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A re-analysis of northern Hudson Bay narwhal surveys conducted in 1982, 2000, and 2011

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Assessing trends associated with long-term monitoring of the abundance of wildlife populations is partly hindered by differences in methodologies as new techniques and equipment are developed. The Northern Hudson Bay (NHB) narwhal population was surveyed in the early 1980s, 2000, and 2011. The three estimate methodologies (from the 1980s, 2000, and 2011) varied in terms of spatial extent, data collection, and analysis. The 2011 visual survey data were re-analysed using the methods of the visual surveys in 1982 and 2000. The ratios of the 2011 abundance results to those that would have been obtained using the methods from 1982 and 2000 were calculated. The 1982, 2000, and 2011 analysis methods, when applied to the 2011 survey data, yielded surface estimates of 1737 (95% Confidence Interval (C.I.) 1002-3011), 1945 (95% C.I. 1089-3471) and 4452 (95% C.I. 2707-7322) narwhals, respectively. The ratios of the 2011 to the 1982 and 2000 surface estimates were 2.56 and 2.29, respectively. These ratios show that large differences in estimates of abundance can be associated with the use of different survey and analysis methods. Nevertheless, these survey ratios assist in assessing trends in the NHB narwhal population by accounting for changes in methodologies over time.

Nouvelle analyse des relevés sur le narval du nord de la baie d'Hudson effectués en 1982, 2000 et 2011

RÉSUMÉ

L'évaluation des tendances reliées à la surveillance à long terme de l'abondance des populations d'espèces sauvages est en partie entravée par les différences méthodologiques résultant de techniques et d'équipement nouvellement mis au point. La population de narvals du nord de la baie d'Hudson (NBH) a fait l'objet de relevés au début des années 1980, en 2000 et en 2011. Les trois méthodes d'évaluation (issues des années 1980, de 2000 et de 2011) étaient différentes sur le plan de l'étendue spatiale, de la collecte des données et de l'analyse. Les données du relevé visuel mené en 2011 ont été analysées à nouveau en faisant appel aux méthodes utilisées pour les relevés de 1982 et de 2000. On a calculé les ratios des résultats de l'abondance de 2011 par rapport aux résultats qu'on aurait obtenus en faisant appel aux méthodes de 1982 et de 2000. Les méthodes d'analyse de 1982, de 2000 et de 2011, lorsqu'elles ont été appliquées aux données du relevé mené en 2011, ont donné des estimations du nombre de narvals à la surface s'élevant à 1737 (intervalle de confiance (IC) de 95 %; 1002 à 3011), 1945 (IC de 95 %; 1089 à 3471) et 4452 (IC de 95 %; 2707 à 7322) individus, respectivement. Les ratios des estimations en surface de 2011 par rapport à celles de 1982 et de 2000 ont été de 2,56 et de 2,29, respectivement. Ces ratios révèlent que des différences importantes dans les estimations de l'abondance peuvent être liées à l'utilisation de méthodes de relevé et d'analyse différentes. Quoi qu'il en soit, ces ratios aident à évaluer les tendances de la population de narvals du NBH tout en tenant compte des changements apportés aux méthodes au fil du temps.

INTRODUCTION

The Northern Hudson Bay (NHB) narwhal population was first assessed through visual and photographic surveys in the early 1980s and estimated to number approximately 1300 animals at the surface (i.e., not accounting for submerged animals that were unavailable to surveyors) (Richard, 1991). In 2000, photographic and visual surveys led to an updated population estimate of 1778 (90% C.I. 1688-2015) animals at the surface (Bourassa, 2003) which Richard (2008) corrected to 5052 (Coefficient of Variation (CV)=0.40) to account for submerged animals. For both the surveys of the early 1980s and those from 2000, the photographic surveys resulted in higher abundance estimates than the visual surveys (Richard, 1991; Bourassa, 2003) and the 2000 photographic results were used for management purposes (e.g., Richard, 2008). An attempt was made in 2008 to re-survey the population, but this attempt was unsuccessful due to a combination of equipment failure and unfavorable weather (Richard, 2010). From 4 to 17 August 2011, northern Hudson Bay was re-surveyed using a combination of visual and photographic methods which led to an updated population estimate of 12,485 (CV=0.26), fully accounting for submerged animals (Asselin et al., 2012).

