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Review of Methods for Eastern Canada-West Greenland Bowhead Whale (*Balaena mysticetus*) Population Abundance Estimation

Évaluation des méthodes d'estimation de l'abondance de la population de baleines boréales (*Balaena mysticetus*) de l'est du Canada et de l'ouest du Groenland

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ABSTRACT

Bowhead whales are a key ecosystem species in the Eastern Canadian Arctic. They are slow-growing, late-maturing baleen wales with low reproductive rates and high survival. Little biological information is available on the Eastern Canada-West Greenland population and population size is unknown. Bowhead hunts have recently been initiated in Canada and Greenland. Reductions in sea ice appear to have resulted in increased predation by killer whales. Historic surveys covered only part of the bowhead's range and are negatively biased as a result. Therefore, there is a need for an estimate of population size to properly manage this population. Five survey options were peer reviewed and are summarised as follows: aerial surveys of summer or overwintering areas, mark-recapture estimates from photographic surveys, mark-recapture estimates from genetic sampling, vessel- or shore-based surveys, and acoustic surveys; none are clearly superior. However, only aerial surveys and photographic mark-recapture estimates are considered viable to make a population estimates in the short term. Advantages and disadvantages of each method are summarised.

RÉSUMÉ

La baleine boréale compte parmi les principales espèces présentes dans l'écosystème de l'est de l'Arctique canadien. Il s'agit d'un cétacé à fanons à croissante lente, qui atteint la maturité tardivement, dont le taux de reproduction est faible et le taux de survie est élevé. On dispose de peu de données biologiques sur la population de l'est du Canada et de l'ouest du Groenland, et sa taille est inconnue. On chasse la baleine boréale depuis peu au Canada et au Groenland. En outre, la diminution de la glace de mer semble avoir donné lieu à l'accroissement de la prédation par les épaulards. Comme les relevés historiques ne portaient que sur une partie de l'aire de répartition de la baleine boréale, ils donnent lieu à une sous-estimation. Par conséquent, il est nécessaire d'estimer la taille de la population pour être en mesure de la gérer adéquatement. Cinq méthodes ont été évaluées par des pairs et résumées comme suit : relevés aériens des aires d'estivage ou d'hivernage, estimations par marquage et recapture à partir de relevés photographiques, estimations par marquage et recapture à partir d'échantillons génétiques, relevés en mer ou à terre, et relevés acoustiques; aucune méthode n'est vraiment meilleure qu'une autre. Cependant, seuls les relevés aériens et les estimations par marquage et recapture à partir de relevés photographiques sont considérés comme des méthodes valables pour estimer la population à court terme. Les avantages et les désavantages de chacune des méthodes sont résumés.

INTRODUCTION

Eastern Canada-West Greenland (EC-WG) bowhead whales are a key species managed by the Fisheries and Oceans Canada (DFO) Central and Arctic Region. The EC-WG bowhead population is shared with Greenland and is an important subsistence fishery in both countries.

Regional Fisheries Management and Science Arctic Aquatic Research Division are developing a multi-year plan to address management and stock assessment needs for this fishery but there are significant outstanding information needs from Science to develop this plan. These deficiencies include (a) an estimate of the current abundance of the population (b) a minimum population size to determine Potential Biological Removal thresholds and Total Allowable Harvest recommendations, (c) information on reproductive rates for this stock, (d) information on natural mortality and harvest rates, and (e) information on the effects of changes of sea ice concentration on production of bowhead prey species.

Science has been asked to determine the most appropriate method and resulting survey design to assess the EC-WG bowhead population abundance in order to meet the data deficiencies. Methods used for long-term studies may differ from those that may be selected in the short term. This assessment reviews potential methods and identifies the risks and benefits of those methods for obtaining a population estimate and evaluates them for use both as short-term and long-term data collection methods.

Bowhead whales are slow growing, late maturing baleen whales with high survival rates. Their only natural predator is the killer whale, which until recently, was rare within their range. Recent observations suggest that killer whale predation may be the major source of mortality for the EC-WG bowhead whale population. EC-WG bowheads are harvested in low numbers in Canadian and Greenland waters; therefore, there are few biological specimens to provide data on this population. Good biological data are available for the Bering-Chukchi-Beaufort (B-C-B) population which can be used for preliminary stock assessments. The main short-term data requirement for a stock assessment of EC-WG bowheads is an estimate of the size of the population and several methods could be used.

Aerial surveys conducted prior to 2002 generally covered only part of the range of the EC-WG population, and therefore, provided only partial estimates of the size of the population. A survey of the wintering range in 1981 provided a reasonably complete estimate of the population size in 1981, but the population has increased substantially over the last 30 years although the rate of increase is unknown. Recent estimates of numbers of whales off West Greenland in spring and in the Canadian Arctic in summer have included only parts of the population, so current estimates of the size of this population are negatively biased. As a consequence, a method for obtaining an unbiased estimate for the EC-WG bowhead whale population needs to be identified to obtain population estimates needed for management. The potential methods include aerial surveys, boat and shore-based surveys, photographic mark-recapture surveys, genetic mark-recapture surveys, and acoustic surveys. The advantages and disadvantages of each method are discussed in this report and were discussed at a workshop held at the DFO's Freshwater Institute in Winnipeg. This report incorporates discussions during that workshop.

SPECIES BIOLOGY

Very little biological information has been collected for the EC-WG bowhead whale population because until recently it was considered too small to support a significant harvest. Biological parameters from the Bering-Chukchi-Beaufort (B-C-B) population, which has been studied in much more detail, are the best available data for bowhead whales, but there is uncertainty whether biological parameters for the B-C-B population are the same as those of the EC–WG population. Regardless of whether they are the same, data from the B-C-B population are the best available data for bowhead whales.

Bowheads are slow-growing (Koski et al. 1992), late maturing whales that have high survival (Zeh et al. 2002) and may live to be more than 150 years old (George et al. 1999; George and Bockstoce 2008). They become sexually mature in their late teens to late twenties (Koski et al. 1992; George et al. 2004a) and females have calves at 3-4 year intervals (Miller et al. 1992; Rugh et al. 1992; George et al. 2004a). Allowing for natural mortality, the maximum possible rate of increase in the B-C-B population appears to have been 3.9% from 1978 to 2001, but they have been harvested at a rate of 0.5%, leaving a net rate of increase of 3.4% (George et al. 2004b; Zeh and Punt 2005).

