SC/69A/ASI/03/Rev2

Sub-committees/working group name:

Abundance of bowhead whales (Balaena mysticetus)in West Greenland, 2022

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Abundance of bowhead whales (*Balaena mysticetus*) in West Greenland, 2022

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Abstract

A proportion of the East Canada-West Greenland population of bowhead whales (*Balaena mysticetus*) spends January-June off West Greenland and several aerial surveys (between 1998-2012) have estimated the abundance of bowhead whales on this wintering ground, with the last estimated abundance of 744 whales (CV=0.34) based on an aerial survey conducted in 2012. Between 26 March and 4 April 2022, visual aerial line-transect surveys of bowhead whales were conducted as a double-platform experiment with independent observation platforms covering the main distribution of the local winter aggregation of bowhead whales in West Greenland. The target region included an area of 34,742 km^2 and was divided into 6 strata with a total of 3667 km of effort on systematically equally placed transect lines. Abundance of bowhead whales were estimated by using a Mark-Recapture Distance Sampling approach and due to the low number of sightings also by a strip census analysis. Both approaches corrected the final estimate of abundance for both perception- and availability bias. The MRDS estimated individual abundance to 915 whales (CV= 0.46, 95% CI: 385-2175). The strip census analysis estimated individual abundance to 993 whales (CV= 0.52, 95% CI: 380-2597). The median time a bowhead whale was visible for observers was 4.5 sec but this was not accounted for in the final estimate. The confidence limits of the abundance of bowhead whales in the survey area in 2022 are within similar estimates obtained between 2006 and 2012 indicating that there is a somewhat constant proportion of the East Canada-West Greenland population of bowhead whales that spend winter in the survey area off West Greenland.

Introduction

Bowhead whales that make annual migrations in response to the seasonal withdrawal and advancement of sea ice (Heide-Jørgensen *et al.* 2006). The total abundance for the East Canada-West Greenland population of bowhead whales (*Balaena mysticetus*) was estimated to be 6,446 (CV =0.26, 95% CI: 3,838–10,827) based on an aerial survey conducted in summer 2013 in the Canadian Arctic (Doniol-Valcroze *et al.* 2020). A proportion of this population spends January-June off West Greenland and several aerial surveys have estimated the abundance of bowhead whales on this wintering ground (Heide-Jørgensen *et al*. 2020, Givens and Heide-Jørgensen 2020). In West Greenland, aerial surveys for bowhead whales were conducted in March/April and where previous studies showed an increase in abundance of bowhead whales from 246 whales (95% CI: 62-978; Heide-Jørgensen, M.P. and Acquarone, M. 2002) in 1998 to 1229 whales (95% CI: 495-2939; Heide-Jørgensen *et al*. 2007) in 2006, this increase has since levelled off and the last survey in 2012 estimated an abundance 744 whales (CV =0.34, 95% CI: 357–1,461; Rekdal *et al.* 2014). Genetic mark-recapture data has estimated abundance of bowhead in the Canadian Arctic to 11,747 (95% CI: 8169-20,043) based on samples collected between 1995-2013 (Frasier 2020). From this data set the proportion of bowhead whales spending winter in Disko Bay was estimated to 2615 individuals (95% CI: 1353-6114) based on samples collected between 2001-2008. In addition, a genetic capture-recapture estimate of abundance based on genetic samples from 427 individuals collected in Disko Bay between 1999-2013 resulted in an estimate of 1538 whales (CV =0.24, 95% CI: 827–2249; Rekdal *et al*. 2015).

Material and methods

Survey design

Visual aerial line-transect surveys of bowhead whales were conducted as a double-platform, or double-observer, experiment with independent observation platforms at the front and rear of a De Havilland Twin Otter survey plane. Target altitude and speed were 700 feet and 90 nm h-1 (213m and 170 km h-1) and only effort recorded during sea states <3 and visibility >10 km was included in the analysis. The Beaufort Sea State Code was used for assessing the survey conditions. The respective values were recorded together with ice coverage (as a percentage coverage of the sea surface at a distance of 0-2 km from the transect line) at the start of each transect line and when conditions changed. Two observers sat in the front seats just behind the cockpit, and two observers sat in the rear seats at the back of the plane. The distance between front and rear observers was approximately 4 m, and a long-range fuel tank and recording equipment installed between the front and rear seats prevented visual or acoustic cueing of sightings between the two platforms. All four observers had bubble windows that allowed them to view the track line directly below the aircraft.

Decisions about duplicate sightings (animals seen by both observer 1 and 2) were based on coincidence in timing and positions, group size and direction of movement. Declination angles (ω) measured with electronic inclinometers when animals were abeam were converted to perpendicular distances (x) using the following equation from Buckland *et al.* (2001): $x = v \times \tan(90 - \omega)$, where v is the altitude of the airplane (Hansen *et al.* 2020). Time-in-view of the sightings was not incorporated into the analysis and observations were treated as an instantaneous sighting process.

