Preliminary evaluation of the potential to use photographs and capture-recapture analyses to estimate the size of the Eastern Canada – West Greenland stock of bowhead whales

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ABSTRACT

The summering areas of the Eastern Canada-West Greenland (EC-WG) stock of the bowhead whale are large and remote and conducting a systematic aerial survey of the entire area in a short period of time is difficult. Surveys that are conducted in different parts of the range at different times or in different years cannot be used to obtain a robust estimate of stock size because whales may move among summering areas within a season and between years. We suggest an alternative approach to estimate the size of the EC-WG stock using photographic surveys of spring and summer aggregation areas. If two years of photographic surveys are conducted, capture-recapture estimates can be made of the number of marked whales in the population and the proportion of the population that is marked (p^*) can be estimated using data from the Bering-Chukchi-Beaufort (BCB) stock of bowheads. These two stocks appear to be increasing near their maximum possible rate based on age at sexual maturity and calving interval data from the BCB stock which justifies the use of the BCB p^*. Confidence intervals for the photographic population estimate can be obtained from either a delta method variance or bootstrap percentiles and are likely to be narrower than confidence intervals from systematic aerial surveys. An additional benefit of the photographic surveys is that life history information, which is sparse for the EC-WG stock, would be obtained.

KEYWORDS: SURVEY-AERIAL, PHOTO-ID, BOWHEAD WHALE, ARCTIC, NORTHERN HEMISPHERE, ATLANTIC

INTRODUCTION

Satellite telemetry data have shown that bowhead whales that occur off Eastern Canada and West Greenland belong to a single stock based on within-season movements between areas that were previously thought to be occupied by different stocks (Dueck *et al*., 2006; Heide-Jørgensen *et al*., 2006). These telemetry data also showed that the whales have a common over-wintering area in Hudson Strait. Scientists from the Canadian Department of Fisheries and Oceans (DFO) conducted aerial surveys during 2002-2004 to estimate the size of the Eastern Canada – West Greenland (EC-WG) stock in its summering areas. However, all areas could not be surveyed in one year and differences in between-year distributions of whales confounded the results of these surveys since different parts of the range were surveyed in different years (IWC, 2009). The data were re-analysed at the Scientific Committee meeting in 2008 and a putatively negatively biased abundance estimate of 6,344 (3,119-12,906) was agreed for management advice (IWC, 2009). The large summer range of the EC-WG bowhead whale stock and the remoteness of much of it make conducting a systematic aerial survey of the entire region in a short period of time very difficult. An alternative approach to estimate the size of this stock would be to use capture-recapture analyses of photographs obtained from aerial photographic surveys. Capture-recapture estimates of abundance based on photographs have been made for several populations of large whales (Bradford *et al*., 2008; Best *et al*., 2001; Calambokidis and Barlow, 2004; Stevick *et al*., 2003). In particular, photographic capture-recapture analysis has been used to estimate the size of the Bering-Chukchi-Beaufort Seas (BCB) stock of bowhead whales (da Silva *et al*., 2000; da-Silva *et al*., 2003; da-Silva and Tiburcio, 2010; Koski *et al*., in press; Schweder, 2003; Schweder *et al*., 2010) and these estimates have been similar to those provided by the ice-based survey (da Silva *et al*., 2000; George *et al*., 2004; Koski *et al*., in press; Schweder, 2003; Schweder *et* *al*., 2010). In this paper we evaluate the potential for photographic studies to provide data that would permit estimation of the size of the EC-WG bowhead whale stock.

METHODS

Bowhead whales acquire permanent scars from encounters with ice, killer whales, polar bears, ropes, fishing gear and many other sources (George *et al*., 1994; Higdon and Ferguson, 2010; Rugh *et al*., 1992a; 1998). Vertical aerial photography generally provides the best view of these markings and has been used during numerous studies on the BCB bowhead stock (Angliss *et al*. 1995; Koski *et al*., 1993; 2006; 2008) and a few studies on the EC-WG stock (Cosens and Blouw, 2003; Finley, 1990). Vertical photography studies should follow the methods of Angliss *et al*. (1995) and Koski *et al*. (1992; 2006; 2008). Photographs are taken through a camera port in the floor of a suitable aircraft such as a Twin Otter using a medium format, hand-held camera which is held vertical to the water surface. A radar altimeter is used to determine the altitude above sea level at the instant that a picture is taken and a Global Positioning System records the precise location. Calibration targets are used to scale the whale images to actual whale size.