HARVESTS

Bowhead whales were not harvested in Greenland prior to 2008 although there is a record of a kill associated with entanglement in gear used for hunting beluga whales (Kapel 1985). Permitted harvests resumed in Canada in 1998 when DFO issued one permit every other year. The number of permits was increased to four per year in 2008 when available data indicated that the population could sustain higher harvest rates.

Greenland

Harvests in Greenland are regulated under a harvest quota issued by the International Whaling Commission Aboriginal Whaling Management Plan (IWC-AWMP). Greenland has an interim quota of two whales per year covering the period 2008-1012, with an allowance for a carry forward of up to two whales per year if a the quota is not taken in any year (IWC 2009). Greenland harvested three bowheads in 2010.

Canada

DFO regulates the harvest of bowhead whales in Canada and has allocated a harvest of up to 4 whales per year. In 2008, three whales were landed and one additional whale was struck and lost; in 2009, four whales were landed; and in 2010, 2 whales were landed and two were struck and lost. A list of whales landed in the Eastern Canadian Arctic from 1996 to 2010 is given in Table 1.

OTHER SOURCES OF HUMAN-INDUCED MORTALITY

There are few other sources of human-related mortality for bowhead whales, at least partly because the whales prefer heavy ice-covered waters which are generally not accessible to human activities (Ferguson et al. 2010). There is one record of a bowhead whale being caught in a beluga trap net off Greenland in 1980 (Kapel 1985) and bowheads harvested from the B-C-B stock (George et al. 1994) and photographs of B-C-B bowhead whales (Koski, personal observation) occasionally have scars that are consistent with entanglement with ropes and collisions with ships.

NATURAL MORTALITY

Killer whales are the only natural predator of bowhead whales and until recently were rarely seen in areas inhabited by bowheads. However, with recent declines in sea ice extent, killer whale sightings have become more common in Foxe Basin and Western Hudson Bay (Higdon and Ferguson 2009; Ferguson et al. 2010). In recent years, an average of five bowhead whale carcasses per year that appear to have been killed by killer whales have been reported by people in the Eastern Canadian Arctic (Ferguson et al. 2010). It is likely that many additional bowheads were killed by killer whales because not all carcasses are likely to be discovered. Thus killer whale kills may be a significant source of mortality for the EC-WG bowhead whale population.

HISTORICAL SURVEYS

Early surveys in Canada

Summering areas

Bowhead whale sightings reported in the early literature were generally collected incidental to aerial surveys of other marine mammal species in the Canadian High Arctic such as belugas and narwhals and covered only a small fraction of the bowhead whale summering range (see Figure 1). Earlier beliefs that there were two non-overlapping stocks, one in Baffin Bay and Lancaster Sound, and another in Hudson Bay and Foxe Basin, also lead to inaccurate perception of the movement patterns. These early surveys provided only guestimates of the size of the bowhead whale population. In 1978 and 1979, a combination of aerial surveys and shore-based observations at Cape Adair, NE Baffin Island, were used to make an estimate of the number of bowhead whales migrating south along eastern Baffin Island in the fall (Koski and Davis 1980). Those surveys plus a mark-recapture estimate of the number of “marked” bowhead whales summering in Isabella Bay from photographic mark-recapture surveys in 1986 and 1987 provided a negatively biased estimate of ~350 bowheads in the putative Baffin Bay-Davis Strait (BB–DS) stock (Zeh et al. 1993). This estimate did not allow for whales that migrated southward past Cape Adair beyond view or after the coastal watches ended and later satellite telemetry data confirms that some whales do migrate south later than the 1978 and 1979 surveys were conducted. The estimate of ~214 marked bowheads from the photographic surveys does not include unmarked whales or whales that may summer farther south than the Isabella Bay area.

Wintering areas

Surveys were conducted of almost all potential wintering areas of the EC-WG bowhead whale stock except for the North Water Polynya during the late winter – early spring of 1981. The results of these surveys are reported in McLaren and Davis (1981) and Koski et al. (2006a). In total, about 27,500 km (~110 h) of aerial surveys were flown and the majority of bowhead sightings were in Hudson Strait where 6,837 km were flown. Twenty-nine of 37 bowhead whales (9 on transect groups and 7 off transect groups) were seen in Hudson Strait (Figure 2). Koski et al. (2006a) corrected their sightings data for perception and availability biases and obtained an estimate of 1,349 (95% CI 402-4,529) bowhead whales in Hudson Strait in late March of 1981. In addition to Hudson Strait, they estimated that 200 bowheads were present off West Greenland in late winter 1981 by applying the same correction factors to the estimate of 36 whales in Reeves and Heide-Jørgensen (1996). Adding 8% to 1,539 to allow for whales seen outside of the two main wintering areas during these surveys gives an estimate of 1,684 in 1981. Some additional whales may have been present in the North Water Polynya, but none were seen there by Finley and Renaud (1980) during aerial surveys in March and April 1978 and March 1979. However, during March 1993, Richard et al. (1998) sighted two single bowhead whales indicating that the North Water Polynya is used by wintering bowhead whales in some years.

Recent Surveys in Canada

The most recent aerial surveys of the EC-WG bowhead whale population were conducted in 2002, 2003 and 2004. At that time, it was still believed that bowheads in Hudson Bay, Foxe Basin and the southern Gulf of Boothia were a separate stock (HB-FB stock) from those that occurred in waters adjacent to Lancaster Sound and in Baffin Bay and Davis Straight. As a consequence, surveys were designed to attempt to cover the HB-FB range in 2003 and different parts of the BB-DS range in 2002 and 2003, with 2004 surveys repeating some of the areas surveyed the first two years. Weather, inadequate funding, and the irregular topography that confounded establishing systematic survey routes prevented coverage of all of the suspected summer range and complicated analyses of the data. An initial analysis of the data by Cosens et al. (2006) produced an estimate of 7,309 whales based on the 2002 surveys. Attempts to account for whales missed by observers using data from independent observations by two observers on the same side of the aircraft by Dueck et al. (2008) were rejected by an international panel of scientists (IWC 2009) because the viewing area of the independent observes appeared to be different and the number of common sightings was small. That panel re-analysed the data and agreed upon an estimate of 6,344 (95% CI 3,119–12,906) based on only the 2002 surveys (Figure 3) and recognised that this estimate was probably negatively biased since it included only part of the known range.

A general conclusion is that future attempts to survey the EC-WG bowhead whale population while in the summering areas needs to be conducted in one year, requires several aircraft and survey crews conducting the surveys simultaneously, and needs to cover more of the range than the 2002–2004 surveys. The 2002–2004 surveys covered the main known summering areas but did not include Cumberland Sound, offshore Foxe Basin and Hudson Bay, Hudson Strait or Lancaster Sound and adjacent areas such as Barrow Strait and Peel Sound.