Survey area and timing

The aerial survey was conducted in coastal and offshore areas in West Greenland between 65°40N and 69°30N, in order to cover the main distribution of the local winter and spring aggregation of bowhead whales and beluga whales (*Delphinapterus leucas*) in West Greenland. The target region included an area of 34,742 km^2 and was divided into 6 strata based on previous information on expected densities of bowhead whales and beluga whales. In total 3667 km of east-west oriented systematically equally placed transect lines were searched between 26 March and 4 April 2022.

Collection of data for the availability correction factor

Data from instrumented bowhead whales with time-depth recorders showed that they spend an average of 26.9% (CV= 0.14) at or above 2m depth which is assumed to be within the maximum depth that observers can detect a bowhead whale from aerial surveys (Heide-Jørgensen *et al.* 2007).

Development of abundance estimates

Mark-Recapture Distance Sampling

Detection function estimation

Although the observers were acting independently, dependence of detection probabilities on unrecorded variables can induce correlation in detection probabilities. Since it may not be possible to record all variables affecting detection probability, unmodelled heterogeneity may persist even when the effects of all recorded variables are modelled. Laake and Borchers (2004) and Borchers *et al*. (2006) developed an estimator based on the assumption that there is no unmodelled heterogeneity except at zero perpendicular distance (i.e. on the trackline) – called a point independence estimator. The alternative – a full independence estimator - assumes no unmodelled heterogeneity at any distance. The point independence model is more robust to the violation of the assumption of no unmodelled heterogeneity than the full independence model.

Incorporating the point independence assumption involves estimating two models: a multiple covariate distance sampling (DS) detection function for combined platform detections, assuming certain detection on the trackline (Marques and Buckland 2004); and a mark-recapture (MR) detection function to estimate detection probability at distance zero for an observer. The MR detection function is the probability that an animal at given perpendicular distance x with covariates z, was detected by an observer q (q=1 or 2), given that it was seen by the other observer, which is denoted by $p_{q|3-q}(x,z)$. It is modelled using a logistic form:

$$p_{1|2}(x,z) = p_{2|1}(x,z) = \frac{\exp\left\{\beta_0 + \beta_1 x + \sum_{k=1}^{K} \beta_{k+1} z_k\right\}}{1+\exp\left\{\beta_0 + \beta_1 x + \sum_{k=1}^{K} \beta_{k+1} z_k\right\}}$$

where $\beta_0, \beta_1, \ldots, \beta_{K+1}$ represent the parameters to be estimated and K is the number of covariates other than distance. Note that if observer is included as an explanatory variable, then $p_{1|2}(0,z)$ will not be equal $p_{2|1}(0,z)$. The intercept of $p_{1|2}(0,z)$ and $p_{2|1}(0,z)$ are combined to estimate their combined detection probability on the trackline. Akaike's Information Criterion (AIC) and goodness of fit tests were used for model selection.

Estimating density and abundance

Group density (D_{Gi}) and abundance (N_{Gi}) of animals available for detection for stratum *i* were estimated as follows:

$$\hat{D}_{Gi} = \frac{1}{2wL_i}\sum_{j=1}^{n_i}\frac{1}{\hat{p}_{ij}} \qquad \text{and} \qquad \hat{N}_{Gi} = A_i\hat{D}_{Gi}$$

where A_i is the size of stratum *i*, *w* is the truncation distance, L_i is the total effort in stratum *i*, n_i is the total number of detections in the stratum *i* and $\hat{p}_{ij}$ is the estimated probability of detecting group *j* in stratum *i*, obtained from the fitted models described previously.

It is assumed that bowhead whales were only available for detection when they were close to the surface (0-2m) and that the proportion of time spent ($\hat{a}$) close to the surface was known from satellite-linked-time-depth recorders.

In order to account for availability bias, corrected abundance (denoted by the subscript '*c*') was estimated by

$$\hat{N}_{Gci} = \frac{\hat{N}_{Gi}}{\hat{a}} \qquad (1)$$

where $\hat{a}$ is the estimated proportion of time animals are available for detection. Using the delta method the coefficient of variation (CV) of $\hat{N}_{Gci}$ is given by

$$cv\left(\hat{N}_{Gci}\right) = \sqrt{cv^2\left(\hat{N}_{Gi}\right) + cv^2\left(\hat{a}\right)}$$

Coefficients of variation (CV) were estimated as the standard error in proportion to the mean and 95% confidence limits were calculated based on the assumption of log-normal distribution (Buckland *et al.* 2001).

