

Visibility of St Lawrence belugas to aerial photography, estimated by direct observation

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ABSTRACT

The depleted population of belugas (*Delphinapterus leucas*) inhabiting the St Lawrence estuary, Canada, was monitored by periodic photographic aerial surveys. In order to correct counts made on aerial survey film and to obtain an estimate of the true size of the population, the diving behaviour and the visibility from the air of these animals was studied. A Secchi-disk turbidity survey in the belugas' summer range showed that water clarity varied between 1.5 m and 11.6 m. By studying aerial photographs of sheet-plastic models of belugas that had been sunk to different depths below the surface, we found that models of white adults could be seen down to about the same depth as a Secchi disk, but no deeper. Smaller models of dark-grey juveniles could only be seen down to about 50% of Secchi-disk depth. By observing groups of belugas from a hovering helicopter and recording their disappearances and re-appearances, it was found that they were visible for 44.3% of the time, and that an appropriate correction for single photographs would be to multiply the photographic count by about 222% (SE 20%). For surveys in which there was overlap between adjacent frames, the estimated correction would be 209% (SE 16%). This correction factor was slightly conservative and gave an estimate of the true size of the population, based on a single survey, of 1,202 belugas (SE 189) in 1997. An estimate for 1997 based on smoothing 5 surveys 1988–1997 was 1,238 (SE 119).

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INTRODUCTION

The population of belugas (*Delphinapterus leucas*) inhabiting the St Lawrence estuary was seriously depleted by intensive hunting—for commercial products, to protect fisheries, and for recreation—which was not controlled in any way until it was closed in 1979. At that time the population was estimated to number in the low hundreds (Pippard 1985). An apparent failure of the population to recover

after hunting was closed (Béland *et al.* 1988) was ascribed to the presence of high levels of various persistent contaminants in the belugas and their environment (Martineau *et al.* 1987, Béland *et al.* 1992, 1993), and generated concern for the future of the population. The status of the population was monitored by examining beach-cast carcasses—sometimes including a full necropsy—and by aerial surveys (Sergeant and Hoek 1988, Kingsley 1998, 1999).

Aerial surveys, with two exceptions (1977 and 1982), used large-format aerial photography from 3,000 or 4,000 feet (914.6 or 1,219.5 m). Belugas dive out of sight in the turbid water of the St Lawrence estuary, and cannot be seen from above, so photographic counts only provide an index of numbers. This could generate information on trend, distribution, and, by inference from the size of the animals seen on the photographs, on the age structure of the population (Sergeant and Hoek 1988, Kingsley and Hammill 1991, Kingsley 1993, 1996). However, while trend information is important in evaluating the status of declining populations, for stationary or increasing populations the absolute size is more important (IUCN 1994). Without knowing how many animals are in the population, it was difficult to evaluate the results obtained from the carcass retrieval programme. Furthermore, the absolute historical size of the population in the late 1800s was estimated by calculating back using data on catches made over the years (Laurin 1982), so an absolute estimate of its size would provide a measure of population recovery.

The proportion of belugas invisible to airborne photography was initially estimated by comparing the images in the overlap areas of adjacent overlapping photo frames (Sergeant and Hoek 1988). Values of 15% and 21% were obtained in surveys flown in 1984 and 1985, but it was recognised that these were underestimates that did not fully account for the belugas unseen in both frames. Since 1988, the lesser of these two values, 15%, was added to counts from photographs to obtain a standard index of the population size (Kingsley and Hammill 1991, Kingsley 1993, 1996, 1999). A recalculation from images in overlap areas on photographs taken in 1995 re-estimated the overall proportion visible at less than 88.4%, and the correction as at least 13.1% (Kingsley 1996).

A more realistic correction for the St Lawrence beluga population should be based on studies of dive behaviour and turbidity. Dive behaviour studies of Arctic belugas using satellite-linked pressure recorders (Martin and Smith 1992, Richard *et al.* 1997, Heide-Jørgensen *et al.* 1998) showed that belugas dived deep for about half their time, and that visibility corrections should add 100% or more to aerial survey counts, not 15%. However, these results could not be immediately applied to the St Lawrence population because the habitat was, and the behaviour might have been, different from those of Arctic populations. Therefore field studies on beluga behaviour and turbidity in the St Lawrence were needed to produce a better estimate of true population size.

