Database of aerial surveys and abundance estimates for beluga whales (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) in the Canadian Arctic

Jeff W. Higdon and Steven H. Ferguson[2]

Central and Arctic Region
Fisheries and Oceans Canada
501 University Crescent
Winnipeg, MB R3T 2N6

2017

Canadian Technical Report of Fisheries and Aquatic Sciences 3211

Pêches et Océans Canada
Fisheries and Oceans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of
Fisheries and Aquatic Sciences 3211

2017

Database of aerial surveys and abundance estimates for beluga whales (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) in the Canadian Arctic

by

Jeff W. Higdon[1] and Steven H. Ferguson[2]

[1] Higdon Wildlife Consulting
912 Ashburn Street
Winnipeg, MB R3G 3C9

[2] Central and Arctic Region
Fisheries and Oceans Canada
501 University Crescent
Winnipeg, MB R3T 2N6

Cat. No. Fs97-6/3211E-PDF ISBN 978-0-660-08279-0 ISSN 1488-5379

Correct citation for this publication:

Higdon, J.W., and Ferguson, S.H.. 2017. Database of aerial surveys and abundance estimates for beluga whales (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) in the Canadian Arctic. Can. Tech. Rep. Fish. Aquat. Sci. 3211: v + 48 p.

TABLE OF CONTENTS

ABSTRACT

Higdon, J.W., and Ferguson, S.H.. 2017. Database of aerial surveys and abundance estimates for beluga whales (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) in the Canadian Arctic. Can. Tech. Rep. Fish. Aquat. Sci. 3211: v + 48 p.

Information on abundance and trends of Canadian beluga whale (*Delphinapterus leucas*) and narwhal (*Monodon monoceros*) stocks is needed for long-term monitoring and sustainable harvest management. We conducted a literature review of surveys and associated abundance estimates for the beluga and narwhal summer stocks that occur in Canadian Arctic waters. Abundance estimates were compiled by management stock as defined by Fisheries and Oceans Canada (DFO). Some stocks are shared with other countries (i.e., USA [Alaska], Greenland), and some occur in multiple Canadian jurisdictions (e.g., Nunavut and Nunavik). Metadata in the database includes area studied, time frame, survey type, uncorrected and corrected (if available) abundance estimate, measures of variability around the point estimate (confidence intervals, coefficient of variation), types of corrections for availability and perception bias, trends in abundance estimates, and limitations and sources of uncertainty. The database contains 34 records for beluga whale surveys conducted between 1965 and 2015, and 22 records for narwhal surveys conducted between 1975 and 2013. All stocks have been surveyed at least once, and some stocks have been surveyed numerous times (e.g., Admiralty Inlet narwhal, Nunavik beluga stocks). The focus has been on peer-reviewed scientific publications and government documents where the primary goal was abundance estimation. For stocks that are shared with other countries, the database includes Canadian studies only, but estimates generated by research in these other jurisdictions could contribute to trend analyses. Similarly, a number of consulting company reports also detail industry-funded surveys that have been conducted throughout the Canadian Arctic. These surveys are generally conducted for different reasons (impact predictions versus population estimates) and are not peer-reviewed. Example reports from relevant industry-funded studies are noted in the text where appropriate but have not been included in the database (unless they were subsequently published in the primary literature). The addition of these studies could provide additional abundance estimates that may be useful for trend analyses for some stocks. The database is complete to 2015. The database can be updated as future surveys are completed and analyzed.

SOMMAIRE

Higdon, J.W., and Ferguson, S.H. 2017. Base de données des relevés aériens et estimations de l'abondance des bélugas (*Delphinapterus leucas*) et des narvals (*Monodon monoceros*) dans l'Arctique canadien. Can. Tech. Rep. Fish. Aquat. Sci. 3211: v + 48 p.

Il est nécessaire d'obtenir de l'information sur l'abondance et les tendances des stocks de béluga (*Delphinapterus leucas*) et de narvals (*Monodon monoceros*) pour assurer la surveillance à long terme et la gestion durable des prises. Nous avons effectué une analyse documentaire des relevés et des estimations connexes de l'abondance des stocks estivaux de bélugas et de narvals présents dans les eaux canadiennes de l'Arctique. Les estimations de l'abondance ont été compilées par stock de gestion, tels qu'ils sont définis par Pêches et Océans Canada. Certains stocks sont partagés avec d'autres pays (p. ex. États-Unis [Alaska]), Groenland), et certains sont présents dans ddes eaux relevant de plusieurs instances canadiennes (p. ex., Nunavut et Nunavik). Les métadonnées figurant dans la base de données comprennent la zone étudiée, la période, le type de relevé, l'estimation de l'abondance non corrigée et corrigée (si elle est disponible), les mesures de la variabilité entourant l'estimation ponctuelle (intervalles de confiance, coefficient de variation), les types de correction des biais relatifs à la perception et à la disponibilité, les tendances dans les estimations de l'abondance, ainsi que les limites et les sources d'incertitude. La base de données contient 34 dossiers de relevés du béluga effectués entre 1965 et 2015, et 22 dossiers de relevés du narval effectués entre 1975 et 2013. Tous les stocks ont fait l'objet d'au moins un relevé, et certains de plusieurs relevés (p. ex., narval de l'inlet de l'Amirauté, stocks de bélugas du Nunavik). L'accent a été mis sur les publications scientifiques examinées par des pairs et les documents gouvernementaux dont le principal objectif était l'estimation de l'abondance. En ce qui concerne les stocks partagés avec d'autres pays, la base de données comprend seulement des études canadiennes, mais des estimations découlant de recherches menées dans ces autres pays pourraient contribuer aux analyses des tendances. De même, un certain nombre de rapports d'entreprises d'experts-conseils contiennent aussi des détails sur les relevés financés par l'industrie qui ont été menés partout dans l'Arctique canadien. Ces relevés sont effectués pour différentes raisons (prévisions des impacts par rapport aux estimations de la population) et ne sont pas examinés par des pairs. Par exemple, les rapports des études pertinentes financées par l'industrie sont indiqués dans le texte, le cas échéant, mais n'ont pas été inclus dans la base de données (à moins qu'ils aient par la suite été publiés en tant que documents spécialisés). L'ajout de ces études pourrait fournir d'autres estimations de l'abondance pouvant être utiles pour les analyses des tendances pour certains stocks. La base de données s'étend jusqu'en 2015. Elle peut être mise à jour au fur et à mesure que d'autres relevés sont réalisés et analysés.

INTRODUCTION

Information on marine mammal abundance and trends is needed for long-term monitoring of Arctic species and sustainable management of Inuit harvests. To support this, a literature review was conducted to summarize survey-based abundance estimates for beluga (*Delphinapterus leucas*) and narwhal (*Monodon monoceros*), two odontocete species of socioeconomic and cultural importance in the Canadian Arctic.

Stock definitions

Survey estimates are provided by population and stock, as defined in Table 1. Only summer (July-September) surveys are included, to ensure that population estimates are limited to a single stock, which are defined based on summer aggregations (e.g., Turgeon et al. 2012; Heide-Jørgensen et al. 2013a).

COSEWIC (2004a) recognizes seven different beluga populations in Canada, including the St. Lawrence Estuary population which is not considered in this assessment. Definitions and names for Nunavut beluga whale stocks (summer stocks) are from DFO (2010a) and Richard (2010), with James Bay identified as a separate stock (included by COSEWIC 2004a as part of the Western Hudson Bay population) (Figure 1). DFO (2010a) and Richard (2010) also use "Western-Northern-Southern Hudson Bay" in place of Western Hudson Bay (COSEWIC 2004a). There are some suggestions that beluga whales found near the Belcher Islands in southeast Hudson Bay may represent a separate stock (L. Postma, DFO, pers. comm.). This is uncertain however, and there are no survey data available that are specific to the Belcher Islands. The Eastern High Arctic/Baffin Bay stock is also sometimes referred to as the Somerset Island stock. An unknown proportion of this stock is thought to over-winter in the North Water polynya, and there are suggestions that this population may consist of two stocks that share the same summer aggregation areas (de March et al. 2002; COSEWIC 2004a), although this is uncertain. According to Inuit knowledge there are two groups, one that occupies Lancaster Sound and eastern and northern Baffin Island, and another centred around Ellesmere Island (Read and Stephansson 1976; Remnant and Thomas 1992). Winter and spring surveys have been conducted in the North Water polynya and Greenland waters by Canadian and Greenland researchers (e.g., Finley and Renaud 1980; Richard et al. 1998; Heide-Jørgensen et al. 2013b, 2016a), but they are not included in the database.

COSEWIC (2004b) recognized that two distinct narwhal populations exist (Baffin Bay and Hudson Bay populations), but assessed the entire population under a single status rank. Stock definitions for narwhal are from DFO (2010a, 2015) and Richard (2010) and represent summer stocks (Figure 2). A portion of the Baffin Bay narwhal population also summers in West Greenland waters. Four narwhal stocks were included by DFO (2010a) and Richard (2010), but it was recognized that narwhals occur elsewhere in the Canadian High Arctic during summer (e.g., Parry Islands, Jones Sound, Smith Sound) (also see DFO 2012; COSEWIC 2004b). The most recent surveys and associated abundance estimates (Doniol-Valcroze et al. 2015) have included the stocks previously recognized by DFO (2010a) and Richard (2010) in addition to a Smith Sound and a Jones Sound stock (Table 1, Figure 2). The summer aggregations in Inglefield Bredning and Melville Bay in northwest Greenland have been surveyed several times (e.g., Born et al. 1994; Heide-Jørgensen 2004; Heide-Jørgensen et al. 2010). The relationship of these whales to those in Smith Sound and Jones Sound is unclear but thought to be separate based on spring surveys (Heide-Jørgensen et al. 2016a). Further substructure of the lesser-known stocks such as Smith Sound is likely, with the JCNB suggesting Makinson Inlet as a separate stock (JCNB 2015).

Several of the Baffin Bay narwhal stocks (Somerset Island and East Baffin Island stocks) cover large areas and may have further sub-structuring. The Hudson Bay narwhal population (COSEWIC 2004b) is included as a separate summer population (Northern Hudson Bay, DFO 2010a; Richard 2010; Petersen et al. 2011).

A number of these stocks are shared with other countries (e.g., USA [Alaska] and Greenland). This review includes Canadian studies only, broadly defined as those led by Canadian researchers or organizations. Relevant surveys conducted by other jurisdictions are available, and while we have noted some sources in the text, this should not be considered an exhaustive list.

At a global scale, both species are ranked by IUCN as "Near Threatened" (Jefferson et al. 2012a, b), with unknown population trends. At the National scale, the Eastern Hudson Bay and Ungava Bay beluga whale populations are considered "Endangered" (COSEWIC 2004a). The Cumberland Sound population (stock) is "Threatened", and the Western Hudson Bay and Eastern High Arctic/Baffin Bay populations "Special Concern" (note that COSEWIC's Western Hudson Bay population includes both the Western-Northern-Southern Hudson Bay and James Bay stocks as presently defined by DFO). Only one beluga population (stock), Eastern Beaufort Sea, is considered "Not at Risk". None of these stocks are listed under the Species at Risk Act (SARA) (the St. Lawrence Estuary population is SARA-listed). COSEWIC (2004b) recognized the existence of two narwhal populations, but assessed both together, giving a Canadian status rank of "Special Concern".

Prior database versions

A previous version of the narwhal database (excluding the 2013 High Arctic surveys which were undergoing data analyses) was prepared as a Working Paper for the Joint Commission on Narwhal and Beluga (JCNB) (Higdon and Ferguson 2014), and the compiled data were used in population modelling exercises to establish sustainable harvest levels for narwhal stocks shared between Canada and Greenland (Witting 2016; Watt et al. 2017).

METHODOLOGY

We focused on peer-reviewed scientific publications and government documents where the primary goal was abundance estimation (several theses have been included as well, supervised by federal Government marine mammal scientists). A number of consulting company reports detail industry-funded surveys that have been conducted throughout the Canadian Arctic. These surveys are generally conducted for different reasons (impact predictions versus population estimates) and are not peer-reviewed. Some examples of reports from relevant industry-funded studies are noted in the text but have not been included in this version of the database. Some of these studies could provide additional abundance estimates that may be useful for trend analyses for specific populations or stocks. Some examples are listed in the Discussion.

For each survey, we extracted the following information for the database: source(s), area surveyed, time frame, survey type, uncorrected and corrected (if available) abundance estimate, measures of variability around the point estimate(s) (confidence intervals, coefficient of variation), types of corrections for availability and perception bias, trends in abundance estimates, and limitations and sources of uncertainty.

RESULTS

The abundance estimate database (see Appendix) is current to 2015 surveys and contains 34 records for beluga whale surveys (Figure 3; Tables 2 and A1) and 22 records for narwhal surveys (Tables 3 and A2). Surveys were conducted between 1965 and 2015 for beluga, and from 1975 to 2013 for narwhal. All abundance estimates for beluga and narwhal stocks in the database come from aerial surveys (strip, line, and photographic transect methods), which are the most commonly used methods to estimate marine mammal abundance and/or density. Photo-identification of individual narwhals is possible (e.g., Auger-Méthé et al. 2010, 2011), but the method has never been used to estimate population size. Genetic capture-mark-recapture (CMR) population estimates have been produced for bowhead whales (*Balaena mysticetus*) (Petersen et al. 2014; Frasier et al. 2015), but this technique has not been used on any beluga or narwhal stocks.

All of the stocks identified in Table 1 have been surveyed at least once (one survey, in 2013, for the Jones Sound and Smith Sound narwhal summer stocks, Table 3). Abundance estimates are reported by stock, and in many cases have multiple entries from the same publication. Examples include surveys that estimated abundance of both narwhal and beluga (Smith et al. 1985; Innes et al. 2002) or surveys of multiple beluga whale (Smith and Hammill 1986; Kingsley 2000; Gosselin et al. 2002, 2009, 2013, 2017; Gosselin 2005) or narwhal (Richard et al. 1994, 2010; Doniol-Valcroze et al. 2015) stocks. Multi-species winter surveys have also been conducted in West Greenland (e.g., Heide-Jørgensen et al. 1993; Heide-Jørgensen and Acquarone 2002), but they are not included in the database for reasons previously discussed.

