Overview of five German helicopter surveys provide insight into spatio-temporal variability of minke whale densities in ice.

Helena Herr[1)], Natalie Kelly[2,3)], Sacha Viquerat[1)], Karl-Hermann Kock[4)], Rob Williams[5)], Meike Scheidat[6)], Linn Sophia Lehnert[1)], Ursula Siebert[1)]

1) Institute for Terrestrial and Aquatic Wildlife Research, University of Veterinary Medicine Hannover, Foundation, Werftstrasse 6, D-25761 Buesum, Germany. helena.herr@tiho-hannover.de

2) CSIRO Digital Productivity and Services, Castray Esplanade, Hobart, Tasmania, 7000, Australia. natalie.kelly@csiro.au

3) Australian Marine Mammal Centre, Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania, 7050, Australia

4) von Thünen Institute, Institute for Sea Fisheries, Palmaille 9, D-22767 Hamburg, Germany

5) Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews KY16 8LB, UK

6) IMARES Wageningen, Postbus 68, 1976 CP IJmuiden, The Netherlands

ABSTRACT

Information on the relationship between Antarctic minke whale *(Balaenoptera bonaerensis)* density and sea ice may provide a tool to account for potential biases in current abundance estimates of the species. Aerial surveys are currently the favoured method for obtaining data on cetacean occurrence in pack ice regions that are difficult to survey from ships. Since 2006, Germany has been conducting five helicopter surveys from the research icebreaker RV *Polarstern*, targeting regions in the Weddell Sea and around the Antarctic Peninsula, gathering sighting data on minke whales in regions of varying ice concentrations. Altogether, 40,985 km of effort were accomplished south of 58°S and provided 157 sightings of minke whale groups, comprising a total of 288 animals. 35 % of all effort was conducted within the 15 % MIZ. We used the obtained line-transect *distance sampling* data for model-based (uncorrected) abundance estimation in selected areas to assess to minke whale density in relation to sea ice parameters. The results show high variability in minke whale numbers over space and time, with a strong relationship to the 15% ice edge (as derived from satellite data) and a longitudinal gradient.

This paper is to present the available data and provide a summary of the surveys as well as results of first analyses. We hereby hope to give an overview over chances and limitations of this dataset and to solicit feedback from IA members for further analyses, rather than to present ultimate density or abundance estimates.

INTRODUCTION

Three circum-Antarctic sighting surveys completed by the IWC (IDCR from 1978/79 to 1995/96; IWC-SOWER 1996/97 to 2003/04; complete programme henceforth SOWER) provide the best data available with which to estimate circumpolar abundance of Antarctic minke whales (*Balaenoptera bonaerensis*; henceforth, minke whale) (Branch 2006). Yet, these sighting surveys were restricted to open ocean and did not access the ice covered regions surrounding the Antarctic, covering at least 3-4 million km^2 in area during the summer months (Gloersen et al. 1993). While it is known that minke whales are highly adapted to sea ice habitats (Ainley et al. 2007) and are regularly observed in a range of sea ice concentrations (e.g. Thiele and Gill 1999, Scheidat et al. 2011), relatively little is known about the specific pack ice habitat preferences of minke whales. It remains unknown to what extent the animals use the ice covered waters and what proportion of the population is contained in the ice at any time. This fact plays a potentially important role in attempts to explain a putative decline in minke whale abundances between the second and the third circumpolar SOWER surveys (IWC 2013). One hypothesis that remains to be tested is based on the assumption that potentially minke whales 'moved into the ice' between the second and third circumpolar surveys, and were thus less accessible for the survey vessels (see Murase & Bravington 2012, Kelly et al 2012 for details). Knowledge on density and distribution of minke whales in relation to sea ice concentrations would provide valuable information in order to account for these potential biases in current abundance estimates. While it remains impossible to produce retrospective estimates of absolute abundance of minke whales in sea ice areas over the years that the IDCR/SOWER surveys were running, it has been suggested by Kelly et al. (2012) that regional density and abundance estimates, including ice covered parts of the habitat, could provide an idea of likely boundaries or magnitudes of abundances of minke whales inside and outside of sea ice regions. This may allow a consideration whether the 'moved-into-sea ice' hypothesis is at least tenable.

Aerial surveys are currently the favoured method for obtaining data on cetacean occurrence in pack ice regions, as these are difficult to survey from ships (Kelly et al. 2012). Germany commenced an aerial survey programme conducting helicopter surveys from the research icebreaker RV *Polarstern,* targeting regions in the Weddell Sea and around the Antarctic Peninsula. Since 2006, five surveys have been completed in the austral summers of 2006/07, 2008/09, 2010/11 and 2011/12 and 2012/13, which have been reported on in several IWC Papers (Scheidat et al. 2007a (SC/59/IA20), 2007b (SC/59/IA21), Kock et al. 2009 (SC/61/IA11), 2010 (SC/62/O15), Williams et al. 2010 (SC/62/IA13), 2011 (SC/63/ IA/14), Feindt-Herr et al. 2013 (SC/65a/SH20)). Obtained line-transect *distance sampling* data allow for detection function modelling and model-based abundance estimation for the surveyed regions and this way offer an opportunity for complementing the IWC surveys, albeit in a geographically restricted sense. Comparisons of inside/outside ice abundance estimates have already been conducted for the first two surveys (2006/07 and 2008/09), providing first indication for substantial numbers of minke whales present in the sea ice (Williams et al. 2013).