The components of this study of beluga behaviour and visibility were: first, a Secchi-disc survey of turbidity in the beluga summering area; second, a study of the visibility of model belugas, submerged to various depths, when photographed from the air; and finally the direct observation of beluga groups from a hovering helicopter with recording of their disappearance and reappearance as they dived and resurfaced.

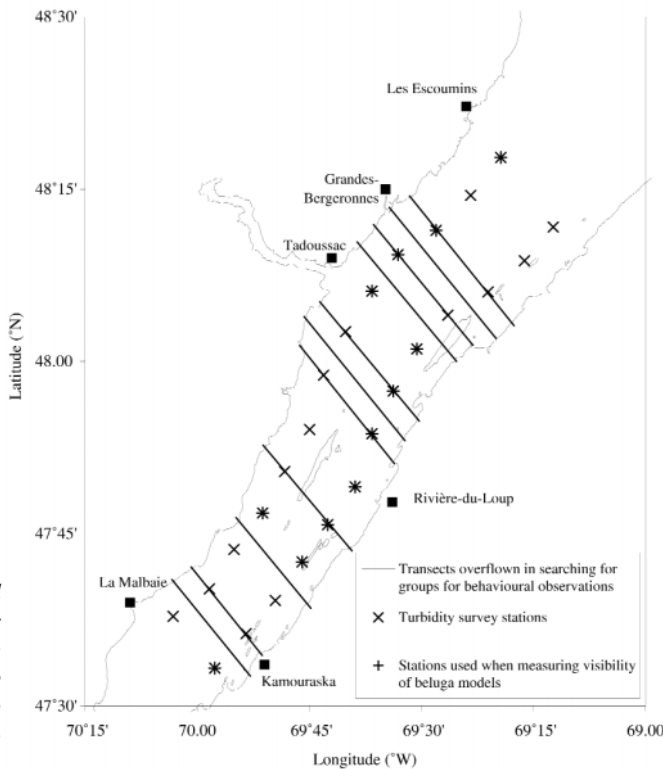


Fig. 1. Stations and transects used for studies on the visibility of belugas and beluga models in the St Lawrence in 1996 and in 1997.

METHODS

Study area

The study area corresponded to most densely frequented parts of the principal summer range of the beluga population in the St Lawrence estuary, between La Malbaie and Les Escoumins on the north coast (Fig. 1).

The turbidity in the beluga range in the St Lawrence estuary varied seasonally. Studies were carried out at the season—between about mid-August and mid-September—at which photographic census surveys were usually flown, to avoid questions associated with applying the results in a different turbidity regime. The distribution of turbidity also varied with the state of the tide, but tidal conditions were not controlled in executing aerial surveys. Therefore, while tidal conditions were noted as the visibility studies were carried out, the analyses did not consider them and results were assumed to be an average over tidal phase.

Turbidity survey of beluga habitat

This experiment was executed in September 1996 and during the third and the last week of August 1997. Thirteen transects in the central part of beluga summer range were selected at a 4 nm spacing. A total of 26 Secchi-disk stations, localised with a Global Positioning System (GPS), were placed 25% of the transect length from each end of each transect (Fig. 1). Standard Secchi-disk readings—on the shady side of the boat, and averaging the disappearance and the reappearance depths—were made with a 30 cm disk, and the state of the tide and the cloud cover were noted.

Visibility of beluga models

Data on the visibility of beluga models was collected on 19–20 September 1996 and 26 August 1997. Beluga silhouettes were cut from 6.4 mm high-density polythene sheet. In 1996 they were 3.05 m long, and the plastic, white and slightly translucent, was left unpainted. In 1997, adult models were made full-size at 3.6 m long (Kingsley 1996) and painted opaque white. Juvenile models were also made, 2.2 m long and painted opaque grey (Fig. 2). This length is reached by either sex at about 1.4 years old (Kingsley 1996).