DISCUSSION

Beluga whale surveys and abundance estimates

All beluga stocks have been surveyed at least twice (Tables 2 and A1). Two surveys for the Eastern Beaufort Sea summer stock are included, and the most recent one was conducted in the 1990s. The population estimate for this stock is therefore dated. A number of other aerial surveys have been conducted in parts of the range of this stock, for example the many Mackenzie Delta surveys sponsored by industry (F.F. Slaney & Company Limited 1975; Fraker 1976, 1977; Fraker and Fraker 1979, 1981). These surveys were subsequently used by Government staff in a variety of assessment reports (e.g., Sergeant and Hoek 1974; Fraker et al. 1978; Harwood et al. 2014), but they were designed to study whale distribution, and not estimate abundance, and were limited to the estuary area which includes only part of the stock in summer (Loseto et al. 2006). Government-led surveys have also provided information on beluga habitat use and relative abundance in the offshore region (Harwood and Kingsley 2013; Hornby et al. 2014, 2016), as have some industry-led efforts (Davis and Evans 1982), but these studies have not reported population estimates for the stock. All of these studies, and work conducted in Alaska (e.g., Braham et al. 1984), could provide additional information that may be useful for trend analysis and population assessment.

There have been no recent surveys for the Ungava Bay beluga whale summer stock, but evidence suggests that it is either extinct (COSEWC 2004a) or extremely small (mean estimate of 32 individuals, 95% CI 0–94) (Doniol-Valcroze and Hammill 2012). The other two Nunavik stocks (i.e. those surveyed by DFO Quebec), Eastern Hudson Bay and James Bay, have been surveyed on multiple occasions (n =7) and recent (2011, 2015) estimates are available (see Gosselin et al. 2017

for discussion on trends in these two stocks). Some industry-sponsored surveys have also been conducted in Eastern Hudson Bay (Finley et al. 1982). The Cumberland Sound beluga stock has also been surveyed seven times, most recently in 2014. There is a long history of population estimates for this stock, with the first survey conducted in 1967 (Tables 2 and A1). Some information is also available from industry-sponsored surveys conducted from 1977 to 1979 (MacLaren Atlantic Ltd. 1978; MacLaren Marex Inc. 1979, 1980).

The wide-ranging Eastern High Arctic-Baffin Bay beluga stock has been surveyed (in Canadian waters) on three occasions from the 1970s to the 1990s (Tables 2 and A1). The current estimate is therefore dated and a new survey should be conducted soon. Animals in this stock summer throughout much of the Canadian Arctic Archipelago and along the eastern coast of Baffin Island (Smith and Martin 1994; Richard et al. 2001). Given this wide distribution, securing a reliable population estimate may be difficult. Surveys should focus on the High Arctic estuaries where belugas aggregate in the summer. Beluga whales in this stock do not concentrate around river estuaries to the same extent as whales in some other regions, but they do aggregate in Creswell Bay, Cunningham Inlet, and Elwin Bay (Smith et al. 1985; Richard et al. 2001; Innes et al. 2002). As noted above, some research and traditional knowledge has suggested additional substructure in this summer stock (Read and Stephansson 1976; Remnant and Thomas 1992; de March et al. 2002; COSEWIC 2004a), but available data are insufficient to justify splitting into multiple units (also see Heide-Jørgensen et al. 2003, who argued that any differentiation between Canadian and Greenland samples is a sampling artifact). Additional information on stock abundance available from West Greenland coastal surveys (Heide-Jørgensen et al. 2016b), winter-spring surveys of the North Water polynya (Finley and Renaud 1980; Richard et al. 1998; Heide-Jørgensen et al. 2013b, 2016a), and from extensive industry-sponsored surveys in the mid- to late-1970s (Finley et al. 1974; Davis et al, 1975; Finley 1976; Koski and Davis 1979, 1980; Koski 1980a, b) may be useful for trend analysis and stock assessment.

The large Western-Northern-Southern Hudson Bay beluga stock has also been surveyed three times (Tables 2 and A1), and a recent estimate (2015) is available. Surveys of this stock have concentrated on the three Manitoba river estuaries (Seal, Churchill and Nelson) where the whales aggregate in summer. The 2015 survey planned to cover areas to the east (Ontario coastline) and north (Nunavut), but delays caused by poor weather forced the survey team to concentrate on the core area (Matthews et al. 2017).

Narwhal surveys and abundance estimates

Most narwhal stocks have been surveyed at least twice - the two exceptions are Jones Sound and Smith Sound, which were first surveyed in 2013 (some additional information on the Jones Sound narwhal stock may be available in industry-sponsored surveys conducted by Koski and Davis (1979, 1980). Only two narwhal stocks have been surveyed at least 5 times - Somerset Island and Admiralty Inlet. No stocks have been surveyed as often as the most-surveyed beluga whale stocks (n = 7, see Tables 2 and 3).

The Somerset Island stock is the largest narwhal summer stock, in both area and number of whales. The summering area includes Prince Regent Inlet and the Gulf of Boothia, Peel Sound, Barrow Strait, and northern Foxe Basin, and in recent years the summer distribution has occasionally extended further west to the Cambridge Bay area (DFO 2013). This stock, or portions thereof, has been surveyed in 1981, 1984, 1996, 2002-2004 and 2013 with variable coverage, but no surveys have covered the entire stock area (and northern Foxe Basin has never been surveyed for narwhal). Industry-sponsored surveys of this stock (Peel Sound, particularly) were also conducted between

1974 and 1979 (Finley et al. 1974; Davis et al. 1975; Finley 1976; Koski 1980a). The most recent survey, in 2013, focused on the summer core area (Doniol-Valcroze et al. 2015, see Figure 2). Narwhals in this stock may have further sub-structuring, but no data are yet available. Narwhals are also known to occur in the Parry Islands area during summer, but no surveys have been conducted and the stock affinity of these animals is unknown (Richard 2010).

Admiralty Inlet has been surveyed more than any other narwhal summer stock, with six estimates between 1975-1976 and 2013. Industry-sponsored surveys of the Admiralty Inlet stock were also conducted in 1978 and 1979 (Koski and Davis 1979; Koski 1980b), and these data may also be of use for stock assessment work.

The Eclipse Sound stock has been surveyed three times in a ca. two decade period, between 1984 and 2013 (Tables 3 and A2). Recent satellite-tagging data has shown that there is a greater degree of within- and between-year range overlap between Eclipse Sound and Admiralty Inlet than had been documented in past studies (Watt et al. 2012). A 2016 survey of Eclipse Sound was conducted by DFO but has not yet been analyzed (DFO, unpublished data). Industry-sponsored surveys to support the oil and gas industry were conducted in this area in 1978 and 1979 (Koski and Davis 1979, 1980), and more recently (2006-2008, 2013-2015) in support of the Mary River Iron mine project (BIMC 2012, 2016), which could potentially provide useful data for stock assessment and trend analysis.

The eastern coastline of Baffin Island (East Baffin Island summer stock) was systematically surveyed for the first time in 2003, and was surveyed again in 2013. The East Baffin Island narwhal summer stock covers a large area and may also have further sub-structuring (Higdon and Ferguson 2014). No tagging has ever been conducted in the summer range of this stock and movements are therefore not understood (Watt et al. 2017).

Systematic surveys of the Northern Hudson Bay narwhal stock/population summer range, or parts thereof, have been conducted four times between 1982-1984 and 2011 (Tables 3 and A2). Industry sponsored aerial surveys have also been conducted in Hudson Strait (Koski and Davis 1994; Elliott et al. 2013). These surveys have occurred outside the summer season but would presumably include animals from this summer stock only, because the other narwhal stocks over-winter in Baffin Bay (Heide-Jørgensen et al. 2013a). Tagged animals from this stock have also wintered in Davis Strait, east of Hudson Strait (Westdal et al. 2010), suggesting that these surveys may not cover the entire over-wintering population, and this would have to be considered if these data were to be used for trend analysis. However, a recent change in winter distribution from Davis Strait to Hudson Strait has been suggested based on feeding habits (Watt and Ferguson 2015).

SUMMARY AND CONCLUSIONS

We constructed a database of aerial surveys and associated population estimates for beluga whale and narwhal stocks in the Canadian Arctic. The database contains a total of 56 records (34 beluga estimates and 22 narwhal estimates) and is current to surveys conducted in 2015 (the database can be updated as future surveys are completed and analyzed). All recognized summer stocks have been surveyed at least once, but estimates for several beluga stocks are dated and should be updated. The database has focused on peer-reviewed scientific publications and government documents where the primary goal was abundance estimation. Only Canadian studies are included, and for shared stocks there are studies from other jurisdictions that could be useful for trend analyses and stock assessments. Consulting company reports on industry-funded surveys are also

available. Some examples are noted in the text, and these may also provide additional useful data for sustainable management.

The database provides a useful data summary that can contribute to a variety of conservation and management efforts, including assessments of impacts of industrial development such as oil and gas exploration (e.g., Heide-Jørgensen et al. 2013c; Reeves et al. 2014); assessment of species and stock status at local, national and international scales (e.g., the Global Review of Monodontids (GROM) being undertaken by NAMMCO, NAMMCO 2017); assessing recovery from and resilience to past over-exploitation (Wade et al. 2012); and to meeting international management obligations regarding hunt sustainability (e.g, CITES assessments for narwhal, DFO 2010b, 2012).

REFERENCES

Auger-Méthé, M., M. Marcoux, and H. Whitehead. 2010. Nicks and notches of the dorsal ridge: Promising mark types for the photo-identification of narwhals. Mar. Mam. Sci. 26: 663-678.

Auger-Méthé, M., M. Marcoux, and H. Whitehead. 2011. Computer-assisted photo-identification of narwhals. Arctic 64: 342-352.

BIMC (Baffinland Iron Mines Corporation). 2012. Mary River Project: Final Environmental Impact Statement. Volume 8: Marine Environment. Appendix 8A-2. Marine Mammal Baseline. Nunavut Impact Review Board, Cambridge Bay, NU.

BIMC (Baffinland Iron Mines Corporation). 2016. Mary River Project: 2015 Annual Report to the Nunavut Impact Review Board. March 2016. Nunavut Impact Review Board, Cambridge Bay, NU.

Braham, H.W., B.D. Krogman, and G.M. Carroll. 1984. Bowhead and White Whale Migration, Distribution, and Abundance in the Bering, Chukchi, and Beaufort Seas, 1975-78. NOAA Technical Report NMFS SSRF-778. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. iv + 39 pp.

COSEWIC 2004a. COSEWIC assessment and update status report on the beluga whale *Delphinapterus leucas* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 70 pp.

COSEWIC 2004b. COSEWIC assessment and update status report on the narwhal *Monodon monoceros* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 50 pp.

Davis, R.A. and C.R. Evans. 1982. Offshore distribution and numbers of white whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981.Rep.by LGL Ltd., for Sohio Alaska Petroleum co., Dome petroleum Ltd. et al. 76 p.

Davis, R.A., K.J. Finley, M.S.V. Bradstreet, C. Holdsworth and M. McLaren. 1975. Studies of the numbers and distribution of birds and marine mammals in the central Canadian arctic, 1974: a supplement. Rep.by LGL Ltd., for Polar Gas Environmental program, Toronto. 205 p.

de March, B.G.E., L.D. Maiers, and M.K. Friesen. 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.

DFO. 2010a. Stock definition of Belugas and Narwhals in Nunavut. DFO Can. Sci. Adv. Sec. Sci. Adv. Rep. 2009/079.

DFO. 2010b. Evaluation of narwhal with respect to making a CITES non-detriment finding. DFO Can. Sci. Adv. Sec. Sci. Resp. 2010/011.

DFO. 2012. Evaluation of Canadian narwhal hunt sustainability with respect to making a CITES non-detriment finding. DFO Can. Sci. Advis. Sec. Sci. Adv. Rep. 2011/073.

DFO. 2013. Integrated Fisheries Management Plan (IFMP) for Narwhal in the Nunavut Settlement Area (Effective April 1, 2013). Department of Fisheries and Oceans, Iqaluit, NU. ii + 48 pp.

DFO. 2015. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO Can. Sci. Advis. Sec. Sci. Adv. Rep. 2015/046.

Doniol-Valcroze, T., and M.O. Hammill. 2012. Information on abundance and harvest of Ungava Bay beluga. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/126. iv + 12 p.

Doniol-Valcroze, T, J.-F. Gosselin, D. Pike, J. Lawson, N. Asselin, K. Hedges, and S.H. Ferguson. 2015. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/060.v + 36 p.

Elliott, R.E., V.D. Moulton, S.W. Raborn and R.A. Davis. 2013. Hudson Strait Marine Mammal Surveys, 10 March – 2 April 2012. LGL Report No. TA8129-2. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Toronto, ON. 87 p.

F.F. Slaney & Company Limited. 1975. Summer Environmental Program, Mackenzie River Estuary. Vol. 3 , White Whale Studies. Report prepared for Imperial Oil Limited, Calgary, AB, Canada by F.F. Slaney & Company Limited, Vancouver, BC, Canada. 53 pp.

Finley, K.J. 1976. Studies of the status of marine mammals in the central District of Franklin, N.W.T. June-August 1975. Rep.by LGL Ltd., for Polar Gas Project. 183 p.

Finley, K.J., and W.E. Renaud. 1980. Marine mammals inhabiting the Baffin Bay North Water in winter. Arctic 33: 724-738.

