Fisheries and Oceans Canada
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Canadian Science Advisory Secretariat

Research Document 2007/026

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Secrétariat canadien de consultation scientifique

Document de recherche 2007/026

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Lack of Recovery in St. Lawrence Estuary beluga

Absence de rétablissement du béluga de l'estuaire du Saint-Laurent

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ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

Estimates of pristine population size and changes in abundance of St. Lawrence Estuary beluga were examined over the period 1866-2006. Overhunting led to a decline in abundance from pristine estimates of 7,800 (SE=600) in 1866, to approximately 1,000 animals in 1985. In spite of almost 30 years of protection from hunting, the St. Lawrence Estuary beluga shows no signs of recovery with a current population of approximately 1,100 (SE=300, 95% CI=500-1,800, rounded to the nearest 100) animals. A carcass monitoring and necropsy program detects on average 15 carcasses per year, which likely represents a fraction of the total number of deaths in this population. The age structure of adult animal carcasses suggests that adult mortality rates (6.5%/yr) are similar to what would be expected in a hunted Arctic beluga population (7.0%/yr) (Burns and Seaman 1985). Estimates of reproductive rates are uncertain, and juvenile animals are under-represented in the stranding record. Among all animals regardless of age class where cause of death could be determined, parasitic and bacterial infections accounted for 38% of mortality, followed by cancer (15%), problems during birth (7%), and trauma (5%), while various other factors accounted for 7%. A paucity of diet information limits attempts to model trophic interactions and habitat requirements. Emigration does not appear to be an important factor, but the loss of only 1-2 animals per year has longer term cumulative impacts that are not beneficial to a small population.

RÉSUMÉ

La taille initiale de la population et les changements d'abondance des bélugas du Saint-Laurent ont été estimés pour la période de 1866 à 2006. La surchasse a entraîné un déclin de l'abondance d'une population initiale de 7 800 (erreur-type=600) en 1866 à environ 1000 animaux en 1985. Malgré 30 années de protection contre la chasse, le béluga du Saint-Laurent ne montre aucun signe de rétablissement avec un indice d'abondance corrigé pour la plongée de 1100 (erreur-type=300, IC 95% = 500-1 800 arrondi à la centaine) animaux. Un programme de suivi des carcasses et de nécropsies rapporte en moyenne 15 carcasses par année, ce qui représente vraisemblablement qu'une faible fraction du nombre total des mortalités de cette population. La structure d'âge des individus adultes suggère que les taux de mortalité des adultes (6,5% par année) sont similaires à ce qui est attendu dans une population saine de l'Arctique (7,0% par année)(Burns and Seaman 1985). Les estimations des taux de reproduction sont incertains et les juvéniles sont sous-représentés dans les rapports d'échouages. Parmi les animaux pour lesquels la cause de mortalité a été identifiée, 38% étaient liées à des infections de parasites et de bactéries, 15% liées au cancer, 7% à des difficultés pendant la mise bas, 5% à un trauma, et 7% à d'autres facteurs. Le manque d'information sur la diète limite la modélisation des interactions trophiques et les besoins en habitat. L'émigration ne semble pas être un problème important, mais la perte de seulement un ou deux individus annuellement a des effets cumulatifs à long terme qui ne sont pas positifs pour la population.

INTRODUCTION

St. Lawrence Estuary (SLE) belugas, *Delphinapterus leucas*, are the most southerly of beluga populations and are geographically isolated from the nearest recognized population in eastern Hudson Bay. Severely depleted by intensive hunting—for commercial products, to protect fisheries, and for recreation—this population of beluga was afforded protection from hunting in 1979 (Lesage and Kingsley 1998). 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 beluga and their environment (Martineau *et al*. 1987, Béland *et al*. 1993), and generated concern for its future. Here we examine changes in the population since aerial monitoring began in 1988.

MATERIALS AND METHODS

The Department of Fisheries and Oceans has carried out a series of systematic aerial photographic surveys since 1988 to monitor abundance and a carcass monitoring program since 1983 (first full year of the program) to monitor causes of mortality (Béland et al. 1987; Kingsley and Hammill 1991; Kingsley 1996; Gosselin et al. 2006).

The aerial survey photographs provide a permanent record of a sample of animals present at the surface at the time of the survey. These data are used to estimate abundance. Length measurements of animals in the photographs can also be used as a proxy for age composition of the population. Animals ≤0.5 body length of adjacently swimming animals are likely to be young of the year (YOY)(Kingsley 1996).

Carcasses that are found on the beach are examined and, if in a reasonably good state of preservation and accessible, are transported to the Faculty of Veterinary Medicine, University of Montreal at Ste-Hyacinthe where a complete necropsy is performed. Carcasses that are not transported are documented, and if possible, total length and sex are determined and teeth are collected for age determination (Béland et al. 1993; Martineau et al. 1987; Sergeant 1973). These carcasses provide an index of deaths and are included in the model as H_t. They also provide an age structure of mortalities.

Changes in population size over time were examined using a discrete time parameterisation of the Pella and Tomlinson model (1969; Innes and Stewart 2002), where the estimated population size (N_{t+1}) at time t+1, is described by:

$$N_{t+1}=N_t+ N_t (\lambda_{max}-1)(1-(N_t /N_{pristine})^{\theta})-b H_t$$

N_t is the population size at time t, $N_{pristine}$ estimated pristine population size in 1866 and theta (θ) is a shaping parameter for the density dependent response that describes where the maximum net productivity level occurs. λ_{max} is the maximum rate of increase. H_t is the reported number of removals from hunting, or after 1982, it is the number of beach-cast carcasses, while b is a fitting parameter that is adjusted to minimize the differences between the aerial survey estimates and the size of the population predicted by the model. Theta (θ) was described by a uniform distribution lying between 1.17 and 7.14 (Innes and Stewart 2002). Belugas are characterised by early reproduction (age 4-7 years), low reproductive rates (crude birth rate: 0.26-0.47) and a long lifespan (longevity = 35 years) (Sergeant 1973; Burns and Seaman 1985; Doidge 1990; Kingsley *et al.* 1995). Little information is available on the maximum natural rate of increase (λ_{max}), but rates of increase of 1.026 to 1.037 have been suggested (Kingsley *et al.* 1995; Doidge 1990; Innes and Stewart 2002), which are similar to rates of 1.020 to 1.040 for species with similar life histories, such as pilot whale and spotted dolphin (Barlow and Boveng 1991; Kasuya et al. 1988). Therefore, λ_{max} in the model was described by a uniform distribution, which varied between 1.02 and 1.04.

