Abundance and distribution of narwhals in Melville Bay in 2014

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ABSTRACT

The smaller of two summer stocks of narwhals in West Greenland occur in the Melville Bay. It is subject to hunting under quota regulations and it is considered susceptible to disturbance from offshore seismic survey activities. In order to assess the long-term effects of seismic activity on this population, and to ensure a continued sustainable catch level, population monitoring was initiated in 2012 when a large-scale seismic exploratory program was conducted in northern Baffin Bay. To assess inter annual changes in abundance an aerial survey was conducted in 2014 that provides data on distribution and abundance comparable to previous surveys. The survey was conducted in late August using a Twin Otter aircraft with four independent observers seated at bubble windows. The double platform setup allowed for MRDS analyses with quantification of observer perception bias ($g(0)$=0.98, *cv*=0.02). Availability bias (*a*=0.22, *cv*=0.09) was corrected for by using independent data from satellite linked time-depth recorders. A total of 1872 km were covered on 32 transects systematically distributed in the Melville Bay. All sightings (n=89) were concentrated in the central part of the Bay in the area with the highest glacial activity. The fully corrected abundance estimate was 3,091 (*cv*=0.50, 95% CI: 1,228-7,783) and compared to surveys in 2007 and 2012, the abundance of narwhals in 2014 was not significantly different. The whales were found significantly closer to the coast of the mainland and the average group size was slightly larger compared to previous surveys. Distance between groups was similar to the survey in 2012 but significantly shorter than in 2007. Comparison of the distribution of on-effort sightings of whales for all three years showed a major contraction in the area used by the whales. The central area of the Bay seems to be increasingly important but it is not certain if this reduction in area usage is part of a long-term contraction from before 2007 or if it is a recent phenomenon. Nothing suggests that it is caused by a general population decline, or by changes in prey concentrations, and it seems more likely a result of external disturbance in the form of hunting or seismic survey activity in previous years. The fronts at active glaciers provide an acoustic environment very different from the other coastal or offshore areas of the Melville Bay. Noise from boats and air gun pulses may be masked by the background noise from ice activity inside the Bay and noise from offshore air gun pulses may be deflected by the silt topography and the highly stratified water masses in front of the glaciers.

INTRODUCTION

A large-scale seismic survey was conducted in northern Baffin Bay during summer and fall 2012. A major environmental concern with seismic surveys in this part of West Greenland is the short-term disturbance of narwhals that spend the summer inside the Melville Bay and the long-term effects on the migratory behaviour of these whales. Narwhals are known to be skittish, highly sensitive to human activities and easily disturbed by approaching boats, even in areas without hunting. Hunting of narwhals in several areas of West Greenland, including the Melville Bay continues to be conducted from kayaks because the whales react with long submergence times and are often lost to the observers when pursued by boats with noisy outboard engines. No direct studies have been conducted of the effects of seismic airgun noise on narwhals but they are known to react at distances of tens of kilometres to underwater noise from vessels, with and without icebreaking but there were also signs of habituation to the ice-breaking activities (Finley et al. 1990). The reactions of narwhals to approaching vessels include long-distance (>50km) displacement, even at relatively low received sound levels (94-105 dB re 1 µPa; 20-1000 Hz). This responsiveness at such long distances is exceptional in the literature on marine mammal disturbance (see Richardson et al. 1995) and is confirmed by the paucity of sightings obtained from non-seismic vessels passing through areas known (from hunting returns and aerial surveys) to have high densities of narwhals (Heide-Jørgensen et al. 2010; GINR unpublished data). In particular, observers on active seismic survey vessels rarely if ever encounter narwhals, even when covering areas where narwhals are known to occur (Lang and Mactavish 2011). It is likely that the animals move away beyond detection range before the survey vessels are within the observers' range of visual detection.

Narwhals are primarily found in the Atlantic sector of the Arctic with the largest numbers centred in Baffin Bay and adjacent waters (Richard et al. 2010; Heide-Jørgensen et al. 2010) where they make long-distance migrations in the spring and autumn (>3000 km per year), moving between coastal summering grounds (Heide-Jørgensen et al. 2003a) and winter feeding areas in the pack ice (Laidre et al. 2004). Narwhal stock delineation is based on summer occurrence in coastal areas of Canada and Greenland (Heide-Jørgensen et al. 2012a). Two stocks of narwhals are currently recognized in West Greenland; the Melville Bay stock and the Inglefield Bredning stock. The Melville Bay stock had an estimated abundance of 5,605 whales (95% CI 1,319-23,815) in 2007 and 2,983 (95% CI 1,452-6,127) in 2012. The two estimates are not significantly different and the abundance estimate from 2012 is more precise. The other summering stock of narwhals in West Greenland (Inglefield Bredning) had an estimated abundance in in 2007 of 8,300 narwhals (95% CI 5,209-13,442; Heide-Jørgensen et al. 2010).

The narwhals arrive in July in Melville Bay and preferentially seek out the front of glaciers for the summer period from August through late September. They feed little during this period but they conduct rapid and wide-ranging movements along the coast from the southern part of the bay at Kullorsuaq northwest to the Nallortoq fjord just east of Savissivik (Dietz and Heide-Jørgensen 1995, Laidre and Heide-Jørgensen 2005). Narwhals from Melville Bay leave the Bay in September and move offshore towards the wintering ground in the southern part of Baffin Bay (Dietz and Heide-Jørgensen 1995). Here they remain for 6 months along the edge of the continental slope where water depths increases from 1000 m to 1500 m. They return to Melville Bay in May and June and coastal areas are only occasionally visited during the migrations between summering and wintering grounds (Heide-Jørgensen et al. 2012a).

Seismic survey activities may affect narwhals both over short-term, where the whales react over hours, days or weeks to airgun noise, or they may show long-term changes (between years) in behaviour, where migratory routes are disrupted or summering grounds abandoned. Noise pollution during critical stages of the lifecycle has in particular been hypothesized to cause changes in migrations that, due to the seasonal ice formation, may be detrimental to the whales (Heide-Jørgensen et al. 2012b). The short-term response of narwhals to seismic explorations in Melville Bay in 2012 was addressed through aerial surveys and hunt monitoring during the period with seismic exploration (Heide-Jørgensen et al. 2013b). Detection of long-term effects requires monitoring of the whales repeated at regular intervals to identify subtle changes in abundance and occurrence. Other factors like removal of whales through hunting needs to be included before the population level effect of seismic activities can be fully assessed. The objective of this study was to extend the time series of abundance estimates from Melville Bay stock of narwhals and to compare abundance and distribution of narwhals in 2014 to similar surveys conducted in 2007 and 2012.