In addition to aerial photography, photographs have been taken during vessel-based surveys that can contribute to resighting histories of EC-WG bowhead whales (Finley, 1990; Higdon and Ferguson, 2008a; 2008b). The vessel-based photographs do not provide consistent imagery of most regions of a whale, but if particular regions of the whale that are frequently captured in photographs are used for determining whether a whale is marked or not, then they can be used to provide sighting histories that supplement the vertical aerial photographs.

The best opportunities to photograph EC-WG bowhead whales are in (a) the spring staging areas where they concentrate along ice edges or in the pack ice before moving to the summering areas and (b) the late summer feeding areas. An ideal survey design would incorporate sampling in both of these settings each year.

Aerial photographic surveys in spring staging areas

Three spring concentration areas have been documented where EC-WG bowheads could be photographed successfully. The first is along the ice edge near Igloolik where large numbers of bowheads congregate in late spring to early summer before they gain access to summering areas in the central High Arctic through Fury and Hecla Straits (Fig. 1) (Dueck *et al*., 2006; Higdon and Ferguson, 2008a). This location is near logistics centres at Igloolik and Hall Beach and large numbers of vertical aerial photographs could be obtained during a study based there. Unlike vessel-based surveys which could not be conducted during heavy ice conditions, aerial photography would be minimally affected by ice cover, provided that the ice edge remains intact to prevent whales from dispersing farther north through Fury and Hecla Straits. In fact, presence of ice tends to result in better-quality photographs because ice dampens waves, resulting in lower sea states.

The second spring concentration area is in the pack ice at the entrances of Pond Inlet and Lancaster Sound. Bowheads congregate in the pack ice in that area during June before they enter Lancaster Sound or move south to summering areas along eastern Baffin Island (Davis and Koski, 1980; Heide-Jørgensen *et al*., 2006; Koski, 1980). The logistics base for photography in this area would be Pond Inlet.

The third spring aggregation area is Disko Bay, West Greenland, where during some spring seasons up to 1,200 bowheads, but more commonly 150-200, are observed during April and May (Heide-Jørgensen *et al*., 2007). The bowheads that occur in and around Disko Bay are primarily adult females (Laidre *et al*., 2007), which tend to be well marked (Miller *et al*. 1992; Rugh *et al*. 1992b; 1998) and so are particularly valuable for capture-recapture studies. The logistics base for this area would probably be either Ilulissat or Kangerlussuaq.

Aerial photographic surveys in summering areas

Aerial photographic surveys of the main summering areas of the EC-WG bowhead whale stock could also provide large numbers of photographs. The weather conditions tend to be favourable for conducting photography during the late summer period and summering areas are relatively well known from surveys conducted in the 1970s (Davis and Koski, 1980; Koski, 1980) and in 2002-2004 (Dueck *et al*., 2008). One or two aircraft could move between the areas shown in Fig. 1. These photographs could be supplemented with photographs taken during other concurrent marine mammal surveys such as bowhead and beluga surveys off West Greenland (Heide-Jørgensen and Acquarone, 2002; Heide-Jørgensen *et al*., 2007) or narwhal and beluga surveys in the Canadian Arctic (Innes *et al*., 2002; Richard *et al*., 1994; 2010).

Boat-based photographic surveys

Boat-based photography studies were conducted in northern Foxe Basin in the 1990s (Weins, 1998) and in 2007-2008 (Higdon and Ferguson, 2008a; 2008b). Large numbers of photographs were obtained during these studies but the number of matchable whales photographed was relatively small because the same region of the whale was not visible on all photographs. Nonetheless, photographs from boat-based surveys conducted during the same year as aerial photography could contribute capture histories for whales that could be incorporated into the population estimate.

Collecting and processing images

The methods for analysing the photographs would be the same as those of earlier studies conducted on the BCB stock (Koski *et al*., 1992, 2006; Rugh *et al*., 1998; Zeh *et al*., 2002). All photographs would be cropped to a uniform size (12.5cm × 17.5cm), labelled, and stored on hard drives. Calibration targets would be photographed in the field to scale digital images to true length as described by Koski *et al*. (1992, 2006). Whale measurements would be taken from uncropped Tag Image Files (TIFs) created from the raw digital files. All photographs taken each year would be examined to identify within-season duplicate images. All images would be scored for identifiability and image quality as described by Rugh *et al*. (1998) and Zeh *et al*. (2002). Between-year matches would be identified with the aid of a computer-assisted matching program (Hillman *et al*., 2008). The data for each image would be entered into a standard database the same as has been done for the BCB photographs with each image having a unique identifier and all images of a whale having the same whale number.