Indices of abundance for SLE beluga (N_{survey}) are from Gosselin et al. (2006)(Table 1). Correction factors (*P*) were required to adjust the aerial survey numbers to account for animals not visible (*i.e.* diving) when the survey plane passed overhead. We used an estimated proportion (P_0) of animals visible on the photographs of 0.478 (SE 0.0625), the reciprocal of which (2.09) is the correction factor developed from experiments on diving behaviour and visibility of belugas from aircraft conducted through the summer range of the population in the St. Lawrence Estuary (Table 1; Kingsley and Gauthier 2002). It is similar to a correction factor of 2.09 that was derived from satellite transmitters deployed on belugas in eastern Hudson Bay, which were also flown in August (Kingsley et al. 2001; Hammill, Lesage and Séguin, unpublished data). This parameter was assumed to follow a normal distribution, and was used to correct the photographic and line-transect estimates (N_{survey}) of population size. Belugas detected in the Saguenay ($N_{Saguenay}$) were added without any correction for diving as observation time was longer and low turbidity in the Saguenay suggests that the 209% correction for the Estuary would be too high.

$$N_t = N_{survey} / P_0 + N_{Saguenay}$$

The variances for the correction factor for the proportion of animals under the water (P_i) and survey estimate combined assume that N_{survey} and P_i are independent and therefore the error variance of the quotient is given by:

$$V_i = N_{uncor}^2 \times V_p / P_i^4 + V_n / P_i^2$$

where: V_p = the variance in the proportion estimated to have been present prior to survey *i*; V_n = the variance in the uncorrected estimate for survey *i* (Mood et al. 1974).

The estimate of pristine population size in 1866, was re-examined using the Pella and Tomlinson model outlined above. We included the reported catch between 1866 and 1960 (Table 2) (Reeves and Mitchell 1984). We also assumed that there was no catch between 1960 and 1985 and that the population in 1985, our starting point was approximately 1000 animals. The struck and loss term was adjusted to 1, 1.5 and 2. Theta (θ) was set at either 1, 4 or 7 and the maximum rate of increase, λ_{max}, was fixed at 0.04.

Changes in estimated population size were determined by fitting the model to the 1988-2003 photographic aerial survey estimates corrected for diving animals. The difference between the model estimates and the aerial survey estimates were minimized by adjusting the initial population size, in the year 1985 and *b* (Risk Optimizer, Palisade Corporation, Newfield, NY, USA). The algorithm operated as follows: 1) take a random sample from the survey estimates assuming a normal distribution, with mean and standard errors equal to the survey estimates; 2) select values for the 1985 population size and for non-recovered carcasses (*b*); 3) calculate the population trajectories and the sum of squares for the trajectory; 4) repeat steps 2 and 3, 600 times; 5) retain the values for the 1985 population size and *b* giving the smallest sum of squares; 6) return to step one and begin the process again 2000 times. The values retained for the 1985 population size and the estimate of *b* were used to generate the population trajectories.

RESULTS

SLE beluga have declined from an estimated pristine population of around 10,000 animals in 1866 (SE=1,189, N=9 scenarios), to number around an estimate of 1,000 animals today (Fig. 1). However, these data incorporated struck and loss factors of 1, 1.5 and 2, which might be excessive for situations where many animals were taken in weir fisheries and may have been recovered by harpoon (Reeves and Mitchell 1984). To look at the impact of changes in this parameter, the pristine population was re-calculated using struck and loss factors of 1, 1.15 and 1.3. This resulted in a pristine population of 7,800 (SE=600) (Fig. 1). For additional projections, the pristine population size was set at 7,800.

Fitting the population model to the aerial photographic survey data, and taking into account numbers of stranded animals as removals from the population, the SLE beluga population has not shown any signs of significant growth since 1988, when aerial monitoring began. This fitting resulted in an initial population in 1985, of 997 (SE=191, 95% C.I. 678-1414) and a value for the fitting factor (*b*) of 1.497 (SE=0.748). From the model, the population in 2006 is estimated to number around 1,090 animals (SE=341, 95% C.I.=508-1,818) (corrected for diving; Fig. 2).

As an alternative, the model was fitted to the aerial survey series by adjusting the population size in 1985 and the rate of increase, and assuming that the reported carcasses represent all mortalities (Fig. 3). This resulted in an initial population estimate of 1,062 (SE=236; 95% CI=670-1,591) animals and the estimated rate of increase was 1.014 (SE=0.0134). In 2006, the population would number 1,042 (SE=209; 95% CI=677-1,493).

If the population after hunting ended, had increased as expected by the model (r_{max}=1.04), then it would have increased from an initial population of 997 (SE=191, 95% C.I. 670-1418) in 1985 to 1,686 (SE=432; 95% CI=988-2,650) in 2006 (Fig. 4).

Using measurements of beluga on aerial survey photographs, YOY accounted for an average proportion of 0.08 (SE=0.033; range=0.02-0.16) of those measured on the photographs (Table 3).

An average of 15 (SE=0.73; Range=9-21; confirmed total of 337 carcasses over 23 years of monitoring: 1983 - 2005) SLE beluga carcasses are documented per year (Table 4). Reliable diagnoses (N=148) were obtained from necropsies conducted between 1983 and 2002. Complete and reliable necropsies have been completed on 148 animals over the period of this program. Causes of death vary with age. Overall, cause of death could not be determined in 28% of cases. Parasitic and bacterial infections resulted in death among 38% of animals, followed by cancer (15%), problems during birth (7%), and trauma (5%), while various other factors accounted for 7% (Fig.

5). When examined by age, the majority of YOY deaths (58%) are associated with the birth process, while infections are associated with 34% of mortalities (Table 5). Among juveniles, 81% of mortalities are associated with parasitic and bacterial infections, while 19% are associated with unknown causes. Among adults, 32% of mortalities are associated with infection, 18% with cancer (neoplasia), 6% with trauma, while 33% died from unknown causes (Table 5).

DISCUSSION

The demographic vigour of a population is defined as its well-being in terms of fecundity and survival. It does not necessarily provide information on future survival, but it does indicate how a population is coping with current conditions (Caughley 1977). The SLE beluga population currently numbers around 1,000 animals, which is considerably less than pristine estimates of 7,800-10,000 animals in the St Lawrence in 1866. Although commercial hunting ended in 1955, some harvesting continued into the mid 1970s (Pippard 1985). Protected since 1979, this population would have been expected to increase from roughly 1000 animals in 1985 to approximately 1,700 animals by 2006. Instead it has not shown any significant change in abundance over the last 18 years.