Secchi-disk stations were classified by turbidity, and a sample of stations was randomly drawn from each turbidity class. At each sampled station the turbidity was first read with the Secchi disk, then a train of beluga models was set up and floated off from the work-boat. Each model was strung between a floating buoy and a stabilising weight, its depth below the surface being fixed by the length of the bridle attaching it to the buoy. In 1996, the train consisted of three models, horizontally separated by 3.5 m. They were sunk to Secchi-disk depth multiplied by 130%, by 100% and by 70%. The 1996 results showed that the visibility limit of a 3.05m model is between 70% and 100% of Secchi-disk depth; all models submerged at 130% of



Fig. 2. Beluga models (white adults and grey juveniles) used to estimate the visibility of belugas to aerial photography.

Secchi depth were invisible. The immersion depths of the models in 1997 were reselected in the light of these results. In 1997, the trains comprised three adult models, horizontally separated by 4 m, and three juveniles, horizontally separated by 2.5 m, one of each sunk to Secchi depth multiplied by 100%, by 90%, and by 81% (*i.e.* 90% of 90%). The grey juvenile models were so hard to see in the early trials that at each of two later stations, one of them was sunk no deeper than 50% of Secchi depth.

Two Hasselblad® 70-mm cameras were used, in a Bell 206-L ‘Long Ranger’ helicopter. One was fixed to the airframe, with a hand-held backup. The fixed camera was mounted vertically, like the cameras used for surveys. The hand-held camera was 10° (±5°) off the vertical. The same aerial survey film was used as for census surveys, *viz.* Kodak Aerographic 2448, and the altitude—400 m with a 50-mm lens—was selected to give the 1:8,000 scale used in the most recent surveys. A single photographic sequence was flown over each model set-up. Simultaneously with the photography, the boat crew re-read the turbidity, because setting up the model trains and calling in the helicopter took so long that the work boat sometimes drifted into water that was significantly more or less turbid than the target for the station.

The photographs were developed and read on a light table in the same way as for aerial survey film (Kingsley 1996). Because the film reader had the advantage over survey-film readers of knowing where the images were supposed to be (underneath a red buoy), the visibility of each model was rated on a scale from 1—white in colour, sharp in outline—through increasing greenness of colour and haziness of outline to invisible at level 5.

Direct observation of beluga behaviour

Beluga groups were observed from a hovering helicopter to measure their visibility between 14 August and 16 September 1997. These visibility studies were carried out under the conditions usually specified for photographic surveys: wind less than 20 km/h and no fog or cloud below flying height. Of the transects used for aerial surveys in 1992 and 1995, the most-frequented 11 (based on the aerial survey data)

were chosen as the basis for sampling (Fig. 1), and a randomly chosen transect was overflown in a random direction.

The first group of belugas seen was made the subject of the observation session. A lap-top computer was used as a stopwatch, the number of visible belugas in the group being entered from the keyboard as often as it changed. For singletons, one of two codes was entered according to whether the beluga was at the surface, *i.e.* white, or visible but submerged, *i.e.* greenish, but this level of detail was impracticable for groups of more than one. For groups of belugas, the size of the group was taken to be equal to the maximum number of belugas recorded as visible at any time in the observation session. The visibility records were time-stamped by the computer clock, and the positions of the observations were simultaneously recorded using data from the GPS. For some observation sessions, the work-boat simultaneously measured the turbidity, with a Secchi disk, near to the group. With these data, it was possible to relate the recorded visibility to the local turbidity.

Initial trials were made at 1,500 feet (458 m). However, the belugas appeared to react to the presence of a hovering helicopter by continually distancing themselves from it, so attempts to record their behaviour tended to turn into pursuits. When the flying height was increased to 2,000 ft (611 m), this flight behaviour was not noticed, so that height was used thenceforward.

Analysis of the visual records gave an estimate, considered unbiased, of the proportions of time visible and invisible. The global visibility proportion of belugas in the 72 observation sessions was estimated as:

$$P = \frac{\sum_{i=1}^k n_i}{\sum_{i=1}^k (L_i N_i)} \quad [1]$$

where:

k = number of observation sessions in the study;

n_i = number of visible-beluga-seconds (*i.e.* the sum, over all periods during which the number of belugas visible was constant, of

the product of the number of belugas visible during the period and its length in seconds) in the i^{th} session;

L_i = length of the i^{th} observation session in seconds;

N_i = number of belugas in the group followed in the i^{th} session, assumed equal to the maximum number seen at any time;

The proportion of visible beluga was transformed to an initial correction factor for photographic counts:

$$f = \frac{1}{P} \quad [2]$$

where f is the correction factor.

