.

The survey efforts in this study were restricted to Norton Sound and nearshore waters off the Yukon River Delta. Belugas are commonly seen in the Bering Sea to the west of Norton Sound during April–May when they are migrating northward through sea ice (Moore *et al*., 1993). However, aerial surveys that were conducted during summer in the northern Bering Sea in 1975–1977 (Harrison and Hall, 1978) and 1981–1983 (Ljungblad *et al*., 1984; Moore *et al*., 1993) did not detect any belugas west of our survey area. The lack of sightings at the western ends of our transect lines also indicates that our study area covered most of the summer concentration area used by the EBS beluga stock.

The density of belugas along tracklines varied from a few sightings near shore to high densities and then to very low densities at the offshore extremity. This gave us confidence that the concentration of belugas along each trackline was fully sampled. The observed density on each trackline was determined by the relative lengths of high and low density segments. Thus, it is likely that the *CV* for this abundance estimate could be reduced significantly if the transect lines were stratified by water depth or distance from shore as well as latitude. However, the mechanisms of choice of water depth and/or distance from shore that result in the observed distribution are not understood and consequently a stratification could not be devised *a priori* to the survey, or necessarily replicated in future surveys. By contrast the stratification by latitude allows greater flexibility for future surveys since a northward or southward shift of the population can be accommodated by adjusting the effort in the survey strata.

For survey counts to be useful for monitoring population trend they should be made in similar circumstances on a regular basis (e.g. annually). In addition, factors that affect the counts should be recorded and accounted for in the analysis (e.g. Frost *et al*., 1999). Using our EBS beluga survey data from 1993–95, DeMaster *et al*. (2001) showed that sightings were much more common in Beaufort state 1 than in state 2, 3 or 4 and they recommended that future data analyses incorporate sea state effects. This was done by using MCDS methods that took into account Beaufort state, glare, sighting conditions and observer. However, for these analyses using both half normal and hazard rate functions the most supported model was the one without covariates. The next two best supported models were half normal with sighting conditions as a covariate and half normal with sea state as a covariate. This apparent contradiction with DeMaster *et al*. (2001) may be due to the generally good sighting conditions encountered in 2000. In that year only 12% of sightings were made in poor or fair sighting conditions and only 9% were in Beaufort states greater than 2. Palka (1996) showed similar effects of Beaufort state on aerial survey counts of harbour porpoises (*Phocoena phocoena*). We continue to believe that sea state, glare and sighting conditions may seriously impact observers' ability to detect belugas and that those parameters should be recorded during surveys and considered as covariates during analyses.

Other factors such as the timing of environmental and biological events (e.g. sea ice breakup, discharge from the Yukon River and the appearance of migratory fishes) may also affect beluga distribution and movements, and therefore counts. Clearly, the biology of belugas in this region is not yet fully understood and more studies will be needed before a satisfactory population assessment and monitoring program can be developed.

Management considerations

Management of subsistence hunting

The ABWC was formed in 1988 to coordinate efforts of Alaska Native hunters, scientists and managers in the conservation and management of western Alaska beluga whale stocks (Adams *et al*., 1993). The Committee is a co-manager of these stocks under an agreement with the US National Marine Fisheries Service and it undertakes a number of research and management activities to fulfil its co-management obligations[6].

One of the first research programs supported by the ABWC was the collection and analysis of genetics samples to determine whether summer concentration areas in the Bering and Chukchi seas comprise separate management units. Results showed that belugas harvested in Norton Sound and the Yukon Delta do comprise a stock that is separate from animals that summer in Bristol Bay and the Chukchi Sea (O'Corry-Crowe *et al*., 1997; 2002). This led

[6] *http://www.north-slope.org/departments/wildlife-management/co-management-organizations/alaska-beluga-whale-committee.*

the Committee to support aerial surveys to develop a more realistic estimate of abundance for the EBS stock.