In this study, two versions of a general population model were used to describe the SLE beluga population. The first approach assumed that the maximum rate of increase (r_{max}) of 4% is what would be expected for a normal beluga population. Differences between model predictions and aerial survey estimates of abundance were minimized by subtracting a fitting factor multiplied by the documented number of beach-cast carcasses from the predicted model population. At a population size of around 1,000 animals, the SLE beluga population should be increasing at a rate that is very close to r_{max}. If births represent about 10% of the population, and mortality represents about 6%, then in a population of approximately 1,000 animals, there should be about 100 births and 60 deaths. Since there has been little change in the population over the last 18 years, the number of deaths in the r_{max}=0.04 version of the model, would be closer to 100, which is much higher than the average of 15 beach-cast carcasses reported annually.

In a second version of the model, it was assumed that all animals dying in the population were recovered by the carcass recovery program. In this case, r_{max} becomes a proxy for births. Differences between model predictions and aerial survey estimates of abundance were minimized by adjusting r_{max}. This version provided an estimate of r_{max}=0.014, which represents a birth rate of only 14 animals annually for a population of 1000 animals.

Carcass recoveries occur primarily from April to November, which corresponds to the period of greatest human activity in the area. The proportion of belugas dying that are cast on the beach in summer and the fate of carcasses trapped in the ice are not known, however, the number of found beach-cast animals provides a minimum estimate of mortality, as well as information on age and sex at death, and some information on reproductive rates. Kingsley (2002) examined the mortality and age structure of beach-cast carcasses in the St. Lawrence, comparing it with that of hunted animals in Alaska. For adults, the average age of stranded animals (21.4 yrs) suggests that mortality rates of adults among the recovered animals are similar to rates reported for a hunted beluga population in Alaska (Burns and Seaman 1985). However, mortality rates among juveniles could not be examined because they were under-represented in the carcass-recovery program, possibly because they are more likely to sink or disappear before being detected (Kingsley 2002). If adult mortality rates appear to be normal, could the lack of recovery be due to problems associated with reproduction? In a life-table constructed for a harvested population of beluga in Alaska, and corrected for hunter bias away from juveniles, the crude birth rate for the population was 0.094, which is similar to estimates of 0.1 to 0.12 from aerial surveys in the Canadian Arctic (Burns and Seaman 1985; Sergeant 1986; Kingsley 2002). Analysis of reproductive rates from SLE beluga carcasses suggests that reproductive rates for this population may be slightly lower than would be expected from a species that has a 3 year reproductive cycle, but these estimates may be negatively biased owing to the nature of the sample (Béland et al. 1993). Aerial survey estimates of the number of YOY observed as a proportion of animals detected have averaged 0.08 (range=0.02-0.16), for beluga in the St Lawrence, with considerable variability between surveys. This variability might reflect real inter-annual variability in YOY production, as has been observed among other odontocetes, such as killer whales (Brault 1999), or it may reflect the considerable difficulties associated with detecting YOY in the water (Kingsley and Gauthier 2002). From the above, it would appear that reproduction is near normal in this population and that the failure of SLE beluga to recover results from problems in recruitment to the population, possibly arising from high rates of juvenile mortality. However, better estimates of reproductive rates and estimates of juvenile mortality are needed to confirm this hypothesis.

Some factors that have been identified as potentially limiting recovery of beluga in the St. Lawrence, include; inbreeding (Patenaude et al. 1994), loss of habitat, effects of contaminants on reproduction or survival (Béland et al. 1993), competition with commercial fisheries or other marine mammals (Curren and Lien 1998), ship strikes and emigration (Curren and Lien 1998; Kingsley 2002). Some of these have been reviewed elsewhere (Reeves and Mitchell 1984; COSEWIC 2004; Kingsley 2002). The following discussion draws heavily from these sources.

The SLE beluga population has been long presumed to be a relict Arctic population. Recognition of the discreteness of this small population, mainly centered near the mouth of the Saguenay River, was based on the absence of any significant contiguous populations (Reeves and Mitchell 1984; COSEWIC 2004). More recent genetic analyses indicates that, although they share a haplotype found only in eastern Hudson Bay and Ungava Bay beluga populations, SLE beluga are genetically quite distinct from all other Canadian beluga populations. Along with the Eastern Hudson Bay beluga, the St. Lawrence animals show the lowest genetic diversity of mtDNA and microsatellite alleles within Canadian beluga populations (de March et al. 2002). The degree to which recovery is limited by inbreeding is difficult to evaluate. For example, northern elephant seal populations were considerably reduced due to commercial harvesting and yet have shown remarkable recovery. However, Murray et al. (1999) suggested that changes in particular loci might be implicated in a reduced capacity of this beluga population to respond to certain pathogens.

The St. Lawrence Estuary is a heavily industrialized, maritime route, with the industrialized region around the Great Lakes at its headwaters. The effects of contaminants on belugas arose as a concern in the 1970s and since then have continued to be of interest. A juvenile beluga found floating dead in the 1970s had extremely high DDT and total PCB levels in the blubber (Sergeant 1986). Since the mid-

1980s, DFO has maintained a carcass monitoring and necropsy program (Béland et al. 1987). Over 330 carcasses have been recorded for the period 1983 to 2002, and reliable diagnoses are available for 148 animals (Table 5). Tissue samples have also been collected and have been used to monitor trends in contaminant levels and to examine genetic relationships between beluga stocks (Martineau et al. 1987; Béland et al. 1993; Brennin et al. 1997; Brown-Gladden et al. 1997; Murray et al. 1999). High levels of organochlorines, lead and mercury in carcasses have been suggested as causing various pathologies, notably cancer, leading to death of some animals (Béland et al. 1993; Martineau et al. 1987; Martineau et al. 2002). Among the etiological agents hypothesized as causing cancer in SLE beluga are polycyclic aromatic hydrocarbons (PAH) (Martineau et al. 2002). PAH concentrations in sediment are quite high in parts of the Saguenay River (Lun et al. 1998), but it has proven difficult to demonstrate that beluga are exposed to high concentrations of PAHs owing in part to a lack of information on their diets and also because PAHs are quickly metabolized by fish and mammals. The apparent high level of cancer in this population has attracted attention and, although the number of reported cancers is believed to be high, cancer rates have been considerably overstated (Hammill et al. 2003). To date, 15% of 148 animals (age and sex combined) given complete and reliable necropsies died of terminal neoplasia (=cancer)(Fig 5). All were adults, which is to be expected in a non-hunted population with few if any predators (Hammill et al. 2003). More important causes of mortality, such as perinatal causes of death (58% of YOY) and parasitic infections (69% of juveniles), especially due to verminous pneumonia have not received as much attention.