This crude correction ignored the overlap between adjacent frames in the continuous lines of survey photography. Belugas in overlap areas had two chances of being photographed at or near the surface. In the analysis of survey photographs, all images found were recorded and those considered to be duplicates of images of the same beluga on the overlapping neighbouring frame were not tallied. The result was a count of distinct belugas, some of which, being in the area of frame overlap, had had two chances of being imaged. A correction was made to the analysis to allow for the increased chance that a beluga would be imaged at least once if two photographs were taken t seconds apart, as follows.

On each surfacing, a beluga is visible for a period that is of similar length to the interval between frames, or is longer; and is invisible at least for similar periods. In an observation session lasting L seconds a beluga makes s surfacings which have a total visibility duration of n seconds. Its probability of being photographed by a random single exposure is equal to its average visibility, or n/L . If two exposures are separated by a fixed interval of t seconds, the second exposure is not independent of the first. The beluga will be imaged *at least once* if the first frame is shot either during a surfacing or within t seconds before the surfacing starts; in the latter case, the beluga will only be imaged on the second frame. Provided dive cycles remain long relative to the interval t , these are a complete and mutually exclusive set of conditions for the animal to be imaged, so their probabilities can be added. The probability that a first shot oc-

curs during a surfacing is given by n/L . The sum of the s periods of t seconds before the starts of surfacings is ts . The probability that a first exposure occurs within t seconds before the start of a surfacing is therefore ts/L . The probability that a given beluga will be imaged at least once is therefore $(n+ts)/L$; this is its effective visibility to double-shot photography. Averaging over individual whales seen, the estimated probability of a whale's being seen in at least one of two photos of the same area taken t seconds apart is:

$$P_D = \frac{\left(\sum_{i=1}^k n_i + t \sum N_i S_i\right)}{\sum L_i N_i} \quad [3]$$

where:

S_i = number of surfacings by the group in the i^{th} observation session;

t = interval between consecutive frames (taken as 16 sec.).

This expression for visibility to double-shot photography would be invalid if dive cycles were short compared with the interval between frames, but this is not so for belugas in the St Lawrence, where in the most highly frequented areas the water is not very turbid and belugas staying near the surface remain visible. About 46% of belugas in the overlap area are liable to be imaged twice (Kingsley 1996 Table 2), indicating that belugas are visible on average for about 2.7 times as long as the time interval between photo frames.

For a photographic survey with a frame overlap of V ($0 < V < 0.5$), each photographed transect strip would comprise $V/(1-V)$ of doubly-photographed overlap area and $(1-2V)/(1-V)$ of single-shot area, the overall probability that a beluga would be imaged at least once given that it was within the survey strip would be:

$$\bar{P} = \frac{(1-2V)P + VP_D}{1-V} \quad [4]$$

$$= \frac{\sum_{i=1}^k n_i + V/(1-V) t \sum N_i S_i}{\sum L_i N_i}, \quad [5]$$

and the overall correction factor for survey counts would be:

$$\bar{f} = \frac{1}{\bar{P}} \quad [6]$$

Converting the probability that a beluga would be imaged to a correction involved taking its reciprocal (Eqns 2 and 6), and was therefore expected to incur a sample-size bias. Sample-size bias was reduced using the ordinary jack-knife (Efron 1982). Observation sessions were considered to be the independent observational units in this study, and results were recalculated deleting each observation session in turn from the data set. The jack-knife output was used to reduce sample-size bias, and also to estimate the standard error of the resulting correction factor.