Another early effort by the ABWC was to systematically collect information on the Alaska Native subsistence harvest of belugas. Results have shown that belugas are a very important resource for people living in the Norton Sound/Yukon Delta area with whales being harvested in at least 20 communities. From 1987 through 2006, the estimated annual harvest from the EBS stock was 191 belugas (range 103–309; Frost and Suydam, 2010).

The only identified human-caused mortality in this population is Alaska Native subsistence hunting (Allen and Angliss, 2013). Using the estimate of 7,000 belugas from this study (which is believed to be conservative), this harvest in recent years has been about 2.7% of the population. Considering that studies in nearby Bristol Bay have shown that Alaska beluga populations can increase by more than 4% per year (Lowry *et al*., 2008), it is likely that this harvest is sustainable. While written records are sparse, those that are available, combined with the local and traditional knowledge of current beluga whale hunters, suggest that there has been a large, healthy, beluga whale population in the Norton Sound/Yukon Delta region since at least the mid 1800s.

Management as a component of the Norton Sound ecosystem

Beluga whales prey on Pacific salmon (*Oncorhynchus* spp.) throughout much of Alaska. In Bristol Bay and Cook Inlet where annual runs of several species of salmon occur, belugas feed on outmigrating smolt in spring and on adult salmon returning to spawn in the summer (Frost *et al*., 1984; Moore *et al*., 2000; Quakenbush *et al*., 2015). In Norton Sound and off the Yukon River, belugas have also been reported to feed on salmon in July and August, although herring and saffron cod (*Eleginus gracilis*) are more commonly found in stomachs examined at other times of year (Nelson, 1887; Seaman *et al*., 1982). Alaska Native subsistence hunters from Norton Sound and Yukon River villages report that belugas arrive during the herring runs and remain throughout the summer feeding on adult salmon (ABWC, unpublished). Because belugas are generally hunted before and after the salmon season (when hunters are engaged in commercial salmon fishing), few summer beluga stomachs have been examined.

Five species of salmon occur off the mouth of the Yukon River and in Norton Sound. These salmon, particularly chinook (*O. tshawytscha*) and chum (*O. keta*) are harvested in commercial, sport and subsistence fisheries. Sockeye (*O. nerka*), pink (*O. gorbuscha*) and coho salmon (*O. kisutch*) are also present, and although they may be quite abundant, they are of less commercial importance. During June when the beluga aerial surveys were conducted, summer-run chum and chinook salmon are the main species present. The average run size for summer chums is about 1.8 million fish (range 0.55–4.0 million), and for chinook about 100,000 (Bergstrom *et al*., 2009; Bue *et al.,* 2009; Evenson *et al*., 2009). The 'run size' is estimated from counting stations in the Yukon River after most predation has occurred and therefore true run sizes for ocean fish would be larger than the estimates made for fishery management purposes. The average annual commercial harvest of summer chums is about 630,000 and there is currently little or no harvest of chinook. In 2012, the commercial harvest of all salmon species for all of Norton Sound and the Yukon was 989,000 salmon (Eggers *et al*., 2013). Frost *et al*. (1984) estimated the consumption of sockeye salmon by belugas in Bristol Bay by using estimates of average beluga body weight (350kg), daily consumption (5% of body weight) and the percentage of salmon in their stomach during the period of interest (70%). Although such estimates are imprecise, particularly without detailed information about diet, they can be useful for identifying the general magnitude of salmon consumption. Data from captive belugas indicates that consumption rate varies by size/age and may range from 4.5% for younger animals to < 2% for larger/older belugas, and about 3% for an average 350kg beluga (Sergeant, 1969; Kastelein *et al*., 1994). Using these figures the daily salmon consumption of a single beluga is estimated to be 7.35 kg (350kg*0.03*0.7). Multiplying that times the abundance estimate developed in this study (6,994 belugas) indicates that eastern Bering Sea belugas could consume about 51,470 kg of salmon per day, or about 1,500,000 kg of salmon in a month. If an 'average' salmon weighs 3.2kg (the average weight of chum and coho salmon in this region), belugas would consume about 16,000 salmon per day, or about 500,000 salmon in a month. Thus, in a single month belugas may eat about half the number of salmon that were harvested in all Yukon and Norton Sound commercial fisheries during the entire 2012 fishing season. This impact could be greater if whales feed predominantly on particular species or stocks. Belugas occur in this region throughout the summer (Frost and Lowry, 1990) and almost certainly eat salmon in other months as well. Considerable quantities of non-salmonid prey are also being taken, especially during spring and fall. While there are several uncertainties in the estimates above, it is clear that beluga whales are very important in the trophic ecology of the Norton Sound/Yukon Delta region.