MATERIAL AND METHODS

Survey performance

Visual aerial line transect surveys were conducted as a double-observer experiment in a fixed-winged, twin-engine aircraft (DeHavilland Twin Otter) with a target altitude and speed of 213m (700 feet) and 168km h^{-1} (90 knot) respectively. The front observers (observer 1) acted independently of those in the rear (observer 2) and *vice versa*. Declination angles to sightings, species and group size were recorded when the animals came abeam. Beaufort sea state was recorded at the start of each transect and then again when it changed. Decisions about duplicate detections (animals seen by both observer 1 and 2) were based on coincidence in timing and location of sightings. Instrumentation of the plane and the procedures for data collection were identical to those previously reported by Heide-Jørgensen et al. (2010, 2013) except that hand-held dictaphones that were synchronized daily were used for recording of observational data and GPS data were logged separately to a GPS-recorder.

The surveys of the Melville Bay were conducted during 25-30 August 2014 and covered the area between 74.30°N and 76°N (~14.821 km^2, Fig. 1). Four strata were identified and the two southern strata were surveyed by transects aligned east west and the two northern were surveyed by north south transects, systematically placed from the coast to offshore areas crossing bathymetric gradients, covering 1872 km (Table 1).

Collection of data on the availability correction

Data from narwhals instrumented with satellite-linked time-depth recorders (Mk10a SLTDRs Wildlife Computers, cf. Dietz and Heide-Jørgensen 1995) were used to developing a correction factor for whales that were submerged below the detection depth (Richard et al. 1994, Heide-Jørgensen 2004). Measurements of the time spent above 2m depths were collected in six-hour bins and relayed through the Argos Data Collection and Location System and decoded using Argos Message Decoder (Wildlife Computers). Daily averages were calculated for daylight hours and used for deriving monthly averages that, to the extent possible, matched the survey area and dates (Table 2).

Development of abundance estimates

The declination angles to sightings when animals were abeam were converted to radial distances using the equation distance(m)=altitude*tan(90-angle). 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 track line) – 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 and is therefore used in the following analyses.

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 track line (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 a 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:

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

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 to $p_{2|1}(0,z)$. The intercepts (i.e. at x=0) of $p_{1|2}(0,z)$ and $p_{2|1}(0,z)$ are combined to estimate their detection probability on the track line by at least one observer.

For the DS model, both half-normal and hazard rate functions were fitted, initially with no covariates (apart from perpendicular distance) and then covariates were included via the scale parameter (Marques and Buckland 2004). The available covariates were group size, side of plane (left and right), Beaufort sea state (0, 1 or 2) and time to next sighting ($\leq$10 or >10s). Group size was also included as a factor variable with three levels to represent groups of size one, two to five whales and more than 5 whales. The same covariates were included in the MR model, in addition to a variable indicating observer (1 and 2). Akaike's Information Criterion (AIC) and goodness of fit tests were used for model selection.

Density (D) and abundance (N) of individual animals in a stratum were obtained using

$$\hat{D}_i = \frac{1}{2wL_i}\sum_{j=1}^{n_i}\frac{s_{ij}}{\hat{p}_{ij}} \quad \text{and} \quad \hat{N}_i = A_i\hat{D}_i \tag{2}$$

where s_j is the recorded size of group j, A is the size in km^2 of the stratum, w is the truncation distance, L is the total effort in km, n is the number of unique detections and $\hat{p}_j$ is the estimated probability of detecting group j (perception bias), obtained from fitted Mark Recapture Distance Sampling (MRDS) models as described in Heide-Jørgensen et al. (2010).

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

$$\hat{N}_c = \frac{\hat{N}}{\hat{a}} \tag{3}$$

where the parameter $\hat{a}$ is the estimated proportion of time animals are available for detection. The coefficient of variation (cv) of $\hat{N}_c$ was given by

$$cv\left(\hat{N}_c\right) = \sqrt{cv^2\left(\hat{N}\right) + cv^2\left(\hat{a}\right)} \tag{4}$$

Confidence intervals were estimated using the log-based method given in Buckland *et al.* (2001).

Spatial analysis of sightings

A geographic information system (GIS: ArcMap 10.2) was used to spatially locate the observations of narwhals. The geographic coordinate system and coastline data for Greenland from the World Vector Shoreline (WSG1984) was projected as standard UTM Zone 21N (in meters). Spatial bathymetric data were extracted as a raster file from a terrain model from The General Bathymetric Chart of the Oceans that had a 30 arc-second spatial resolution (*GEBCO.net*).

Four relations were tested using nonparametric Kruskal-Wallis tests with a significance level of 5% and then compared pairwise by using the Steel-Dwass-Critchlow-Fligner procedure (two-tailed test).

1) Distance between narwhal groups and the shoreline (the mainland, islands excluded).
2) Distance between neighbouring groups.
3) Group size and distance to shoreline (the mainland).
4) Group size and distance to closest group.

Data from similar surveys in 2007 and 2012 in the Melville Bay were included for comparisons (Heide-Jørgensen et al. 2010, 2013).

RESULTS

The aerial surveys were designed to cover the entire Melville Bay within one day with an intensified effort in the central stratum, however, not all transect lines were covered during one day (Fig. 1). The realized survey effort nevertheless ensured that all but 6 transect lines were covered at least once (Table 1). The sightings were concentrated in the central stratum with a few sightings in the neighbouring northeast stratum (Fig. 2). There were no off-effort sightings outside the two strata with on-effort sightings.

Development of abundance estimates

MRDS models do not require $g(0)$ to be one but they do rely on the probability of detection on the track line being at a maximum. A few duplicate sightings had different declination angles and thus the sightings had different perpendicular distances. Pairwise testing of declination angles from the front and rear observers showed no systematic bias in any of the two estimates (t-test, p=0.21). It was decided to use the mean angle and hence perpendicular distance for all duplicate sightings. Systematic bias between observers for recorded group size was not found (p=0.16) and the average group size for the duplicate sightings was used.

Detection function and perception bias estimation was established based on the common sampling of sightings by the two observation platforms (Table 3).

In the MRDS model a half-normal key functional form and a hazard rate form were tested with the half-normal chosen based on its lower AIC (1255, Table 4, Figs 3-6) with a distance detection range fixed at 0-1200 m. The final DS model had distance and Beaufort sea state as explanatory variables.