Computing population estimates

Population estimates for the initial years would be calculated using the methods of Koski *et al*. (in press). An estimate of the number of marked whales would likely be made using a closed population model for capture-recapture data (Huggins, 1989; 1991) as implemented in Program MARK (White and Burnham, 1999). It is likely that a simple model with no covariates will produce the most precise estimate unless a very large number of photographs and recaptures are obtained (Koski *et al*., in press). However, other models will be investigated to find the best model for the data that are collected.

To estimate the size of the EC-WG stock from the number of marked whales in the population one must divide the estimated number of marked whales (N^m) by the estimated proportion of the population that is marked (p^*). Bowhead whales acquire their markings throughout their life. Young or small whales are rarely marked and most large, old mature whales have some distinguishing marks (Rugh *et al*., 1992a; 1998). The proportion of the population that is marked is, therefore, related to the population structure. Both the BCB and EC-WG stocks of bowhead whales were severely reduced during the commercial whaling period (Bockstoce and Burns, 1993; Ross, 1993; Zeh *et al*., 1993), and therefore, it is reasonable to assume that both populations are increasing at near their maximum possible rate, given their low reproductive rates and late age at sexual maturity. The proportions of these two populations that are made up of immature and mature animals are likely similar. Given the large range of the EC-WG stock and the difficulty and cost of achieving complete coverage of that range in a year, the photographic effort is, like the aerial transect survey effort, unlikely to obtain a fully representative sample of the overall population. Therefore, we propose to use the same value of p^* that has been obtained for the BCB stock (0.2897 in Koski *et al*., in press) for the proportion of marked whales in the EC-WG stock. Although the BCB and EC-WG stocks may be at different stages of recovery from commercial whaling, the BCB stock appears to be closer to its pre-whaling size than the EC-WG stock. Thus the true p^* for the EC-WG stock, if it differs from that of the BCB stock, would be lower and population estimates using the BCB value of p^* would be conservative (negatively biased). The uncertainty in the estimate of p^* is likely to be much smaller than the uncertainty associated with aerial surveys of different parts of the stock's range at different times.

To quantify the potential range of values of p^* for the EC-WG stock, we propose to use the photographic data from the 1985-2004 BCB studies near Barrow, Alaska, to create a time series of estimates of p^* with 95% confidence intervals using the bias-correcting procedures described in Koski *et al*. (in press) and data from each year separately. This approach is likely to produce wide confidence intervals for p^* since an estimate of p^* based on several years is likely to be more accurate as well as more precise: year-to-year biases average out when several years of data are used.

The methodology of Koski *et al*. (in press) would be followed to calculate population estimates $N = N^m/p^*$ and their estimated variances. The estimated variances can be obtained via either a delta method calculation or a bootstrap procedure. In the former case, confidence intervals can be obtained as recommended by Burnham *et al*. (1987) and Buckland (1992), and, in the latter case, from percentiles of sorted bootstrap values of N (Buckland and Garthwaite, 1991). The bootstrap confidence limits may be more reliable because they do not depend on the simplifying assumptions used to obtain the delta method variance for N and the corresponding confidence limits.

DISCUSSION

Two years of aerial photographic surveys in the major spring aggregation and summering areas of the EC-WG bowhead whale population could provide an unbiased estimate of population size. This is something that aerial surveys are unlikely to be able to provide in a single year because of the large size of the summer range of this stock. In addition, confidence intervals for the photographic survey are likely to be narrower than an aerial survey of the EC-WG summering areas. For example, the 2002-2004 aerial surveys of the EC-WG stock of bowhead whales were conducted over three seasons and the estimate of 14,400 whales had lower and upper 95% bounds of 4,811 and 43,105 (Dueck *et al*., 2008) while the estimate of 12,631 for the BCB stock based on photographic surveys (Koski *et al*. in press) had lower and upper bounds of 7,900 and 19,700. Koski *et al*. (in press) showed that the precision of their 2004 estimate for the BCB stock of bowheads increased by including surveys in a third season, even though the effort in the third season was much lower than the first two seasons. The increased precision was a result of an increased number of different "captured" and "recaptured" whales when the third season was included. Thus co-ordination among the various researchers in Canada and Greenland can improve estimates from photographic surveys.