The three estimate methodologies (from the 1980s, 2000 and 2011) varied in terms of spatial extent, data collection and analysis. Assessing trends from long-term monitoring of the abundance of wildlife populations is difficult due to changes in methodologies as new techniques and equipment are developed. Kingsley et al. (2012) developed a population model for the NHB narwhal population based on the surveys conducted before 2011 and updated it using the recent survey results (Kingsley et al. 2013). The population model incorporated the changes in spatial extent of the surveys but not the differences in data collection and analysis.

The objectives of this paper were to re-analyse the 2011 survey data using the methods of the 1980s and 2000 visual surveys and to then calculate the ratios of the 2011 results to those that would have been obtained using the methods from 2000 and 1982. These ratios of abundance were then used in the updated stock-dynamic model by Kingsley et al. (2013).

BACKGROUND

EARLY SURVEYS

Surveys were conducted in August 1981, July 1982, 1983 and 1984 and March 1983 (Richard 1991). Only the July 1982 survey was a systematic visual survey. This visual survey was flown in a DeHavilland Twin Otter (DH-6) at 305 m of altitude and at an air speed of 185 km/hr. A single observer sat on each side of the aircraft and counted narwhals within an 800 m strip that was marked on the window and strut of the aircraft (i.e., single-observer strip-transect survey). Notably, this survey was analyzed as a 600 m strip width based on the work of Norton and Harwood (1985) which found that beluga detection dropped off beyond 600 m from the track line and narwhals were assumed by Richard (1991) to have similar or worse detection rates. The visual survey from 23 July 1982 resulted in a mean estimate of 1038 narwhals at the surface.

2000 SURVEYS

The systematic visual survey was flown in a DeHavilland Twin Otter at 324 m of altitude and at an air speed of 200 km/hr (Bourassa 2003). Two observers sat on either side of the aircraft and counted groups of narwhals. When a group was sighted, it was assigned to a distance bin, at 200 m intervals, outlined on the window of the aircraft, to allow for distance analysis. While there were two observers on either side of the aircraft, the recording method used to note the sightings did not make it possible to match up sightings between the two observers. The data were thus analyzed using Conventional Distance Sampling (Thomas et al., 2010) and two separate abundance estimates were determined: one for the front observers, and one for the back observers. The surface estimates for the front and back observers were 2231 (90% C.I. 1258-5926) and 1195 (90% C.I. 1094-6190) respectively.

METHODS

Full descriptions of the data collection and analysis methods can be found in Richard (1991) for the early 1980s surveys, Bourassa (2003) for the 2000 surveys and Asselin et al. (2012) for the 2011 surveys. Short summaries of the methods are presented here and in Table 1.

Table 1. Summary of analysis methods for 2011, 2000 and 1982 methods.

	2011	**2000**	**1982**
Observers per side of plane	2	1[1]	1
Survey type	Mark-recapture Distance Sampling (MRDS)	Conventional Distance Sampling (CDS)	Strip Transect Sampling
Near-side truncation	200 m	None	32 m[2]
Far-side truncation	None	800 m	632 m[3]
Distance Analysis Engine	MRDS	CDS	CDS
Detection Function	Hazard Rate	Hazard Rate	Uniform
Distance Model Covariates	Cloud Cover	None	None
Mark-Recapture Model Covariates	Distance, observer (primary or secondary), side of aircraft (left or right) and ice concentration	N/A	N/A
Additional information collected	Aerial photos	None	None

[1] During the 2000 survey, 2 observers were on each side of the aircraft and the data were analyzed as two CDS surveys. Using the 2011 dataset, only the primary observer data were used.
[2] 32 m is the closest distance for the 2011 dataset.
[3] Sightings go out to 813 m but analyzed as a strip from 32 to 632 m (600 m strip).