Finley, K.J., R.A. Davis and W.J. Richardson.1974. Preliminary studies of the numbers and distribution of marine mammals in the central Canadian arctic, 1974. Rep. by LGL Ltd., for Polar Gas Environmental Program, Toronto. 68 p.

Finley, K.J., G.W. Miller, M. Allard, R.A. Davis and C.R. Evans. 1982. The white whales (Delphinapterus leucas) of northern Quebec: distribution, abundance, stock identity, catch history and management. Can. Tech. Rep. Fish. Aquat. Sci. 1123: 57 p.

Fraker, M.A. 1976 . Summer Environmental Program, Mackenzie River Estuary, Volume 2 , White Whale Studies. Prepared for Imperial Oil Limited, Calgary, AB, Canada by F.F. Slaney & Company Limited, Vancouver, BC, Canada. 62 pp.

Fraker, M.A. 1977. The 1976 White Whale Monitoring Program, Mackenzie Estuary, N.W.T. Prepared for Imperial Oil Limited, Calgary, AB, Canada, by F.F. Slaney & Company Limited, Vancouver, BC, Canada. 73 pp.

Fraker, M.A. and P.N. Fraker. 1979. The white whale monitoring program Mackenzie estuary. Rep. by LGL Ltd., for Esso Resources Canada Ltd., Edmonton. 51 p.

Fraker M.A. and P.N. Fraker. 1981. The 1980 whale monitoring program Mackenzie estuary. Rep. by LGL Ltd., for Esso Resources Canada Ltd., Edmonton.

Fraker, M.A., D.E. Sergeant, and W. Hoek. 1978. Bowhead and White Whales in the Southern Beaufort Sea. Beaufort Sea Project Technical Report No. 4.

Frasier, T.R., S.D. Petersen, L. Postma, L. Johnson, M.P. Heide-Jørgensen, and S.H. Ferguson. 2015. Abundance estimates of the Eastern Canada-West Greenland bowhead whale (*Balaena mysticetus*) population based on genetic capture-mark-recapture analyses. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/008. iv + 21 p.

Gosselin, J.-F. 2005. Abundance indices of belugas in James Bay and eastern Hudson Bay in summer 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/011. 22 pp.

Gosselin, J.-F., V. Lesage, M.O. Hammill, and H. Bourdages. 2002. Abundance indices of belugas in James Bay and eastern Hudson Bay in summer 2001. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/042. 27 pp.

Gosselin, J.-F., V. Lesage, and M. Hammill. 2009. Index estimates of abundance for beluga in eastern Hudson Bay, James Bay and Ungava Bay in summer 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/006. 25 pp.

Gosselin, J.-F., T. Doniol-Valcroze, and M.O. Hammill. 2013. Abundance estimate of beluga in eastern Hudson Bay and James Bay, summer 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/016. vii + 20 p.

Gosselin, J.-F., M.O. Hammill, and A. Mosnier, A. 2017. Indices of abundance for beluga (*Delphinapterus leucas*) in James Bay and eastern Hudson Bay in summer 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/nnn. vi + xx p.

Harwood, L.A. and M.C.S. Kingsley. 2013. Trends in the offshore distribution and relative abundance of Beaufort Sea belugas, 1982-85 vs 2007-09. Arctic 66(3): 247-256.

Harwood, L.A., J. Iacozza, J.C. Auld, P. Norton, and L. Loseto. 2014. Belugas in the Mackenzie River estuary, NT, Canada: Habitat use and hot spots in the Tarium Niryutait Marine Protected Area. Ocean and Coastal Management 100: 128-138.

Heide-Jørgensen, M.P. 2004. Aerial digital photographic surveys of narwhals, Monodon monoceros, in Northwest Greenland. Mar. Mam. Sci. 20: 58-73.

Heide-Jørgensen, M.P., and M. Acquarone. 2002. Size and trends of the bowhead whale, beluga and narwhal stocks wintering off West Greenland. NAMMCO Sci. Pub. 4: 191-210.

Heide-Jørgensen M.-P., H. Lassen, J. Teilmann, and R.A. Davis. 1993. An index of the relative abundance of wintering belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, off West Greenland. Can. J. Fish. Aqu. Sci. 50: 2323-2335.

Heide-Jørgensen, M., P. Richard, R. Dietz, K. Laidre, J. Orr, and H. Schmidt. 2003. An estimate of the fraction of belugas (*Delphinapterus leucas*) in the Canadian High Arctic that winter in West Greenland. Polar Biol. 26:318-326.

Heide-Jørgensen, M.P., K.L. Laidre, M.L. Burt, D.L. Borchers, T.A. Marques, R.G. Hansen, M. Rasmussen and S. Fossette. 2010. Abundance of narwhals (*Monodon monoceros*) on the hunting grounds in Greenland. J. Mam. 91: 1135-1151.

Heide-Jørgensen, M.P., P.R. Richard, R. Dietz, and K.L. Laidre. 2013a. A metapopulation model for Canadian and West Greenland narwhals. Anim. Conserv. 16: 331-343. doi:10.1111/acv.12000

Heide-Jørgensen, M.P., L.M. Burt, R.G. Hansen, N.H. Nielsen, M. Rasmussen, S. Fossette, and H. Stern. 2013b. The significance of the North Water Polynya to arctic top predators. Ambio 42: 596-610.

Heide-Jørgensen, M.P., R.G. Hansen, K. Westdal, R.R. Reeves, and A. Mosbech. 2013c. Narwhals and seismic exploration: Is seismic noise increasing the risk of ice entrapments? Biol. Cons. 158: 50-54.

Heide-Jørgensen, M.P., M.H. Sinding, N.H. Nielsen, A. Rosing-Asvid, and R.G. Hansen. 2016a. Large numbers of marine mammals winter in the North Water polynya. Polar Biology 39: 1605-1614.

Heide-Jørgensen, M.P., R.G. Hansen, S. Fossette, N.H. Nielsen, D.L. Borchers, H. Stern, and L. Witting. 2016b. Rebuilding beluga stocks in West Greenland. Anim. Cons. doi:10.1111/acv.12315

Higdon, J.W., and S.H. Ferguson. 2014. History of narwhal aerial surveys and abundance estimates in the Canadian Arctic. Working Paper NAMMCO/SC/21-JCNB/SWG/2014-JWG/09 presented at NAMMCO/JCNB Joint Working Group on narwhals and belugas, 10-12 March 2014, Copenhagen, DK.

Hornby, C., C. Hoover, A. Joynt, V. Torontow, K. Hynes, and L. Loseto. 2014. Arrival of beluga (*Delphinapterus leucas*) to the Mackenzie Estuary in relation to sea ice: report on spring 2011–2013 aerial surveys. Can. Data Rep. Fish. Aquat. Sci. 1251

Hornby, C.A., C. Hoover, J. Iacozza, D.G. Barber, and L.L. Loseto. 2016. Spring conditions and habitat use of beluga whales (*Delphinapterus leucas*) during arrival to the Mackenzie River Estuary. Polar Biology 39(12): 2319-2334. DOI 10.1007/s00300-016-1899-9.

Innes, S., M.P. Heide-Jørgensen, J.L. Laake, K. Laidre, H. Cleator, and P. Richard. 2002. Surveys of belugas and narwhals in the Canadian High Arctic in 1996. NAMMCO Scientific Publications 4:169-190.

JCNB. 2015. Report of the Joint Meeting of the NAMMCO Scientific Committee Working Group on the Population Status of Narwhal and Beluga in the North Atlantic and the Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga Scientific Working Group, Ottawa, ON, Canada, 11-13 March 2015.

Jefferson, T.A., L. Karkzmarski, K. Laidre, G. O'Corry-Crowe, R. Reeves, L. Rojas-Bracho,E. Secchi, E. Slooten, B.D. Smith, J.Y. Wang, and K. Zhou. 2012a. *Delphinapterus leucas*. In: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.1.

Jefferson, T.A., L. Karkzmarski, K. Laidre, G. O'Corry-Crowe, R. Reeves, L. Rojas-Bracho,E. Secchi, E. Slooten, B.D. Smith, J.Y. Wang, and K. Zhou. 2012b. *Monodon monoceros*. In: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.1.

Kingsley, M.C.S. 2000. Numbers and distribution of beluga whales, *Delphinapterus leucas*, in James Bay, eastern Hudson Bay and Ungava Bay in Canada during the summer of 1993. Fish. Bull. 98: 736-747.

Koski, W.R. 1980a. Distribution and migration of marine mammals in Baffin Bay and Eastern Lancaster Sound, May-July 1979. Report prepared for Petro-Canada Explorations by LGL Ltd, Toronto, ON.

Koski, W.R. 1980b. Distribution of marine mammals in the Canadian Central High Arctic, July-September 1979. Report prepared for Petro-Canada and the Arctic Biological Station by LGL Ltd, Toronto, ON.

Koski, WR. and R.A. Davis. 1979. Distribution of marine mammals in northwest Baffin Bay and adjacent waters, May-October 1978. Rep. by LGL Ltd., for Petro-Canada, Calgary. 305 p. + Map Appendix (223 p.).

Koski, W.R. and R.A. Davis. 1980. Studies of the late summer distribution and fall migration of marine mammals in NW Baffin Bay and E Lancaster Sound, 1979. Rep. by LGL Ltd., for Petro-Canada, Calgary. 274 p.

Koski, W.R. and R.A. Davis. 1994. Distribution and numbers of narwhals (*Monodon monoceros*) in Baffin Bay and Davis Strait. Meddelelser om Greenland, Bioscience 39:15-40.

Loseto, L.L., P. Richard, G.A. Stern, J. Orr, and S.H. Ferguson. 2006. Segregation of Beaufort Sea beluga whales during the open-water season. Can. J. Zool. 84: 1743-1751.

MacLaren Atlantic Ltd. 1978. Aerial surveys 77-2, 77-3, 77-4. Studies of seabirds and marine mammals in Davis Strait, Hudson Strait and Ungava Bay. Unpubl. rep. prep. by MacLaren Atlantic, Dartmouth, NS.

MacLaren Marex Inc. 1979. Report on aerial surveys of birds and marine mammals in the southern Davis Strait between April and December, 1978. Vol. III, Marine Mammals. Unpubl. rep. prep. by MacLaren Marex, Dartmouth, NS.

MacLaren Marex Inc. 1980. Aerial monitoring of marine birds and mammals: the 1979 offshore drilling programme near southeast Baffin Island. Unpubl. rep. prep. by MacLaren Marex, Dartmouth, NS.

Matthews, C.J.D., C.A. Watt, N.C. Asselin, J.B. Dunn, B.G. Young, L.M. Montsion, K.H. Westdal, P.A. Hall, J.R. Orr, S.H. Ferguson, and M. Marcoux. 2017. Estimated abundance of the Western Hudson Bay beluga stock from the 2015 visual and photographic aerial survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/nnn. iv + 22 p.

NAMMCO. 2017. Upcoming events: NAMMCO/JCNB Joint Scientific Working Group. The North Atlantic Marine Mammal Commission, Tromso, Norway. Online: http://www.nammco.no/news/archive/2017.

Petersen, S.D., D. Tenkula and S.H. Ferguson. 2011. Population genetic structure of narwhal (*Monodon monoceros*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/021.

Petersen, S.D., L. Johnson, B. LeBlanc, J.W. Higdon, D. Yurkowski, C. Matthews, L. Postma, and S.H. Ferguson. 2014. Preliminary investigation of genetic capture-mark-recapture to census bowhead whales (*Balaena mysticetus*) in Nunavut, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/017. v + 9 p.

Read, C.J., and S.E. Stephansson. 1976. Distribution and migration routes of marine mammals in the Central Arctic region. Fisheries Marine Services Technical Report 667: v + 13 pp.

Reeves, R.R., P.J. Ewins, S. Agbayani, M.P. Heide-Jørgensen, K.M. Kovacs, C. Lydersen, R. Suydam, W. Elliott, G. Polet, Y. van Dijk, and R. Blijleven. 2014. Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic. Mar. Pol. 44: 375-389.

Remnant, R.A., and M.L. Thomas. 1992. Inuit traditional knowledge of the distribution and biology of High Arctic narwhal and beluga. North/South Consultants Inc., Winnipeg for the Canada/Greenland Joint Commission for the Conservation and Management of Beluga and Narwhal. vii + 96 pp.

Richard, P.R. 2010. Stock definition of belugas and narwhals in Nunavut. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/022. iv + 14 p.

Richard, P., P. Weaver, L. Dueck, and D. Barber. 1994. Distribution and numbers of Canadian High Arctic narwhals (*Monodon monoceros*) in August 1984. Medd. Grønl. Biosci. 39: 41-50.

Richard, P.R., J.R. Orr, R. Dietz, and L. Dueck. 1998. Sightings of belugas and other marine mammals in the North Water, late March 1993. Arctic 51: 1-4.

Richard, P.R., M.P. Heide-Jorgensen, J.R. Orr, R. Dietz, and T.G. Smith. 2001. Summer and autumn movements and habitat use by belugas in the Canadian High Arctic and adjacent areas. Arctic 54(3):207-222.

Richard, P.R., J.L. Laake, R.C. Hobbs, M.P. Heide-Jørgensen, N.C. Asselin, and H. Cleator. 2010. Baffin Bay narwhal population distribution and numbers: Aerial Surveys in the Canadian High Arctic, 2002-04. Arctic 63:85-99.

Sergeant, D.E. and W. Hoek. 1974. Seasonal distribution of bowhead and white whales in the eastern Beaufort Sea, p. 705-719 in: J.C. Reed and J.E. Sater [eds.] The coast and shelf of the Beaufort Sea. Arctic Institute of North America.

Smith, T.G., and M.O. Hammill. 1986. Population estimates of the white whale, *Delphinapterus leucas*, in James Bay, eastern Hudson Bay and Ungava Bay. Can. J. Fish. Aquat. Sci. 43: 1982-1987.