Recent Surveys in Greenland

Aerial surveys have been conducted off West Greenland between 65º 30’ and 73º 50’ N in spring to monitor beluga or white whale populations since 1981. The most recent survey in 2006 estimated that 1,229 (95% CI 495 – 2,939) bowhead whales were present there in March and April (Heide-Jørgensen et al. 2007). The majority of the whales sighted were in the vicinity of Disko Bay (Figure 4).

In addition to the aerial survey estimates for West Greenland, genetic samples of whales collected from 2000 to 2010 were analysed to make a mark-recapture estimate of the number of whales occurring off West Greenland during spring (Wiig et al. 2011). The genetic mark-recapture estimate was 999 (95% CI 546 – 1452) female and 1410 (95% CI 628-2038) total whales. Other studies off West Greenland suggest that the whales seen there are mostly adult females (Heide-Jørgensen et al. 2010) and so the estimate of 999 may represent an estimate of the adult female population when the sampling period extends over a long period such as was done by Wiig et al. (2011).

POTENTIAL ASSESSMENT METHODS

AERIAL SURVEYS

Aerial surveys have been widely used to estimate the population size of many cetacean species and therefore are a readily accepted method for making population estimates. Two potential approaches could be used if aerial surveys were the selected method for determining population size for the EC-WG bowhead: surveys of the summering areas and surveys of the main wintering areas.

Summer Areas

Surveys of the summering areas have been attempted several times in the past but only the most recent survey covered the majority of the known summering areas. While reliable estimates have been obtained for specific geographic regions, to date no survey has been successful at surveying all of the summering areas in one season such that an overall population estimate could be obtained for the EC-WG bowhead whale population.

Estimated Cost of Survey

The approximate cost of conducting an aerial survey of the main summering areas using three aircraft (~150 flight hours) with a pilot, co-pilot, and five observers on each aircraft (to allow for double-observer analyses to correct for sightings missed by the primary observer), would be ~$650,000, including all three aircraft and if all personnel and accommodation costs are included. The workshop held at the Freshwater Institute 28-29 September noted that information on the availability bias collected for different components of the population was needed for the survey period and recommended that 20-30 satellite tags should be applied to whales before the survey to collect information on diving behaviour and distribution during the survey. This would increase the cost of the aerial survey to ~$900,000, if 30 satellite tags are deployed. If the weather is good, the survey could be completed in 10 to 12 days. If bad weather is encountered and increases the time required to complete the survey to more than 12 days, the cost of the survey would increase by about $50,000 per day, or about $17,000 per day for each of the three aircraft and crew.

Advantages

Aerial surveys have been used to estimate stock sizes of many other species of large cetaceans and so the methods are well established.

An estimate can be made from a survey conducted in one field season.

Whales do not respond to the survey aircraft whereas they do respond to vessel-based surveys.

A large area can be covered in a relatively short period of time if several aircraft and survey crews are available and weather is good.

A population estimate can be obtained within 6-12 months of conducting the survey, which is faster than other methods.

Some information can be obtained on sizes of whales but too few whales are seen during an aerial survey to obtain reliable estimates of calving rates.

Disadvantages

The biggest challenge to conducting aerial surveys for the EC-WG bowhead whale stock during the summer is the extremely large geographic area that would need to be surveyed in a short period of time.

Secondly, a large number of experienced surveyors and three aircraft are needed to survey the entire summer range in a short period of time. Sufficient numbers of surveyors may not be available.

Bowhead whales are difficult to see despite their large size because they are dark and provide low contrast against the water. As a result, perception bias is large and the CV of the perception bias is large and results in a large CV around the population estimate.

Correction factors for availability bias specific to the survey period and to the different segments of the population (i.e., for immature whales, adult whales, and mothers with calves) are needed and are best obtained from satellite tagged whales that are in the survey area at the time of the survey.

The CV of the population estimate is high because whales are not seen on most transects and a few transects have the majority of the sightings.

Aerial surveys do not provide quantitative information on body condition, reproductive rates or stock structure which are important for signaling changes in health of individuals and in population health and size. Some information on sizes of whales can be obtained but it is highly dependent on the experience of the observers and calf count data tend to be negatively biased unless each sighting is circled by the survey aircraft. In addition, too few animals are seen during aerial surveys to provide useful information on size structure or percent calves in the population.

The cost of completing the survey could increase substantially if poor weather is encountered. In the worst case scenario, the survey would not be completed and only a partial estimate would be obtained.

Winter Areas

The winter distribution of the EC-WG bowhead whale is restricted compared to the distribution at other times of the year (Koski et al. 2006a; Heide-Jørgensen et al. 2006). If the surveys were restricted to core wintering areas in Hudson Strait and the Disko Bay region off West Greenland, surveys could be conducted in a short period of time using only two aircraft and two survey crews. This would minimize the possibility of whales moving between survey areas during the survey, minimizing double counting or missing whales moving between survey areas. Additional surveys of the North Water Polynya and other suitable habitat would contribute little to the overall estimate and so could be conducted as budgets, aircraft and weather permitted. There are three main concerns related to surveys of wintering areas. First, changes in the winter distribution may have occurred with increases in population size since 1981, and data from satellite-tagged whales in late February to mid-March are too few to evaluate the extent of such changes. Second, the window for conducting surveys is short and weather could prevent surveys from being completed before the spring migration starts. Third, correction factors prepared from satellite tagging data are not available for the winter period but are available for the summer period.

Estimated Cost of Survey

The cost of conducting a survey of the main wintering areas in Hudson Strait and off West Greenland is ~$260,000 using two aircraft (60 flight hours) with a pilot, co-pilot and five observers. If bad weather extended the survey by more than two days, the cost would increase by ~$17,000/day for each aircraft. As noted for surveys of summering areas, season-specific and site-specific data on diving behaviour to calculate availability bias and to document whale distribution are needed. This requires spending an additional ~$240,000 (or more since satellite tags may not last until mid-March) to apply satellite tags to whales. This increases the cost of surveys of the wintering areas to ~$500,000.

Advantages
As, noted above for surveys of the summering areas, aerial surveys have been widely used for estimating abundance of other large cetaceans so the methods are well established.

The wintering areas in Hudson Strait could be surveyed in a relatively short period of time because the bowhead distribution is restricted compared to other times of year when they are dispersed over a broad geographic area.

The population estimate from a winter survey would be obtained during a single field season and analyses could be completed 6-12 months after the survey is completed.