The MR model had distance, observer and group size (as a factor with three levels) as explanatory variables (Model 23, Table 4). The g(0) for observer 1 was 0.91 (*cv* =0.047) and 0.77 (*cv*=0.081) for observer 2 with a combined g(0)= 0.98 (*cv*= 0.019).

The abundance estimates were stratified by geographic strata (Table 1). The largest abundance was detected in the central stratum with some additional whales in the northeast stratum, and no whales in the northwest or south strata.

Correction for availability of the at-surface-abundance was based on availability correction factors obtained from five whales from August-September (*a*=0.22 (*cv*=0.09); see Table 2).

Spatial analysis of sightings

The distance from the shoreline of the mainland to the narwhal sightings has decreased significantly since 2007 ($p<0.01$, Fig. 7).

There was no significant difference in the distance between neighbouring groups of narwhals between the surveys in 2012 and 2014 (p=0.176, but groups of narwhals were significantly further apart in the survey conducted in 2007 than in the surveys in 2012 and 2014 ($p<$ 0,01, Fig. 8). The average group size increased slightly from 2007 to 2014 ($p<0.01$, Fig. 9).

No significant relationships between neither *group size* and the distance to shoreline nor *group size* and the distance between sightings could be detected which is similar to previous surveys indicating that the group size remain constant independent of its distance to the shoreline.

In addition to narwhals four species of seals were also detected during the survey (Fig. 10). Hooded seals were mainly seen on small icebergs, whereas ringed and harp seals were mostly in the water. Bearded seals were seen hauled on ice floes.

DISCUSSION

This report deals with the possible long-term population changes in the narwhal population in Melville Bay. An aerial survey was conducted late in August 2014 at a time when most of the whales have not yet initiated their southbound migration (Heide-Jørgensen et al. 2013). The timing was also similar to surveys conducted in 2007 and 2012 thus allowing for direct comparison of distribution and abundance estimates.

The selected covariates in the MRDS model suggest that sighting probability increased with group size and declined with the improved sighting conditions during lower Beaufort sea states. Furthermore, observer was selected as a variable in the MR model, suggesting the front observers had more detections than the rear observers. The inclusion of one inexperienced observer at the rear position probably augmented the effect of observers in the covariate model.

The fully corrected abundance estimate in 2014 was 3,091 narwhals (*cv*=0.50, 95% CI: 1,228-7,783) and it is not significantly different from the 2nd survey that was conducted around the same time in 2012 (2,983; 95% CI 1,452-6,127, Heide-Jørgensen *et al.* 2013). Both estimates indicate an abundance in the same magnitude and are both more precise than the abundance estimated in Melville Bay in 2007 (5,605; 95% CI 1,318-23,815; Heide-Jørgensen et al. 2010 modified in Table 5). The low precision in 2007 is partly due to lower sighting rate but also to more dispersed occurrence of whales.

The narwhal's showed affinity to the central strata where the most glacial activity takes place and this overall distributional pattern is not different from the survey in 2012. This is also the same area where several hooded seals were detected (Fig. 10).

Comparison of the three years with aerial surveys shows a clear contraction of the range of the narwhals where they in 2014 primarily were concentrated in the central stratum. Other independent evidence supports such a long-term reduction in area usage by narwhals of the Melville Bay. The southern part of Melville Bay used to have conspicuous numbers of narwhals during summer especially around Tuttulissuaq (Meldgaard and Kapel 1981). Similarly, has satellite tracking in the 1990's, demonstrated a wider use of the Bay by the whales than observed in the recent surveys (Dietz and Heide-Jørgensen 1995). The preferred hunting grounds for the summer hunt has also moved inside the central stratum in Melville Bay and the traditional hunting localities at Nallortoq east of Savissivik and at Tuttulissuaq north of Kullorsuaq are, according to the local hunters, no longer important for the local harvest (GINR in litt.).

Due to the large variance of the abundance estimates no obvious trend in abundance of narwhals in Melville Bay over the medium-term period with surveys (2007-2014) could be detected and the contraction in range cannot be attributed to a simple decline in abundance. Narwhals usually display extreme site fidelity to summering grounds and there are no reasons to believe that changes in oceanographic and other non-anthropogenic factors could affect the narwhal's affinity for Melville Bay, however, several anthropogenic factors could, alone or in synergy, have caused the contraction. Although hard to quantify, small-boat traffic has over the past 20-30 years increased and a major part of the traffic is involved in hunting narwhals in the Bay. During the survey in 2012 several outboard dinghies were observed inside the Bay (Heide-Jørgensen et al. 2013) and during the survey in 2014 a small cutter was involved in deploying nets in the central stratum. The presence of boats and the associated hunting activities may likely contribute to the disturbance of the whales and perhaps also to the contraction of the area used by the whales. The large-scale seismic survey activity in 2012, and perhaps seismic activities in earlier years off the coast of Melville Bay, could potentially also have disturbed the whales that ventured outside areas with glacial activity. Relatively inactive glaciers generally dominate coastal areas in the Melville Bay, but the central stratum, that in recent years is the preferred habitat for the narwhals, has a lot of glacial activity. There is little doubt that the acoustic environment in front of active glaciers is a very noisy environment due to the calving of glaciers, movements of ice and presence of katabatic winds. This habitat is also protected from offshore noise transmission by the shallow silt and the strong water column stratification driven by the freshwater outflow. This acoustic environment probably mask noise made by boat engines and airgun pulses.

The series of abundance estimates obtained confirms that the narwhal population in the Melville Bay is one of the smallest exploited whale populations in Greenland and that great care is needed when assessing levels of removals. Any possible cumulative effects from anthropogenic disturbances need to be included when evaluating the future status of this population. A full assessment of the population changes that may have occurred during the period with abundance estimates (2007-14) and an assessment of the current population status, will require a full reconstruction of the hunting mortality (including whales that are killed but lost) at least for the period 1993-2013. Such an assessment is currently under development for presentation to the Scientific Working Group of the Canada-Greenland Joint Commission for Conservation and Management of Narwhal and Beluga in March 2015.

If further oil exploration activities are planned for northern Baffin Bay and in Melville Bay it is recommended that the aerial survey monitoring of abundance of narwhals is continued to assess whether there are any long-term changes in abundance in the Bay.