Smith, T.G., and A.R. Martin. 1994. Distribution and movements of belugas, Delphinapterus leucas, in the Canadian High Arctic. Canadian Journal of Fisheries and Aquatic Sciences 51:1653-1663.

Smith, T.G., M.O. Hammill, D.J. Burrage, and G.A. Sleno. 1985. Distribution and abundance of belugas, Delphinapterus leucas, and narwhals, Monodon monoceros, in the Canadian High Arctic. Canadian Journal of Fisheries and Aquatic Sciences 42:676-684.

Turgeon, J., P. Duchesne, G.J. Colbeck, L.D. Postma, and M.O. Hammill. 2012. Spatiotemporal segregation among summer stocks of beluga (*Delphinapterus leucas*) despite nuclear gene flow: implication for the endangered belugas in eastern Hudson Bay (Canada). Conserv. Genet. 13(2): 419-433. doi:10.1007/s10592-011-0294-x

Wade, P.R., R.R. Reeves, and S.L. Mesnick. 2012. Social and behavioural factors in cetacean responses to overexploitation: Are odontocetes less "resilient" than mysticetes? J. Mar. Biol. 2012: 567276. http://dx.doi.org/10.1155/2012/567276.

Watt C.A., and S.H. Ferguson. 2015. Fatty acids and stable isotopes (δ13C and δ15N) reveal temporal changes in narwhal (Monodon monoceros) diet linked to migration patterns. Mar. Mamm. Sci. 31: 21-44.

Watt, C.A., J. Orr, B. LeBlanc, P. Richard, and S.H. Ferguson. 2012. Satellite tracking of narwhals (*Monodon monoceros*) from Admiralty Inlet (2009) and Eclipse Sound (2010-2011). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/046. iii + 17 p.

Watt, C.A., Witting, L., Marcoux, M., Doniol-Valcroze, T., Guldborg Hansen, R., Hobbs, R., Lee, D.S., Ferguson, S.H., Heide-Jørgensen, M.P. 2017. Population modelling for narwhal (*Monodon monoceros*) stocks shared between eastern Canada and West Greenland. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/nnn. vi + xx p.

Westdal, K. H., P.R. Richard, and J.R. Orr. 2010. Migration route and seasonal home range of the northern Hudson Bay narwhal (Monodon monoceros). In: S.H. Ferguson, L.L. Loseto, and M.L. Mallory (eds.). A Little Less Arctic Top Predators in the World's Largest Northern Inland Sea, Hudson Bay. Springer. Netherlands. 71-92.

Witting, L 2016. Meta population modelling of narwhals in East Canada and West Greenland. Working paper NAMMCO/SC/22 - JCNB/SWG/2015-JWG/10 prepared for Joint Commission on Narwhal and Beluga. Online: http://www.biorxiv.org/content/early/2016/09/30/059691.

Table 1**. Stocks of narwhals and beluga whales occurring in Canadian Arctic waters.**

Species	Stock
Beluga (*Delphinapterus leucas*)	Eastern Hudson Bay (EHB)
	Ungava Bay (UB)
	Cumberland Sound (CS)
	Eastern High Arctic-Baffin Bay (EHA-BB)[1]
	Western-Northern-Southern Hudson Bay (WNSHB)
	James Bay (JB)
	Eastern Beaufort Sea (EBS)
Narwhal (*Monodon monoceros*)[2]	Jones Sound (JS)
	Smith Sound (SS)
	Somerset Island (SI)
	Admiralty Inlet (AI)
	Eclipse Sound (ES)
	East Baffin Island (EBI)
	Northern Hudson Bay (NHB)

[1] Also known as the Somerset Island beluga whale stock

[2] Narwhal also occur in the Parry Channel area, but no survey results are available

Table 2. Number of beluga whale surveys (and associated abundance estimates) in the Canadian Arctic, by summer stock, per decade.

Beluga whale stock	Decade						
	1960	1970	1980	1990	2000	2010	Total
Eastern Hudson Bay			1	1	3	2	7
Ungava Bay			1	1	2		4
Cumberland Sound	1		2	2	1	1	7
Eastern High Arctic-Baffin Bay		1	1	1			3
Western-Northern-Southern Hudson Bay	1		1		1	1	4
James Bay			1	1	3	2	7
Eastern Beaufort Sea			1	1			2
Total	2	1	8	7	10	6	34

Table 3. Number of narwhal surveys (and associated abundance estimates) in the Canadian Arctic, by summer stock, per decade.

Narwhal stock	Decade						
	1960	1970	1980	1990	2000	2010	Total
Jones Sound						1	1
Smith Sound						1	1
Somerset Island			2	1	1	1	5
Admiralty Inlet		1	2		1	2	6
Eclipse Sound			1		1	1	3
East Baffin Island					1	1	2
Northern Hudson Bay			1		2	1	4
Total		1	6	1	6	8	22

Figure 1. Summer ranges of beluga (*Delphinapterus leucas*) stocks in the Canadian Arctic.

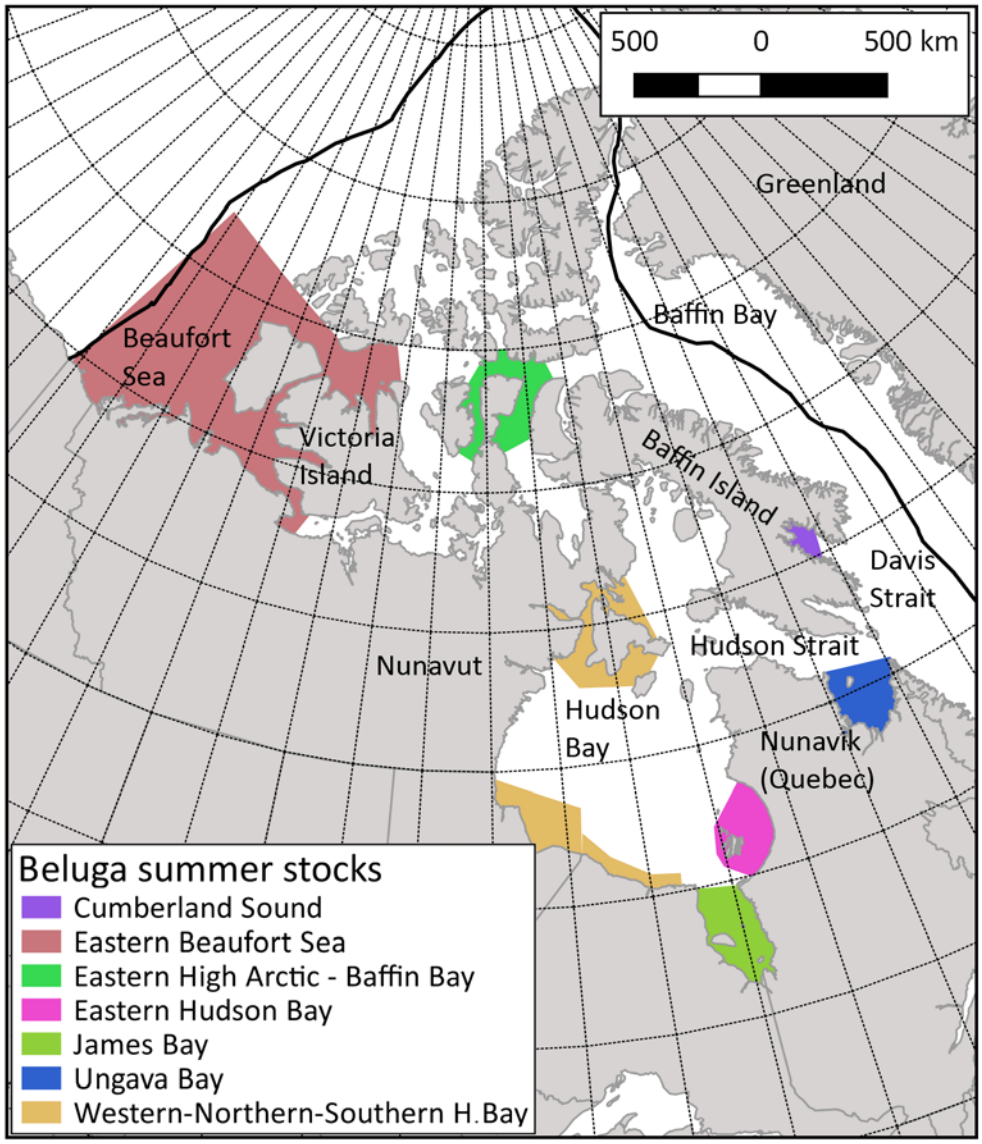


Figure 2. Summer ranges of narwhal (*Monodon monoceros*) stocks in the Canadian Arctic. For Somerset Island stock, the map shows the overall stock range (stippled green) and the early August concentration area (solid green) where aerial surveys have focused. Some West Greenland stocks (that do not range into Canadian waters) not shown.

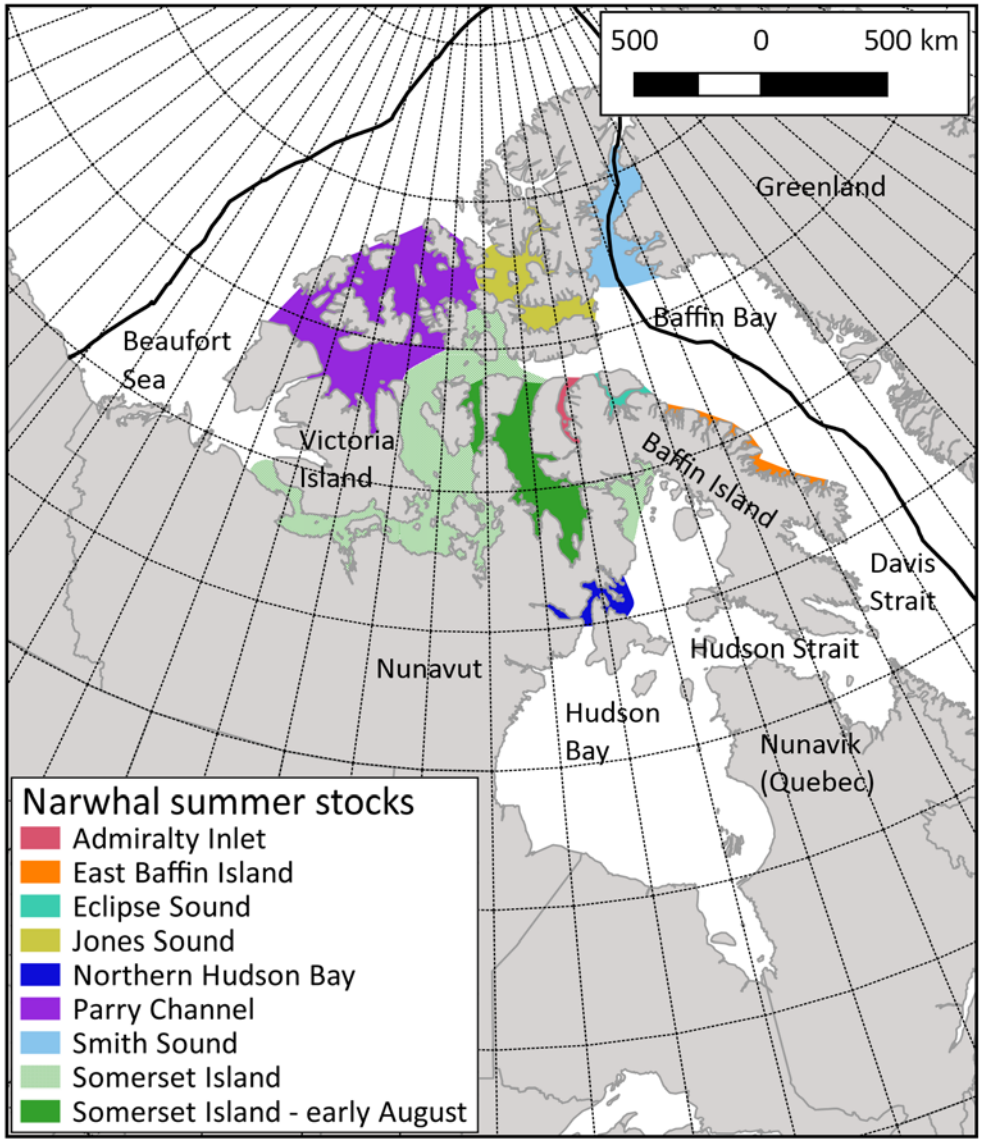
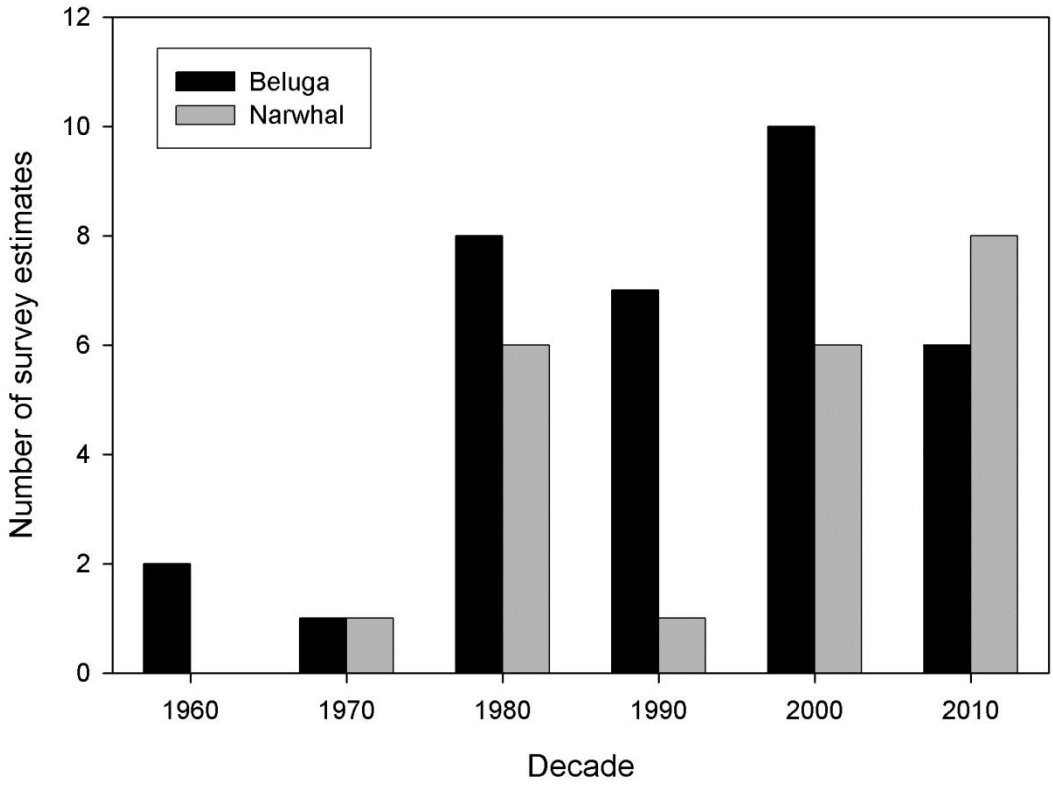


Figure 3. Number of beluga (*Delphinapterus leucas*) and narwhal (*Monodon monoceros*) surveys and associated population estimates in the Canadian Arctic, for all summer stocks, per decade.