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REFERENCES

Adams, M., Frost, K.J. and Harwood, L.A. 1993. Alaska and Inuvialuit Beluga Whale Committee (AIBWC) – an initiative in 'at home management'. *Arctic* 46:134–7.

Allen, B.M. and Angliss, R.P. 2013. Alaska marine mammal stock assessments, 2012. *NOAA Tech. Memo. NMFS-AFSC*-245: 282pp.

Bergstrom, D.J., Evenson, D.F. and Newland, E.J. 2009. Yukon River summer chum salmon stock status, 2009; a report to the Alaska Board of Fisheries. *Alaska Dep. Fish and Game, Spec. Publ.* No. 09–22. 29pp.

Brooks, J.W. 1955. Beluga investigations. *Ann. Rep. Alaska Dep. Fisheries* 7:98–106. [Available at: *http://www.arlis.org/docs/vol1/A/31110164etc/index.html*]

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. *Introduction to Distance Sampling: Estimating Abundance of Biological Populations*. Oxford University Press, Oxford, UK. 440pp.

Burnham, K.P. and Anderson, D.R. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretical Approach*. 2nd Edn. Springer-Verlag, New York, New York, USA. 488pp.

Bue, F.J., Borba, B.M., Cannon, R. and Krueger, C.C. 2009. Yukon River fall chum salmon fisheries: management, harvest, and stock abundance. pp.703–42 *In*: C.C. Krueger and C.E. Zimmerman (eds). *Pacific Salmon: Ecology and management of western Alaska's populations*. American Fisheries Society, Symposium 70, Bethesda, Maryland, USA. 1,235pp.

Citta, J.J., Suydam, R.S., Quakenbush, L.T., Frost, K.J. and O'Corry-Crowe, G.M. 2013. Dive behavior of eastern Chukchi beluga whales (*Delphinapterus leucas*), 1998–2008. *Arctic* 66:389–406.

DeMaster, D.P., Lowry, L.F., Frost, K.J. and Bengtson, R.A. 2001. The effect of sea state on estimates of abundance for beluga whales (*Delphinapterus leucas*) in Norton Sound, Alaska. *Fish. Bull.* 99:197–201.

Eggers, D.M., Tide, C. and Carroll, A.M. (eds). 2013. Run forecasts and harvest projections for 2013Alaska salmon fisheries and review of the 2012 season. *Alaska Dep. Fish and Game, Spec. Publ.* No. 13–03. 106pp.

Evenson, D., Hayes, S.J., Sandone, G. and Bergstrom, D.J. 2009. Yukon River Chinook Salmon: Stock Status, Harvest, and Management. pp. 1–27 *In*: C.C. Krueger and C.E. Zimmerman (eds). *Pacific Salmon: Ecology and Management of Western Alaska's Populations*. American Fisheries Society, Symposium 70, Bethesda, Maryland, USA. 1,235pp.

Frost, K.J. and Lowry, L.F. 1990. Distribution, abundance and movements of beluga whales, *Delphinapterus leucas*, in coastal waters of western Alaska. *Can. Bull. Fish. Aquat. Sci.* 224:39–57.

Frost, K.J. and Suydam R.S. 2010. Subsistence harvest of beluga or white whales (*Delphinapterus leucas*) in northern and western Alaska, 1987–2006. *J. Cetacean Res. Manage*. 11:293–9.