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Table 1. Summary of survey effort and number of sightings detected by each platform for the aerial survey in 2014. Note that the number of unique sightings is the number of sightings seen by observer 1 plus the number seen by observer 2 minus duplicates. Estimates uncorrected for availability bias of expected group size, group abundance, group density (groups/km^2), narwhal abundance, narwhal density (animals/km^2) and narwhal abundance corrected for availability bias are provided. Coefficient of variance (*cv*) is given in parenthesis. The at-surface-abundance is corrected for an availability correction factor based on five whales from August-September (a=0.22 (*cv*=0.09); see Table 2).

Survey	Stratum	Area (km^2)	Number of transects	Effort (km)	Number seen by observer			Number of unique sightings	Expected cluster size	Abundance of groups	Density of groups (groups/km^2)	Abundance of whales	Density of whales (whales/km^2)	Abundance of whales corrected for availability bias
					1	2	Duplicates							
2014	S	6,376	10	573	0	0	0	0	-	-	-	-	-	-
	C	2,076	9	682	66	37	29	74	3.95 (0.08)	50 (0.54)	0.0446 (0.54)	366 (0.53)	0.1762 (0.53)	1,693 (0.54)
	NE	2,721	10	467	12	12	9	15	2.48 (0.05)	113 (0.93)	0.0464 (0.93)	302 (0.89)	0.1152 (0.89)	1,393 (0.89)
	NW	3,748	3	170	0	0	0	0	-	-	-	-	-	-
	TOTAL	**14,821**	**32**	**1872**	**78**	**49**	**38**	**89**	**3.25 (0.13**	**163 (0.67)**		**668 (0.50)**		**3,091 (0,50)**

Strata: South (S); Central (C); Northeast (NE); Northwest (NW)

Table 2. Data on time available for detection collected from five narwhals instrumented in Melville Bay in August-September 2007 and 2012, one female instrumented in November 2008 and one whale instrumented in Qaanaaq 2012. The monthly averages for #20162 and #10946 were calculated from the daily averages based on recordings during 24-hr of the fraction of time spent at, or above, 2m depth. For the other whales monthly averages are based on 6-hr time-at-depth readings. In this table, *n* is the daily average of surfacing events collected between 10:00 and 20:00, SD is the standard deviation of the daily averages.

		August *	September	March	April	May	June	July
	Mean	0.15	0.23	0.18	0.2	0.21	0.16	0.13
20162	*n* (days)	31	24	24	26	31	28	31
Melville Bay	SD		0.02	0.01	0.01	0.01	0.01	0.01
	Mean	0.25	0.20					
10946	*n* (days)	2	30	na	na	na	na	na
Melville Bay	SD	0.04	0.02					
	Mean			0.25	0.27	0.13	0.11	0.05
3961	*n* (6 hr)	na	na	9	11	19	13	9
Uummannaq	SD			0.05	0.16	0.15	0.09	0.02
	Mean		0.25					
7931	*n* (6 hr)	na	6	na	na	na	na	na
Melville Bay	SD		0.14					
	Mean					0.21		
20168	*n* (6 hr)					3		
Qaanaaq	SD					0.04		
	Mean	0.20	0.23			0.18		
	n	2	3			3		
	SD	0.07	0.03			0.04		

Table 3. Distribution of sightings from the survey combined on the two survey platforms in the detection range 0-1200 m with duplicates (resightings) indicated. Number of unique sightings is the sum of sightings seen by the primary and the secondary platform minus the number of duplicate sightings.

	2007	2012	2014
Unique sightings	32	200	80
Sightings seen by primary	22	162	70
Sightings seen by secondary	21	145	47
Duplicate sightings	11	107	37

Table 4. AIC values after fitting explanatory variables to the DS and MR models. The final model chosen are given in bold and 'ΔAIC' indicates the difference between the chosen model and the specified model. HN indicates a half-normal form and HZ indicates a hazard rate form for the DS model. The explanatory variables are perpendicular distance (D), group size (S), group size as a factor with three classes (1, 2-5 and ≥6 narwhals) (S_3), Beaufort sea state (BF), side of plane (SP), observer (O) and time to next observation ≤10 sec (T).

Model	DS model	MR model	AIC	ΔAIC
1	HN: D	D	1286	31.07
2	HZ: D	D	1287	32.38
3	HN: D + BF	D	1268	13.64
4	HN: D + S	D	1287	31.78
5	HN: D + S_3	D	1288	32.98
6	HN: D + SP	D	1288	32.77
7	HN: D + T	D	1285	29.86
8	HN: D	D + BF	1288	33.07
9	HN: D	D + S	1285	30.28
10	HN: D	D + S_3	1283	28.40
11	HN: D	D + SP	1283	28.26
12	HN: D	D + T	1284	29.52
13	HN: D	D + O	1275	20.10
14	HN: D	D + S_3 + T	1283	28.48
15	HN: D	D + O + T	1273	18.56
16	HN: D	D + O + S_3	1272	17.44
17	HN: D	D + S_3 + SP	1282	27.66
18	HN: D + BF	D + S_3	1267	12.85
19	HN: D + BF	D + T	1269	13.97
20	HN: D + BF	D + O	1257	2.67
21	HN: D + BF	D + S_3 + T	1266	11.05
22	HN: D + BF	D + O + T	1256	1.12
23	**HN: D + BF**	**D + O + S_3**	**1255**	**0.00**

Table 5. Abundance estimates from surveys of narwhals in Melville Bay in 2007, 2012 and 2014. The 2007 survey has been updated with the areas of strata and availability correction factor used in the later surveys. The at-surface-abundance is corrected for an availability correction factor based on five whales from August-September (a=0.22 (cv=0.09); see Table 2).