Over the last two decades, there are indications that PCB, DDT, toxaphenes, and HCH levels have declined in tissues of beluga in the St Lawrence, little change has been observed in Mirex levels, while bromide levels, although low, have increased (Gouteux et al. 2003; Lebeuf et al. 2004, 2005). Overall, effects of contaminants on the population are difficult to quantify. Controlled experiments on a reduced population of large mammals are not feasible, resulting in a reliance on a `weight of evidence approach`, the usefuless of which may be questionable (Addison 1989). Nonetheless, PCB and DDT levels from beach-cast carcasses sampled during the 1980s and 1990s are similar to levels that have caused physiological stress in laboratory animals (reviewed in Kingsley 2002), while *in vitro* studies have shown that some contaminants affect the function of the immune system at the cellular level in samples from Arctic beluga (De Guise et al. 1995, 1998). In more recent studies, it has been suggested that tissues freshly collected from other beluga populations might be used as models for contaminant biotransformation studies on SLE beluga, which could permit hypothesis-testing of the effect of contaminants on this population (McKinney et al. 2004).

Other factors that might affect recovery include changes in environmental carrying capacity, competition with other species, ship collisions, and emigration. Collisions with ships do occur, but are not considered to be an important source of mortality being responsible for only 7 likely cases. However, ship traffic may affect beluga by masking communication, which may interfere with social behaviour, navigation, and possibly, foraging (Lesage et al. 1999).

Emigration is also thought to be low, but could have a cumulative effect on the population over time, if as few as two animals were to leave per annum (Fig. 2). Habitat changes are also likely to be important but are difficult to evaluate, since the current summer distribution of animals is actually quite limited. Large numbers of beluga were associated with the Bersimis River, Manicougan Banks near Baie Comeau on the north shore during the previous century, but beluga are rarely seen in these areas now. It is not clear whether the abandonment of these areas results from overharvesting, or changes in the habitat structure, and food abundance as a result of construction of hydro-electric dams during the 1950s and 1960s (Reeves and Mitchell 1987). Over the last 50 years there has been considerable change in environmental conditions in the St Lawrence Estuary. Salmon and cod were once abundant in the St. Lawrence, but are rare today. In contrast, other species such as harp seals and grey seals are quite abundant. There is some trophic overlap between these seal species, which both appear to consume small pelagic species (Lesage et al. 2001; Nozères 2006), although carbon isotope signatures suggest a greater use of benthic resources by beluga than by harp seals (Lesage et al. 2001). However, potential interactions are not possible to examine further since diet data are limited to a few stomach samples recovered from stranded animals (Lesage, Lair, Béland et al., unpublished data) and the qualitative collections of Vladykov (1946), come largely from the Manicougan area in summer, an area no longer frequented by beluga.

LITERATURE CITED

Addison, R.F. 1989. Organochlorines and marine mammal reproduction. Canadian Journal of Fisheries and Aquatic Sciences 46:360-368.

Barlow, J. and Boveng, P. 1991. Modelling age-specific mortality for marine mammal populations. Marine Mammal Science 7(1):50-65.

Béland, P., Vézina, A. and Martineau, D. 1988. Potential for growth of the St Lawrence (Quebec, Canada) beluga whale (*Delphinapterus leucas*) population based on modelling. ICES Journal of Marine Science 45:22-32.

Béland,P., De Guise, S., Girard, C., Lagacé, A., Martineau, D., Michaud,R., Muir, D.C.G., Norstrom, R.J., Pelletier, E., Ray, S. and Shugart, L.R. 1993. Toxic compounds and health and reproductive effects in St Lawrence beluga whales. Journal of Great Lakes Research. 19:766-775.

Béland,P., Martineau, D., Robichaud, P., Plante, R. and Greendale, R.. 1987. Échouages de mammifères marins sur les côtes du Québec dans l`estuaire et le golfe du Saint-Laurent de 1982 à 1985. Canadian Technical Report of Fisheries and Aquatic Sciences 1506 :44+iv pp.

Brault, S. 1999. When are there “too few” newborns in a small population of marine mammals. American Fisheries Society Symposium 23:107-114.

Brennin,R., Murray, B.W., Friesen, M.K. Maiers, D., Clayton, J.W. and White, B.N. 1997. Population genetic structure of beluga whales (*Delphinapterus leucas*): mitochondrial DNA sequence variation within and among North American populations. Canadian Journal of Zoology 75:795-802.

Brown-Gladden, J.G., Ferguson, M.M. and Clayton, J.W. 1997. Matriarchal genetic population structure of North American beluga whales, *Delphinapterus leucas*, (Cetacea:Monodontidae). Molecular Ecology 6:1033-1046.

Burns, J. J. and Seaman, G.A. 1985. Investigations of Belukha whales in coastal waters of western and northern Alaska. II. Biology and ecology. U.S. Dept. of commerce, NOAA, Anchorage, Alaska; OCSEAP final reports 56 (1988): 221 - 291.

Caughley, G. 1977. Analysis of vertebrate problems. J. Wiley and Sons. New York. 234 pp.

COSEWIC. 2004. COSEWIC Assessment and update status report on the beluga whales *Delphinapterus leucas* in Canada. Ottawa. ix+70 pp. http://www.sararegistry.gc.ca

Curren, K. and Lien, J.. 1998. Observations of white whales, *Delphinapterus leucas*, in waters off Newfoundland and Labrador and in the Gulf of St.Lawrence, 1979-1991. Canadian Field-Naturalist 112:28-31.

De Guise, S., Martineau, D., Béland, P. and Fournier, M. 1995. Possible mechanisms of action of environmental contaminants on St Lawrence beluga whales (*Delphinapterus leucas*). Environmental Health Perspectives 103:73-77.

De Guise, S., Martineau, D., Béland, P. and Fournier, M. 1998. Effects of *in vitro* exposure of beluga whale leukocytes to selected organochlorines. Journal of Toxicology and Environmental Health A, 55:479-493.

de March, B.G.E., Maiers, L.D. and Friesen, M.K. 2002. An overview of genetic relationships of Canadian and adjacent populations of belugas (*Delphinapterus leucas*) with emphasis on Baffin Bay and Canadian eastern Arctic populations. NAMMCO Scientific Publications 4:17-38.

Doidge, D.W. 1990. Age and stage based analysis of the population dynamics of beluga whales, *Delphinapterus leucas,* with particular reference to the northern Quebec population. Ph.D. thesis, McGill University, Montreal. 190 pp.

