

## The effect of sea state on estimates of abundance for beluga whales (*Delphinapterus leucas*) in Norton Sound, Alaska

**Douglas P. DeMaster**

National Marine Mammal Laboratory  
National Marine Fisheries Service, NOAA  
7600 Sand Point Way, NE  
Seattle, Washington 98115  
E-mail address: douglas.demaster@noaa.gov

**Lloyd F. Lowry**

**Kathryn J. Frost**

Alaska Department of Fish and Game  
1300 College Road  
Fairbanks, Alaska 99701

**Rebecca A. Bengtson**

National Marine Mammal Laboratory  
National Marine Fisheries Service, NOAA  
7600 Sand Point Way, NE  
Seattle, Washington 98115

Beluga whales (*Delphinapterus leucas*) are relatively small odontocete cetaceans; standard lengths of newborn calves are about 160 cm and adults range from 300 to 450 cm (Doidege, 1990). At birth, calves are dark slate gray, and the color gradually lightens until they become pure white as adults (Brodie, 1989). When actively swimming or diving, their bodies break the surface only for brief periods. Frost et al. (1985) reported that the average length of surfacing intervals for two radio-tagged beluga whales were 0.9–2.2 seconds.

Aerial surveys are the most common method for estimating the abundance of beluga whales (e.g. Frost and Lowry, 1990; Richard et al., 1990; and Harwood et al., 1996). Beluga whales are readily seen from aircraft in calm, clear waters but become increasingly difficult to detect when the water is murky or when whitecaps are present. Although a reduction in detectability in higher sea states is expected, there have been no published reports to quantify this effect on beluga whale counts. Rather, researchers have usually restricted survey effort to condi-

tions where whitecaps are uncommon (see Harwood et al., 1996). Under those conditions, it has been assumed that the probability of detecting a beluga, given it is at or near the surface, is independent of sea state.

Beluga whales are one of the more important species of marine mammals used by native subsistence hunters in Alaska, Canada, Greenland, and Russia (Lowry et al., 1989; Reeves, 1990; Harwood et al., 1996). To facilitate the sustained use of beluga whales by subsistence-based communities throughout the Arctic, it is necessary to determine safe levels for annual removals. One piece of information required for developing guidelines for these removals is a realistic estimate of the minimum population size (Wade, 1998). In the past, counts of beluga whales have been converted to estimates of abundance by using correction factors based on the following probabilities: 1) the probability that an animal is unavailable to be observed because of being submerged (Frost and Lowry<sup>1</sup>); 2) the probability that an adult-size animal at the surface was missed (Hobbs<sup>2</sup>); and 3) the probability a calf or year-

ling at the surface was missed (Brodie, 1971). We report the results of an analysis designed to determine whether sea state, as measured by the Beaufort (BF) scale, affects beluga whale density estimates. If such an effect is significant within the range of sea states that are routinely surveyed, failure to consider sea state effects would produce negatively biased estimates of beluga whale abundance.

### Methods

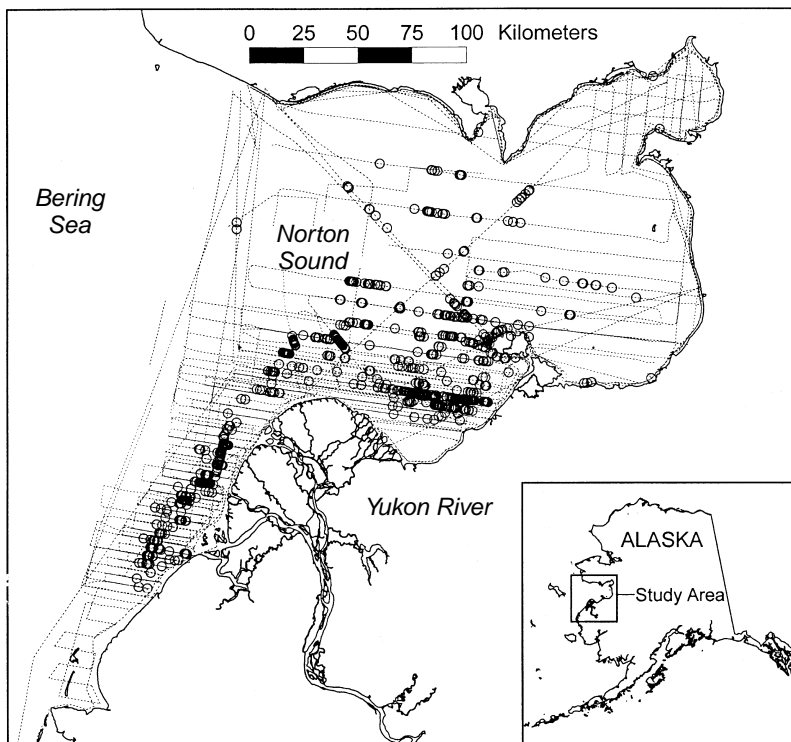
Beluga whale aerial surveys were flown in the vicinity of Norton Sound, Alaska (Fig. 1), in June 1993, 1994, and 1995. Two primary observers were used during the line-transect surveys, one looking out each side of the aircraft. Within any particular year, the same observers flew the entire survey period and did not rotate positions. Surveys were flown between the hours of 0900 and 1800 local time. The survey was done in a passing mode, where whales were counted, while the survey aircraft remained on the trackline.