The visibility records were made with the naked eye, but the objective was to correct counts made from film, so the observer's visual acuity was checked against film readings. For a sample of the observation sessions, the group was photographed at the same time as the observer recorded the visual counts. The film was later read, and the counts obtained from the film were compared with the computer records of visual observations. The time imprint on the film was compared with the time record in the computer to match the two data sequences. The same flying height was used as for the other observations, and the photographic scale was the same as used for surveys. Considering each photograph as an estimate of relative visibility, the mean ratio of belugas visually counted to belugas counted on film was estimated as:

$$P_v = \frac{\sum_{i=1}^o \left(\frac{v_i}{p_i} \right)}{o} \quad [7]$$

where :

o = number of photographs used in the analysis

v_i = number of belugas visually counted

p_i = number of belugas count on the photographs

RESULTS AND DISCUSSION

Turbidity survey

A turbidity survey of the summer range was not a primary objective of the study, but was carried out to improve planning of other activities. The results presented here are therefore summary. Turbidity varied in the study area from 1.5 m Secchi depth (1997 minimum) to 11.6 m (1997 maximum) (Fig. 3). The turbidity in 1996 var-

ied from 2.1 to 5.9 m. The water was more turbid in the western part of the study area than in the east, and on the south side than the north; the latter difference more marked in the clearer downstream (western) part of the study area. Upstream of Rivière-du-Loup, Secchi-disk depths were less than 2.5 m. Downstream, they were 3.5 to 6.5 m on the south side of the river and 4.5 to 11.6 m on the north. At the mouth of the Saguenay fjord, the tidal variation is marked, with high turbidity when the tide is flooding and lower when the ebb tide flushes clear oligotrophic water out of the Saguenay fjord (Sergeant and Hoek 1988, Hamblin *et al.* 1986). The maximum Secchi-disk reading for the entire study (11.6 m) was observed on an ebbing tide in this area in 1997. The water was generally more turbid in 1996 (mean 3.3 m) than 1997 (mean 4.02 m) in the clearer north-eastern part of the study area, probably owing to catastrophic rainwater runoff at the head of the Saguenay Fjord and elsewhere on the north shore in July 1996.

Model visibility

The Secchi-disk depth was a good estimator of the depth at which adult belugas could be seen from the air. In general, models of all sizes were not visible on the film when submerged deeper than Secchi depth (Fig. 4). White models, whether the full-size ones used in 1997 or the slightly smaller ones used in 1996, could almost always be seen when they were at Secchi depth or less.

Models of grey juveniles used in 1997 were invisible at almost all depths. Only in the tests at 50% of Secchi-disk depth could the grey-juvenile models be made out on the film.

Similar results were obtained in Arctic waters, where in 1:6,000-scale photographs 4.20 m adult models could be seen down to 10 m, but 2.5 m models of juveniles only at depths of 5 m and 1.6 m dark-grey neonate models not even as deep as 2 m (Richard *et al.* 1994).

These results were somewhat influenced by the weather, models being harder to see in rough water and on cloudy days. Aerial surveys are usually only done in fine weather, and model studies were mostly done in fine weather for

reasons of practicality and safety as well as for similarity with survey conditions. The experiment was designed to avoid weather-related variation in visibility by picking good weather, not to study it by working in a range of different conditions. We did not make quantitative estimates of weather-related effects.

Direct observation of dive behaviour

A total of 89 sessions totalling 20 h 24 min were carried out (Fig. 5). The data was screened to retain only those in which the observer was sure of not having changed groups in the course of the session, and 72 sessions totalling 11 h 37 min were retained. The longest was 41 min 31 s, and the shortest 26 s. Singletons were observed 27 times, and the rest of the observation sessions (45) were on groups up to 18 individuals for a mean group size of 3.2 (SE 0.7)

The crude visibility proportion (Eq. 1) was 44.3% (SE 3.8%), equivalent to a crude correction factor of 226% (Eq. 1). The estimate of P_D appropriate to doubly photographed overlap areas (Eq. 3) was 51.7% (SE 3.0%). Calculating \bar{P} for a survey with a 30% overlap (Eq. 5), converting it to a correction (Eq. 6), and then applying the standard jack-knife to reduce sample-size bias (Efron and Tibshirani 1993), the resulting overall survey correction factor was 209% (SE 16%) to be applied, as a multiplier, to photo counts obtained by tallying all images and leaving out duplicates in overlap areas. Visibility correction factors of this size are in line with dive behaviour data obtained from pressure recorders mounted on Arctic belugas (Table 1).