Appendix - Database of aerial surveys for beluga whales and narwhal in the Canadian Arctic

Table A1. Database of beluga whale (*Delphinapterus leucas*) aerial surveys and associated abundance estimates, by summer stock, in the Canadian Arctic.

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
1	Western-Northern-Southern Hudson Bay	Nelson River, MB to Arviat, NU	1965 (July)	Aerial survey (airplane)	Strip transect (227 m per side)	n/a	ca. 10,000 (8,713 in Sergeant 1981)	None	None	n/a	n/a	Visual count only. No corrections or analyses, no measure of variance.	Sergeant 1973, 1981
2	Cumberland Sound	Clearwater Fiord	1967 (August)	Aerial survey (platform not stated)	Other (visual count in C. Fiord)	Declined (from historic, due to over-harvest)	476, 455 (2 consecutive counts)	769	Availability bias (cliff based obs. of diving behaviour); corrections for newborns and yearlings assumed missed due to small size and dark coloration.	n/a	n/a	Visual count only. Count limited to C. Fiord, no measure of variance.	Brodie 1971; Brodie et al. 1981
3	E High Arctic-Baffin Bay	Lancaster Sound	1973 (August)	Aerial survey (platform not stated)	Not stated but focus on river mouths and bays	n/a	at least 10,000	None	None (?)	n/a	n/a	No details on survey design reported by Sergeant and Brodie (1975), but survey reported as incomplete: "Incomplete surveys by Sergeant and by Mr J. D. Heyland of the Quebec Wildlife Service showed at least 10,000 animals at river mouths and bays in early August 1973", cited as Sergeant (unpublished data).	Sergeant (unpublished data) in Sergeant and Brodie (1975)
4	E High Arctic-Baffin Bay	Lancaster Sound, Barrow Strait, Peel Sound, and Prince Regent Inlet	1981 (July-August)	Aerial survey (helicopter)	Strip transect (800 m total), photographic group counts (estuary aggregations)	n/a	8,304 (July); 3,702 (August) (plus 2,064 belugas from off-transect locations and estuarine aggregations in July; 5,100 in August)	None	Corrected for ice cover, and weighted for transect area; but no correction for availability bias.	95% CI: 4,214-16,49 7 (July); 1,670-8,967 (August)	n/a	No correction for availability bias.	Smith et al. 1985

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
5	Cumberland Sound	Cumberland Sound, concentrated on Clearwater Fiord	1980-82 (August) (highest single estimate - 1980)	Aerial survey (airplane) (also cliff counts in 1979, 1982-84)	Strip and photo (C. in Fiord)	Uncertain, but no major decline since 1967	25 (Clearwater Fiord) plus 500+ (other areas)	541 +	Counts in clear water uncorrected, counts in silted water corrected for submerged whales and neonate-yearlings (as per Brodie 1971)	n/a (highest count per year ranged from 411 (1982) to 541+ (1980))	Two groups (one of 25 whales, one of 500+)	Systematic transect design used only in Clearwater Fiord and only for 1982 photo surveys (lower estimate than 1980). Flight paths arbitrarily chosen to cover as much area as possible within coastal zones of the sound identified by local people as occupied by belugas.	Richard and Orr 1986
6	Eastern Beaufort Sea	SE Beaufort Sea from Alaska-Yukon border east to Cape Bathurst, from mainland coast seaward to 9+/10 pack-ice	1984 (July-August)	Aerial survey (airplane)	Strip transect (800 m per side) ((data re-analyzed during 1992 workshop using line-transect analyses - see Duval 1993)	n/a	7,081 (10,519 using line-transect methods)	17,702 (21,000 using line-transect methods)	Corrected for whales missed by observers using info from July 5 survey when both observers used bubble windows on left side of the aircraft (correction factor of 2.5 used to get estimate of the number of sightable whales, used to calculate possible upper limit of population estimate) (Line transect analysis - corrected using line transect sightability function and a conservative estimate of 50% of the animals being below the surface)	SE = 1,584 (uncorrected estimate); 95% CI = 3,335 - 10,827 (uncorrected estimate) (SE = 1,478 for line-transect analysis, uncorrected; corrected 95% CI = 15,000-27,000)	218 sightings (383 whales) on-transect, 36 sightings (73 whales) off-transect	Population estimate not a program objective. Effective transect width not adjusted (narrowed) to reflect decreased detectability of whales along outer portions of the transect strip because distance measurements were not available for half of the sightings. The number of whales on-transect was probably underestimated, and densities calculated on the basis of the 1600 m transect strip are conservative. Conservative estimate due to limited survey coverage (particularly inshore areas which were not included - unknown but substantial numbers of animals remained in the inshore areas at the time of the survey).	Norton and Harwood 1985 (Duval 1993 for line-transect analysis)
7	Ungava Bay	Whole of Ungava Bay	1985 (July-August)	Aerial survey (airplane)	Strip transect (2 km total)	n/a	No estimate (no whales seen)	No estimate	n/a	n/a	None	No whales observed.	Smith and Hammill 1986; Hammill et al. 2004

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
8	Eastern Hudson Bay	EHB offshore arc to the Belcher Islands	1985 (July-August)	Aerial survey (airplane)	Strip transect (2 km total) (photos of aggregations)	n/a	968 (additional 474 whales counted in traditional areas of coastal concentration, added to survey estimate)	None (but see Gosselin et al. 2013 - corrected for availability bias and beluga counted in estuaries, but not perception bias)	None	95% CI: 650-1,430 (1,124-1,904 when inshore sightings added); SE = 165	205 animals (number of sightings not stated)	Estimates on conservative side as there was no correction for animals missed because they were underwater.	Smith and Hammill 1986; Hammill et al. 2004
9	James Bay	Whole of James Bay	1985 (July-August)	Aerial survey (airplane)	Strip transect (2 km total) (photos of aggregations)	n/a	1213	None (but see Gosselin et al. (2013), all stock abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	None	95% CI 740-1,970); SE = 290	131 animals (number of sightings not stated)	Estimates on conservative side as there was no correction for animals missed because they were underwater.	Smith and Hammill 1986; Hammill et al. 2004
10	Western-Northern-Southern Hudson Bay	MB coastline, also northern HB from Rankin Inlet to 67 North latitude, and southern HB area (Cape Henrietta Maria to near ON-MB border)	1981-1988 (March, July-August) (1987 estimate, except northern Hudson Bay - 1982) (estimate from 1987, except northern HB - 1982)	Aerial survey (airplane)	Strip (800 m per side) and photo (high concentration areas)	Historic information not precise enough to determine trends	23,000 (11,300 in Churchill-Seal stratum, 11,700 in Nelson stratum) (plus 1000 in NHB 1982) (another 1,300 seen along Ontario coast)	None	None	95% CI 11,000-56,500 (95% CI 621-1,627 for NHB 1982)	1,184 + 1,209 animals counted (number of observations not stated)	No correction for availability bias.	Richard et al. 1990; Richard 1991

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
11	Cumberland Sound	Cumberland Sound (also Frobisher Bay)	1985-1986 (August) (estimates reported for both years)	Aerial survey (airplane)	Strip (800 m per side) and photo (high concentration areas)	Not stated	1985: 398 photographed in Clearwater Fiord (+9 near mouth of Frobisher Bay); 1986: 442 photographed near mouth of C. Fiord (+ 43 by cliff-based crew + 2 seen in C. Sound - 487 total)	None	None	n/a	1 in 1985 (all whales seen together), 3 groups in 1986	No corrections. Systematic survey design, but unable to derive population estimate due to extreme clumping of relatively small population.	Richard et al. 1990; Richard 1991a
12	Cumberland Sound	C. Fiord plus North stratum	1990	Aerial survey (airplane)	Strip (800 m per side) and photo (C. Fiord)	Not stated	459 (C. Fiord), 0 (North stratum)	1087 (C. Fiord), 0 (North)	Corrected for availability bias using satellite-tag data.	No CV for C. Fiord, no sightings in North stratum; corrected CV = 0.077 for C. Fiord; 95 percentile of bootstrapped estimate: 989-1202	n/a	Surface counts in Clearwater Fiord calculated from photo mosaic, some issues with plane drift during photo surveys.	Baratin 2001; DFO 2002a,b, 2005; Richard and Baratin 2002; Richard 2013

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
13	Eastern Beaufort Sea	Mackenzie estuary, SE Beaufort Sea, west Amundsen Gulf	1992 (July)	Aerial survey (airplane)	Strip (400 m/side, estuary stratum) and line (offshore stratum)	n/a	15,307 (using data collected by primary observers only)	19629	Corrected using non-duplicate sightings made by secondary observers to adjust for missed-at-surface and about-to-surface beluga. Not corrected for availability bias (i.e., corrected at-surface counts only).	Uncorrected 95% CI = 12,305 - 18,309 (SE = 1501); Corrected 95% CI = 15,134 — 24,125	Primary observers - 253 groups (404 in beluga) estuary, 251 groups (414 in whales) offshore (secondary observers - 37 groups (69 whales) and 108 groups (232 whales), respectively)	Data collected by secondary observers used for identifying non-duplicate sightings and calculating adjustment factor for missed-at-surface and about-to-surface beluga - some uncertainty around classifying secondary observer sightings as duplicates, erred on the conservative side. All possible duplicates were classified as duplicates, which produced an adjustment factor that was an underestimate. Negatively biased due to non-accounting for belugas far below the surface and not available for sighting by either primary or secondary observer and beluga outside of the survey area.	Harwood and Norton 1996; Harwood et al. 1996
14	Ungava Bay	Whole of Ungava Bay	1993 (July and August)	Aerial survey (airplane)	Strip (600 m per side) (but sightings so few that all were recorded, on- or off-effort and on- or off-transect)	n/a	38 and 50 whales in July and August	None	None	Approximate 90% upper CLs of 119 and 157 whales	None	Few sightings made on transect survey, none within designed strip (maximum daily count 20 individuals). Sightings made outside transect strip converted to population estimate by assuming effective strip width based on statistics from other line-transect surveys that used similar platforms. No SE calculated, but an upper CL on the number of groups calculated. Estimates and confidence limits are imprecise and do not account for the uncertainty of mean group size or for the known lower bound on numbers.	Kingsley 2000; Hammill et al. 2004

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
15	Eastern Hudson Bay	EHB offshore to Belcher Islands	arc the 1993 (August)	Aerial survey (airplane)	Line	Stable (similar to 1985 estimate)	1014	None (added whales seen during coastal surveys) (also see Gosselin et al. (2013), all six stock abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	None (estimate uncorrected for diving and observer errors)	SE=421; Error coefficients of variation (ECV) up to 86% (northern stratum of widely spaced transects) (ECV of overall estimate 23% - common sighting curve)	63 sightings (150 whales)	Surface whales only, no correction for diving whales or observer errors. Effective number of sightings less than recommended minimum so sample-size bias in the estimate of survey expansion factor reduced by using standard jack-knife bias reduction.	Kingsley 2000; Hammill et al. 2004
16	James Bay	Whole of James Bay	1993 (August)	Aerial survey (airplane)	Line	Increase (3X higher) from 1985, possibly related to differences in ice cover between surveys	3141	None (but see Gosselin et al. (2013), all six population abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	None (estimate uncorrected for diving and observer errors)	SE=787; Error coefficients of variation (ECV) = 25% (ECV of overall estimate 23% - common sighting curve)	123 sightings (295 whales)	Surface whales only, no correction for diving whales or observer errors. Effective number of sightings less than recommended minimum so sample-size bias in the estimate of survey expansion factor reduced by using standard jack-knife bias reduction. Used a common sighting curve to reduce estimated SE for individual strata.	Kingsley 2000; Hammill et al. 2004

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
17	E High Bay	Arctic-Baffin Prince Inlet, Strait, Sound	Regent Barrow Peel 1996 to 3 (31 July August)	Aerial survey (airplane)	Line (photos of beluga concentration areas)	Higher estimate than 1985 survey, but differences in coverage and survey timing	9,577 (including photographic survey counts)	Corrected for missing data on distance to sightings = 10,347 (CV=0.28); corrected for submerged whales = 18,930 (CV=0.28); addition of estuaries, corrected for inshore availability factor = 21,213	Corrected for perception bias, availability bias, and missing distances (fully-corrected)	Uncorrected CV = 0.28; 95% CI: 10,985 to 32,619 (fully-corrected estimate)	120 sightings (average group size 1.64)	Never surveyed entire range.	summer Innes et al. 2002
18	Cumberland Sound	C. Fiord plus North and West strata	1999	Aerial survey (airplane)	Strip (800 m per side) and photo (C. Fiord)	Increase from 1990	Replicate 1: 720 (C. Fiord), 213 (North stratum); Replicate 2: 777 (C. Fiord), 60 (North stratum)	1: 1704 C. Fiord, 503 N (2,207); 2: 1834 + 142 (1977)	Corrected for availability bias using satellite-tag data.	Replicate 1: No CV for C. Fiord, CV = 0.367 (North) (uncorrected); replicate 2: No CV for C. Fiord, CV = 0.768 (North); corrected CV = 0.077 and 0.371 (replicate 1), 0.77 and 0.770 (replicate 2); ; 95 percentile of bootstrapped estimate: 1,877-2,554; 1,837 - 2,197	n/a	Low overlap in photos did not allow precise identification of duplicate sightings between consecutive frames.	Baratin 2001; DFO 2002a, b; Richard 2013