The survey aircraft was a twin-engine, high-wing Aero Commander. Mean air speed was 220 km/h during surveys, and the target survey altitude was 330 m. However, when cloud cover precluded survey effort at 330 m, the survey altitude was reduced to 264 m. Each of the viewing ports contained a flat window, which was marked with a grease pencil to establish five consecutive "bins" for recording sightings (Lowry and DeMaster<sup>3</sup>). An inclinome-

<sup>1</sup> Frost, K. J., and L. F. Lowry. 1995. Radiotag based correction factors for use in beluga whale population estimation. Working paper for the Alaska Beluga Whale Committee, Scientific Workshop, 5–7 April 1995. [Available from ADF&G, 1300 College Road, Fairbanks, AK 99701.]

<sup>2</sup> Hobbs, R. 1998. Personal commun. National Marine Mammal Laboratory, 7600 Sand Point Way, NE., Seattle, WA 98115.

<sup>3</sup> Lowry, L. F., and D. P. DeMaster. 1996. Beluga whale surveys in Norton Sound, Alaska: June 1995. Alaska Beluga Whale Committee Report 96-2, 6 p. [Available from ADF&G, 1300 College Road, Fairbanks, AK 99701.]



**Figure 1**

Map of the Norton Sound and Yukon River delta region showing beluga whale aerial survey transects flown in June 1993–95 (dashed lines). Circles reflect sightings of beluga whales, where all three years of data are combined.

ter was used to measure sighting angles for the bins. The inner edge of the first sighting bin was offset 330 m from the center of the track line, and the outer edge of the outer bin was 2100 m from the center of the track line. Position data were collected by means of an onboard global positioning system that sent data directly to a laptop computer. All sightings were reported by the observers to a third person who entered the data into the onboard laptop computer. A continuous record of sea state was maintained by the recorder, according to the BF scale (Table 1).

Within the study area, surveys were conducted along the coast and on offshore transects. Very few beluga whales were seen on the coastal flights and they were always on the shoreward side of the aircraft, very near shore. To minimize the effect of very low densities of beluga whales seen in a wide range of BF sea states in the coastal band (defined as survey effort conducted while the aircraft was centered approximately 1.1 km offshore), only survey data from the offshore transects were used in our analysis. The number of on-effort track miles surveyed during offshore transects was 10,362 km.

Survey data were analyzed with the computer program DISTANCE (Laake et al., 1994). Each sighting of beluga whales was considered to be a grouped cluster within a single sighting bin. Animals were sighted in juxtaposed bins only a few times. In those situations, the bin that included a majority of animals in the group was used to designate the sighting bin for that sighting. However, it

**Table 1**

Summary of the relationship between Beaufort (BF) sea state number, wind speed, and sea surface condition.