We were unable to detect large differences in visibility proportion associated with group size or, in general, with turbidity. However, when we compared the data from the most turbid part

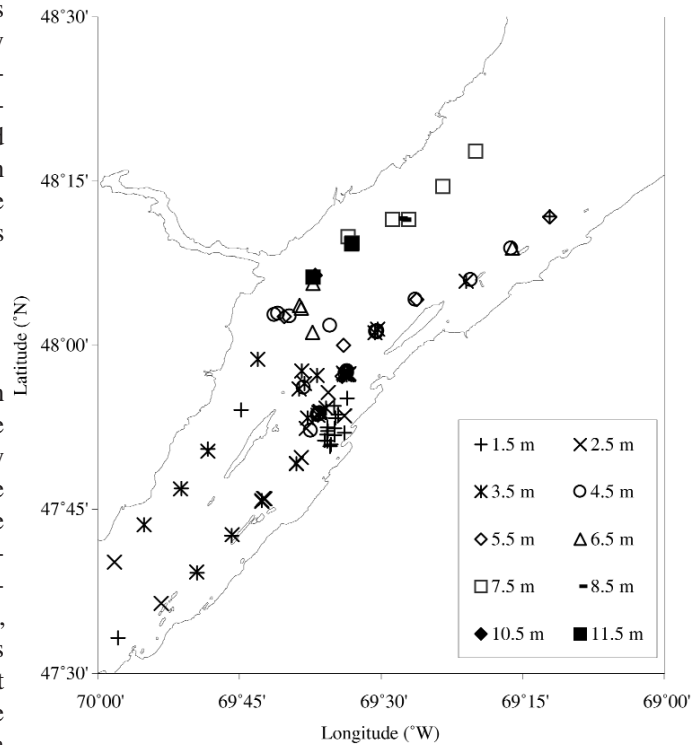


Fig. 3. Secchi-disk measures of water clarity obtained in the St Lawrence estuary in 1997.

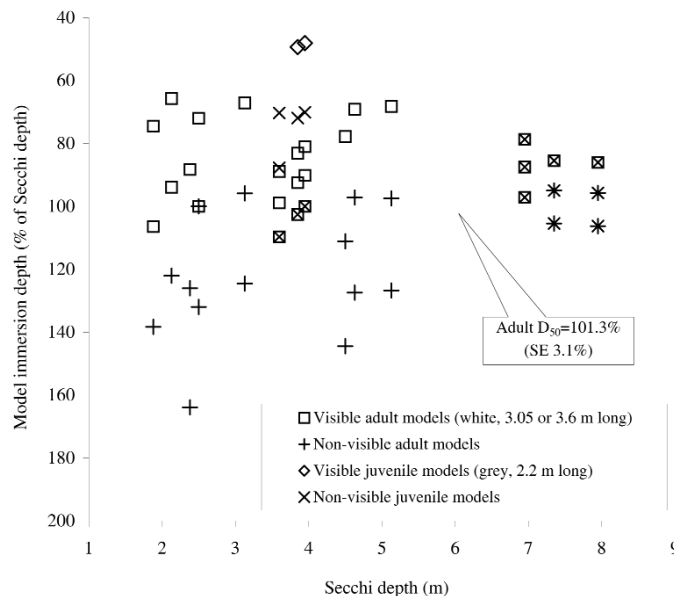


Fig. 4. Visibility of models of adult and juvenile belugas related to their depth of immersion and to the turbidity of the water.

of the St Lawrence with that obtained from the least turbid, we could detect a difference. The correction factor for the most turbid waters (Secchi-disc reading 1 to 1.99 m) was 247% (SE 60%), and for the least turbid waters (Secchi-disc depth over 4m), 184% (SE 26%).

Fig. 5.
Locations of
helicopter
observations
for measurement
of the visibility
of beluga
groups in the
St Lawrence
in 1997.