The expected group size in stratum *i* is estimated by

$$\hat{E}[s_i] = \frac{\hat{N}_i}{\hat{N}_{Gi}} \qquad (2)$$

Strip census analysis

MRDS models require a relatively large number (>40) of sightings to be able to estimate model parameters reliably. The sample size for bowhead whales was low (N=29) and possibly do not allow for distance sampling estimation and therefore a strip census estimation of density, with a constant probability of detection within a species-specific strip width, was developed (Magnusson *et al*. 1978, Chapman 1951). It was based on the numbers of sightings and duplicates and does not model dependence of detection probability on distance or other covariates. The strip census estimate was developed with an average group size across all strata. A Chapman estimator was used to estimate perception bias (*p'*) by the observers within a strip (*w*) from the track line across all strata where bowhead whales were observed within *w*:

$$\hat{p}' = \frac{\sum n}{\frac{(S_1 + B + 1)(S_2 + B + 1)}{(B+1)} - 1}$$

where, S_1 and S_2 are the total number of sightings for each observer (unique sighting) and B is the number of sightings made by both observers (duplicate sighting). Variance was estimated using Jackknife methods.

The detection probability for both observers (p') across all strata was estimated as follows:

$$\widehat{p'} = \frac{n}{\hat{N}_G}$$

where, *n* is the total number of sightings across all strata.

A global average group size, *G*, was used to convert group abundance to animal abundance in each stratum, *v*, and the individual abundance, $\widehat{N}_v$ was estimated in stratum 1, 2, 3 as follows:

$$\widehat{N}_v = \left(\frac{n_v \cdot G}{2 \cdot L \cdot w} \cdot A\right)$$

Where n_v is the number of unique sightings in each stratum v, L is the total length of transects in stratum v, A is the surface area of stratum v.

Individual abundance in all strata, ($\widehat{N}'$) was estimated by the sum of estimates from strata 1, 2, 3 ($\widehat{N}_v$) and dividing that with the detection probability, $\widehat{p}'$:

$$\widehat{N}' = \frac{(\frac{n \cdot G}{2 \cdot L \cdot w} \cdot A)}{\hat{p}'}$$

In order to account for availability bias, the corrected abundance (denoted by the subscript 'c') was estimated by:

$$\hat{N}'_c = \frac{\hat{N}'}{\hat{a}'}$$

The addition of variance for each component was done using the Delta method with estimation of coefficients of variation (CV) and confidence limits as for the MRDS analysis.

Results

Survey effort and distribution of sightings

The survey area was divided into 6 strata (34,742 km2) and each transect was treated as an independent sample. Observations (N=29) of bowhead whales were made in strata 1-3 and 5 with a group size of either 1 or 2 individuals (Fig. 1, Table 1-2). The majority of bowhead whale sightings were made in strata 2 and sightings of bowhead whales were encountered at the rate of 0.0173 whales per kilometre or app. 1 whale per 100 km across the strata with bowhead whale sightings (Table 5).

The time-in-view (TIV) when a whale was first sighted until abeam ranged between 0-60 sec with a median TIV of 4.5 sec.

Estimates of abundance

The probability of detecting a bowhead whale estimated from the MRDS model was 0.62 (cv= 0.22) for the combined observer effort (Table 3). Truncation at 1720m (10%) left 26 sightings for analysis (Table 1). To simplify the MRDS model, a half normal detection function with no covariates except for distance in the DS model was used (Fig. 2). The estimated abundance of bowhead whales using MRDS methods, corrected for perception bias, was 246 whales (CV= 0.44, 95% CI: 385-2175; Table 4). The estimated abundance of bowhead whales, corrected for perception- and availability bias, was 915 whales (CV= 0.46, 95% CI: 385-2175; Table 5).

The distribution of sightings of bowhead whales as a function of distance to the track line indicates a somewhat uniform distribution between 0-700 m (Fig. 3). Even though sample size is small, the strip width used in the estimate of abundance of bowhead whales was therefore set to 700m (Table 6). The average group size across all strata (N=22) was 1.18 (cv= 0.07). Encounter rate was estimated for each stratum and the combined variance for the encounter rate (*n/L*) across all strata was 0.23. Perception bias was estimated to be 0.72 (cv=0.44, Table 6). The resulting estimated abundance of bowhead whales, corrected for perception- and availability bias, and incorporating variance from group size, encounter rate, perception bias and availability bias was 993 whales (CV= 0.52, 95% CI: 380-2597; Table 7).

Discussion

There was a low number of sightings (N=29) and a low median time-in-view of 4.5 seconds. Since the time bowhead whales were available to be detected was small compared to the duration of the stay at the surface (mean times between 21s-123s) it was decided not to apply a correction for the bias associated with the time an animal is within detectable range (time-in-view; Rekdal *et al.* 2015). Therefore, all sightings were treated as an instantaneous process and hence correction of availability was made correcting for the daily averaged time a bowhead whale was in the water column where it is considered visible to observers (0-2m).