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
19	Ungava Bay	Whole of Ungava Bay	2001	Aerial survey (airplane)	Line	n/a	No estimate (no whales seen)	n/a	n/a	n/a	None	No whales observed.	Gosselin et al. 2002; Hammill et al. 2004
20	Eastern Hudson Bay	EHB offshore to arc Belcher Islands	2001 (August)	Aerial survey (airplane)	Line (also analyzed using strip-transect methods)	Almost 50% decline since 1985	1155	1,195 (SE = 507) (index estimate with addition of 39 whales observed in estuaries) (but see Gosselin et al. (2013), all six population abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	None (estimate uncorrected for diving and observer errors)	SE = 507	64 (160 whales, mean group size 2.5)	Surface estimate only.	Gosselin et al. 2002; Hammill et al. 2004

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
21	James Bay	Whole of James Bay	2001 (August)	Aerial survey (airplane)	Line (also analyzed using strip-transect methods)	Fourfold increase since 1985	7901	None (but see Gosselin et al. (2013), all six population abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	None (estimate uncorrected for diving and observer errors).	SE = 1,744	306 (557 whales, mean group size 1.82)	Surface estimate only.	Gosselin et al. 2002; Hammill et al. 2004
22	Eastern Hudson Bay	Eastern Hudson Bay arc	2004 (August-Sept.)	Aerial survey (airplane)	Line	44% higher than 2001 estimate, but falls within 95% CI of both 1993 and 2001 surveys	2040	Five belugas in Nastapoka estuary added to estimated number in offshore - index of 2045 (also see Gosselin et al. (2013), all six population abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	No corrections for detection or availability bias, 5 animals from estuary added to systematic estimate	95% CI: 1,047 – 3,977 - 3,982	1 group of 6 detected in northern stratum, 103 clusters with mean of 2.087 (CV = 12.0%) detected in southern stratum (93 clusters with distance in southern Hudson Bay averaged 1.817 (CV = 13.1%)	No corrections for availability or detection biases. Local weather conditions affected order in which lines were surveyed and imposed important delays between adjacent lines. Variation between survey estimates illustrates difficulty of estimating abundance of small clumped populations. Changes in survey protocol (reduction of altitude, delays, different observer teams) might have affected sampling efficiency between years.	Gosselin 2005

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
23	James Bay	James Bay	2004 (August-Sept.)	Aerial survey (airplane)	Line	Decline from 2001 estimate	3993	Five belugas in Moose River added to estimated number of animals at surface in systematic survey to provide abundance index of 3,998 (also see Gosselin et al. (2013), all six population abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	No corrections for detection or availability bias, 5 animals from estuary added to systematic estimate	95% CI: 2,374 - 6,716 (2,379 - 6,721)	251 groups within truncation distances of 100 m to 1400 m, mean cluster size of 2.68 (CV = 16.9%) (196 groups with measured distances, mean cluster size of 2.78 (CV = 19.5%))	No corrections for availability or detection biases. Local weather conditions affected order in which lines were surveyed and imposed important delays between adjacent lines. Variation between survey estimates illustrates difficulty of estimating abundance of small clumped populations. Changes in survey protocol (reduction of altitude, delays, different observer teams) might have affected sampling efficiency between years.	Gosselin 2005

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
24	Western-Northern-Southern Hudson Bay	western and southern Hudson Bay (Thlewiaza estuary near NU border to Cape Henrietta Maria at mouth of James Bay)	2004 (July-August)	Aerial survey (airplane)	Line and photo	Stable (no detectable change since 1987 surveys)	27,200 (Churchill-Seal and Nelson areas)	57300 (Churchill-Seal and Nelson areas)	Corrected for availability bias (correction factor obtained from target experiment and beluga surfacing observations conducted in similarly-silted waters of St. Lawrence).	95% C.L.: 37,700-87,100	73 in Churchill stratum, 613 and 917 Nelson stratum (2 days - averaged estimate), 17 in western transects, 53 in eastern stratum (direct counts in photo surveys)	Recorder malfunction caused loss of data on left side during the first transect, so estimate could only be obtained from the right observer's sighting data, multiplier of two applied to the density calculation because Distance software assumes data input from both sides of a survey track when it calculates estimate from estimated effective strip width. Conservative estimate because additional 7,000 + whales estimated to occur along Ontario coast, but difficult to assign to a single stock due to lack of stock identity information, also possible that some moved out of Nelson stratum into Ontario coast stratum between survey days.	Richard 2005
25	Ungava Bay	Ungava Bay	2008	Aerial survey (airplane)	Line	n/a	No estimate (no whales seen)	n/a	n/a	n/a	None	No whales observed.	Gosselin et al. 2009
26	Eastern Hudson Bay	EHB arc offshore to the Belcher Islands	2008(July-August)	Aerial survey (airplane)	Line	Decline from last estimate.	1,797 and 652 for first and second surveys, weighted average = 1,237; 15 in the Richmond Gulf; 13 in low coverage area. Total surface estimate = 1,265	None (but see Gosselin et al. (2013), all six population abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	None (estimate uncorrected for diving and observer errors).	CV = 0.27 and 0.38 for first and second surveys, CV = 0.46 for weighted average; CV = 1.03 for Richmond Gulf; overall CV for total estimate = 0.45, 95 CI for overall estimate = 545 - 2,939	2.8 times more whales detected on first survey of the high coverage area than on second survey: 107 clusters of average size of 2.97 (CV = 0.13) versus 45 groups with average size of 2.49 (CV = 0.30); only one animal seen in northern part of lower coverage area; one cluster of 3 beluga whales detected on effort in Richmond Gulf.	Abundance indices not corrected for availability of diving animals nor for observer perception.	Gosselin et al. 2009

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
27	James Bay	Whole of James Bay	2008 (July)	Aerial survey (airplane)	Line	Significantly higher estimate than last survey.	9292	None (but see Gosselin et al. (2013), all six abundance estimates corrected for availability bias and beluga counted in estuaries, but not for perception bias)	None (estimate uncorrected for diving and observer errors)	CV = 0.64	214 clusters and 853 individuals (average size of 3.99 (CV = 0.31))	High CV associated with high clumping of whales. Abundance indices not corrected for availability of diving animals nor for observer perception.	Gosselin et al. 2009
28	Cumberland Sound	C. Fiord plus North and West strata	2009	Aerial survey (airplane)	Line (but insufficient sightings for M-R and analyzed using 800 m strip per side) and photo (C. Fiord)	Decrease from 1999, but sampling error a likely factor.	118 Fiord), (North stratum), (West stratum)	(C. 190 279 Fiord), (C. 450 (North), 59 (West) (total 788)	Corrected for availability bias using satellite-tag data.	No CV for C. Fiord, CV = 0.660 (North) and 0.245 (West) (uncorrected); corrected estimate CV = 0.077, 0.662, 0.432 (overall CV = 0.513); 95% of bootstrapped estimate: 279 - 1,600	n/a	Low overlap in photos did not allow precise identification of duplicate sightings between consecutive frames. Sampling error unaccounted for by survey results (comparison of population estimates implies that population changed with rates of increase or total mortality that are unrealistic).	Richard 2013

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
29	Eastern Hudson Bay	EHB arc offshore to the Belcher Islands	2011 (July-August)	Aerial survey (airplane)	Line	Higher than 2008 estimate, lower than 2004 estimate	1433	3351	Corrected for availability bias but not perception bias (single platform), and added 354 individuals counted during coastal survey	surface corrected estimate CV = 47.1%; corrected estimate CV = 48.9%, 95% CI = 1,552 – 7,855	65 groups, 210 beluga whales in high-coverage stratum (63 groups within the truncation distances) (no beluga observed in lower coverage areas)	No corrections for perception bias (single platform). Belugas have clumped distribution and abundance indices for small populations may be strongly influenced by the detection of a small number of large groups, increasing sampling effort could reduce clumping problem, but the second survey planned for the high coverage area could not be completed in 2011. Survey suffered from several logistical problems (mostly a combination of plane maintenance and bad weather) that resulted in numerous interruptions and delays.	Gosselin et al. 2013
30	James Bay	Whole of James Bay	2011 (July-August)	Aerial survey (airplane)	Line	Higher than 2004 estimate, lower than 2008 estimate	7154	14967	Corrected for availability bias but not perception bias (single platform).	surface corrected estimate CV = 27.3%; corrected CV = 30.2%, 95% CI = 8,316 – 26,939	183 clusters, 615 individuals (173 groups within truncation distances)	No corrections for perception bias (single platform).	Gosselin et al. 2013

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
31	Cumberland Sound	C. Fiord plus North and West strata	2014 (August)	Aerial survey (airplane)	Line (but insufficient beluga sightings so analyzed using 500 m strip per side) and photo (C. Fiord)	Estimate higher but not significantly different from 2009 estimate (Bayesian population model suggests stock may be declining)	North stratum replicate 1, 2 = 389, 41 (78 (10 groups), 8 (5 groups) observed); CF photo surveys 1-4 = 285-598 (total # in photos)	North Stratum replicate 1, 2 = 867, 103, weighted average = 548; CF photo surveys, average of four surveys = 603; Sum averaged visual and photo surveys = 1151	Corrected for availability bias but not perception bias	North Stratum replicate 1, 2: CV = 0.48, 0.57, weighted average CV = 0.45, 95% CI = 240–1,256; CF photo surveys, average of four surveys: CV = 0.076, 95% CI = 519–699; Sum averaged visual and photo surveys: CV = 0.214, 95% CI = 761–1744)	North stratum replicate 1, 2 = 78 (10 groups), 8 (5 groups) observed; CF photo surveys 1-4 = uncorrected estimate)	Estimates from the four photo surveys differed - unclear if difference is due to communal behaviour affecting collective availability at surface or movement of animals out of CF. Availability bias corrected using limited data (3 female whales) from outside the survey time. No correction for perception bias, visual survey assumed observers detected all animals from 100 m to 600 m of track line.	Marcoux et al. 2016 (and see Marcoux and Hammill 2016 for model-based estimates)

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
32	Western-Northern-Southern Hudson Bay	Similar to 2004, 5 strata (3 visual, 2 photo) of high use areas around 3 estuaries (Seal, Churchill and Nelson rivers), planned survey further north and east not completed	2015 (August)	Aerial survey (airplane)	Line and photo	Near-surface estimate similar (slightly higher) than 2004 for the five strata surveyed, similar coverage and effort. Application of different availability bias correction factors limits direct comparison of estimates in 2004 and 2015, and comparison of both surveys to the 1987 survey is further complicated by different survey area coverage.	Total = 43,256 (52 to 18,748 in the 5 strata)	Total = 54,473 (64 to 23,248 in the 5 strata)	Corrected for availability bias (using concurrent dive data) but not perception bias	CV = 0.143 for combined uncorrected estimate (0.226 to 0.982 per stratum); CV = 0.098 for combined corrected estimate (0.04 to 0.977 per stratum), 95% CI = 44,988–65,957	443 groups on detected visual surveys, photo surface counts of 1,855 and 16,249 whales (2 strata)	Photo surveys completely covered high density aggregations, but poor weather conditions prevented replicated surveys of all but Churchill River photo stratum. Poor weather conditions also prevented a complete survey of the Churchill High Density strata on any one day, results from two different days combined. Poor weather also caused gaps of several days between surveys of adjacent strata. Killer whales present north of the study area may have influenced beluga movements. Survey originally included a low density stratum extending along coast to James Bay and survey of northern Hudson Bay, but poor weather conditions forced cancellation of these strata. No correction for perception bias as only observations made by the two front (experienced) observers analyzed.	Matthews et al. 2017

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
33	James Bay	James Bay	2015 (July-August)	Aerial survey (airplane)	Line	2015 abundance index is median value of 7 surveys flown since 1985, slight decline from 2011 index but not significant	5,074	10,615	Not corrected for perception bias, corrections applied for availability bias using proportion of time beluga remain visible from an aerial survey platform estimated in the St Lawrence estuary.	95% CI = 3,354-7,676 for uncorrected estimate; CV = 0.25, and 95% CI = 6,559-17,178 for corrected estimate	Total of 324 groups/890 individuals detected while effort - JB and EHB combined. JB - 202 groups, 432 individuals (not all included in ESHW calculations)	Some delays/gaps in survey completion due to weather. Availability bias correction factor used was developed to correct photographic surveys of St Lawrence estuary beluga and assumes instantaneous observation of the whales. However, these surveys are visual surveys flown using fixed wing aircraft and availability correction factor will likely be lower (will not increase the abundance as much) because any given point at the surface of the water remains in the observer field of view for a variable amount of time during a visual survey. No correction for perception bias that would also increase the abundance estimates applied - more detailed information on diving behaviour of belugas is needed. Double platform sampling should be implemented for visual surveys in the future to estimate a correction factor for perception bias.	Gosselin et al. 2017

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
34	Eastern Hudson Bay	Eastern Hudson Bay arc	2015 (August-Sept.)	Aerial survey (airplane)	Line	2015 abundance index similar in both value and CV to 2011 index	1,746	3,819 (including count of 167 belugas in the Little Whale River estuary)	Not corrected for perception bias, corrections applied for availability bias using proportion of time beluga remain visible from an aerial survey platform estimated in the St Lawrence estuary.	95% CI: 760-4,009 for uncorrected estimate; CV = 0.43 and 95% CI = 1,664-8,765 for corrected estimate	Total of 324 groups/890 individuals detected while effort - JB and EHB combined. EHB: 369 belugas detected during first replicate of high coverage area, number counted on second pass of high coverage area was much lower - 89 individuals. Total 122 groups/458 individuals - 0 + (58/43 +18 - 2 replicates) +1 +0	Some delays/gaps in survey completion due to weather. Second survey of high coverage area of EHB provided lower density and abundance estimates than first survey, mainly due to detection of two large groups and some other larger groups on the first pass, as encounter rate on second survey was higher than on first survey. Differences in the two surveys an example of how clumping in beluga distribution may influence estimation of density and abundance. Also see above re: availability bias correction factor.	Gosselin et al. 2017

Table A2. Database of narwhal (*Monodon monoceros*) aerial surveys and associated abundance estimates, by summer stock, in the Canadian Arctic.