BF sea state	Wind speed (km/h)	Sea surface conditions
0	0	no ripples
1	1–5	ripples, no foam on crests
2	6–11	small wavelets, crests glassy
3	12–19	large wavelets, scattered whitecaps
4	20–28	small waves, numerous whitecaps
5	29–38	moderate waves, many whitecaps, some spray

should be noted that in this area at this time of year, we did not observe coherent schooling behavior of beluga whales. Rather, beluga whales were observed in highly dispersed linear aggregations. Therefore, analysis of group size by sea state was not undertaken because group size was predominantly a function of whether the transect was crossing or flying parallel to a "line" of beluga whales.

**Table 2**

Summary of beluga whale densities (animals seen/km<sup>2</sup>) from Norton Sound, Alaska, by Beaufort (BF) sea state number. Numbers in parentheses represent 95% confidence intervals.

BF sea state	1993	1994	1995
1	0.217 (0.115–0.409)	0.107 (0.048–0.243)	0.294 (0.122–0.710)
2	0.111 (0.060–0.207)	0.052 (0.032–0.087)	0.046 (0.015–0.142)
3	0.039 (0.022–0.069)	0.138 (0.075–0.256)	0.111 (0.043–0.288)
4	0.009 (0.003–0.031)	0.075 (0.015–0.367)	insufficient survey effort

**Table 3**

Summary of sighting statistics for beluga whales in Norton Sound, Alaska, by Beaufort (BF) sea state, for 1993–95 data combined. Densities were estimated as weighted average, where weights were proportional to survey effort.

BF sea state	No. of observations	Survey effort (km)	Average density (SE) (animals seen/km <sup>2</sup> )
1	653	2343	0.206 (0.051)
2	416	3916	0.071 (0.014)
3	397	3618	0.069 (0.013)
4	19	490	0.053 (0.026)

The line-transect analysis was stratified by BF sea state. Using Eberhardt's (1968) multiple comparison test, we did not reject the null hypothesis that sea state specific density was independent of survey year; therefore, sighting data by BF sea state were pooled across years, where average density for each sea state was calculated as a weighted average proportional to distance searched. Differences in average density by BF sea state pooled across years and in the effective strip width by BF sea state in a given year were also tested using Eberhardt's multiple comparison test, whereas differences in the average encounter rate by BF sea state were tested by using a goodness-of-fit test based on the number of sightings and survey effort for each BF sea state. All statistical tests were performed with the type-I error set at 0.05. The variance of the ratio of the estimated average density in BF sea state 1 to the weighted average density in BF sea states 2, 3, and 4 was estimated with the delta method (Seber, 1973). Search effort in BF sea state 0 and BF sea state 5 was conducted only in 1995 and was relatively small (e.g. 264 km of effort in BF sea state 0 and 50 km of effort in BF sea state 5); therefore, sightings data for these sea states were not used in our analysis.

Density estimates reported in our note have not been corrected for either the period of time that animals were underwater (and therefore not observable), or the number of animals at the surface that were missed. Further, it was necessary to assume that the actual density of beluga whales was independent of sea state and was relatively constant between years. Given the distribution of sightings observed during the three years of survey effort, this assumption seemed reasonable, except for the northern portion of Norton Sound, where beluga whales were

not observed (Fig. 1). The proportion of total survey effort conducted in this area was relatively small (8%); whereas the percent of survey effort conducted in BF sea-state-1 conditions in this area was approximately three times the percent of survey effort in the overall survey (i.e. 63% vs. 23%). The effect of this heterogeneity in the distribution of sightings in relation to BF sea state was assumed to be negligible, although it was recognized that the bias associated with this factor would produce negatively biased density estimates in BF sea state 1 in contrast to other sea states.

## Results and discussion

The yearly density estimates for beluga whales in June of 1993, 1994, and 1995 by sea-state category are presented in Table 2. In two of the three years, the highest annual density estimate always occurred in BF sea state 1. For the pooled data for all three years (Table 3), the encounter rate (i.e. number of sightings per km of survey effort) was not random with respect to sea state (chi square=403,  $P<0.001$ ); the largest chi square value was associated with the number of sightings in BF sea state 1. In addition, the estimated density for BF sea state 1 was significantly greater than the estimated density for BF sea states 2, 3, or 4. There were no significant differences between estimated density for BF sea states 2, 3, and 4, although the estimated density for BF sea state 4 was approximately 50% of the estimated density in BF sea states 2 and 3. These data are consistent with the hypothesis that the probability of sighting beluga whales in BF sea state 1 is significantly greater than that for sighting beluga whales