FIELD METHODS

2011 surveys

A visual survey was conducted from 4 to 17 August 2011. Surveys were flown in a DeHavilland Twin Otter equipped with bubble windows and an optical glass-covered camera hatch at the rear. Surveys were conducted at an altitude of 305 m (1000 ft) and a ground speed of 185 km/hr (100 kn) with four observers, two on each side. Using black curtains, observers were visually isolated from each other to ensure that each observation was independent (i.e., that observers were not cueing each other in to sightings). Aircraft noise combined with disconnected aviation headsets provided auditory isolation. Standard distance sampling techniques were used and the declination angle to each sighting was measured and then later converted to a distance from the track line using the altitude of the aircraft. In addition to the visual surveys, we photographed the area directly below the aircraft throughout the flights. (For a more complete description of the 2011 survey methods see Asselin et al., 2012.)

ANALYTICAL METHODS

The 2011 surveys were analyzed using the Mark-Recapture Distance Sampling engine in Distance 6.0 (Thomas et al., 2010). Data from all four observers were used in the analysis and Asselin et al. (2012) corrected for perception bias and availability bias (Marsh and Sinclair, 1989). In addition, the aerial photos were used to confirm species identification (e.g., between narwhal and beluga), to validate narwhal sightings for which the observers were uncertain and to determine distance from the track line for sightings not measured by the observers or measured incorrectly (see full details in Asselin et al. 2012). The data were left truncated by 200 m to account for the decrease in detection rates below the plane and near the track line.

2011 dataset

To determine a correction factor for the 1982 and 2000 visual surveys, data from the front observers were used. These two observers were more consistent and had higher detection rates than the back observers (Asselin et al., 2012). Only sightings identified with certainty were used. Those included in the 2011 estimate through the use of the aerial photographs or by confirmation with the secondary observers were omitted from the analysis, as these methods were not used in the 1982 or 2000 analysis.

2000 survey methods

For re-analysis of the 2011 data using the 2000 survey methods, the 2011 data were not truncated following Bourassa (2003) who makes no mention of truncation. The data were binned at 0, 200, 400, 600 and 800 m and analyzed in Distance 6.0 (Thomas et al., 2010) as a single-observer Conventional Distance Sampling (CDS) survey. Two observations above 800 m were removed from the analysis to improve model fit. Model selection for the best of detection function was based on the lowest Akaike's Information Criterion (AIC) (Buckland et al., 2001; Burnham and Anderson, 2002). A global detection function was modeled and then used to calculate surface estimates by stratum. Covariates were not included in the analysis.

1982 survey methods

The 2011 narwhal observations ranged from a distance of 32 m to 813 m from the track line. Consequently, as these observations did not cover a strip wider than 800 m they were all included in the re-analysis. The re-analysis was conducted in two ways. First, the data were analyzed using methods similar to Richard (1991) which were based on the methods of Kingsley et al. (1985). For each transect, the extrapolated narwhal count and the extrapolated total area were calculated using modified versions of the formulae in Kingsley et al. (1985) [(1) and (2)]

(1) $Y_i = W_i t_i$

where: Y_i = extrapolated total narwhals on *i* th transect

W_i = transect spacing for *i* th transect (in transect-widths)

t_i =narwhals counted on *i* th transect

(2) $X_i = W_i A_i$

where: X_i =extrapolated total area of *i* th transect

A_i = area of *i* th transect

The stratum density ($\hat{R}_S$) was calculated as the standard ratio estimate (3).

(3) $$\hat{R}_S = \frac{\sum_{i=1}^{I} Y_I}{\sum_{1}^{I} X_I}$$

where: $I =$ Number of Transects

A variance estimate based on serial differences was calculated following Kingsley et al. (1985) (4).