Two survey crews could conduct the survey in a relatively short period of time.

Unless poor weather delayed the surveys for an extended period of time, the cost of conducting an aerial survey of the main wintering areas is cheaper than surveys of summering areas or photographic mark-recapture studies.

Disadvantages
The major weakness with a survey of the wintering areas in Hudson Strait is that it is unknown whether the winter distribution of EC-WG bowhead whales has changed between 1981 and the present. The population appears to have increased and when populations are increasing their range may expand.

The period of daylight is too short to conduct the survey before late February to early March and whales start to move toward summering areas about mid-March, so the window to conduct a survey of the wintering areas is small. As a result, surveys could easily be compromised by a period of unfavourable weather.

Information on diving behaviour is needed to estimate availability bias and few historic data are available for the late February to mid-March period because most tags deployed during earlier studies have stopped transmitting before mid-March. Although some of the currently-used tags have lasted until late spring, few of those deployed are likely to provide the data needed for a late winter survey.

BOAT AND ICE- OR SHORE-BASED VISUAL SURVEYS

Vessel-based surveys for bowhead whales are extremely difficult to conduct because some bowheads avoid vessels at ranges farther than they can be seen from the vessel. Those that remain in the area sometimes modify their behaviour by diving for longer periods of time, thus making them more difficult to see. Thus, vessel-based surveys are likely to seriously underestimate the numbers of bowheads in the survey area.

Ice-based surveys have been used since the early 1970s to estimate the size of the B-C-B bowhead whale population. That population passes by a single point near Barrow, Alaska each spring where they can be seen by ice-based observers if the observing conditions are good. Acoustic monitoring is used to account for the proportion of the migration passing farther offshore than observers can see and to estimate passage rates during periods when observations are not possible due to ice or weather restrictions. This method has been the preferred method to estimate the B-C-B population size because a large fraction of the population is actually counted during the survey and the 95% confidence intervals of the population have generally been tighter than capture-recapture methods using aerial photography. It is worth noting that deteriorating sea ice conditions have reduced the success of ice based observations in recent years and both ice-based and photography surveys are currently being conducted.

Satellite telemetry studies of the EC-WG bowhead whale population show that there are no suitable census locations where the majority of the population passes one location where shore-based surveys could be used to make a reliable population estimate. Bowheads move to widely dispersed summering areas by two or more routes and travel from summering areas to wintering areas includes offshore routes that cannot be observed from land. Partial counts could be obtained by establishing watches at Cape Adair, NE Baffin Island and Fury and Hecla Strait, SW Baffin Island, but the proportion passing each location would vary from year to year and would not include whales that remain in Foxe Basin, Cumberland Sound and along SE Baffin Island. Thus neither boat-based nor shore-based surveys are likely to be useful as a census method for the EC-WG bowhead stock, and this was agreed by participants at the workshop.

Estimated Cost of Survey

The cost of the vessel-based and coastal surveys has not been estimated because they are not considered a viable alternative.

Advantages

There would be local participation in the shore-based observation watches and boat-based surveys which would incorporate local and traditional knowledge.

Disadvantages

Bowhead whales avoid vessels and so vessel surveys are likely to provide seriously negatively biased estimates of population size.

There is no single coastal location where the majority of the population passes so counts would be incomplete.

It is extremely difficult to conduct shore-based watches late in the season during the latter part of the bowhead migration because of fog, darkness and the cold.

PHOTOGRAPHIC MARK-RECAPTURE ESTIMATES

Mark-recapture estimates based on photographic re-identification of individual marked whales have been used to estimate the population sizes for several stocks of whales including bowheads (Rugh 1990; Zeh et al. 1993; da Silva et al. 2000; Schweder 2003; Schweder et al. 2010; Koski et al. 2010), right whales (Best et al. 2001; Cooke et al. 2001; Carroll et al. 2011), gray whales (Bradford et al. 2008) and humpback whales (Stevick et al 2003). Photographic mark-recapture estimates have been used for several populations with large ranges which would make aerial surveys difficult or impossible to conduct.

Estimated Cost of Survey

The cost of a photographic survey depends on the number of photographs that needs to be obtained to conduct the mark-recapture estimate. The number of photographs required depends on the size of the population and the proportion of the whales that are marked. The population size in 2002 was estimated at 6,344 as accepted by IWC (2009) but was acknowledged to be negatively biased. If we assume that the population size was ~10,000 in 2003, it would be 13,500 in 2012, assuming a rate of increase of 3.4% per year (the B-C-B rate of increase). A minimum of 150 different marked whales would need to be photographed in each year to obtain ~6 recaptures, which is the minimum number of recaptures to give a reliable estimate. Based on the B-C-B mark rate of ~0.30, about 500 photographs of different whales (750 photographs based on past photographic surveys) would have to be taken. This would require about 25 days of field work (plus travel) and 100 hours of aerial photography to collect the photographs. The cost of a two-year photographic survey including analysis of photographs and the mark-recapture analysis would be ~$850,000 (without indexing for inflation) and including costs for all personnel time.

Advantages

Information on stock structure (length-frequency distribution), which is useful in the stock assessment, can be obtained from the aerial photographs.

Body condition indices from the photographs can be used to monitor the health of whales over time.

Life history information such as growth rates, survival and calving intervals can be obtained when photography is conducted over longer periods of time. These are all useful for assessing the health of the stock.

Once a photographic database is established and a few surveys are conducted, more complex models such as those by Schweder et al. (2010) can be used that require less photographic effort and that can provide considerable life history information and the rate of increase (or decrease) of the population.

A computer matching program has been developed for use on the B-C-B population that will facilitate between-year matching.

Methods and models have been developed for data analysis of the B-C-B photographs which could be used on the EC–WG photographs.

Movements between the B-C-B and EC-WG stocks could be documented with photographic surveys.

Photographs from several years can be combined to increase the precision of an estimate. If unfavourable weather causes premature stoppage of a survey, the photographs can still contribute to an unbiased population estimate; whereas, an incomplete aerial survey provides an estimate of only part of the population.

A single crew of observers and photographers operating over a 25-day window will have less risk of not flying the minimums than multiple crews of aerial surveyors flying over a 10-day period. Thus there is a higher probability of success for the photographic survey than the aerial survey.

Photographic surveys can be conducted when cloud ceilings are below 305 m and so are more likely to be successful than aerial surveys.

The separate spring and summer sampling events during two seasons (four total sampling events) lessens the need to representatively sample throughout the summer range because of the potential for mixing between sampling events, whereas, aerial surveys require representative sampling throughout the range during the single sampling event.