Gosselin, J-F., Hammill, M.O. and Lesage, V. 2006. Photographic and visual abundance indices of belugas in the St Lawrence Estuary in 2003 and 2005.Canadian Science Advisory Secretariat, Ottawa. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/025. 28 p.

Gouteux, B., Lebeuf, M., Muir, D.C.G. and Gagné, J.-P. 2003. Levels and temporal trends of toxaphene congeners in beluga whales (*Delphinapterus leucas*) from the St Lawrence Estuary, Canada. Environmental Science and Technology 37(20):4603-4609.

Hammill, M.O., Lesage, V. and Kingsley, M.C.S. 2003. Cancer in Beluga from the St Lawrence estuary. Letter to the editor. Environmental Health Perspectives 111:A77-A78.

Innes, S. and Stewart, R.E.A. 2002. Population size and yield of Baffin Bay beluga (Delphinapterus leucas) stocks. NAMMCO Scientific Publications 4:225-238.

Kasuya, T., Sergeant, D.E. and Tanaka, K. 1988. Re-examination of life-history parameters of long-finned pilot whales in the Newfoundland waters. Sci. Rep. Whales Res. Inst. 39: 103-119.

Kingsley, M.C.S. 1996. Population index estimate for the belugas of the St Lawrence in 1995. Canadian Technical Report of Fisheries and Aquatic Sciences 2117. 37pp.

Kingsley, M.C.S. 2002. Status of the belugas of the St Lawrence estuary, Canada. NAMMCO Scientific Publications 4: 239-257.

Kingsley, M.C.S. and Gauthier, I. 2002. Visibility of St Lawrence belugas to aerial photography, estimated by direct observation. NAMMCO Scientific Publications 4: 259-270.

Kingsley, M.C.S., Gosselin, S. and Sleno, G.A. 2001. Movement and dive behaviour of belugas in northern Quebec. Arctic 54(3):262-275

Kingsley , M.C.S. and Hammill, M.O. 1991. Photographic census surveys of the St Lawrence beluga population, 1988 and 1990. Canadian Technical Report of Fisheries and Aquatic Sciences 1776. 19 pp.

Kingsley, M.C.S., Richard, P. and Innes, S. 1995. The effect of management options on the dynamics of beluga populations. Unpubl. MS, prepared for the Northern Quebec and Native Affairs Division, Fisheries and Oceans Canada, Quebec Region. 21 pp.

Lebeuf, M., Gouteux, B., Measures, L.N. and Trottier, S. 2004. Levels and temporal trends (1988-1999) of polybrominated diphenyl ethers in beluga whales (*Delphinapterus leucas*) from the St Lawrence Estuary, Canada. Environmental Science and Technology 38:2971-2977.

Lebeuf, M., Noël, M., Trottier, S. et Measures, L. 2005. Temporal trends (1987-2002) of regulated POPs in beluga whales from the St Lawrence Estuary, Canada. Proceeding of the 25th International Symposium on Halogenated Environmental Organic Pollutants and POPs,DIOXIN 2005, Organohalogen Compounds, 67; 1233-1235

Lesage, V., and Kingsley, M.C.S. 1998. Updated status of the St Lawrence River population of the beluga, *Delphinapterus leucas*. Canadian Field-Naturalist 112: 98-114.

Lesage, V., Barrette, C., Kingsley, M.C.S. and Sjare, B. 1999. The effect of vessel noise on the vocal behaviour of belugas in the St. Lawrence River Estuary, Canada. Marine Mammal Science 15:65-84.

Lesage, V., Hammill, M.O. and Kovacs, K.M. 2001. Marine mammals and the community structure of the estuary and Gulf of St Lawrence, Canada: evidence from stable isotope analysis. Marine Ecology Progress Series 210:203-221.

Lun, R., Lee, K., De Marco, L., Nalewajko, C. and MacKay, D. 1998. A model of the fate of polycyclic aromatic hydrocarbons in the Saguenay Fjord, Canada. Environmental Toxicology and Chemistry 17(2):333-341.

Martineau, D., Béland, P., Desjardins, C., and Lagacé, A. 1987. Levels of organochlorine chemicals in tissues of beluga whales (*Delphinapterus leucas*) from the St Lawrence estuary, Quebec, Canada. Archives of Environmental Contamination and Toxicology 16:137-147.

Martineau, D., Lemberger, K., Dallaire, A., Michel, P., Labelle, P., Lipscomb, T.P., Michel, P. and Mikaelien, I. 2002. Cancer in wildlife, a case study: Beluga from the St Lawrence Estuary, Quebec. Canada. Environmental Health Perspectives 10:285-292.

McKinney, M.A., Arukwe, A., De Guise, S., Martineau, D., Béland, P., Dallaire, A., Lair, S., Lebeuf, M. and Letcher, R.J. 2004. Characterization and profiling of hepatic cytochromes P450 and phase II xenobiotic-metabolizing enzymes in beluga whales (*Delphinpaterus leucas*) from the St Lawrence River Estuary and the Canadian Arctic. Aquatic Toxicology 69:35-49.

Mood, A. M., Graybill, F.A. and Boes, D.C. 1974. Introduction to the Theory of Statistics, 3rd edition. McGraw-Hill, Toronto. xvi, 564p.

Murray, B.W., Michaud, R. and White, B.N. 1999. Allelic and haplotype variation of major histocompatibility complex class II DRB1 and DQB loci in the St Lawrence beluga (*Delphinapterus leucas*). Molecular Ecology 8:1127-1139.

Nozeres, C. 2006. Régime alimentaire du béluga, D*elphinapterus leucas,* de l'estuaire du Saint-laurent, Canada, tel que révélé par l'analyse des acides gras du lard. MSc thèse, Université Laval, Quebec, QC. 207 pp.

Patenaude, N.J., Quinn, J.S., Béland, P., Kingsley,M.C.S. and White, B.N. 1994. Genetic variation of the St Lawrence beluga population assessed by DNA fingerprinting. Molecular Ecology 3:375-381.

Pella, J.J. and Thomlinson, P.K. 1969. A generalized stock production model. Bulletin of the Inter-American Tropical Tuna Commission 13:420-496.

Pippard, L. 1985. Status of the St Lawrence River population of beluga, *Delphinapterus leucas.* Canadian Field-Naturalist 99:438-450.

Reeves, R.R. and Mitchell, E.D. 1984. Catch history and initial population size of white whales, *Delphinapterus leucas*, in the river and Gulf of the St Lawrence, eastern Canada. Naturaliste Canadien 111:63-121.