In West Greenland, aerial surveys for bowhead whales are conducted in March/April and where previous studies showed an increase in abundance of bowhead whales from 1998-2006 this increase has since levelled off and the last aerial survey in 2012 estimated an abundance 744 whales (CV =0.34, 95% CI: 357-1,461; Rekdal *et al.* 2014). The estimated abundance of bowhead whales from the aerial survey in 2022, corrected for perception- and availability bias by using MRDS methods, was 915 whales (CV= 0.46, 95% CI: 385-2175). The estimated abundance of bowhead whales corrected for perception and availability bias for the strip census estimate by using the Chapman estimator for perception bias, was 993 whales (CV= 0.52, 95% CI: 380-2597).

The confidence limits of the abundance of bowhead whales in the survey area in 2022 from both the MRDS analysis and the strip census analysis are within similar estimates obtained between 2006 and 2012 indicating that there is a constant number of the East Canada-West Greenland population of bowhead whales that spend winter in the survey area off West Greenland.

Reliable estimates of the availability bias factors are important; if animals are only available for a short period of time the bias factors can substantially increase the abundance estimates. The availability correction factors used assume that the survey was instantaneous which is not strictly true as the animals will have been within detectable range for more than an instant, thus the correction in this way may yield somewhat positively biased results. On the other hand, Chapman's estimator (Chapman 1951) and the strip census estimation are likely to result in a negatively biased estimate of bowhead whales in the surveyed area assuming constant detection in the strip width.

Due to the low number of observations we propose to use the estimated abundance, using the strip census analysis where the correction of availability is considered to be an instantaneous process.

Figure 1

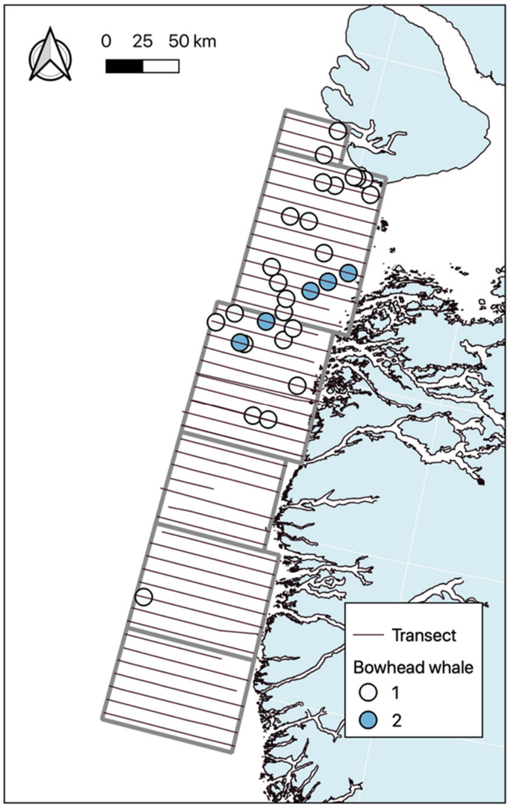

Fig. 1. Transects on effort for an aerial survey off West Greenland with distribution of sightings of bowhead whales shown in white (group size=1) and blue (group size=2) in March/April 2022. Strata 1 (North) to 6 (South).

Figure 2.

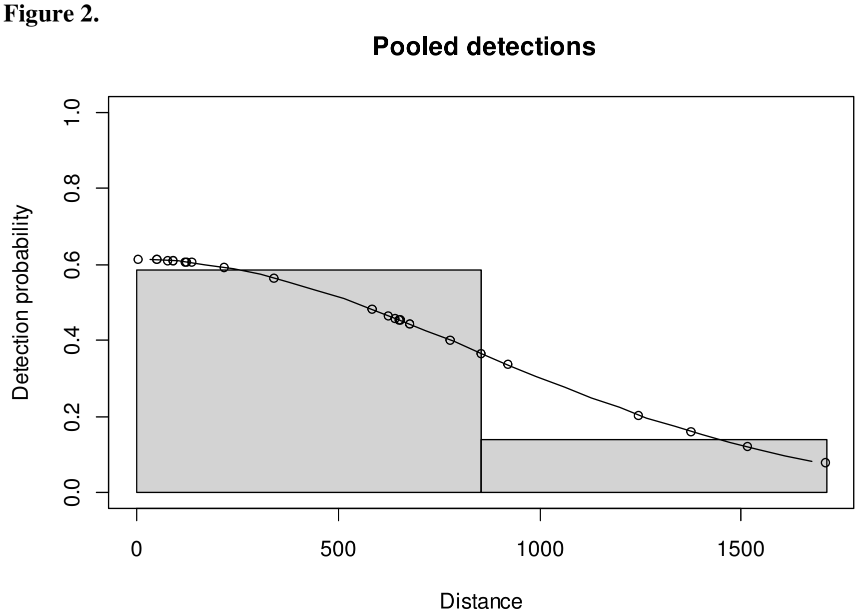

Fig. 2. Fitted perpendicular detection function superimposed on histogram of detection frequencies for bowhead whales in the West Greenland winter survey.