Aerial and vessel-based photographs of EC-WG bowheads have been obtained during earlier studies (Cosens and Blouw, 2003; Finley, 1990; Heide-Jørgensen and Finley, 1991; Higdon and Ferguson, 2008a; 2008b) and during recent surveys in the Disko Bay area in spring such as those reported by Heide- Jørgensen *et al*. (2007). After the first few photographic surveys have been completed and the EC-WG bowhead whale photographic catalogue has grown in size, it will be possible to obtain a future estimate of population size from a single survey using the models developed by Schweder *et al*. (2010). Other key population parameters such as rate of increase and survival rates would also be obtained from the Schweder *et al*. (2010) modelling approach. The precision of population estimates and other life history parameters estimated using the Schweder *et al*. (2010) model increases as the number of photographs in the overall database increases (Schweder and Sadykova, 2009). Unlike aerial line transect surveys, which are useful only for estimating the number of animals present in the survey area at the time of the survey, each photographic survey contributes to future estimates and results in improved precision.

Table 1 summarises some of the benefits and shortcomings of using aerial photographic studies compared to aerial transect surveys for estimating the size of the EC-WG bowhead stock.

An additional benefit of conducting aerial photographic studies rather than visual aerial surveys for estimating population size is that life history information can be obtained from analyses of photographs. The life history information is not obtained from visual transect surveys. Photography projects conducted in the Beaufort and Chukchi Seas intermittently from 1981 to 2005 have provided much of the life history information that is available on the BCB stock of bowhead whales. This includes estimates of growth rates of individuals, adult survival, the length-frequency distribution of the population, year-to-year timing of migration of individual whales, calving intervals, the proportion of calves in the population and first-year survival of calves (Angliss *et al*., 1995; da-Silva *et al*., 2007; Koski *et al*., 1992; 1993; 2006; 2008; 2010; in press; Miller *et al*., 1992; Nerini *et al*., 1984; Rugh *et al*., 1992b; 2009; Zeh *et al*., 1993; 2002).

The widely reported observation of a gray whale (*Eschrichtius robustus*) in the eastern Mediterranean Sea in May 2010 was interpreted by many as an indication that this individual, almost certainly from the eastern North Pacific stock, had found its way through the Northwest Passage and entered the North Atlantic via one of the channels in the Canadian Arctic archipelago. If this interpretation is correct, it is reasonable to assume that other cetaceans have immigrated, or soon will immigrate, into the North Atlantic. Given that bowhead whales are much more abundant than gray whales in the eastern Beaufort Sea and Amundsen Gulf, and that they are considerably more 'ice-adapted' than gray whales, the movement of bowheads from the western to eastern Arctic probably has happened, and may happen, much more frequently than the movement of gray whales. Thus, it will be important at some stage to compare catalogues of bowhead whales from the Pacific and Atlantic sectors of the Arctic to estimate the exchange. The suggested study will provide a large number of new photographs to the relatively small collection of EC-WG photographs to permit better quantification of exchange.