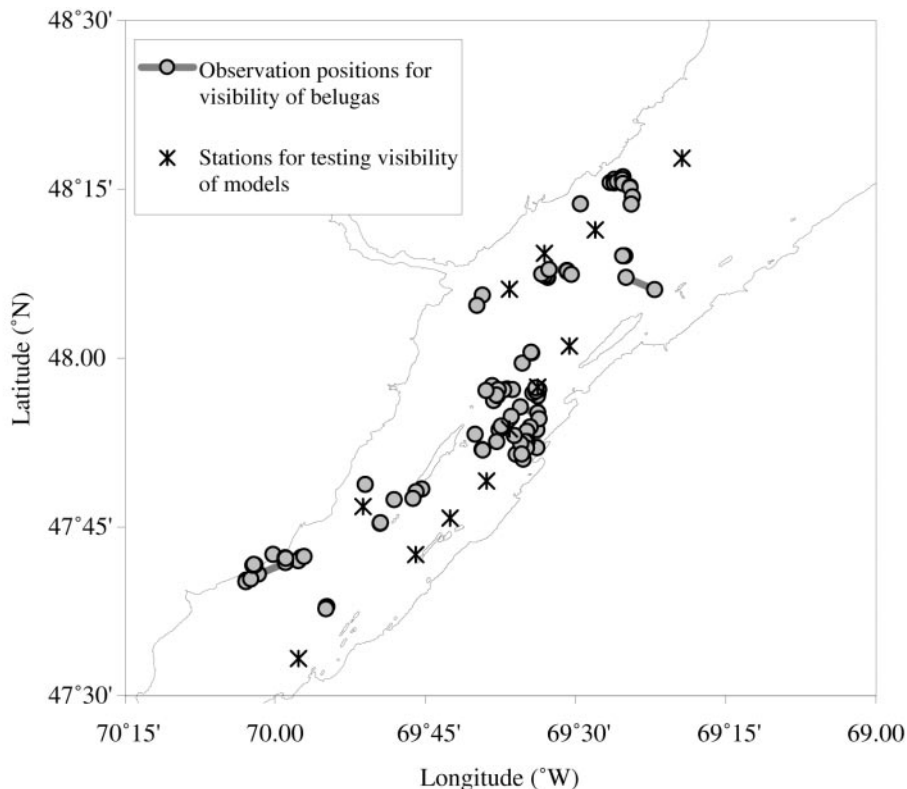


Table 1. Correction factors for aerial survey counts to obtain total population numbers of monodontid whales estimated from studies in the St Lawrence and in the Arctic between 1973 and 1998.

Correction factors	Methods	Places	Year(s)	References
209% ¹	Visual observations (helicopter)	St Lawrence	1997	this study
250 – 290% >113% ³	Pressure-recording tag Counts on overlapping aerial photographs	Arctic St Lawrence	1995 1995	Heide-Jørgensen <i>et al.</i> 1998 Kingsley 1996
254% ²	Pressure-recording tag	Arctic	1993–1994	Heide-Jørgensen and Dietz, 1995
166 – 180%	Pressure-recording tag	Arctic	1991	Martin <i>et al.</i> 1994
180 – 250%	Pressure-recording tag	Arctic	1990	Martin and Smith 1992
115 – 121% ³	Counts on overlapping aerial photographs	St Lawrence	1984–1985	Sergeant and Hoek 1988
190 – 340% ²	Visual observations (helicopter)	Arctic	1983–1985	Dueck 1989
275%	VHF radio signal tag	Arctic	1983	Frost <i>et al.</i> 1985
≈ 303%	Visual observations (fixed-wing aircraft)	Hudson Bay	1973	Sergeant 1973

1) This study

2) Study on narwhals (all others on belugas)

3) Published as a minimum correction factor, *i.e.* known to have negative bias.

When comparing visual observations with photographic film counts (Eq. 8), the visual observer saw 99.37% of the animals that could be discerned on the film. The correction factor of 209% could be applied directly to the number of belugas, net of duplicated images on overlapping frames, counted in photographic surveys of the population.

We could identify four possible biases. The first was in the selection of groups to observe. A group could not be selected if it could not be seen, so there may have been a bias toward groups that were engaged in more visible behaviour, of whatever kind. This bias would lead to overestimating the average proportion of time visible, and underestimating the correction factor. The second bias was in estimating the true size of the group that was observed. As stated above, the maximum number of animals recorded during the session was always taken to be the size of the group. However, it was possible for this to underestimate the true group size, if all the members of the group had never been visible simultaneously. This bias would lead to overestimating the visibility of the group, and to underestimating the correction factor.