Frost, K.J., Lowry, L.F. and Nelson, R.R. 1984. Beluga whale studies in Bristol Bay, Alaska. pp. 187–200 *In*: *Proceedings of the workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea*. Univ. Alaska Sea Grant Rep. 84-1. 300pp.

Frost, K.J., Lowry, L.F. and Nelson, R.R. 1985. Radiotagging studies of beluga whales, *Delphinapterus leucas*, in Bristol Bay, Alaska. *Mar. Mamm. Sci*. 1:191–202.

Frost, K.J., Lowry, L.F. and Carroll, G. 1993. Beluga whale and spotted seal use of a coastal lagoon system in the northeastern Chukchi Sea. *Arctic* 46:8–16.

Frost, K.J., Lowry, L.F. and Ver Hoef, J.M. 1999. Monitoring the trend of harbor seals in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. *Mar. Mamm. Sci.* 15:494–506.

Harrison, C.S. and Hall, J.D. 1978. Alaskan distribution of the beluga whale, *Delphinapterus leucas*. *Can. Field-Nat*. 92:235–41.

Heide-Jorgensen M.P., Richard, P.R. and Rosing-Asvid, A. 1998. Dive patterns of belugas (*Delphinapterus leucas*) in waters near eastern Devon Island. *Arctic* 51:17–26.

Hobbs, R.C., Waite, J.M. and Rugh, D.J. 2000. Beluga (*Delphinapterus leucas*), group sizes in Cook Inlet, Alaska, based on observer counts and aerial video. *Mar. Fish. Rev*. 82(3): 46–59.

Huntington, H.P. 1999. Traditional knowledge of the ecology of beluga whales (*Delphinapterus leucas*) in the eastern Chukchi and northern Bering seas, Alaska. *Arctic* 52:49–61.

Kastelein, R.A., Ford, J., Berghout, E., Wiepkema, P.R. and van Boxsel, M. 1994. Food consumption, growth, and reproduction of belugas (*Delphinapterus leucas*) in human care. *Aquatic Mamm.* 20(2):81–97.

Kingsley, M.C.S. and Gauthier, I. 2002. Visibility of St Lawrence belugas to aerial photography, estimated by direct observation. pp. 259–270 *In*: M.P. Heidi-Jorgensen and Ø. Wiig (eds). *Belugas in the North Atlantic and Russian Arctic*. NAAMCO Scientific Publications Vol. 4. Tromsø, Norway.

Kingsley, M.C.S., Gosselin, S. and Sleno, G.A. 2001. Movements and dive behaviour of belugas in northern Quebec. *Arctic* 54:262–5.

Lensink, C.J. 1961. Status report: beluga studies. Unpublished report to Alaska Dept. Fish and Game, 20pp. [Available from ADF&G, Div. Wildl. Conserv., 1300 College Road, Fairbanks, AK, 99701 USA].

Lerczak, J.A., Shelden, K.E.W. and Hobbs, R.C. 2000. Application of suction-cup-attached VHF transmitters to the study of beluga, (*Delphinapterus leucas*), surfacing behavior in Cook Inlet, Alaska. *Mar. Fish. Rev*. 82(3):99–111.

Ljungblad, D.K., Moore, S.E., Van Schoik, D.R. and Winchell, C.S. 1982. Aerial surveys of endangered whales in the Beaufort, Chukchi, and northern Bering seas. Naval Ocean Systems Center, San Diego, CA, Tech. Doc. 486. 215pp.

Ljungblad, D.K., Moore, S.E. and Van Schoik, D.R. 1984. Aerial surveys of endangered whales in the northern Bering, eastern Chukchi, and Alaskan Beaufort seas, with a five year review, 1979–1983. Naval Ocean Systems Center, San Diego, CA, Tech. Rep. 955. 119pp.