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate (by strata if applicable)	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
1	Admiralty Inlet	Admiralty Inlet	1975-76 (July-August) (estimate from 1975)	Aerial survey (helicopter)	Strip transect (400/side)	n/a	9,683	n/a	n/a	SE = 2089	1198 (number of whales, not observations)	Seven systematic surveys flown, no complete coverage in any one survey. Population estimates varied widely = 443 - 9,683 narwhals. High variability in number of narwhal between transects of equal length. No correction factors used, estimates negatively biased.	Fallis et al. 1983
2	Somerset Island	Barrow Strait, Prince Regent Inlet	1981 (July-August) (recon surveys from 1974-1982)	Aerial survey (helicopter)	Strip transect (400/side)	n/a	BS: 335, PRI: 10807 (August surveys)	n/a	n/a	SE = 128 (BS), 937 (PRI); 95% CI = BS: 150-747 (BS), 8,885-13,144 (PRI)	(Not clear from reporting)	Survey precision affected by whale density and amount of clumping. Also surveyed Lancaster Sound, no narwhal in August; July survey found more narwhal in Barrow Strait than in August. Large numbers of narwhals were seen off-transect in Peel Sound. Pop. size range: 0 - 10,807	Smith et al. 1985

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate (by strata if applicable)	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
3	Northern Hudson Bay	Repulse Bay, Frozen Strait, Gore Bay, Lyon Inlet, the northern part of Roes Welcome Sound, and Duke of York Bay	1982-1984 (July) (estimate from 1984, recon in 1981)	Aerial survey (airplane)	Strip (600 m) and photos	n/a	1,355 (most precise estimate)	n/a	n/a	90% CI = 1000-1900; 95% CI = 910-2100; CV = 30, 31%	n/a	No corrections for availability bias and surveys limited to open water or areas with 2/10ths ice or less, estimate negatively biased. Four systematic surveys in total, different stratification in different years. Complete survey coverage, but variable across years. Four July surveys: population estimate ranged between 1,038 and 1,517, varying degree of precision.	Richard 1991b
4	Admiralty Inlet	Admiralty Inlet	1984 (August)	Aerial survey (airplane)	Photo	Lower estimate than previous survey	5,556	n/a	n/a	CV = 22%; 90% CL = 3759-8213	469 (number of whales, not observations	No corrections for submerged animals, photo readers may miss some narwhals that are visible on the film; sources of error will cause an under estimation of true population size.	Richard et al. 1994
5	Somerset Island	Peel Sound, Prince Regent Inlet	1984 (August)	Aerial survey (airplane)	Photo	PRI estimate similar to 1981 study.	PS I - 847, PS II - 854, PRI I - 5,461, PRI II - 4,293. Total: 1701 BS; 9,754 PRI	n/a	n/a	CV: PS I - 26%, PS II - 23%, PRI I - 29%, PRI II - 17%; 90% CI: PS I - 531-1352, PS II - 498-1464, PRI I - 3139-9500, PRI II - 2918-6316	Number of whales seen: PS I - 65, PS II - 68, PRI I - 447, PRI II - 394	No corrections for submerged animals, photo readers may miss some narwhals that are visible on the film; sources of error will cause an under estimation of true population size. Some survey areas (Peel Sound, Prince Regent Inlet) divided into two strata that were flown on different days.	Richard et al. 1994

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate (by strata if applicable)	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
6	Eclipse Sound	Navy Board Inlet, Eclipse Sound, western Pond Inlet	1984 (August)	Aerial survey (airplane)	Photo	n/a	Eclipse I: 0 (no whales seen), Eclipse II: 543, Eclipse III: 675	n/a	n/a	CV: Eclipse I: 0 (no whales seen), Eclipse II: 59%, Eclipse III: n/a (only 1 transect); 90% CI: Eclipse I: no whales seen; Eclipse II: 166-1784; Eclipse III: n/a (only 1 transect)	Number of whale, Eclipse I: 0, Eclipse II: 111, Eclipse III: 102	No corrections for submerged animals, photo readers may miss some narwhals that are visible on the film; sources of error will cause an under estimation of true population size. Eclipse Sound divided into 3 strata, flown over two days. Some indication of movement from stratum II to stratum III during Eclipse Sound survey, could have led to double-counting and biased estimate. However, the small number of narwhals involved would result in little bias. Southern part of Eclipse Sound, Milne Inlet and adjacent bays and fjords (Tremblay Sound, Tay Sound, Paquet Sound, Oliver Sound) were not surveyed.	Richard et al. 1994
7	Admiralty Inlet	Admiralty Inlet	1983-85	Aerial survey (airplane)	Photo	Similar to other 1984 survey (see above)	5,619	n/a	n/a	SE = 0.43; 95% CI: 2,819-11,200	872 counted on photos	Negatively biased - counting bias, no corrections for submerged animals, sightability issues, weather limitations on camera system (best around midday). Only one survey of entire study area, in 1984 - flown at half designed coverage. Population estimate range: 2,256 - 5,619.	Dueck 1989
8	Somerset Island	Prince Regent Inlet, Barrow Strait and Peel Sound (three strata)	1996 (July-August)	Aerial survey (airplane)	Line (double-platform w/ distance sampling)	PS similar to 1984 estimate, PRI similar to other reported estimates, BS estimate much higher than previous survey	No uncorrected (surface) estimates	45,358 total (5,898 in BS; 5240 in PS; 34,159 in PRI)	Missing distances, availability bias (0.38 (CV=0.25)), perception bias	CV = 0.35 (total), 0.75 BS, 0.60 PS, 0.35 PRI; 95% CI: 23397-87932 (total)	143 sightings (9 missing distance), avg. group size 2.08	Precision of corrected abundance estimate affected by high variability of estimate for availability bias; variance estimate most influenced by low precision on availability bias (52%), sighting rate was second largest contributor to the variance (40%), detection probability contributed 8% to variance	Innes et al. 2002
9	Northern Hudson Bay	Same as July 1984 plus northern Lyon Inlet and Foxe Channel	2000	Aerial survey (airplane)	Strip and photo (effective width 600 m/side for visual, 1.34 km for photos)	Similar to 1984 survey	Photo = 1,778; visual = 1,195	n/a	Not corrected	95% CI: 1688-2015 (photo), 1094-6190 (visual)	n/a	Used both visual trip transects and photographs - no significant differences in estimate. Photo coverage much higher, and estimate more precise.	Bourassa 2003

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate (by strata if applicable)	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
10	Admiralty Inlet	Admiralty Inlet	2003-04 (August) (estimate from 2003)	Aerial survey (airplane)	Line (double-platform w/ distance sampling)	Lower than previous surveys	1,857	5,362	Fully corrected for availability and perception bias	SE = 2681; CV = 0.50; 95% CI: 1920-12199	8 sightings with distance (average group size 5.0, 1.8)	Survey influenced by clumping behaviour of animals. Biases reduced by correction, but estimates quite low in precision (i.e., high variance), in large part because of large variations in encounter rate from one transect to the next. Surface estimate in 2004 much lower, corrected estimate not reported.	Richard et al. 2010
11	Somerset Island	Prince Regent Inlet, Gulf of Boothia, Barrow Strait	2002, 2004 (August) (estimates for both years - different areas)	Aerial survey (airplane)	Line (double-platform w/ distance sampling)	PRI: Lower than previous estimates, but significant variability; GB: n/a (first time surveyed); BS: between two previous estimates	PRI 2002: 7,429; GB 2002: 2,407; BS 2004: 963	PRI 2002: 20,871; GB 2002: 6,770 (sum 27,656); BS 2004: 2,925	Fully corrected for availability and perception bias	SE = 14,939 (PRI + GB); CV = 0.71 PRI, 0.30 GB, 0.46 BS; 95% CI: PRI: 4805-59157; GB: 3638-11862; Sum: 9080-66061; BS: 1140-6270	PRI 2002: 94 sightings with distance, average group size 1.8; GB 2002: 10 sightings, 3.0 average group; BS 2004: 11 sightings, 1.4 average group	Surveyed over two years - PRI and GB in 2002, BS in 2004. Peel Sound not surveyed (due to weather).	Richard et al. 2010
12	Eclipse Sound	2 strata in 2002, 4 in 2004 - Navy Board-Milne Inlet, Eclipse Sound, Pond Inlet, Eclipse Sound bays	2002, 2004 (August) (estimate from 2004)	Aerial survey (airplane)	Line (double-platform w/ distance sampling)	Much higher than 1984 estimate (but comparison difficult due to methodological differences)	6,677	20,225	Fully corrected for availability and perception bias	CV = 0.36 (surface); 95% CI: 9471-37096, SE = 7285 (corrected estimate)	144 sightings w/ distance, avg group size 2.6; 55 sightings w/ distance, avg group size 2.1; 13 sightings w/ distance, avg group size 1.8 (< 0.17)	Different survey design (different strata, etc.) in different years. Adjustment for unequal coverage in fiords (fiords were flown along a single transect down the middle). Surface estimate higher in 2002, but less precise (7,578 (1.26) in 2002; 6,677 (0.36) in 2004).	Richard et al. 2010
13	East Baffin Island	East Baffin coast, unable to get as far South as Cumberland Pen.	2003 (August)	Aerial survey (airplane)	Line (double-platform w/ distance sampling)	n/a (first time surveyed)	3,487	10,073	Fully corrected for availability and perception bias	SE = 3,123 (corrected estimate); CV = 0.27 (surface), 0.31 (corrected); 95% CI: 5333-17474 (corrected)	181 sightings with distance, average group size1.5		Richard et al. 2010

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate (by strata if applicable)	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
14	Northern Hudson Bay	Repulse Bay, Frozen Strait, Gore Bay, Lyon Inlet, northern part of Roes Welcome Sound (did not survey Duke of York Bay)	2008	Aerial survey (airplane)	Photo	Much lower than previous surveys, but numerous problems and delays with survey	610 (645 in un-stratified case, but much larger variance)	n/a	Not corrected	CV = 30% for un-stratified estimate (versus 37% and 108% for two-stratum estimates); 95% CI: 377-988	56 whales counted in total	Numerous problems and delays due to camera malfunction, sea ice conditions, and poor weather. Two strata, containing contiguous water bodies, more or less divided by Vansittart Island (but stratification did not improve precision, and final estimate not stratified - better precision). Estimate highly negatively biased.	Richard 2010
15	Admiralty Inlet	Admiralty Inlet	2010	Aerial survey (airplane)	Line (double-platform w/ distance sampling) and photo surveys of large aggregations	Similar to 1980s estimates, higher than 2003 survey (which was negatively biased)	Survey 1 (photos and visual): 7,799; Survey 2 (visual only): 4,704	Survey 1 (photos and visual): 24,398; Survey 2 (visual only): 13,729; average using effort-weighted mean: 18,049	Fully corrected for availability and perception bias for 1 and 2	CV = 0.25 (survey 1), 0.40 (survey 2); 95% CI: 11,613-28,053 (effort-weighted mean)	407 groups in visual surveys: 241 in Survey 1, 166 in Survey 2	Non-random movement of narwhals may have positively biased Survey 1 and negatively biased Survey 2. Bias caused by animal movement cannot be quantified, but abundance estimate for Survey 1 may have been positively biased as most animals were moving in same direction as plane while the opposite situation may have occurred during Survey 2, possibly causing a negative bias. Final abundance estimate calculated by combining the estimates from Survey 1 (Visual and Photo) and Survey 2 (Visual only) using a mean weighted by effort	Asselin and Richard 2011
16	Northern Hudson Bay	Repulse Bay, Frozen Strait, Wager Bay, Roes Welcome Sound, Lyon Inlet, Gore Bay and parts of Foxe Channel and Foxe Basin	2011 (August)	Aerial survey (airplane)	Line (double-platform w/ distance sampling) and photos (directly below aircraft)	Increase (but larger survey area and fully corrected)	4,452	12,485	Fully corrected for availability and perception bias	CV = 0.26; 95% CI: 7515-20743	114 sightings with distance	Total surface estimate calculated by summing the individual estimates from all strata flown from 14 to 17 August. May be slightly negatively biased (some narwhals seen by Inuit further south, outside survey zone).	Asselin et al. 2012