Figure 3.

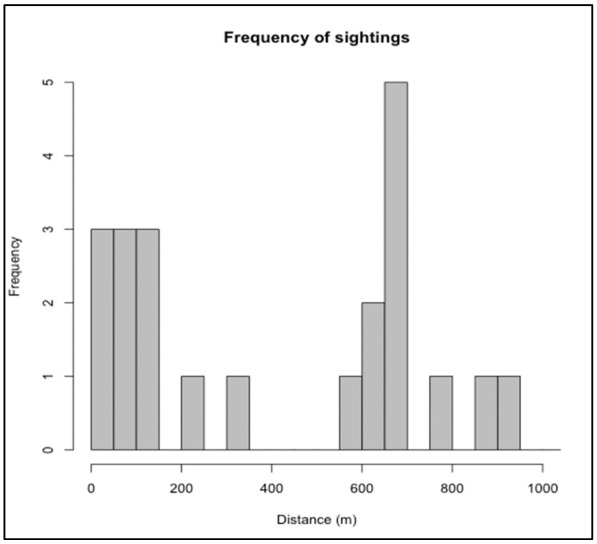

Fig. 3. Histogram of bowhead whale sightings as a function of distance (meter) to the track line in the West Greenland winter survey.

Table 1. Summary information of survey data; *k* is the number of transects searched in a stratum. Column 5 show the number of unique sightings for bowhead whales. Sightings used in MRDS analysis are all sightings between 0-1720 m and in the strip census analysis between 0-700 m.

Stratum	**Size (km^2)**	***k***	**Effort (km)**	**Sightings unique**	**Sightings used in MRDS analysis**	**Sightings used in strip census analysis**
1	1,275	3	137.6	2	1	1
2	8,941	12	945.9	16	15	14
3	7,813	10	865.6	10	9	7
4	4,928	7	406.5	0	0	0
5	6,605	8	702.7	1	1	0
6	5,180	7	608.7	0	0	0
Total	**34,742**	**47**	**3667**	**29**	**26**	**22**

Table 2. Summary of group sizes for unique sightings.

Group size	No. of sightings
1	24
2	5
Total	**29**

Table 3. MRDS probability of detection (*p'*) by observer on the trackline; CVs are given in parentheses.

Observer	*p'*
1	0.38 (0.17)
2	0.38 (0.17)
Both	0.62 (0.22)

Table 4. MRDS estimates uncorrected for availability bias of encounter rate (groups/km), animal density ($\widehat{D}$, animals/km^2), animal abundance ($\widehat{N}$); CV's are given in parentheses and expected group size ($\widehat{E}[s]$) with standard error.

Stratum	Encounter rate	$\widehat{D}_{Gi}$	$\widehat{N}_{Gi}$	$\widehat{E}[s]$
1	0.0073 (0.10)	0.0059 (1.07)	8 (1.07)	1 (0.9)
2	0.0173 (0.25)	0.0168 (0.45)	150 (0.45)	1.2 (2.1e-08)
3	0.0104 (0.42)	0.0103 (0.59)	80 (0.59)	1.22 (0.11)
4	0	Na	Na	Na
5	0.0014 (1.00)	0.0012 (1.07)	8 (1.07)	1 (0.0)
6	0	Na	Na	Na
Total	**0.0103 (0.21)**	**0.0010 (0.44)**	**246 (0.44)**	**1.19 (7.4e-02)**

Table 5. MRDS abundance estimates corrected for availability of individual animal abundance ($\widehat{N}$); CV's are given in parentheses and 95% Confidence intervals (CI).

Stratum	$\widehat{N}_{Gci}$	CI
1	30 (1.08)	5 - 167
2	588 (0.47)	231 - 1348
3	298 (0.61)	99 - 894
5	30 (1.08)	5 - 167
Total	**915 (0.46)**	**385 - 2175**

Table 6. Number of sightings of bowhead whale groups used in the strip census analysis and probability of detection (p') by observer on the trackline by observer 1 (front), observer 2 (rear) and by both observers after truncation at 700 m using the Chapman estimator, CV's is given in parentheses.

	Number of sigthtings	p'
Front observer	16	0.5
Rear observer	12	0.38
Both observers	6	0.72 (0.44)

Table 7. Strip census abundance estimates by stratum ($\widehat{N}_v$) with total abundance corrected for perception bias ($\widehat{N}'$) and availability bias ($\widehat{N'}_c$); CV's are given in parentheses and 95% Confidence intervals (CI).