Lowry, L.F., Burns, J.J. and Frost, K.J. 1989. Recent harvests of belukha whales, *Delphinapterus leucas*, in western and northern Alaska and their potential impact on provisional management stocks. *Rep. int. Whal. Commn* 39:335–9.

Lowry, L.F., DeMaster, D.P. and Frost, K.J. 1999. Alaska Beluga Whale Committee surveys of beluga whales in the eastern Bering Sea, 1992–1995. Paper SC/51/SM34 presented to the IWC Scientific Committee, May 1999 (unpublished). 22pp. [Paper available from the Office of this Journal].

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

Moore, S.E., Clarke, J.T. and Johnson, M.M. 1993. Beluga distribution and movements offshore northern Alaska in spring and summer, 1980–84. *Rep. int. Whal. Commn* 43:375–386.

Moore, S.E., Sheldon, K.E.W., Litsky, L.K., Mahoney, B.A. and Rugh, D.J. 2000. Beluga, *Delphinapterus leucas*, habitat associations in Cook Inlet, Alaska. *Mar. Fish. Rev*. 62:60–80.

Nelson, E.W. 1887. Report upon natural history collections made in Alaska between the years 1877 and 1881. *Arctic Series Publ.* No. 3, Signal Service, US Army, Washington, DC, USA. 337pp.

O'Corry-Crowe, G.M., Suydam, R.S., Rosenberg, A., Frost, K.J. and Dizon, A.E. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western nearctic revealed by mitochondrial DNA. *Mol. Ecol*. 6:955–70.

O'Corry-Crowe, G.M., Dizon, A.E., Suydam, R.S. and Lowry, L.F. 2002. Molecular genetics studies of population structure and movement patterns in a migratory species: the beluga whale, *Delphinapterus leucas,* in the western nearctic. pp.53–64. *In:* C.J. Pfeiffer (ed). *Molecular and Cell Biology of Marine Mammals*. Krieger Publishing Co., Malabar, Florida, USA. 464pp.

Palka, D. 1996. Effects of Beaufort Sea state on the sightability of harbor porpoises in the Gulf of Maine. *Rep. int. Whal. Commn* 46:575–82.

Quakenbush, L., Suydam, R., Bryan, A., Lowry, L.F., Frost, K.J. and Mahoney, B.A. 2015. Diet of beluga whales (*Delphinapterus leucas*) in Alaska from stomach contents, March–November. *Mar. Fish. Rev*. 77(1):70–84.

Reeves, R.R., Brownell, R.L., Jr., Burkanov, V., Kingsley, M.C.S., Lowry, L.F. and Taylor, B.L. 2011. Sustainability assessment of beluga (*Delphinapterus leucas*) live-capture removals in the Sakhalin–Amur region, Okhotsk Sea, Russia. Report of an independent scientific review panel. Occasional Paper of the Species Survival Commission, No. 44. IUCN, Gland, Switzerland. 34pp.

Seaman, G.A., Lowry, L.F. and Frost, K.J. 1982. Foods of belukha whales (*Delphinapterus leucas*) in western Alaska. *Cetology* 44:1–19.

Seaman, G.A., Frost, K.J. and Lowry, L.F. 1988. Investigations of belukha whales in coastal waters of western and northern Alaska. Part I. Distribution and abundance. U.S. Dep. Commerce, NOAA, OCSEAP Fin. Rep. 56:153–220.

Sergeant, D.E. 1969. Feeding rates of cetacea. *Fisk. Dir. Skr. Ser. HavUnders*. 15:246–58.

Sergeant, D.E. 1973. Biology of white whales (*Delphinapterus leucas*) in western Hudson Bay. *J. Fish. Res. Board Can*. 30:1,065–90.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B., Marques, T.A. and Burnham, K.P. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *J. Applied Ecol*. 47:5–14.

Zagoskin, L.A. 1967. Lieutenant Zagoskin's travels in Russian America, 1842–1844. *In*: H.N. Michael (ed.) *Anthropology of the North: Translations from Russian Sources* 7. University of Toronto Press. Toronto, Canada. 358pp.