Reeves, R.R. and Mitchell, E.D. 1987. Hunting whales in the St Lawrence. The Beaver 67:35-40.

Sergeant, D.E. 1973. Biology of white whales (*Delphinapterus leucas*) in western Hudson Bay. Journal of Fisheries Research Board of Canada 30:1065-1090.

Sergeant, D.E. 1986. Present status of white whales, *Delphinapterus leucas* in the St Lawrence estuary. Naturaliste canadien 113:61-81.

Vladykov, V. 1946. Études sur les mammifères aquatiques. IV Nourriture du marsouin blanc ou béluga (Delphinapterus leucas) du fleuve Saint-Laurent. Département des Pêcheries, Québec, QC.

Table 1. Photographic survey indices corrected for diving animals by multiplying numbers from aerial surveys by 2.09 and adding in the Saguenay River counts (Gosselin et al. 2006). The 2005 visual survey index is also included but was not used to fit the population model.

Year	Surface estimate	Saguenay	Corrected Estimate	SE
1988	427	5	898	144
1990	527	5	1106	567
1992	454	3	952	149
1995	568	52	1239	217
1997	575	20	1222	190
2000	453	6	953	134
2003	630	2	1319	263
2005	*564*	*39*	*1218*	*151*

Table 2. Reported catches of SLE beluga (Reeves and Mitchell 1984). It was assumed that there were no catches from 1960 to 1988. Reeves and Mitchell (1984) applied a struck and loss factor of 1.2 to their catch estimates. This factor was removed prior to including harvest estimates in the model.

Year	Kill	Year	Kill	Year	Kill	Year	Kill	Year	Kill	Year	Kill
1866	6	1884	118	1902	26	1920	247	1938	322	1956	11
1867	36	1885	35	1903	26	1921	166	1939	44	1957	1
1868	10	1886	142	1904	22	1922	5	1940	72	1958	2
1869	137	1887	595	1905	184	1923	102	1941	70	1959	0
1870	166	1888	368	1906	170	1924	68	1942	322	1960	6
1871	92	1889	680	1907	45	1925	0	1943	90		
1872	23	1890	431	1908	134	1926	2	1944	86		
1873	2	1891	287	1909	98	1927	1	1945	63		
1874	81	1892	328	1910	37	1928	2	1946	40		
1875	85	1893	226	1911	29	1929	170	1947	24		
1876	96	1894	90	1912	45	1930	7	1948	32		
1877	112	1895	194	1913	72	1931	82	1949	21		
1878	102	1896	178	1914	0	1932	187	1950	22		
1879	216	1897	296	1915	720	1933	222	1951	49		
1880	59	1898	383	1916	254	1934	446	1952	38		
1881	10	1899	210	1917	154	1935	554	1953	19		
1882	75	1900	168	1918	460	1936	27	1954	0		
1883	47	1901	22	1919	260	1937	500	1955	0		

Table 3. Number and proportion of young of the year (YOY) counted/measured on photographs from aerial surveys completed in the St Lawrence Estuary. (Data are from Kingsley 1996; J.F. Gosselin unpublished).

Year	YOY	Number animals	Proportion
1988	3	152	0.0197
1990	23	148	0.1554
1992	33	227	0.1454
1995	9	197	0.0457
1997			
2003	10	311	0.0322
2005			

Table 4. Number of beluga carcasses documented as part of an ongoing carcass monitoring program in the St Lawrence Estuary (Measures unpublished).

Year	Number of carcasses	Year	Number of carcasses
1983	15	1996	14
1984	12	1997	13
1985	12	1998	14
1986	10	1999	17
1987	11	2000	14
1988	20	2001	12
1989	19	2002	17
1990	15	2003	15
1991	16	2004	19
1992	15	2005	9
1993	21		
1994	13		
1995	14		

Table 5. Causes of death of SLE beluga by age class (N=148 reliable diagnoses) from necropsies for the period 1983 - 2002

Primary cause of death	GLG	Age class	Sample	Percentage
bacterial infections	1	YOY	2/12	17%
parasitic infections	"	"	2/12	17%
neonatal	"	"	7/12	58%
other	"	"	1/12	8%
bacterial infections	F:>1 to 10 M:>1 to 14	juvenile	2/16	13%
parasitic infections	"	"	11/16	69%
unknown	"	"	3/16	19%
bacterial infections	F:>10 M:>14	adult	23/120	19%
parasitic infections	"	"	16/120	13%
neoplasia (terminal)	"	"	22/120	18%
other	"	"	10/120	8%
unknown	"	"	39/120	33%
dystocia	"	"	3/120	3%
trauma	"	"	7/120	6%