Photographs are more easily obtained than genetic samples, particularly in ice-covered waters. As a result, the sample sizes will be higher and fewer years of photographs are required to obtain the same precision in the population estimate.

A smaller crew is required to conduct photographic surveys than aerial surveys.

A less expensive survey platform (UAS or smaller fixed winged aircraft) could be used rather than a Twin Otter, reducing the aircraft costs.

Data from boat-based photographic surveys can be integrated into the estimate, although the number of usable photographs from boat-based studies is likely to be small.

The photographic mark-recapture study is less expensive than surveys of summering areas that include applying satellite tags to 30 bowheads at the ice edge in Foxe Basin during the spring.

The confidence intervals associated with a photographic mark-recapture estimate are likely to be smaller than for an aerial survey estimate, even if the survey is successful. However, the CV for the mark-recapture estimate depends on the number of recaptures, and therefore, the CV will depend on the actual population size which is not known at this point. With the mark-recapture methods, the CV can be improved by adding an additional season of sampling.

Disadvantages

A population estimate is not available until one-to-two years, or longer depending on funding, after the photographic survey because analysis of photographs takes time. Thus, a population estimate is slower to obtain than for aerial surveys where results can be available sooner. The time required for analyses of photographic surveys is similar to that of genetic studies.

Although a photographic survey could be completed in one season, it is recommended that it extend over two seasons, with each season having two sampling periods, to maximize mixing within and between years.

Poor weather can result in few photographs being obtained during the period that the aircraft is chartered; however, photographs can be obtained during lower cloud cover conditions than aerial surveys are conducted.

The crews to obtain photographs and to conduct the matching require considerable training.

The initial cost of a two-year photographic survey would be higher than a one-year aerial survey of the primary wintering areas and higher than the genetic mark-recapture estimate if the genetic samples can be obtained from the remote locations along SE Baffin Island, Prince Regent Inlet, Arctic Bay and Pond Inlet. It would be lower than a single season aerial survey of summering areas that included application of 30 satellite tags on whales.

GENETIC MARK-RECAPTURE ESTIMATES

Genetic mark-recapture methods have the potential to produce unbiased population estimates if samples can be obtained from several representative locations over a several year period. Satellite tagging studies show that whales move between different summering areas within and probably between years. However, bowhead whales do segregate while in their summering areas (see Koski et al. 1988; Finley 1990; Cosens and Blouw 2003) so it is important to obtain samples before the whales segregate and/or to get samples from each of the main summering areas to ensure that each segment of the population is represented adequately in the samples.

If genetic mark-recapture analyses were to be used to estimate the population size of the EC-WG bowhead population, additional genetic sampling locations should be incorporated. These include E Baffin Island (Isabella Bay), Prince Regent Inlet (Creswell Bay – Bellot Strait), Admiralty Inlet and Pond Inlet. The current sampling locations appear to poorly sample the adult male segment of the population. The workshop held at the Freshwater Institute 28-29 September recommended that a summary be made of the existing genetic samples to evaluate whether they could be used to make an unbiased estimate of the size of the EC-WG bowhead population.

<u>Estimated Costs of Survey</u>

As noted above in the photographic mark-recapture section, samples of about 150 different whales should be obtained in each of the mark and recapture samples to get a reliable population estimate. Allowing for duplicate sampling and some samples not being usable, about 240 samples should be obtained for the recapture sample. One season of genetic sampling where 240 samples are obtained and analyzed would cost ~$200,000. This sampling for the “recapture” dataset could be spread over 2-3 years.

Although some of the earlier samples can provide some of the data for the marked sample, additional samples should be obtained from areas that have not yet been sampled. Thus, 2-3 years of sampling in unsampled areas is needed prior to collecting the recapture samples and this additional sampling and analysis will cost an additional ~$75,000.

<u>Advantages</u>

Genetic markers provide a high probability of accurately classifying each sample as a new whale or a recapture.

Repeated analyses of the same sample provides accurate information on error rates.

Bowhead whale mortality rates appear to be very low (~1%) and so data from several years can be combined to increase the precision of the population estimate. Precision of the population estimate increases with increases in numbers of recaptures in the analysis.

Collection of genetic samples provides community involvement through the collection of samples and incorporates local and traditional knowledge.

If the required samples can be obtained from the remote locations, the cost of the genetic mark-recapture method is lower than the aerial surveys of the summering and wintering areas or the photographic mark-recapture approach.

<u>Disadvantages</u>

Many of the locations where genetic sampling should take place are remote and it is difficult or impossible to obtain genetic samples from these locations. If samples are not obtained from these areas, the population estimate may be negatively biased.

It is more difficult to obtain genetic samples than photographs and so it will take more years of sampling to obtain a population estimate.

Analysis time is longer than for aerial surveys but similar to photographic surveys.

If samples are obtained over long periods of time, mortality needs to be accounted for because whales in the sample may have died between sampling occasions.

ACOUSTIC SURVEYS

A variety of acoustic methods have been used to detect marine mammals. Acoustic recorders deployed on or near the ocean floor or from buoys have been used to document the presence or absence of marine mammals over extended periods of time. Hydrophone arrays suspended through holes in ice have been used to estimate the proportion of bowhead whales that migrate beyond view of observers or during periods of poor visibility during ice-based surveys conducted near Barrow, Alaska, in spring (Zeh et al. 1993; George et al. 2004b). Directional and omnidirectional hydrophone arrays have been used to assess changes in whale distribution around industrial activities (Blackwell et al. 2007). These acoustic methods provide relative data, but do not provide a method of assessing the number of individuals present unless concurrent visual observations are made to provide a basis for converting call rates to numbers of whales passing. Call rates vary widely from day to day and depend on the activity of the whales. An additional complication is that bowheads may stop calling when subjected to disturbance such as sounds from industry activities or hunting. Thus acoustic surveys, on their own, are not a useful census tool. If visual shore- or ice-based observations are conducted, acoustic monitoring is a useful supplement to expand visual counts to areas and times that cannot be monitored visually.

Similarly, towed passive acoustic monitoring (PAM) has been used during visual vessel-based surveys to detect animals missed by observers. However, current towed PAM arrays, although they work well for mid- and high-frequency calls or clicks made by dolphins and sperm whales, do not work well for low-frequency calls of species like bowhead whales.

<u>Estimated Cost of Survey</u>

The cost of acoustic surveys is not estimated because they are not considered a viable alternative at this time.

<u>Advantages</u>

Acoustic surveys can be conducted during all weather and light conditions, unlike visual surveys.