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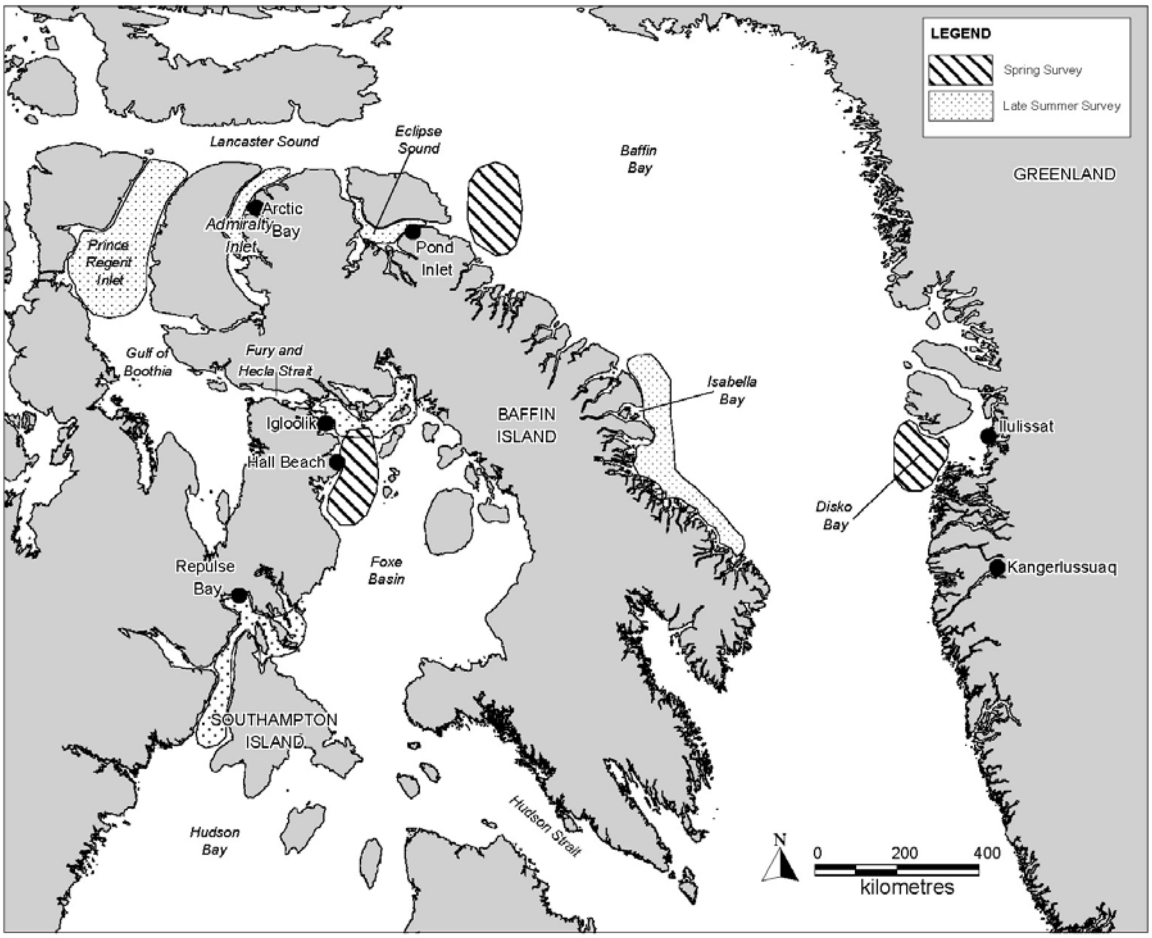

Fig. 1. Areas where concentrations of bowhead whales are known to occur during spring and late summer (from various sources of published and unpublished data).

Table 1

A comparison of the advantages and disadvantages of the two approaches – photographic capture-recapture analysis and aerial transect survey – to estimate abundance for the Eastern Canada - West Greenland stock of bowhead whales.

Problems	Photography	Aerial surveys
Whales move between areas during survey	Samples of photographs are more nearly random if there are movements of whales between areas	Reduces reliability of estimate because some whales may be missed and others could be counted more than once
Weather is bad	Reduced number of photographs but population estimate still possible by continuing the survey longer or by continuing the survey the following year	If the survey is not completed within a short period of time, the estimate is a partial estimate and cannot be combined with later surveys because whales move among areas
Ice cover is high	Whales are more difficult to find when ice is heavy but seas are dampened and quality of photographs is good. Once whales are found they tend to be easier to photograph in ice than in open water	Whales are difficult to see in heavy ice, reducing the number of sightings and widening confidence intervals of estimates. Correction factors are very different for whales in ice and open water and are often not available
Cannot cover entire range of the population during the survey	Not a serious problem if there is mixing between sampling periods	Results in negative bias in estimate. Cannot be accounted for
Whales are segregated by age and sex classes and by reproductive state	An estimate of the proportion of population that is marked is needed. The probability of an animal being marked depends on its size (age). If the proportion marked comes from the survey photographs, then photographic effort must be proportional to the number of animals in each area. If that number is generated from outside data, then there is less concern about proportional sampling	Survey effort must be uniform throughout the range to avoid biased estimate. An alternative is to have separate survey designs for each area but the CV tends to be larger then because small numbers of sightings go into each individual estimate. Correction factors should be established for different age and sex classes
Qualified scientists are required to conduct the study	The required skill level is higher for conducting photographic surveys, but a much smaller crew (2-3, 1 photographer and 1-2 data recorders/observers) can conduct the entire survey	A large number of experienced observers are needed for a short period of time because all parts of the range need to be surveyed during a short time period