A third bias was the observer effect on behaviour: whether the belugas dived more often or for longer in response to the presence of the helicopter. This would have biased the visibility correction factor and the resulting population estimate upwards, but was not thought to be a serious source of bias for two reasons. The first was that for a beluga, diving in response to the disturbing presence of a hovering helicopter would be no solution, as the nuisance would still be there when the animal resurfaced. A beluga trying to avoid a stationary hovering helicopter would be more likely to flee. And, as noted above, in initial trials at 1,500 ft, a flight response was observed. This flight reaction was not noticed when observations were made from 2,000 ft. Pippard and Malcolm (1978) observed that St Lawrence belugas quickly dived in response to helicopter overflights at 700 ft (213.4 m), but when observed from a helicopter at 1,000 to 1,200 ft (304.9 to 365.9 m) they tended to remain at the surface, some watching the helicopter, with a tighter group structure.

The fourth bias was in the effect of sun-glare on the double-exposure correction. The above analysis assumed that all the area of frame overlap was effectively photographed twice. However, on sunny days, the reflection of the sun on the water obscures part of each frame, usually (because of the orientation of the transects and the timing of the survey) at the end of the frame within the overlap area. Under such circumstances eq. 5 weights the double exposure too highly, so this bias also caused the present study to underestimate numbers. This bias could not be quantitatively estimated in general, as it would vary with cloud cover (more cover reducing sun glare) and wind (which would ruffle the water and extend the glare area).

A further bias, the possible failure of the interpreters of aerial survey film to find all the belugas present, was not a subject of this study and has not been considered.

Implication of the correction factor for status evaluation of the St Lawrence beluga population

Information on the detection rate of belugas from the air did not change the estimated trend, which for the St Lawrence population was estimated at a 2.9%/yr increase (SE 1.21%/yr) from 1988 through 1997 (Kingsley 1999). It allowed a more satisfactory estimate of numbers to be made from aerial survey. A revised estimate of numbers for the population in 1997, based on the single survey flown in that year, was 1,202 with SE 189. A linear smoothing of 5 surveys flown in 1988–1997 gave an estimate of 1,238 (SE 119) (Kingsley 1999). The population appeared therefore not to satisfy quantitative criteria for ‘Endangered’ status (IUCN 1994, COSEWIC 2002), but its numbers would appear still to be low enough to qualify it for IUCN ‘Vulnerable’ status (COSEWIC ‘Threatened’).

The larger estimate of numbers in this population obtained by using this visibility correction factor should impose greater caution in interpreting data obtained from beach-cast carcasses. An average of 15 stranded carcasses per year would become a small fraction of the probable total deaths. Sampling bias would probably

therefore be greater than formerly thought, and analysis of data from strandings could give unreliable estimates of life expectancy, age-specific mortalities, or relative frequencies of causes of death.

CONCLUSIONS

The Secchi-disk depth used as a standard measure of water turbidity gave an adequate indicator of the depth at which a white adult beluga could be seen on aerial survey film, at least for vertical viewing, either visually or photographically, and in turbidities ranging from moderately turbid to moderately clear. Pressure-record data on dive behaviour could thus be converted to visibility estimates for these or similar conditions without repeating visibility experiments. However, caution may still be appropriate in correcting visual surveys where some observations are made at rather flat viewing angles.

Small grey juveniles could only be seen down to about 50% of Secchi depth. Photograph counts of different sized animals (*e.g.* Kingsley

1993, 1996) would therefore be likely to underestimate the proportion of juveniles.

It was possible to collect data from a hovering helicopter on the visibility of belugas, to estimate their mean visibility, and to convert that into a correction factor for photographic surveys. Correction factors to convert counts from photographic surveys into population estimates for the St Lawrence belugas appeared to be of the order of 200%; the value obtained in this study was 209% (SE 16%) for photography with forward overlap of 30%. The correction was less in less turbid water, and the value obtained was an average over the visibility study, not formally weighted for the distribution of belugas in photographic surveys. The correction was conservative, probably including some small negative biases. It gave a minimal estimate of the true size of the population of 1,238 belugas (SE 119) in 1997. With this revised estimate, this population would appear to qualify for 'Vulnerable' status under IUCN criteria, but not for 'Endangered'.

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