They can provide evidence of presence or absence over long periods of time at modest cost.

<u>Disadvantages</u>

There is no reliable method of converting call detections to numbers of animals without concurrent visual observations.

Call rates vary from day to day depending on the activity of the animals and changes in call rates do not necessarily reflect changes in numbers of animals present.

Detection rates depend on background noise levels and so are not directly comparable from one day to the next.

Towed PAM systems do not work well for bowhead whales.

CONCLUSIONS

None of the methods for estimating the size of the EC-WG bowhead whale population discussed here has a clear advantage over the other methods. The method that is selected will need to consider the time period that is available to obtain the estimate, the available funding and time over which funding can be committed, and the both the short-term and long-term data needs for monitoring the population size and trends.

The potentially lowest cost approach of genetic mark-recapture surveys requires many years of data collection before an estimate can be obtained and so is unlikely to meet short-term data needs. It was suggested at the workshop that an inventory of genetic samples should be assembled so that it can be determined whether sufficient samples exist from summering areas to make a mark-recapture estimate similar to the one made by Wiig et al. (2011) for whales that occur off West Greenland during winter and spring. The genetic mark-recapture approach has the advantage that data collected over several years can be combined, so that if sampling is compromised in any given year, it still contributes to the overall population estimate. However, some important areas occupied by whales are remote and it will be very difficult to obtain adequate genetic samples from those areas without greatly increasing the cost of sampling.

Surveys of the primary wintering areas have a high risk of failure due to a short window to conduct the survey and potential failure of satellite tags to obtain dive and position data in late winter because tags do not generally continue to broadcast that late in the season. The dive and position data are needed to estimate availability bias and confirm the winter distribution of whales, which is not available from recent surveys or from many recent satellite tags. A failure to complete the aerial survey will result in a partial estimate, which may seriously underestimate the size of the population, but the estimate may still provide a higher estimate of minimum population size than a less precise estimate of all of the range.

Two methods were considered most likely to be able to provide the short-term and long-term data needs for stock assessments for the EC-WG bowhead whale population. They are aerial surveys of the summering areas and photographic mark-recapture studies.

Surveys of the summering areas are the most expensive method when the cost of satellite tagging to obtain concurrent availability bias and distribution data are included. They have been attempted before and were not successful at covering the entire summer range, but the method is widely used for other species and would provide a reliable estimate in a short period of time, if it were successful. An incomplete survey of summering areas provides only a partial estimate and data collected cannot be used to supplement future surveys. Planning for surveys would benefit from up-to-date summaries of data obtained from satellite tagged bowheads during the periods when various surveys would be conducted. For example, aerial surveys of the summering or wintering areas could use positions from satellite tagged whales during past studies to stratify potential survey areas. Then adaptive survey methods could be used to increase coverage in areas with observed concentrations of whales. A potential problem is that satellite tags cannot be applied to ensure random sampling of population. Two tagging areas used in the past are West Greenland and northern Foxe Basin, and due to segregation during migration, these locations may not permit tagging of whales headed to all of the summering areas. Aerial surveys can provide some information on whale sizes but that depends on the experience of the observers. Although data on the proportion of calves can be obtained during aerial surveys, calves are missed and data are negatively biased unless each whale is circled. Aerial surveys can also provide information on more than one species, which might have advantages; however, multispecies surveys typically result in negatively biased estimates for difficult to detect species such as bowhead whales

The photographic mark-recapture surveys are the second most expensive alternative and are only slightly less expensive than aerial surveys of summering areas, but photographs can be obtained from an aerial platform in remote areas and data from incomplete surveys due to bad weather can be combined with another survey to obtain an unbiased population estimate. Smaller aircraft or unmanned aerial systems (UAS) could possibly be used, which would reduce the cost of the study. In addition, the photographic surveys provide information on life history parameters and the health of whales that will be useful in future stock assessments and that cannot be obtained using the other methods. Over the long term, photographic surveys are "data rich" compared to alternative approaches and future photographic surveys will be considerably less expensive than aerial surveys if earlier photographs are used to provide the sample of marked whales. Photographic surveys do not require as high flight ceilings as aerial surveys and so are less likely to be interrupted by poor weather.

Depending on the method or methods selected to estimate the size of the EC-WG bowhead population, data could be collected with more than one objective in mind. During genetic sampling, for instance, photographs should be taken of the whales that will contribute to future photographic mark-recapture and life-history analyses. Vessel-based photographs do not provide an optimum and consistent view of the whale like vertical aerial photographs, but they can still provide valuable information. Also, if an aerial survey approach is selected, and the survey aircraft has a ventral camera port, short breaks from the survey could be taken to obtain vertical aerial photographs which could be used for future mark-recapture and life history studies. Small collections of vertical aerial photographs were taken in Isabella Bay during the summers of 1986 and 1987 and photographs were obtained during aerial surveys off West Greenland during the spring. These earlier photographs, plus any taken during a 2012 or later survey, can be used to provide needed life history information like that collected for the B-C-B stock (Koski et al. 1992; 2006b; Miller et al. 1992; Rugh et al. 1992; Zeh et al. 2002). When combined with a later more comprehensive survey, these photographs could be the basis of a future mark-recapture estimate. It should be noted, however, that interruptions to aerial surveys could impact the ability to complete a survey and the numbers of photographs that would be obtained incidental to an aerial survey would not be sufficient to provide a population estimate.

A major consideration for selection of a method for estimating the EC-WG bowhead population size is the expected precision of the estimate. Aerial surveys of bowhead whales have large CVs because sightings are clumped and most transects surveyed have no sightings. In addition, the availability bias introduces considerable variation due to the small amount of time that whales are available at the surface of the water where they can be detected. The CV for the aerial survey estimate of Dueck et al. (2006) for the EC-WG population was 43% (14,400, 95% CI = 4811-43,105) and the CV for the mark-recapture estimate by Koski et al. (2010) for the B-C-B population was 24% (12,631, 95% CI = 7,900-19,700). Thus confidence intervals for photographic mark-recapture estimates are expected to be lower than for aerial surveys but confidence intervals are directly related to the number of recaptures and the preliminary estimate of the population size.

The application of satellite tags to bowhead whales would benefit all of the methods discussed in this assessment. Knowledge of the distribution and concentrations of whales would benefit aerial photography, genetic sampling and aerial surveys and ensure that areas with significant numbers of whales were sampled by the chosen method. However, only the aerial survey studies would require satellite tagged whales. The data from the satellite tags are necessary to estimate availability bias and distribution of whales specific to the time and geographic area where surveys are conducted. The genetic and photographic mark-recapture studies are conducted over several sampling periods, and so mixing between sampling occasions ensures that most, if not all, of the population is included in the sampling even if they are not included in individual sampling occasions.