in BF sea states 2, 3, and 4. The average density in BF sea state 1 (0.206 whales/km<sup>2</sup>) was more than three times greater than the average density in BF sea states 2, 3, and 4 (0.068 whales/km<sup>2</sup>, SE=0.009). Further, the average density in BF sea state 1 was greater than the average density observed in any individual year by a factor of two or more. That is, the average density estimates (whales sighted/km<sup>2</sup>) for beluga whales derived from our surveys in 1993, 1994, and 1995 were 0.074 (SE=0.023), 0.083 (SE=0.027), and 0.097 (SE=0.035), respectively (Lowry and DeMaster<sup>3</sup>) compared with an average density of 0.206 whales/km<sup>2</sup> for BF sea state 1.

A preliminary estimate for a correction factor that would account for sea state, based on the ratio of the estimated average density for BF sea state 1 in relation to the weighted average density in BF sea states 2, 3, and 4, is 3.023 (CV=0.285). Given our inability to discriminate among density estimates for BF sea states 2, 3, and 4, it is not possible at this time to develop a BF-specific correction factor for Norton Sound beluga whale surveys.

As noted earlier, we did not observe coherent groups of beluga whales during the survey, although they were aggregated in their general distribution. Therefore, we have not reported on the effect of sea state on estimates of group size. Further, because surveys were conducted at survey altitudes of either 264 m or 330 m in some years, interpreting the effect of sea state on average effective strip width (ESW) was not possible. However, the available data for a given year at a constant altitude (i.e. 330 m) indicated that there was not a significant relationship between sea state and ESW. For example, in 1994 the ESWs for BF sea states 1, 2, 3, and 4, were 0.35, 0.58, 0.54, 0.20 km, respectively, where there were no significant differences in ESW for a given sea state. The effect of sea state on encounter rate (i.e. number of sightings per km of survey effort), as noted earlier, was significant (Table 3). Not surprisingly, the same pattern reported for estimated density versus sea state was observed for encounter rate. That is, the encounter rate for BF sea state 1 (0.28 sightings/km) was significantly greater than the encounter rates for BF sea states 2, 3, or 4 (0.11, 0.11, and 0.04 sightings/km, respectively).

Beluga whale aerial surveys are flown in a variety of conditions and with methods adapted to regional circumstances. The results and conclusions presented in this note relate specifically to line-transect surveys in the Norton Sound region flown in an airplane similarly configured to the Aero Commander used in our study. Norton Sound is a large, exposed area and has frequent windy conditions. Some of the transects that we flew were very long, and sea state sometimes varied considerably along a transect. Nonetheless, because of the strong effect of sea state on density that we were able to detect, possible sea state effects should be considered in all beluga whale surveys. However, the authors recognize other factors not controlled for in our study may have influenced the results (e.g. behavioral responses of beluga whales to sea state). Clearly, additional studies are warranted.

Several approaches that should be considered in designing aerial surveys for the purpose of estimating beluga

whale abundance are 1) restrict survey effort to conditions of BF sea state 1 or less; 2) continue to survey in sea states higher than BF sea state 1 and incorporate sea state effects in data analysis, 3) estimate the probability of sighting through the use of a third (independent) observer, or 4) increase the probability of sighting animals on the track line through the use of a belly window and third observer. The first approach is not feasible in the Norton Sound region and might prove difficult to implement in other localities. The latter approaches provide more flexibility in the field. Correction factors can then be used to adjust for reduced sightings in higher sea states, or analytical models can be developed that incorporate sea state as a covariate, as was done for harbor porpoise (*Phocoena phocoena*) by Forney et al. (1991).

## Acknowledgments

Surveys were expertly flown by Tom Blaesing. Observers and data recorders in addition to DeMaster, Lowry, and Frost, included Robert Nelson, Debbie Blaesing, and Dieter Betz. Funding for this study was provided by the Alaska Beluga Whale Committee, the National Marine Fisheries Service, and the Alaska Department of Fish and Game. Early versions of the manuscript were improved by comments from John Bengtson, Rod Hobbs, Pierre Richard, and Janice Waite, two anonymous reviewers, and the scientific editor.

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