Stratum	$\widehat{N}_v$	$\widehat{N}$'	$\widehat{N'}_c$	CI
1	8	-	-	-
2	123	-	-	-
3	61	-	-	-
Total	**192**	**267**	**993 (0.52)**	**380 - 2597**

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Consolidated Reviews for a Paper Estimating Abundance of West Greenland Bowhead Whales for SC69A

Geof H. Givens and Leslie New

One paper with an abundance estimate for bowhead whales off West Greenland (Hansen, 2023) was reviewed intersessionally by the Abundance Steering Group (ASG); see Table 1.

The ASG/ASI review process is established by IWC (2020, 2022) and subsequent amendments. The key portions of those documents, and the instructions given to reviewers, are provided for this meeting in SC/69A/ASI/WP/01.

Reviewer 1 provided R code to demonstrate the calculations used in his review. This was provided to the authors, and could be provided to ASG/ASI if necessary.

The review and our recommendation are provided in the Appendix. The authors provided a detailed response, including re-analysis, which is also provided.

Table 1: Papers reviewed and reviewers.

SC69A document	Title	Reviewer
ASI 03	Hansen, R. (2023). Abundance of bowhead whales (*Balaena mysticetus*) in West Greenland, 2022	

References

Hansen, R. (2023). Abundance of bowhead whales (*Balaena mysticetus*) in West Greenland, 2022. Paper SC/69A/ASI/03 submitted to SC69A.

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Appendix: Reviews and Recommendations

Hansen (2023)

Recommended Category: Category 1A	We concur with both concerns of Reviewer 1, and consider that the author's response adequately addresses these, provided that the "MRDS, Greenland data, C_a" estimate of 888 is chosen from the table in the response. Sample sizes for all portions of the analysis are notably small, but tolerable.

Reviewer 1

General comments

The overall design and implementation of data collection is appropriate for the population of interest. The field techniques are appropriate to ensure data of sufficient quality. The applicable IWC guidelines for line transect surveys appear to have been followed. The data used in the analysis have been clearly specified. The methods used have been adequately documented, are appropriate for the biology and behaviour of the species, the specific nature of the data collected and are useful.

The methods have been previously used to collect and analyse similar data and these are appropriately referred to. The method assumptions, the way the data were collected and the way the analysis has been implemented are fully described. Data collection and analysis appear to have been implemented as intended. The estimates are probably as precise as they could be, given the small number of sightings on the implemented surveys.

I have two concerns.

MRDS vs strip transect

I question the conclusion in the paper that the cruder strip transect method of analysis to obtain a perception bias corrected estimate of abundance is more appropriate than MRDS. Although more sightings are desirable, the MRDS analysis is quite able to generate reliable estimates with a relatively small sample size, especially given that the conditional probability (MR) model used in this analysis did not include perpendicular distance as a covariate and is thus equivalent to the simple Petersen/Chapman estimate used in the strip transect analysis. I see no reason not to use the MRDS estimated detection probability on the transect line of 0.62 (CV=0.22), despite the small number of sightings. The equivalent Chapman estimate from the strip transect analysis of 0.72 likely differs (and is less precise) because of the different (smaller) number of sightings used.

Availability

The mark-recapture distance sampling estimates (which account for perception bias) are corrected for availability bias by applying an estimate of instantaneous availability for a single individual, previously estimated from telemetry data (the proportion of time an animal is estimated to be in the top 2m of the water column: 0.269). The paper states that because the median time-in-view was short (4.5s) it was decided not to apply an estimate of availability that incorporated the time an animal is available to be detected. Resulting bias has been assumed to be small, but the paper recognises that it may yield positively biased estimates. I think the bias is likely more than small and therefore also question the decision to ignore this.

Although the median time-in-view is short, whales are clearly available to be detected for much longer. Indeed, the paper states that time-in-view ranged from 0 to 60 seconds. Availability accounting for time available to be detected can be estimated using the method of Laake et al (1997). Additional data needed are two-fold: mean near surface and dive times; and an estimate of the distance ahead that animals may be detected. Near surface and dive times are presumably available from the telemetry studies used to estimate instantaneous availability. If not, there are published surface/dive data for bowhead whales in the Beaufort Sea (Robertson et al 2013) that could be used. The distance ahead could be assumed to be the same as the perpendicular truncation distance (here 1,720m) on the assumption that the viewing area is square (Barlow et al 1988), but it could be greater than this (see below).