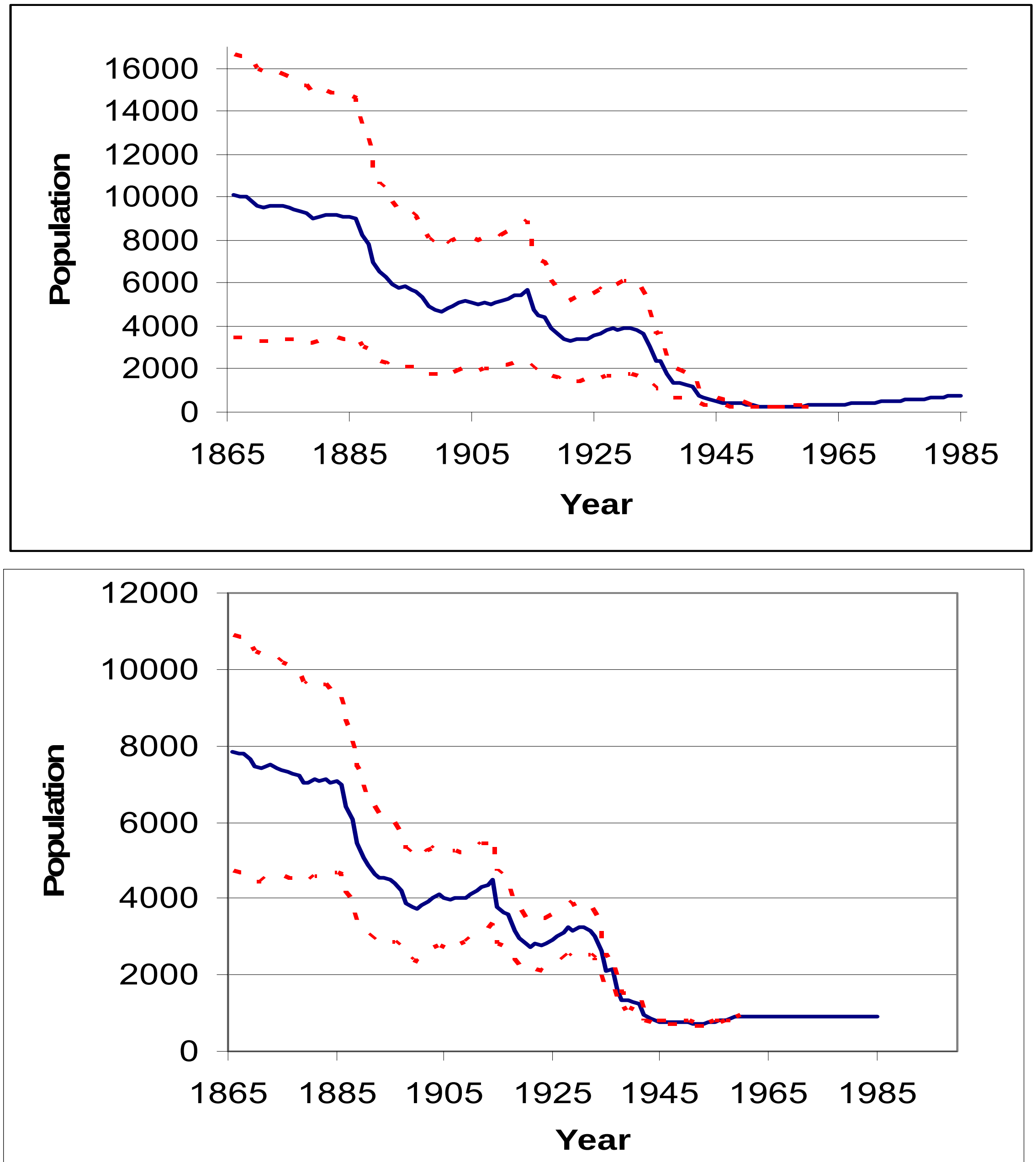

Figure 1. Estimated changes in abundance of SLE beluga from 1866 to the present. If struck and loss factors of 1, 1.5 and 2 are used, the pristine population was 10,000 (SE=1.189)(top figure). If struck and loss declines to 1, 1.15 and 1.3, then the estimate of pristine population size also declines to 7,800 (SE=600)(bottom figure). The solid lines represent the mean and the dashed lines are the 95% CL.

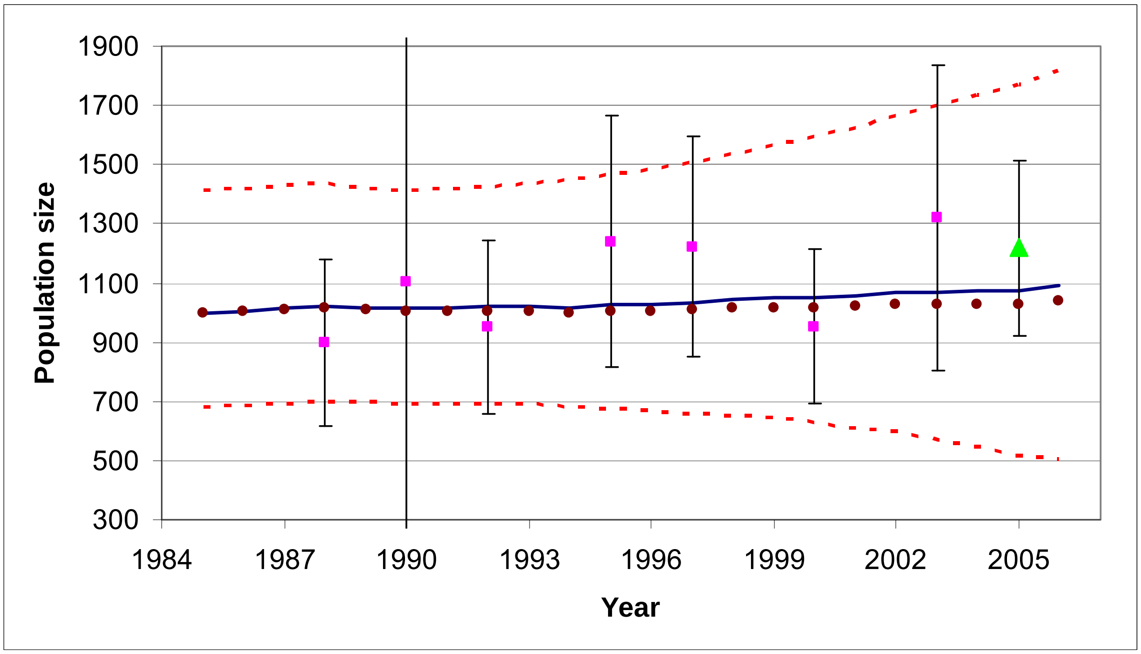

Figure 2. Photographic aerial survey estimates corrected for diving (circular points ± 95% confidence interval), and modelled estimates of SLE beluga population abundance since 1985 (solid line, mean ± 95% C.I.). The initial population in 1985 was 997 (SE=191), with a fitting factor (b) of 1.497 (SE=0.748), yielding an estimated population of 1,090 animals (SE=341)(corrected for diving) in 2006. The square points with vertical error bars represent aerial survey estimates. The large triangle represents 2005 visual survey estimates, but these were not used to fit the model. The circular points represent the effect on the population of a small number of animals (N=2) emigrating from the population in every year.