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate (by strata if applicable)	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
17	Somerset Island	Presumed core areas of Prince Regent Inlet, Peel Sound and Gulf of Boothia	2013 (August)	Aerial survey (airplane)	Line (double-platform w/ distance sampling) and spatial modelling in narrow fiords	Increase over previous survey (but uncertain due to large area and variation previous survey variation by strata)	GB stratum = 7,335; PRI stratum = 3,627; PSHI stratum = 5,781; PSLO stratum = 179 (total = 16,921)	49,768	Corrected for both perception and availability bias	CV = 0.20 (uncorrected and corrected estimates)	GB stratum = 81; PRI stratum = 88; PSHI stratum = 165; PSLO stratum = 4 (total = 338 unique sightings)	Proportion of sightings made by both front and rear observers was relatively low, resulting in low detection probability and large precision bias correction, and estimates might have been inflated.	Doniol-Valcroze et al. 2015
18	Admiralty Inlet	Admiralty Inlet	2013 (August)	Aerial survey (airplane)	Line (double-platform w/ distance sampling) and spatial modelling in narrow fiords	Increase over previous survey (similar magnitude as decrease in ES)	AIH stratum = 535; AIL = 11,237 (offshore total = 11,772); AI fiords = 143 (total = 11,915)	35,043	Corrected for both perception and availability bias	CV = 0.42 (uncorrected and corrected estimates)	AIH stratum = 26; AIL = 220 (offshore total = 246); AI fiords = 132 (total = 478 unique sightings)	Proportion of sightings made by both front and rear observers was relatively low, resulting in low detection probability and large precision bias correction, and estimates might have been inflated. Sightings were extremely clustered which increased uncertainty around estimate (CVs) and could introduce bias. Movements between ES and AI stocks add uncertainty.	Doniol-Valcroze et al. 2015
19	Eclipse Sound	Navy Board Inlet, Eclipse Sound, Pond Inlet	2013 (August)	Aerial survey (airplane)	Line (double-platform w/ distance sampling) and spatial modelling in narrow fiords	Decrease over previous survey (similar magnitude as increase in AI)	ESH stratum = 16; ESL stratum = 2,415 (offshore total = 2,431); ES fiords = 1,135 (total = 3,566)	10,489	Corrected for both perception and availability bias	CV = 0.24 (uncorrected and corrected estimates)	ESH stratum = 2; ESL stratum = 68 (offshore total = 70); ES fiords = 673 (total = 743 unique sightings)	Proportion of sightings made by both front and rear observers was relatively low, resulting in low detection probability and large precision bias correction, and estimates might have been inflated. Sightings were extremely clustered which increased uncertainty around estimate (CVs) and could introduce bias. Movements between ES and AI stocks add uncertainty.	Doniol-Valcroze et al. 2015
20	East Baffin Island	East Baffin Island coast including Cumberland Sound	2013 (August)	Aerial survey (airplane)	Line (double-platform w/ distance sampling) and spatial modelling in narrow fiords	Increase over previous survey	EBO stratum = 122; EB fiords = 3,799 (total = 3,921)	17,555	Corrected for both perception and availability bias	CV = 0.63 and 0.35 (uncorrected for offshore and fiords); 0.35 (corrected pooled)	EBO stratum = 3; EB fiords = 773 (total = 776 unique sightings)	Proportion of sightings made by both front and rear observers was relatively low, resulting in low detection probability and large precision bias correction, and estimates might have been inflated.	Doniol-Valcroze et al. 2015

ID	Stock	Survey area	Study year(s) (month(s))	Platform type	Study design	Observed trend	Uncorrected estimate (by strata if applicable)	Corrected estimate	Type of correction	Variance	No. of primary observations	Limitations and biases	Source(s)
21	Jones Sound	Jones Sound, eastern Norwegian Bay	2013 (August) (reconnaissance surveys in 2012)	Aerial survey (airplane)	Line (double-platform w/ distance sampling) and spatial modelling in narrow fiords	n/a (first time surveyed)	JS stratum = 940; NB stratum = 3,331 (offshore total = 4,271); JS fiords = 45 (total = 4,316)	12,694	Corrected for both perception and availability bias	CV = 0.32 (uncorrected estimate); 0.33 (corrected estimate)	JS stratum = 16; NB stratum = 41 (offshore total = 57); JS fiords = 24 (total = 81 unique sightings)	Proportion of sightings made by both front and rear observers was relatively low, resulting in low detection probability and large precision bias correction, and estimates might have been inflated. Relatively large numbers found in Norwegian Bay, only a few narwhals seen in the Jones Sound stratum where most hunting takes place due to proximity to Grise Fiord.	Doniol-Valcroze et al. 2015
22	Smith Sound	Smith Sound (eastern Ellesmere Island coast)	2013 (August) (reconnaissance surveys in 2012)	Aerial survey (airplane)	Line (double-platform w/ distance sampling) and spatial modelling in narrow fiords	n/a (first time surveyed)	SS stratum = 3,647; SS fiords = 1,916 (total = 5,563)	16,360	Corrected for both perception and availability bias	CV = 0.65 (uncorrected and corrected estimates)	SS stratum = 76; SS fiords = 165 (total = 241 unique sightings)	Proportion of sightings made by both front and rear observers was relatively low, resulting in low detection probability and large precision bias correction, and estimates might have been inflated. Area could not be surveyed completely due to unfavorable weather conditions, density estimate based on relatively few lines in northern part of stratum, cannot be extrapolated to entire stratum, should be considered a minimum estimate. Stock may be further sub-divided once more information is available on movements, relationship with other stocks is unclear.	Doniol-Valcroze et al. 2015

References used in aerial survey database

Asselin, N.C. and P.R. Richard. 2011. Results of narwhal (*Monodon monoceros*) aerial surveys in Admiralty Inlet, August 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/065. iv + 26 p.

Asselin, N.C., S.H. Ferguson, P.R. Richard, and D.G. Barber. 2012. Results of narwhal (*Monodon monoceros*) aerial surveys in northern Hudson Bay, August 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/037. iii + 23 p.

Baratin, M. 2001. Tendance rétrospective, taux de croissance et probabilités de croissance de la population de bélugas (*Delphinapterus leucas*) de la baie de Cumberland, terre de Baffin, Nunavut, Canada. MSc thesis. Université du Québec à Rimouski. xv + 130 p.

Bourassa, M.N. 2003. Inventaires de la population de narvals (*Monodon monoceros*) du nord de la Baie d'Hudson et analyse des changements démographiques depuis 1983. Thesis (M.Sc.) Université du Québec, Rimouski, xii + 69 p.

Brodie, P.F. 1971. A reconsideration of aspects of growth, reproduction, and behaviour of the white whale (*Delphinapterus leucas*) with reference to the Cumberland Sound, Baffin Island, population. J. Fish. Res. Board Can. 28: 1309-1318.

Brodie, P.F., J.L. Parsons, and D.E. Sergeant. 1981. Present status of the white whale, *Delphinapterus leucas*, in Cumberland Sound, Baffin Island. Rep. Int. Whal. Comm. No. 31, p. 579-582.

DFO. 2002a. Cumberland Sound Beluga. DFO Science Stock Status Rep. E5-32.

DFO. 2002b. Proceedings of the central and Arctic Regional Advisory Process on Cumberland Sound beluga. DFO Can. Sci. Advis. Sec. Res. Doc. Proc. Ser. 2002/026.

DFO. 2005. Recovery Potential Assessment of Cumberland Sound, Ungava Bay, Eastern Hudson Bay and St. Lawrence beluga populations (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/036.

Doniol-Valcroze, T, J.-F. Gosselin, D. Pike, J. Lawson, N. Asselin, K. Hedges, and S.H. Ferguson. 2015. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/060.v + 36 p.

Dueck, L. 1989. The abundance of narwhal (*Monodon monoceros*) in Admiralty Inlet, Northwest territories, Canada, and implications of behaviour for survey estimates. MSc thesis, University of Manitoba, Winnipeg, MB. 81 pp.

Duval, W.S. 1993. Proceedings of a workshop on Beaufort Sea beluga: February 3-6, 1992. Vancouver, B.C. Env. Studies Res. Found. Rep. No 123. Calgary.

Fallis, B.W., W.E. Klenner, and J.B. Kemper. 1983. Narwhal surveys and associated marine mammal observations in Admiralty Inlet, Navy Board Inlet, and Eclipse Sound, Baffin Island, N.W.T., during 1974-1976. Can. Tech. Rep. Fish. Aquat. Sci. 1211: iv + 20 p.

Gosselin, J.-F. 2005. Abundance indices of belugas in James Bay and eastern Hudson Bay in summer 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/011. 22 pp.

Gosselin, J.-F., V. Lesage, M.O. Hammill, and H. Bourdages. 2002. Abundance indices of belugas in James Bay and eastern Hudson Bay in summer 2001. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/042. 27 pp.

Gosselin, J.-F., V. Lesage, and M. Hammill. 2009. Index estimates of abundance for beluga in eastern Hudson Bay, James Bay and Ungava Bay in summer 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/006. 25 pp.

Gosselin, J.-F., T. Doniol-Valcroze, and M.O. Hammill. 2013. Abundance estimate of beluga in eastern Hudson Bay and James Bay, summer 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/016. vii + 20 p.

Gosselin, J.-F., M.O. Hammill, and A. Mosnier, A. 2017. Indices of abundance for beluga (*Delphinapterus leucas*) in James Bay and eastern Hudson Bay in summer 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/nnn. vi + xx p.

Hammill, M.O., Lesage, V., Gosselin, J.-F., Bourdages, H., De March, B.G.E., and Kingsley, M.C.S. 2004. Evidence for a decline in northern Quebec (Nunavik) belugas. Arctic 57: 183-195.

Harwood, L.A., and P. Norton. 1996. Aerial survey data from the southeast Beaufort Sea, Mackenzie River estuary and west Amunsden Gulf, July 1992. Can. Data Rep. Fish. Aquat. Sci. 965: iv + 25 p.

Harwood, L.A., S. Innes, P. Norton and M.C.S. Kingsley. 1996. Distribution and abundance of beluga whales in the Mackenzie Estuary, southeast Beaufort Sea, and west Amundsen Gulf during late July 1992. Can. J. Fish. Aquat. Sci. 53: 2262-2273.

Innes. S., M.P. Heide-Jørgensen, J.L. Laake, K. Laidre, H. Cleator, and P. Richard. 2002. Surveys of belugas and narwhals in the Canadian High Arctic in 1996. NAMMCO. Sci. Publ. 4: 169-190.

Kingsley, M.C.S. 2000. Numbers and distribution of beluga whales, *Delphinapterus leucas*, in James Bay, eastern Hudson Bay and Ungava Bay in Canada during the summer of 1993. Fish. Bull. 98: 736-747.

Marcoux, M., and M.O. Hammill. 2016. Model estimates of Cumberland Sound beluga (*Delphinapterus leucas*) population size and total allowable removals. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/077.

Marcoux, M., B.G. Young, N.C. Asselin, C.A. Watt, J.B. Dunn, and S.H. Ferguson. 2016. Estimate of Cumberland Sound beluga (*Delphinapterus leucas*) population size from the 2014 visual and photographic aerial survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/037.

Matthews, C.J.D., C.A. Watt, N.C. Asselin, J.B. Dunn, B.G. Young, L.M. Montsion, K.H. Westdal, P.A. Hall, J.R. Orr, S.H. Ferguson, and M. Marcoux. 2017. Estimated abundance of the Western Hudson Bay beluga stock from the 2015 visual and photographic aerial survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/nnn. iv + 22 p.

Norton, P., and L.A. Harwood. 1985. White whale use of the south-eastern Beaufort Sea, July-September 1984. Can. Tech. Rep. Fish. Aquat. Sci. 1401. 46 pp.

Richard, P.R. 1991a. Status of the belugas, *Delphinapterus leucas*, of Southeast Baffin Island. Canadian Field-Naturalist 105: 206-214.

Richard, P. 1991b. Abundance and distribution of narwhals (*Monodon monoceros*) in northern Hudson Bay. Can. J. Fish. Aquat. Sci. 48: 276-283.

Richard, P.R. 2005. An estimate of the Western Hudson Bay beluga population size in 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/017.

Richard, P.R. 2010. Survey index of the Northern Hudson Bay narwhals, August 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/021.

Richard, P.R. 2013. Size and trend of the Cumberland Sound beluga whale population, 1990 to 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/159.

Richard, P.R., and J.R. Orr. 1986. A review of the status and harvest of white whales (*Delphinapterus leucas*) in the Cumberland Sound area, Baffin Island. Can. Tech. Rep. Fish. Aquat. Sci. 1477: 25 p.

Richard, P.R., J. Orr, and D.S. Barber. 1990. The distribution and abundance of belugas, *Delphinapterus leucas*, in eastern Canadian sub-Arctic waters: a revision and update. Can. Bull. Fish. Aquat. Sci. 224: 23-38.

Richard, P., P. Weaver, L. Dueck, and D. Barber. 1994. Distribution and numbers of Canadian High Arctic narwhals (*Monodon monoceros*) in August 1984. Medd. Grønl. Biosci. 39: 41-50.

Richard, P.R., J.L. Laake, R.C. Hobbs, M.P. Heide-Jørgensen, N.C. Asselin, and H. Cleator. 2010. Baffin Bay narwhal population distribution and numbers: Aerial surveys in the Canadian High Arctic, 2002-04. Arctic 63: 85-99.

Sergeant, D.E. 1973. Biology of white whales (*Delphinapterus leucas*) in Western Hudson Bay. J. Fish. Res. Board Can. 30: 1065-1090.

Sergeant, D.E. 1981. On permissible exploitation rates of Monodontidae. Rep. Int. Whal. Comm. 31: 583-588.

Sergeant, D.E. and P.F. Brodie. 1975. Identity, abundance, and present status of populations of white whales, *Delphinapterus leucas*, in North America. J. Fish. Res. Bd. Can. 32(7): 1047-1054.

Smith, T.G., and M.O. Hammill. 1986. Population estimates of the white whale, *Delphinapterus leucas*, in James Bay, eastern Hudson Bay and Ungava Bay. Can. J. Fish. Aquat. Sci. 43: 1982-1987.

Smith, T.G., M.O. Hammill, D.J. Burrage, and G.A. Sleno. 1985. Distribution and abundance of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, in the Canadian High Arctic. Can. J. Fish. Aquat. Sci. 42: 1653-1663.