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TABLES AND FIGURES

Table 1. Information on bowhead whale harvests in the Eastern Canadian Arctic 1996–2010.

Year	Community	Date harvested (dd-mmm-yy)	Struck	Landed	Sex	Length (metres)
1996	Repulse Bay	15-Aug-96	1	1	M	14.91
1998	Pangnirtung	21-Jul-98	1	1	M	12.75
2000	Coral Harbour	16-Aug-00	1	1	M	11.65
2002	Igloolik	10-Aug-02	1	1	F	14.19
2005	Repulse Bay	18-Aug-05	1	1	F	16.40
2008	Hall Beach	18-Aug-08	1	1	M	13.43
2008	Kugaaruk	4-Sep-08	2	1	M	10.51
2008	Kangiqsujuaq	9-Aug-08	1	1	M	14.88
2009	Rankin Inlet	28-Aug-09	1	1	F	16.15
2009	Kugaaruk	n/a*	0	0	n/a	n/a
2009	Cape Dorset	29-Sep-09	1	1	M	15.77
2009	Kangiqsujuaq	22-Aug-09	1	1	F	17.29
2010	Pond Inlet	5-Aug-10	1	1	M	12.80
2010	Repulse Bay	28-Aug-10	1	1	F	14.32
2010	Kugaaruk	3-Sep-10	2	0	n/a	n/a

* n/a = not available

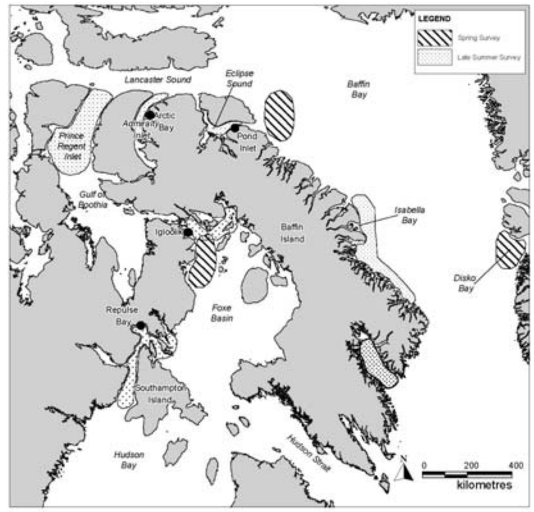

Figure 1. On the left is a photograph of a bowhead whale with a calf take in spring. On the right is a map showing the main spring and summer concentration areas of the Eastern Canada-West Greenland bowhead whale population.

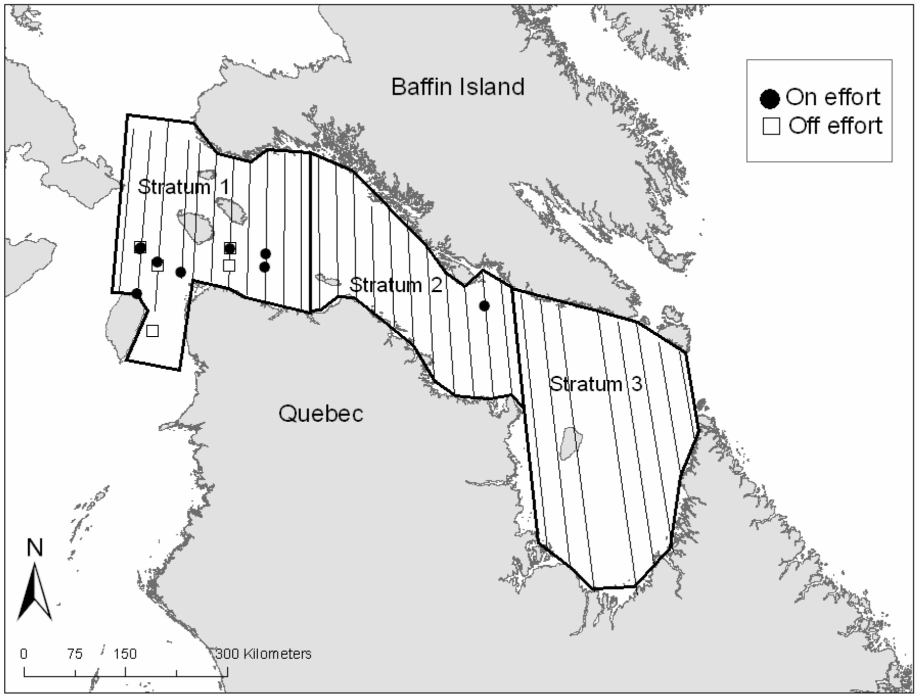

Figure 2. Transects surveyed and bowhead whale sightings during aerial transect surveys in Hudson Strait during March 1981 (from Koski et al. 2006a).