Stratum	2007				2012				2014			
	density	*cv*(D)	^Nc	*cv*(^Nc)	density	*cv*(D)	^Nc	*cv*(^Nc)	density	*cv*(D)	^Nc	*cv*(^Nc)
Central	0.0493	0.75	474	0.76	0.0283	0.79	836	0.80	0.2555	0.38	1,693	0.54
Northeast	0.0092	1.02	116	1.02	0.1877	0.46	1,804	0.47	0.1152	0.89	1,397	0.89
Northwest	0.0109	1.04	189	1.04	0.0283	1.01	343	1.01	-	-	-	-
South	0.1635	0.98	4,826	0.98	-	-	-	-	-	-	-	-
Total			**5,605**	0.85	0.0435	0.38	**2,983**	0.38	0.1772	0.41	**3,091**	0.50
95% confidence limits	**1,319-23,815**				**1,452-6,127**				**1,228-7,783**			

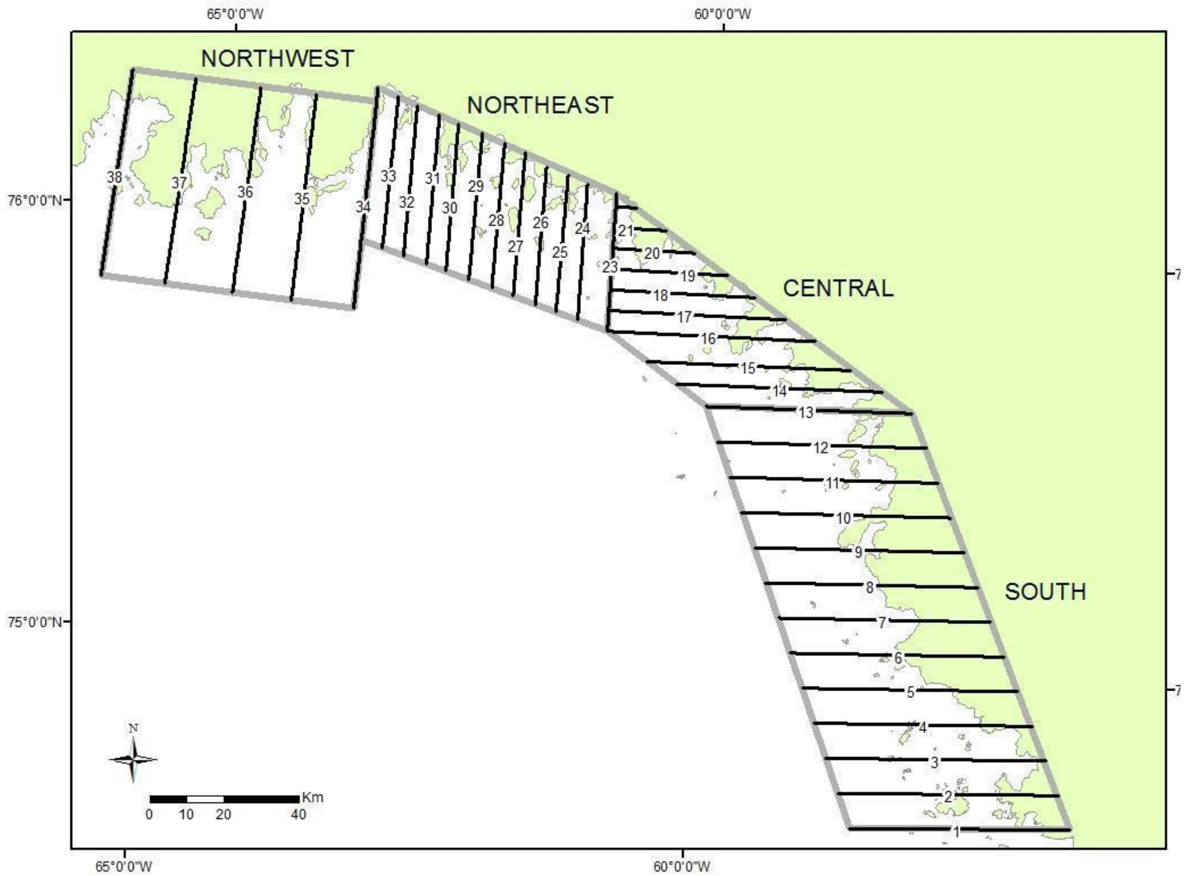

Figure 1. Design of strata and transects for the survey conducted in Melville Bay in 2014.