(4) $$S^2 = \frac{I \sum_{1}^{I-1} (d_i - d_{i+1})^2}{2 \times (I-1) \times (\sum X_i)^2}$$

where: $d_i = Y_i - \hat{R} X_i$

The abundance of each stratum was calculated by multiplying the estimated stratum density and the stratum area.

In addition to the abundance calculations using the formulae from Kingsley et al. (1985), the data were also analyzed in Distance 6.0 as one 600 m strip, with a Uniform detection curve.

For all of the analyses, as narwhals had time to re-locate within the study area between 8 August and 14 August, only the surveys flown from 14 August to 17 August were used in the abundance estimates. The final abundance estimate for the Repulse Bay stratum ($\hat{N}_R$) was calculated by averaging the estimates from the two surveys conducted on 14/15 August and 17 August. Averaging was done using a mean weighted by effort (eq. 5):

(5) $$\hat{N}_R = \frac{E_{R1}\hat{N}_{R1} + E_{R2}\hat{N}_{R2}}{E_{R1} + E_{R2}}$$

Where E_i is the effort calculated as the area covered by the survey *i*.

The variance of the mean estimate was calculated as follows (eq. 6):

(6) $$\text{var}(\hat{N}_R) = \frac{E_{R1}^2 \text{var}(\hat{N}_{R1}) + E_{R2}^2 \text{var}(\hat{N}_{R2})}{\left(E_{R1} + E_{R2}\right)^2}$$

The total surface estimate was calculated by summing the individual estimates from all strata flown from 14 August to 17 August. The variance of that surface estimate is the sum of the variances of the individual stratum estimates. The ratios of the total surface abundance estimates from 2011 methods to the 2000 methods and the 1982 methods were calculated.

RESULTS

Using the methods from the 1982 and 2000 visual surveys, changed the data available for analysis and the resulting abundance estimates for each stratum (Table 2). For the 2011 survey, using Distance 6.0, the selected analysis model used a Hazard Rate detection function with distance, observer (primary or secondary), side of aircraft (left or right) and ice concentration as covariates of the Mark-Recapture model and cloud cover as a covariate of the Distance model (Asselin et al., 2012) (Figure 1, Table 1). For the 2000 survey methods, analyzed using the Conventional Distance Sampling engine in Distance 6.0, a Hazard Rate detection function once again resulted in the lowest Akaike's Information Criterion (AIC) value (Figure 1, Table 1). No covariates were added as these were not used in the analysis by Bourassa (2003). For the 1982 survey methods, a Uniform Detection function was used with the data in one 600 m bin (Figure 1, Table 1). For the 1982 survey methods, the analysis using Distance 6.0 gave the same abundance results as the analysis using the methods of Kingsley et al. (1985) but different estimates of the coefficients of variation of the abundance estimates (Table 2).

The use of a MRDS analysis for the 2011 survey data resulted in a higher abundance estimate than would have been calculated using the methods of the 2000 survey or of the 1982 survey (Table 3). The 2000 survey methods also lead to a higher abundance estimate than that of the 1982 survey methods.

Table 2. Survey coverage, sightings and surface estimates by stratum (CVs are shown in parentheses, surveys in bold were used in the population abundance estimates).