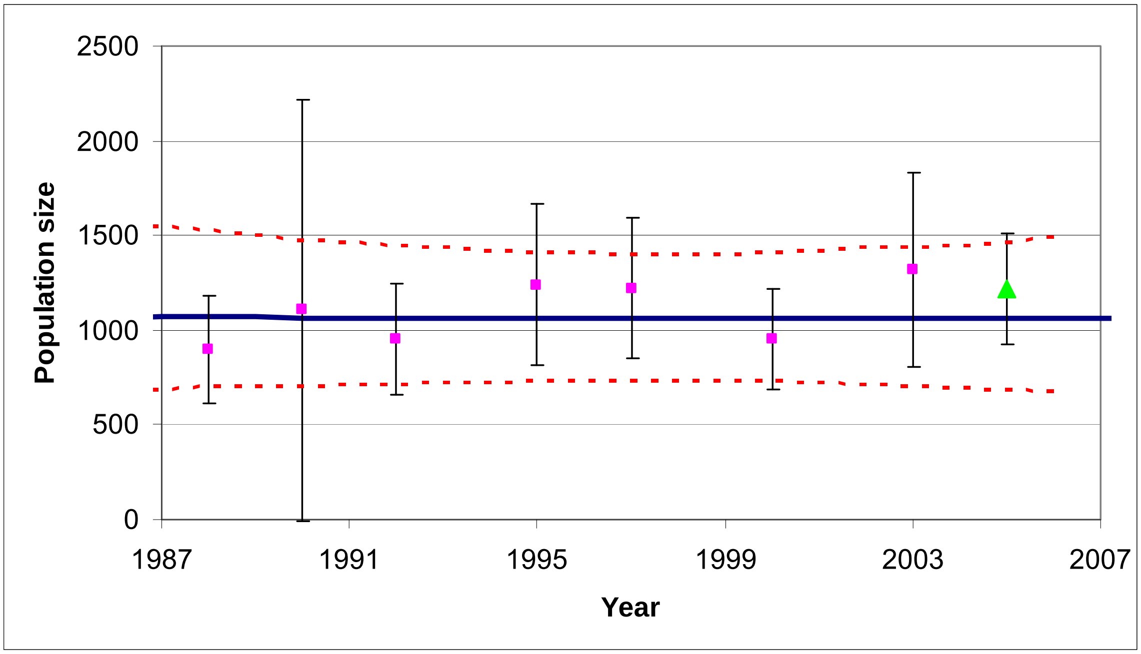

Figure 3. Aerial survey point estimates (mean±95% C.I.) and changes in abundance (solid line) (mean±95% C.I.) of SLE beluga as predicted by the population model determined from fitting a starting population of 1,062 (SE=236) beluga in 1985 and a rate of increase of 1.014 (SE=0.013). The 2005 visual survey point (triangle) is shown but was not include as part of the fitting procedure. In 2006, the model predicts that the population would number 1,042 (SE=209; 95% CI=677-1,493).

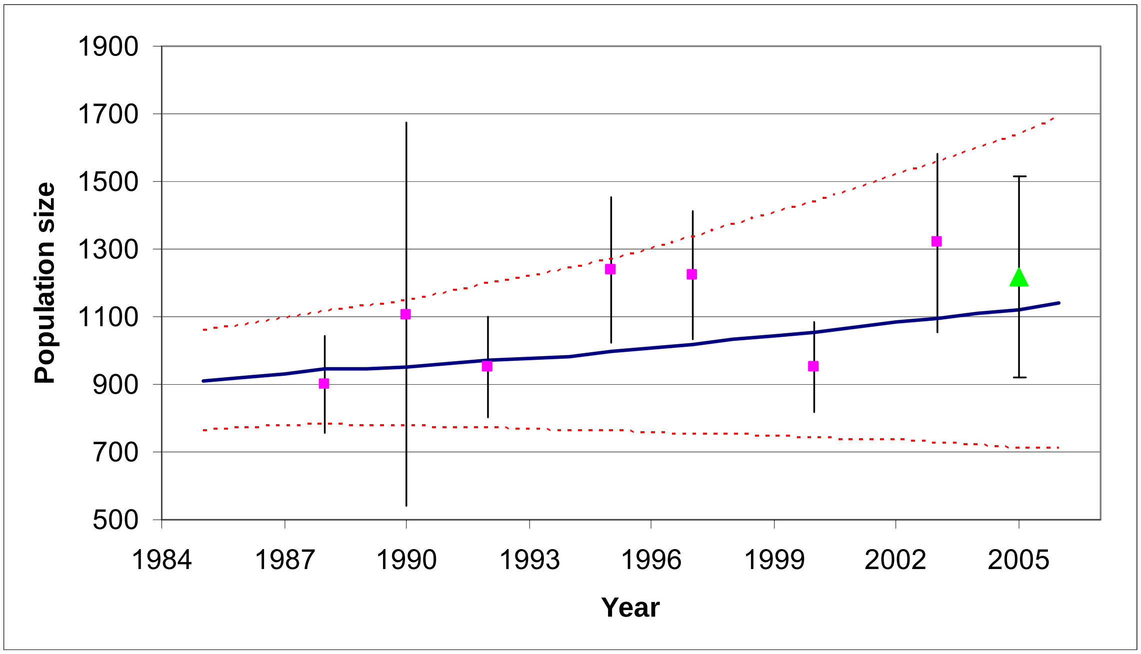

Figure 4. Aerial survey point estimates (mean±95% C.I.) and expected changes in abundance (solid line)(mean ±95% C.I) of SLE beluga, as predicted by the population model, if the population had recovered as expected when hunting ended. The starting population in 1985 was 900 (SE=73, 95% C.I. 760-1,050), increasing to 1,130 (SE=270; 95% CI=700-1,670) in 2006. The 2005 visual survey point (triangle) is shown but was not include as part of the fitting procedure.

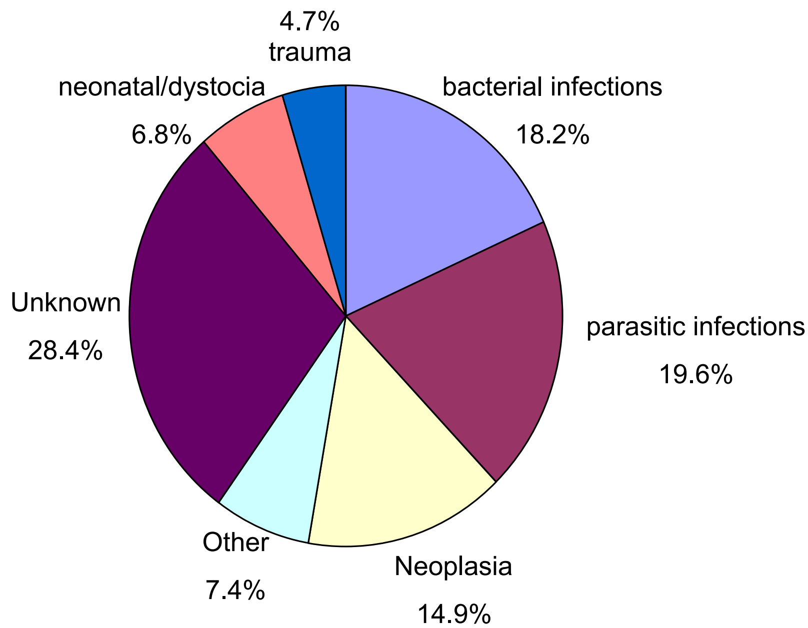

Figure 5. Causes of death of all beluga, all age classes (N=148 reliable diagnoses) 1983 – 2002.