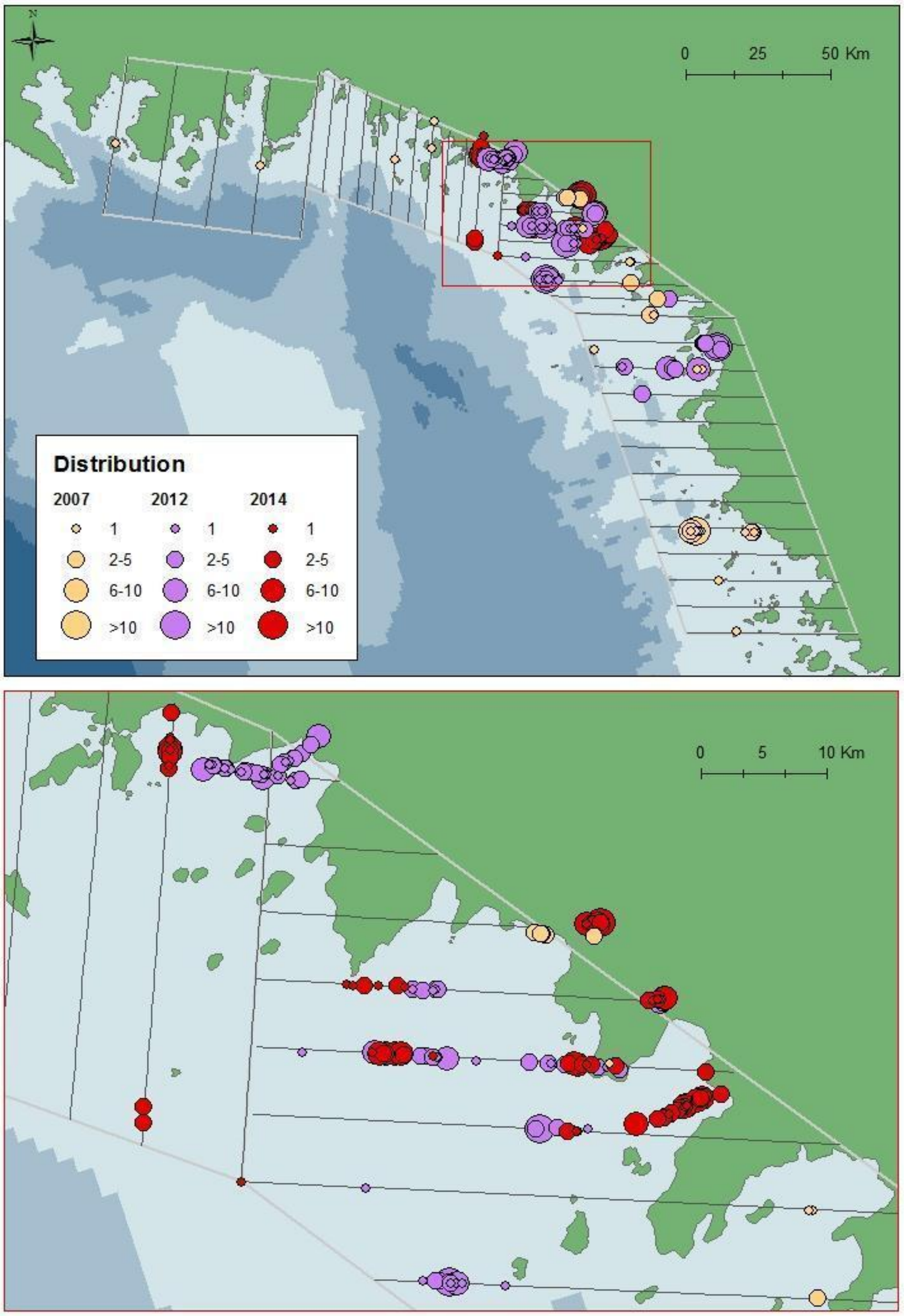

Figure 2. Sightings of narwhals during the survey in 2007, 2012 (2nd survey) and 2014.

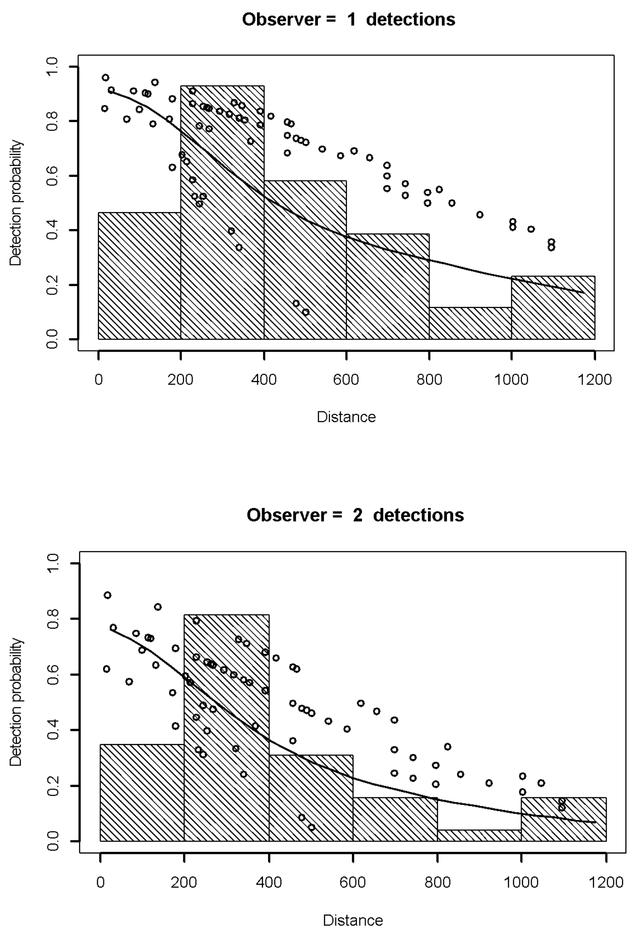

Figure 3. Detection function plots for the aerial survey in Melville Bay in 2012. Perpendicular distance distributions for each observers with the chosen model superimposed. The dots indicate the values for each observer. Upper panel observer 1 detections lower panel show observer 2 detections. Lines are fitted models.

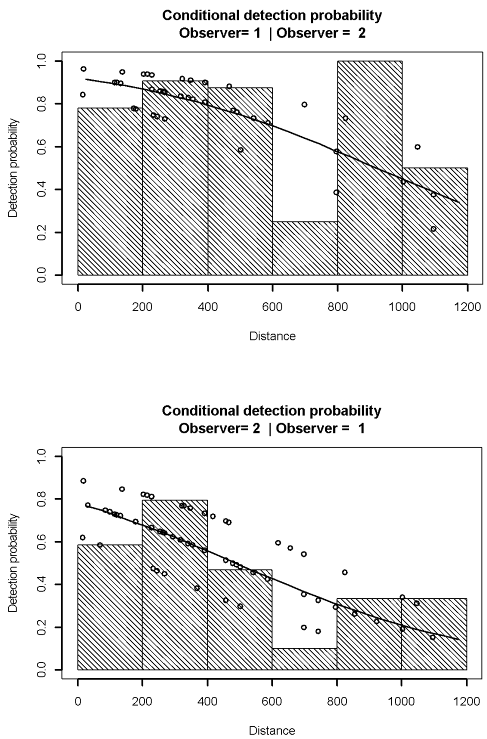

Figure 4. Detection function plots for the aerial survey in Melville Bay 2014. Conditional distributions for each observer with the chosen MR model superimposed. Upper panel shows detection plot of observer 1 given detection by observer 2. Lower panel shows detection plot of observer 2 given detection by observer 1.