	METHOD	**STRATUM**									
		Repulse Bay (Partial)	Roes Welcome Sound	Gore Bay	**Wager Bay**	**Repulse Bay (1)**	Northern Bays (Partial)	**Foxe Channel**	**Roes Welcome Sound (Partial)**	**Northern Bays**	**Repulse Bay (2)**
Date		4-Aug	6-Aug	8-Aug	**14-Aug**	**14+15 Aug**	15-Aug	**15+16 Aug**	**16-Aug**	**16-Aug**	**17-Aug**
Area (km^2)		6884	4706	435	**2819**	**6884**	1233	**6689**	**3407**	**1233**	**6884**
Total Transect Distance (km)		326	313	63	**150**	**529**	34	**533**	**220**	**226**	**539**
Surveyed Area (km^2)[1]	2011	399	384	77	**184**	**648**	42	**653**	**269**	**277**	**660**
	2000	522	501	101	**240**	**846**	54.4	**853**	**352**	**362**	**862**
	1982	391	376	76	**180**	**635**	41	**640**	**264**	**271**	**647**
Sightings with Distance	2011	4	0	13	**19**	**20**	4	**3**	**3**	**49**	**20**
	2000	3	0	20	**20**	**21**	7	**4**	**0**	**61**	**16**
	1982	3	0	20	**20**	**21**	7	**4**	**0**	**62**	**17**
Cluster size	2011	1.5	0	3.4	**1.8**	**2.1**	3.4	**1**	**1.3**	**2.8**	**2.5**
	2000	1.7	0	3.2	**1.8**	**2**	3.1	**1.8**	**0**	**2.6**	**1.5**
	1982	1.7	0	3.2	**1.8**	**2**	3.1	**1.8**	**0**	**2.6**	**1.6**
Average Probable Detection over Distance *g(x)*	2011	0.41 (0.04)	0.41 (0.04)	0.41 (0.04)	**0.41 (0.04)**	**0.41 (0.04)**	0.41 (0.04)	**0.41 (0.04)**	**0.41 (0.04)**	**0.41 (0.04)**	**0.41 (0.04)**
	2000	0.64 (0.07)	0.64 (0.07)	0.64 (0.07)	**0.64 (0.07)**	**0.64 (0.07)**	0.64 (0.07)	**0.64 (0.07)**	**0.64 (0.07)**	**0.64 (0.07)**	**0.64 (0.07)**
	1982	1.00	1.00	1.00	**1.00**	**1.00**	1.00	**1.00**	**1.00**	**1.00**	**1.00**
Estimated Coverage (%)[2]	2011	2.4	3.4	7.2	**2.7**	**3.9**	1.4	**4**	**3.3**	**9.3**	**3.9**
	2000	4.8	6.8	14.8	**5.4**	**7.9**	2.8	**8.2**	**6.6**	**18.8**	**8.0**
	1982	5.7	8.0	17.4	**6.4**	**9.2**	3.3	**9.6**	**7.7**	**22.0**	**9.4**
Average Probable Detection at Track Line *p(0)*	2011	0.91 (0.03)	0.91 (0.03)	0.91 (0.03)	**0.91 (0.03)**	**0.91 (0.03)**	0.91 (0.03)	**0.91 (0.03)**	**0.91 (0.03)**	**0.91 (0.03)**	**0.91 (0.03)**
	2000	1.00	1.00	1.00	**1.00**	**1.00**	1.00	**1.00**	**1.00**	**1.00**	**1.00**
	1982	1.00	1.00	1.00	**1.00**	**1.00**	1.00	**1.00**	**1.00**	**1.00**	**1.00**
Surface Estimate	2011	335 (0.60)	0 (0)	521 (0.55)	**1095 (0.63)**	**1160 (0.69)**	933 (1.09)	**76 (0.52)**	**107 (0.77)**	**1746 (0.44)**	**1692 (0.34)**
	2000	104 (0.76)	0 (0)	420 (0.45)	**705 (0.65)**	**389 (0.64)**	810 (1.20)	**86 (0.79)**	**0 (0)**	**812 (0.42)**	**295 (0.33)**
	1982[3]	88 (0.78; 0.67)	0 (0; 0)	371 (0.58; 0.43)	**562 (0.76; 0.64)**	**456 (0.82; 0.63)**	660 (1.43; 1.1.4)	**73(0.79; 0.78)**	**0 (0; 0)**	**731 (0.25; 0.41)**	**288 (0.34; 0.32)**

[1] Total transect distance multiplied by twice the largest perpendicular distance. (Note: The largest perpendicular distance was first truncated by 200 m for the 2011 survey methods.)
[2] [(Surveyed Area · g(x)) / Area] · 100
[3] The surface estimate was calculated using two methods (from Kingsley et al. 1985 and in Distance 6.0) with the same results. One CV was calculated using formula from Kingsley et al. 1985; the other in Distance 6.0.