An additional point is that the availability correction used is for a single individual but the sightings data are of detections of groups. Table 2 shows that groups were mostly single animals but there were some pairs. If pairs of animals surface synchronously, their availability is the same as for a single animal. But if they surface asynchronously, availability of the group will be greater than that of a single animal. An estimate of the availability of a group, *a(Group)*, assuming all individuals in a group surface independently, is given by Paxton et al (2016):

$$a(Group) = 1 - (1 - a(Individual))^{GroupSize}.$$

Availability could be estimated thus, using the mean group size of 1.19. In the absence of information on synchronicity of diving, availability for a singleton and availability corrected for group size could be considered as lower and upper bounds.

I explored the impact on the MRDS estimates of abundance of applying a non-instantaneous availability correction using Equation 4 from Laake et al (1997) and groups greater than one using the equation above.

I estimated time available for detection as perpendicular truncation distance (1,720m) divided by aircraft speed (170 $km.h^{-1}$) = 36.4s. I also explored the impact of using the median time-in-view (4.5s) and the maximum time-in-view (60s) as time available for detection.

I summed summer undisturbed mean surface time (1.11 minutes) and mean dive time (6.57 minutes) from Robertson et al (2013, Table 4b) to give an estimate of the mean length of the dive cycle, and multiplied this by the instantaneous availability in the top 2m of the water column given in the paper (0.269) to give mean near surface (0-2m) time of 124s, and by 1 - 0.269 to give mean dive (>2m) time of 337s.

Results are in the table below. Increasing the time available for detection from 0 (instantaneous as used in the paper) to 4.5s, 36.4s and 60s leads to a decrease in estimated corrected abundance compared with that estimated in the paper of 3%, 22% and 31%, respectively. Additionally applying the group size correction leads to decreases of 17%, 32% and 39% respectively.

Time available for detection	**Group size**	**Availability (0-2m)**	**Corrected abundance**
0 (instantaneous – from paper)	1	0.269	915
Median time-in-view (4.5s)	1	0.279	883
Median time-in-view (4.5s)	1.19	0.322	764
Perp dist / aircraft speed (36.4s)	1	0.344	715
Perp dist / aircraft speed (36.4s)	1.19	0.394	624
Max time-in-view (60s)	1	0.388	634
Max time-in-view (60s)	1.19	0.443	556

My conclusion is that relaxing the assumptions made in the paper of instantaneous availability and single individuals have non-trivial effects on estimated corrected abundance, which need to be considered before these estimates are used for management. As such, I would assign an ASI category P to the estimate(s) but I see no reason why it should not be category 1A, once the issues above have been addressed.

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Reviewer 2

The goal of this paper was to estimate the abundance of the part of the East Canada-West Greenland population of bowhead whales that were in waters off West Greenland during the winter, January – May. The goal was not to derive a full population abundance estimate. To achieve their goals, they conducted a 2 independent 2-person team visual aerial line transect survey at 700 feet altitude in good sighting conditions (< Beaufort 3) during 26 Mar – 4 Apr 2022 in a Twin Otter aircraft off the coast of northern West Greenland to estimate the surface abundance corrected for perception bias. In addition, they used previously collected dive-depth data from individual tagged bowhead whales to develop a correction factor for availability bias.

In brief, the authors provided sufficient information to evaluate these estimates that were derived with appropriate field and analytical methods using reasonable assumptions and leading to appropriate conclusions. The design of the survey, parallel track lines in multiple strata, covered the area of interest during the desired period. Although in hindsight, the results indicated there were animals at some of the edges of the study area, so slightly longer track lines may have resulted in more sightings. The field techniques (a line transect 2-team aerial survey) and analysis methods (mark-recapture distance sampling and strip transect methods) were sufficiently described and implemented and should be appropriate to ensure high quality data and appropriate conclusions.

The complicating factor in this analysis was the small sample size of bowhead whale sightings detected in the current survey, 29 groups in 3667 km of track line. Thus, the reason to use a strip-transect analysis method in addition to the standard mark-recapture distance sampling analysis methods. Estimates of variance incorporated the line-transect and dive correction aspects using the delta method and appears to be sufficient. The resulting abundance from both analysis methods were similar: 915 whales (CV=0.46) from mark-recapture distance sampling analysis and 993 whales (CV=0.52) from strip-transect analysis. Due to the small sample size, the authors proposed to use the strip-transect results as their best estimate. This proposal seems justifiable. To increase the sample size for the detection function, the authors could have also considered pooling the bowhead whale sightings from this survey either with bowhead sightings from previous surveys (assuming the field methods were similar) or with other large whale sightings from the current survey (assuming there were other large whale sightings).

A major influencing factor on the abundance estimate is the availability bias correction factor, an average of 26.9% (CV=0.14) of the time that the bowhead whales spend within 2m of the surface, where they could be detected by the aerial survey team. As always, more dive data would be useful to confirm this average is appropriate. The authors did not incorporate time-in-view (0-60 sec, median was 4.5 sec) into the availability bias correction factor. Although the small time-in-view would not have altered the correction factor much.