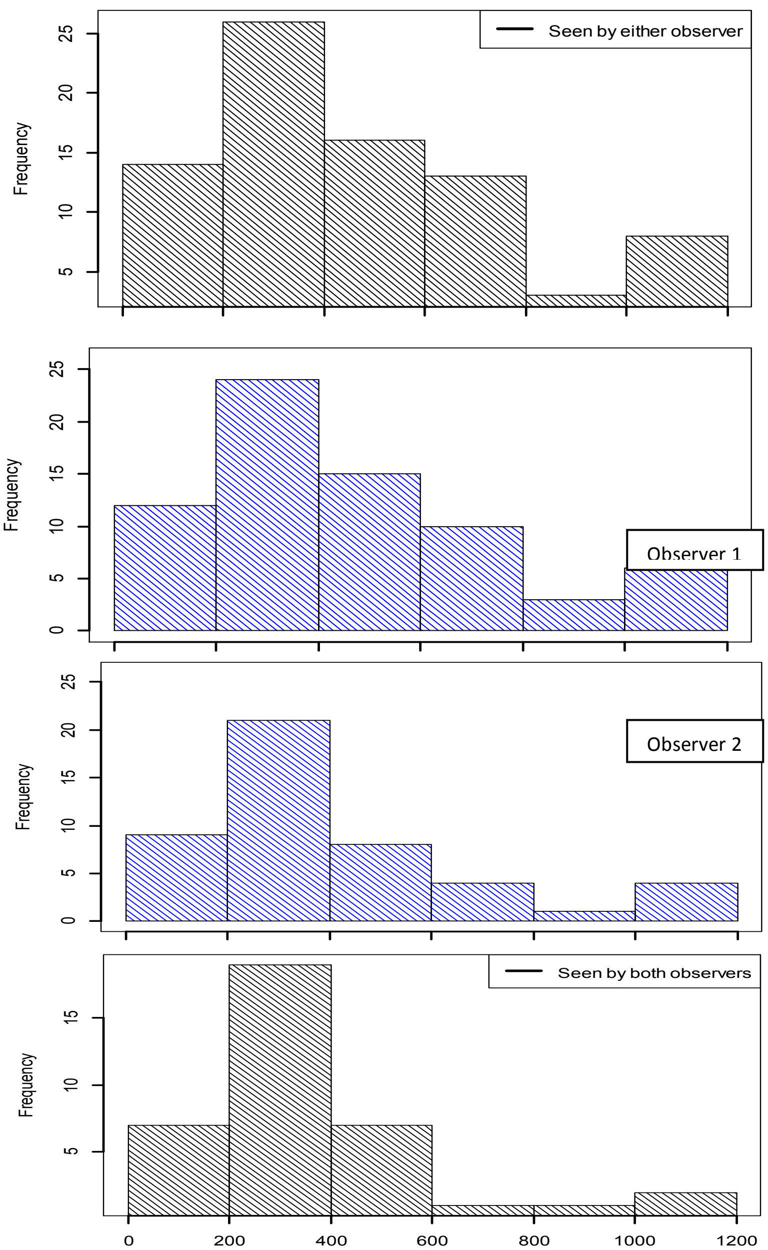

Figure 5. Histogram of detections (upper panel). The second panel show the detections made by observer 1, the third panel show the detections made by observer 2 and the lowest panel show the duplicate detections.

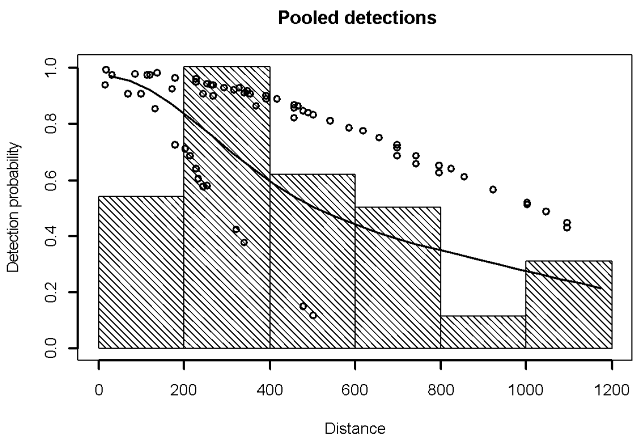

Figure 6. Detection function plot for the aerial survey in Melville Bay in 2014. Perpendicular distance distributions for both observers combined with the chosen DS model superimposed and intercept obtained from the MR model. The dots indicate the probability of each detection given its perpendicular distance and other covariate values.

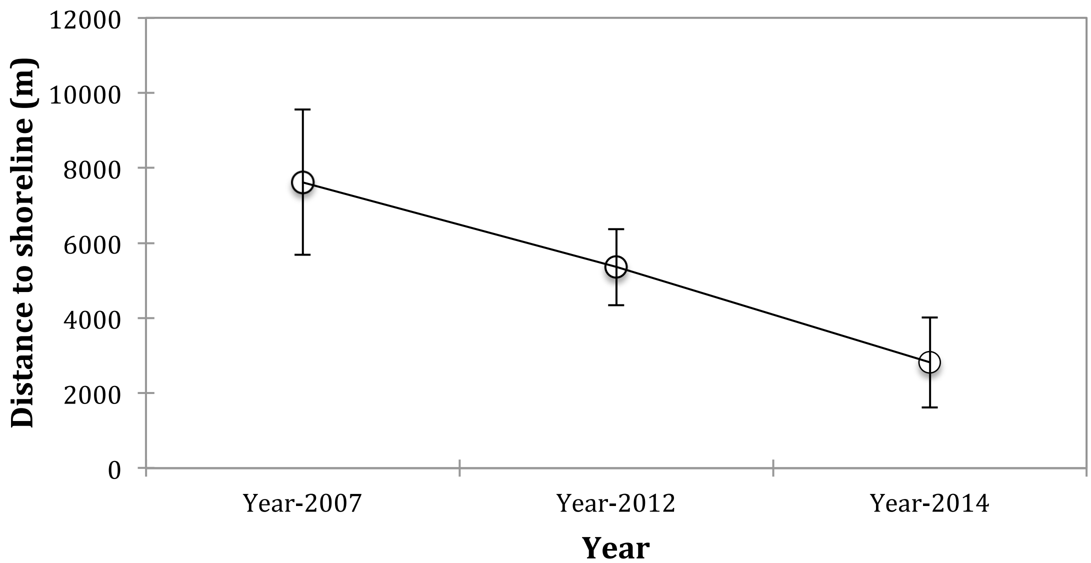

Figure 7. Distance of sightings of narwhals in Melville Bay to the shore of the mainland for the aerial surveys in Melville Bay in 2007, 2012 and 2014.

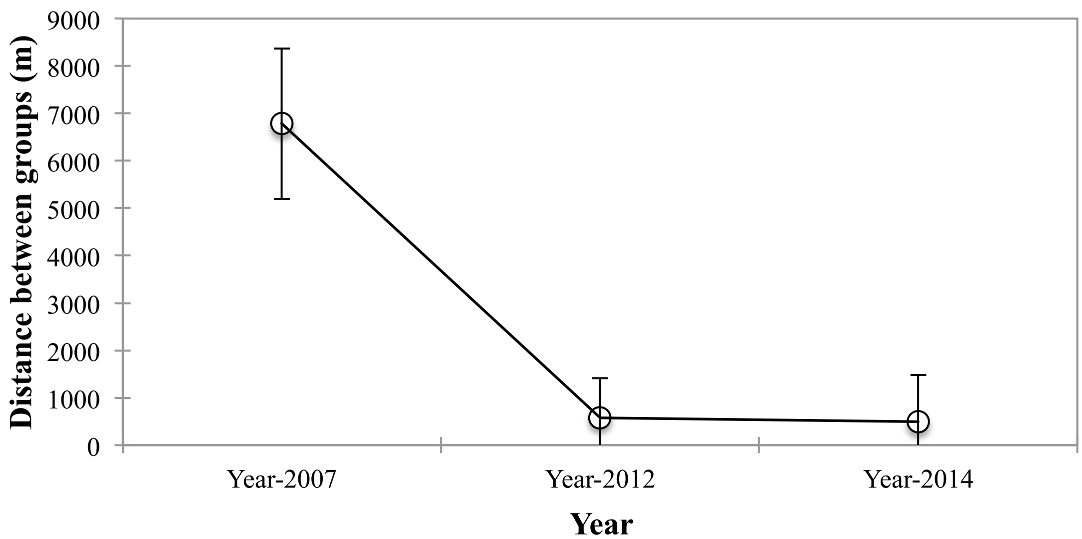

Figure 8. Straight-line distance between sightings of groups of narwhals in Melville Bay for the aerial surveys in 2007, 2012 and 2014.