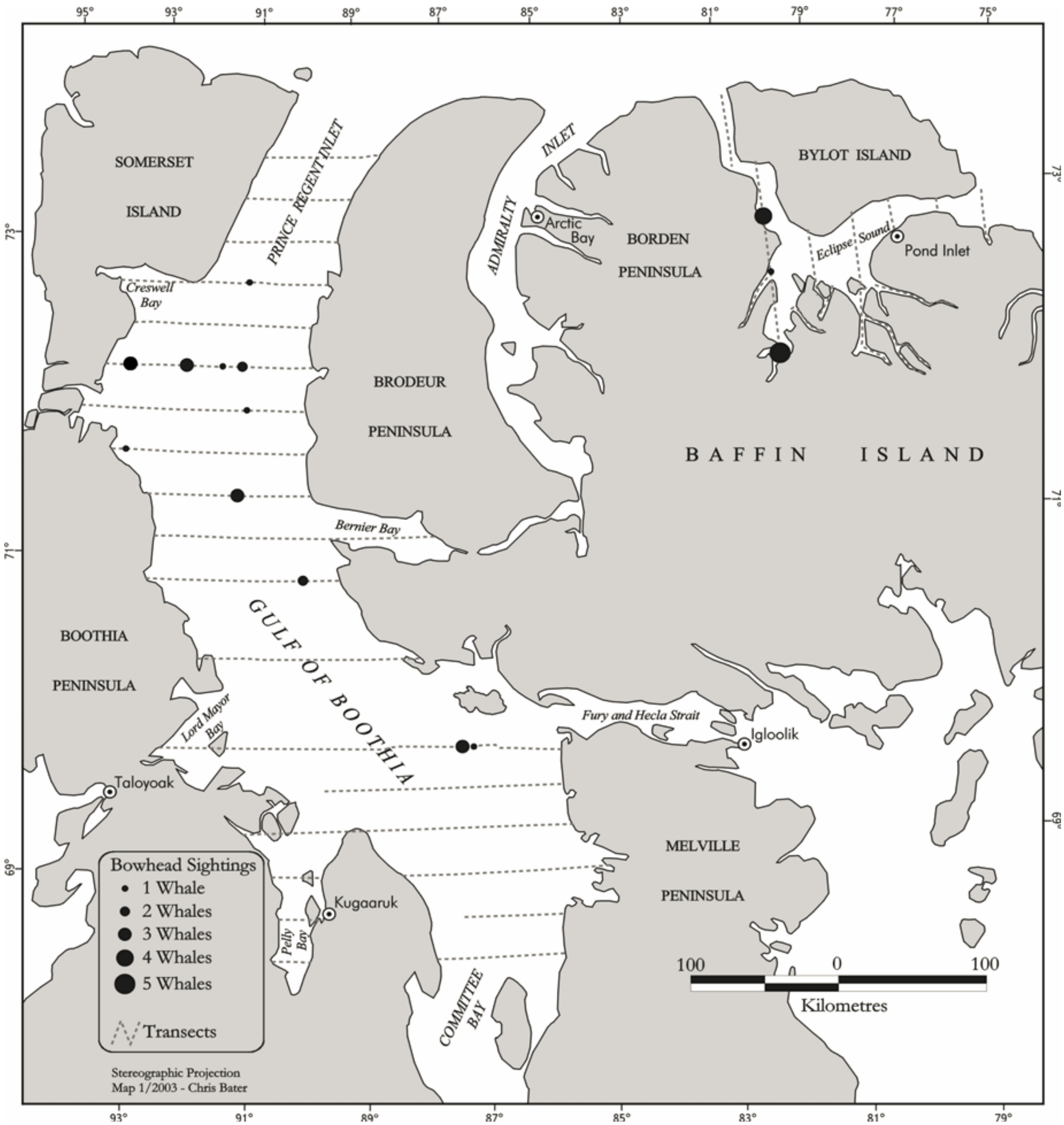

Figure 3. Transects surveyed and bowhead whale sightings during 2002 surveys of Eclipse Sound, Prince Regent Inlet and Gulf of Boothia.

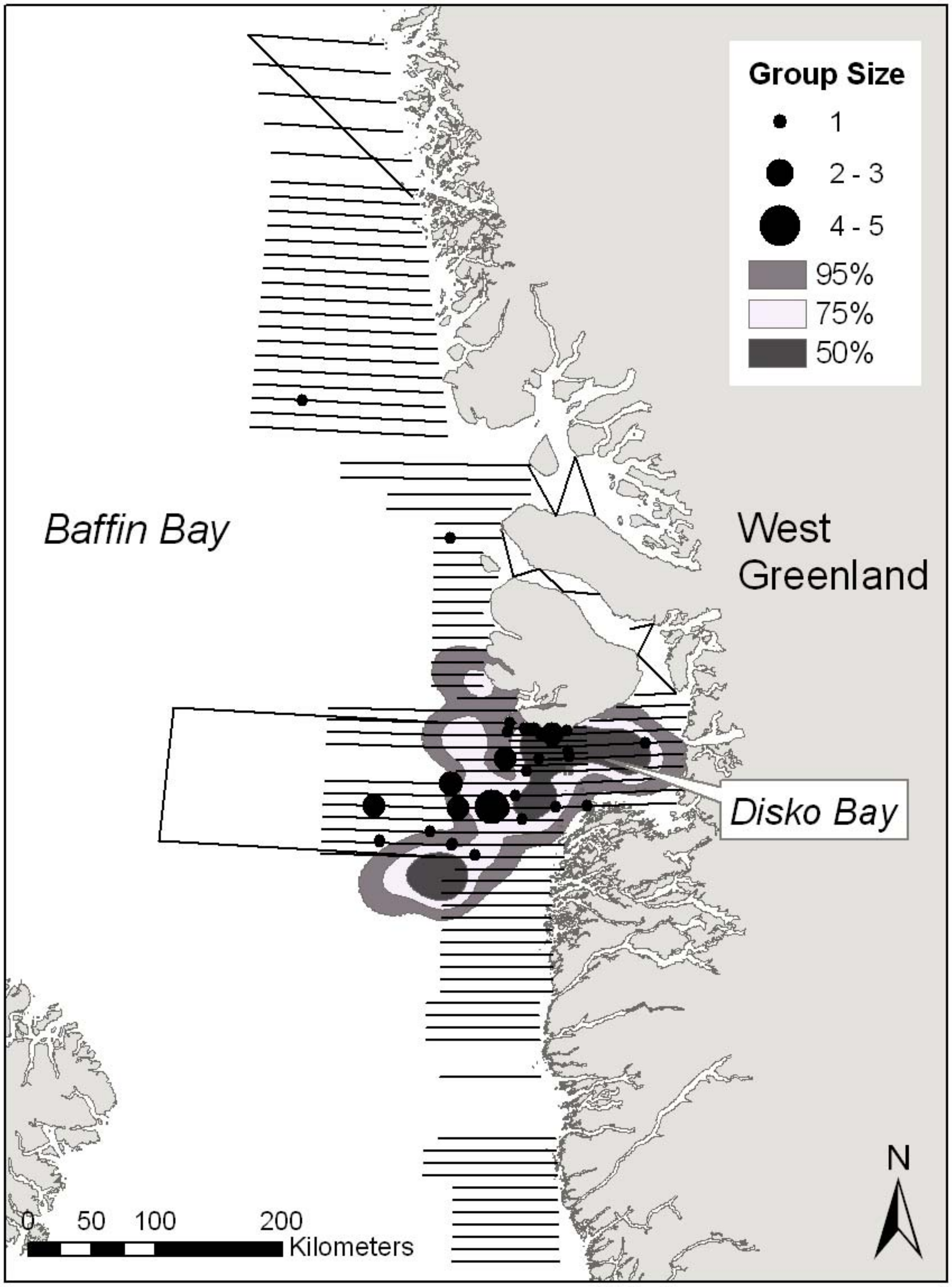

Figure 4. Survey effort and bowhead whale sightings off West Greenland during March and April 2006 (from Heide-Jørgensen et al. 2006).