In conclusion, this estimate could be categorized as 1A, where the estimate could be acceptable for use in in-depth assessments or for providing management advice, where the assessment accounts for the fact that this is an estimate of a subset of the North Atlantic bowhead whale population that is using a subset of their habitat, waters off west Greenland in the winter.

Author Response

Rikke G. Hansen and Lars Witting

Thanks for the two reviews of the abundance estimation paper for bowhead whales in West Greenland in 2022. We agree with both reviewers that we obtain a better estimate by correcting for time-in-view, and we provide the correction below.

We also realise that it can be necessary to include group size dive patterns in the availability correction in some cases. Yet, we do not think that this is the case for our bowhead survey, where we observe only a single individual most of the time, and in few cases a group of two whales. Quite generally, we only count a group of two whales as a group-of-two when the two individuals are surfacing at the same time. If we, as suggested for the group size correction proposed by reviewer 1, assume that whales dive independently of one another with an individual surface availability of 0.27, then a group-of-two is counted as a group-of-two only in 0.27*0.27/(2*0.27*0.73+0.27*0.27) = 16% of the cases, while the group-of-two is counted as a single whale in 88% of the cases. In other words, our time-in-view corrected estimate is an estimate of the instantaneous density of whales at the surface based on independent dives of individuals and should thus be corrected for availability by the average 0.27 availability of an individual. It is currently our view that this is the correct correction model to use for most surveys of large whales that surfaces as single individuals most of the time.

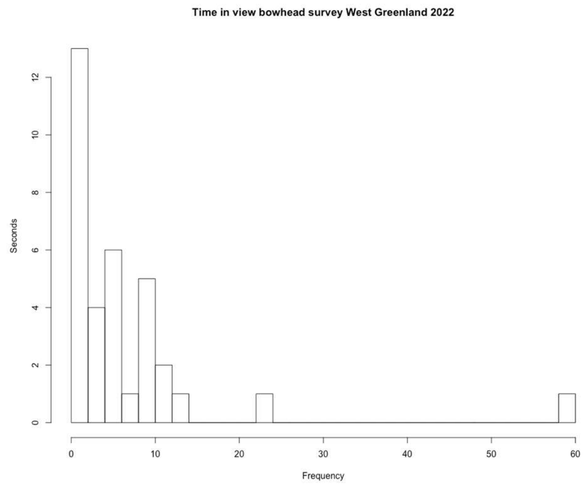
Time-in-view

For the time-in-view question we have made the following calculations: Based on the availability correction factor of 0.269 we have used a subsample of TDR data from three bowhead whales in West Greenland for estimating the mean duration of surfacing periods (*ts*) and the mean duration of dives (*td*). See Heide-Jørgensen et al. (2013) for the original data collection.

Whale	***ts* (0-5m)**	***td* (>5 m)**
#1	136 s	800
#2	123 s	1036
#3	339 s	413

There are several other data series from West Greenland but it will take some time to extract the relevant data.

The observed TIV values from the survey in 2022 are shown in the histogram below:



Following the approach by Richard et al. (2010) a weighted availability bias correction factor C_a was calculated as:

$$C_a = C_i \cdot \frac{\sum_{i=1}^{n} obs_i * (1 - b_i)}{\sum_{i=1}^{n} obs_i}$$

where *n* is the longest time-in-view, *obs* is the frequency of time-in-view observations with a duration of *i* seconds and b_i is the percent bias of an instantaneous correction C_i for i seconds:

$$b_i = \frac{C_M(0) - C_M(i)}{C_M(0)}$$

Only C_i was assumed to contribute to the variance of C_a.

Revised estimates were calculated where the Greenland data consist of TDR recordings from three whales in spring in West Greenland and the Robertson data (Robertson et al. 2013) are from visual observations in Alaska. There is a major difference in bathymetry between the two areas with the Alaska coast being mostly shallow (<200m) whereas the Greenland bowhead habitat mainly consist of deep waters (200-1000 m). Thus, the Greenland TDR data more closely represent the expected behavior of bowhead whales during a survey in this area.

Survey method and correction	**Availability**	**CV**	**Abundance**	**CV**
Strip census no tiv correction, C_i	0.268	0.15	993	0.52
Strip census Greenland data, C_a	0.277	0.15	964	0.52
Strip census Robertson et al. 2013, C_a	0.292	0.15	914	0.52
MRDS no tiv correction, C_i	0.268	0.15	915	0.46
MRDS Greenland data, C_a	0.277	0.15	888	0.46
MRDS Robertson et al. 2013, C_a	0.292	0.15	842	0.46

References:

Heide-Jørgensen, M.P., K.L. Laidre, N.H. Nielsen, R.G. Hansen, A. Røstad. 2013. Winter and spring feeding behavior of bowhead whales. Animal Biotelemetry 1-15.

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