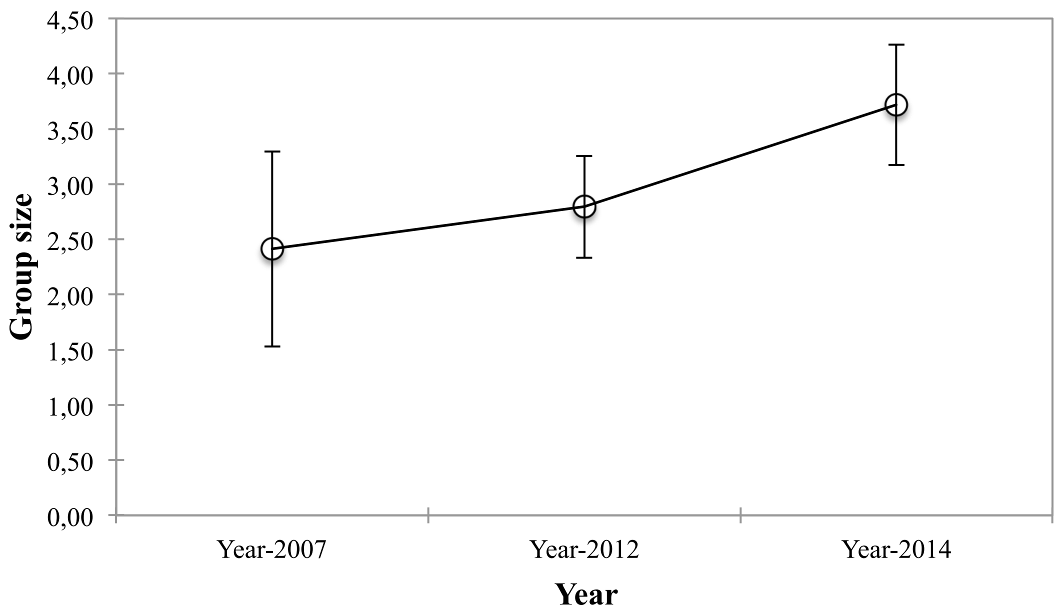

Figure 9. Average group size estimates for sightings of narwhals in Melville Bay during aerial surveys in 2007, 2012 and 2014.

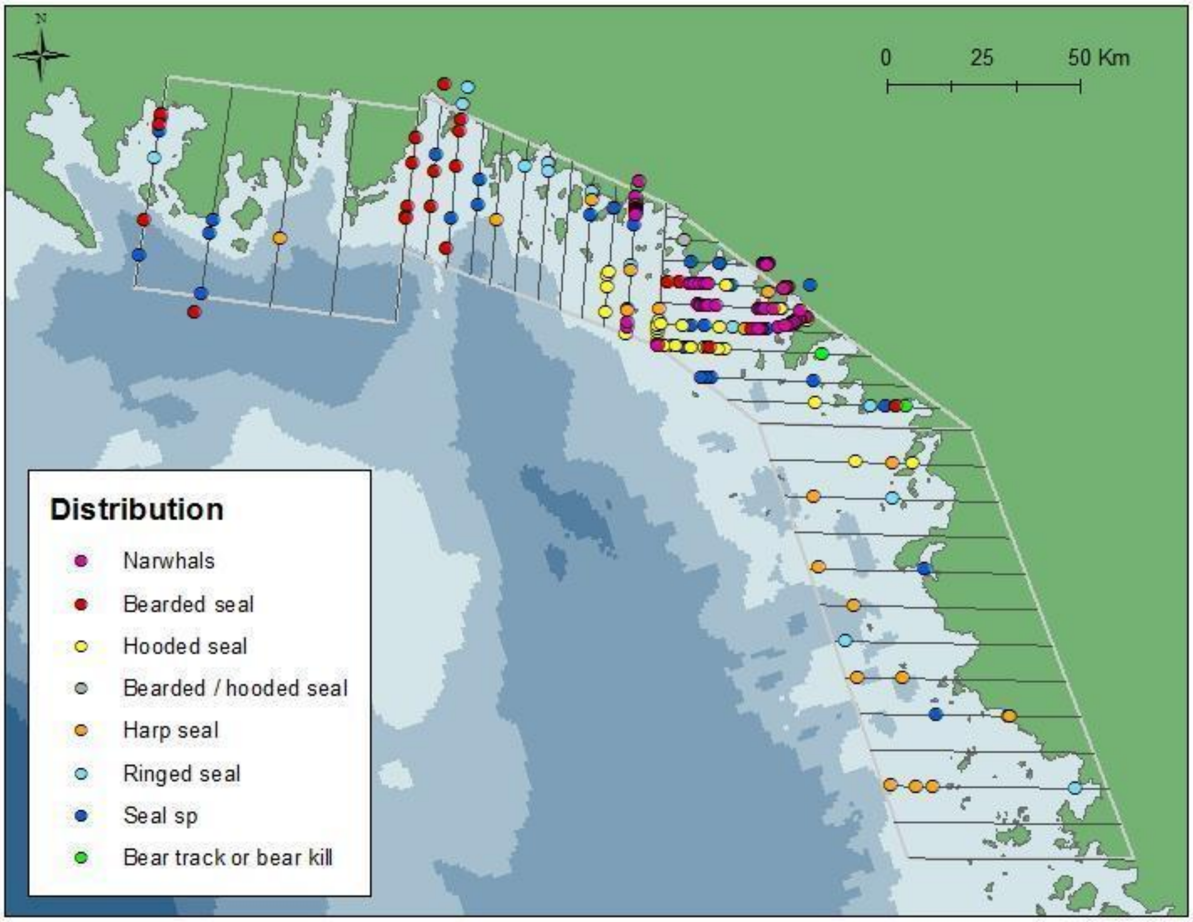

Figure 10. Sightings of all marine mammals during the survey in 2014.