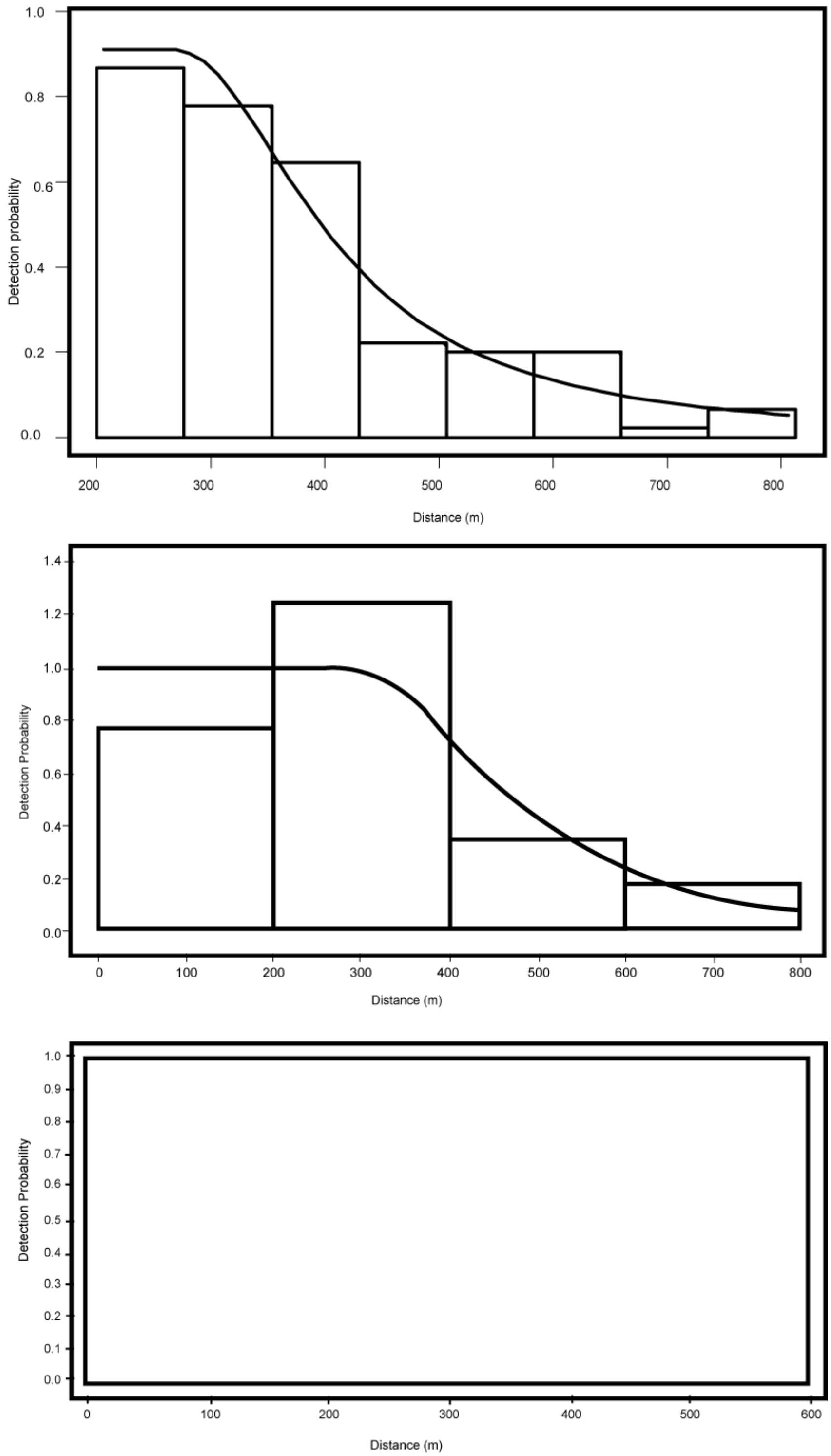

Figure 1. Fitted detection functions and histograms of detection distances for the 2011 double-observer Mark Recapture Distance Sampling pooled observation (top), the 2000 Conventional Distance Sampling single observer methods (middle), and the 1982 single observer strip survey methods bottom using a Uniform Detection function with the data in one 600 m bin, from Distance 6.0 (Thomas et al., 2010).

Table 3. Surface estimates of the 2011 aerial survey dataset using the methods of 2011, 2000 and 1982, and the ratios of the results. C.L. = confidence limit

	C.L. 2.5%	Mean	C.L. 97.5%	CV
Method				
2011	2707	4452	7322	0.26
2000	1089	1945	3471	0.30
1982	1002	1737	3011	0.29
Ratios				
2011:2000		2.29		
2011:1982		2.56		
2000:1982		1.12		

DISCUSSION

All of these results are based only on the 2011 dataset. Variations in observers and survey conditions during the 1982 and 2000 surveys make it unlikely these ratios are exact.

Specific to the 1982 survey, the field survey methods for a strip survey differ from those of a distance sampling survey. While conducting a strip survey (as in 1982), observers attempt to count all animals within the strip. In contrast, for Distance sampling (as in 2000 and 2011), observers are advised to pay most attention to the area closest to the line and that missing animals farther off is not a problem. Consequently, the abundance results from the 2011 dataset analyzed as a strip survey (as in 1982) may underestimate what the true abundance results might have been had a strip survey been conducted from the start (i.e., for the field work and the analysis).

For the 2000 survey, the lack of truncation of the area directly below the aircraft effectively increased the estimated coverage and thus decreased the density estimate and the resulting narwhal surface abundance estimate. Truncation can be used in Distance to compensate for the inadequate view of the trackline in aerial surveys (Buckland et al. 2001) and has been used for other narwhal aerial surveys conducted in DeHavilland Twin Otters: e.g., Richard et al. 2010 (altitude=335.3 m, truncation=200-300 m), Asselin and Richard 2011 (altitude=305 m, truncation=150 m), and Asselin et al. 2012 (altitude=305 m, truncation=200 m). The lack of truncation is the largest contributor to the ratio we calculated for the difference in results between the 2000 and 2011 survey methods.

The narwhal detection distances for the 2000 survey indicate that for three of four observers, more narwhals were observed in the 200-400 m bin than in the 0-200 m bin (Bourassa 2003: p.39, Figure 5A), but the 0-200 m bin contains most of the sightings when data from all observers are summed (Bourassa 2003: p.39, Figure 5B). Consequently, the impact of the lack of truncation is not as readily apparent in the 2000 dataset as it is in the 2011 dataset. We hypothesize that the large number of detections in the 0-200 m bin in the Bourassa dataset may be due to observers overly focusing their attention on the visible area closest to the trackline, to meet the Distance sampling assumption that g(0)=1. Described as ‘guarding the centre-line’ (Buckland et al. 2001), this can lead to heaped data in the closest area visible to observers. The lack of truncation may have obscured this effect. As the data were collected in bins during the 2000 survey, it is difficult to estimate how large an area was not visible to observers and should have been truncated. Based on the above cited narwhal surveys analyses and the 2011 dataset, we hypothesize that some narwhals were likely missed out to a minimum of 100 m; the area directly below the plane was not visible to observers.

For the various reasons discussed above, some caution is needed when using these calculated ratios but they do provide a better understanding of the impacts of analysis methods on abundance estimates. They can thus aid in determining trends in population size in spite of changes in methodologies over time.

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