Here we present the first analyses of the combined data of all five German helicopter surveys conducted between 2006 and 2013. In addition to a general overview, we chose three substrata of the area surveyed, which were visited during more than one survey. For these areas we conduct spatial and temporal comparisons of density and abundance (uncorrected for *g(0)* and availability bias) to look into variability of minke whale densities in relation to sea ice and to explore opportunities for analyses provided by the data set. We are not claiming to present trends in density or abundance over space or time, but rather want to present the available data and solicit feedback from IA members for further analyses.

METHODS

Data Acquisition

Aerial surveys were conducted during five expeditions of RV *Polarstern* (**Figure** 1) using the two on-board helicopters of type BO 105. For all expeditions, the ship's track was designed for purposes of other research projects on-board and the helicopter surveys "piggy-backed" (see Scheidat et al. 2011) along the given route.

All flights were planned in an "ad-hoc" manner when weather conditions and ship's logistics permitted. Track lines were designed around the current position of *Polarstern*, applying basic principles of good survey design following Buckland et al. (2001), and aiming at achieving a good coverage of the survey area. All covered track lines are shown in **Figure 2**. All survey flights were conducted following line transect *distance sampling* methodology (Buckland et al. 2001), and were flown at a constant altitude of 600 feet and at a speed of 80-90 knots. Two observers were seated in the back of the helicopter observing the area to the right and to the left side of the helicopter, respectively. As the helicopters were not equipped with bubble-windows, the observers in the back were not able to observe the area directly under the helicopter, omitting approximately the closest 80 m to each side of the transect line, respectively. Therefore, a third observer was seated in the port front seat of the helicopter, which allowed a direct view onto the transect line through the front window of the helicopter. This way, the port front observer covered the left part of the transect line not visible to the left observer in the back. Together, the left and front observers were able to provide full coverage of the left side of the transect line. Only these data, from the completely surveyed left side of the helicopter, were later used in the detection function modelling.

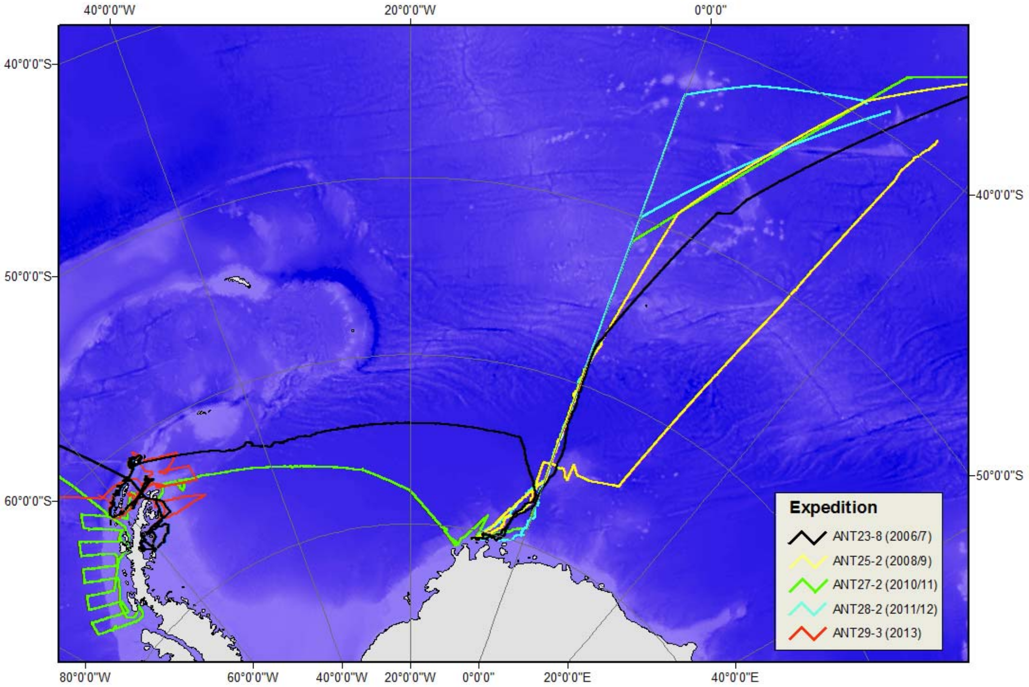


Figure 1: Ship tracks of five expeditions of RV *Polarstern* during which helicopter surveys were conducted. Projection: South Polar Stereographic.

All data were entered directly into a computer running the VOR software (Hiby & Lovell 1998), continuously storing GPS data obtained by a handheld GPS device (Garmin eTrex summit and Garmin 72H) in intervals of 4 s, operated by one of the observers, preferably the right observer in the back. Environmental and sighting conditions (sea state, cloud cover, glare, ice coverage, sighting condition (a compound variable which describes the overall ease to observe whales dependent on weather and ambient light conditions, taking four levels: 'good', 'moderate', 'poor' and 'unacceptable', 'unacceptable' equalling no survey effort) were entered as assessed by the observers and entries updated whenever any change therein occurred. The following data were recorded for each sighting of a group or of a single cetacean: species, distance to transect (estimated later via declination angle), group size including potential calves, group composition (adults / calves), behaviour, cue that triggered the detection, swimming direction and the response (reaction) to the helicopter. Declination angles to each sighting were always measured using inclinometers when the group was abeam the helicopter, in order to enable calculating the distance of the sighting to the transect line post-survey through trigonometry given the known flight altitude of the helicopter. This information is crucial for the latter estimation of the effectively covered strip width. If a sighting occurred and species could not be identified or group size could not be determined immediately, the survey was suspended in order to approach the sighting for closer inspection (closing mode). After identification, the helicopter returned to the transect line and the survey was resumed.

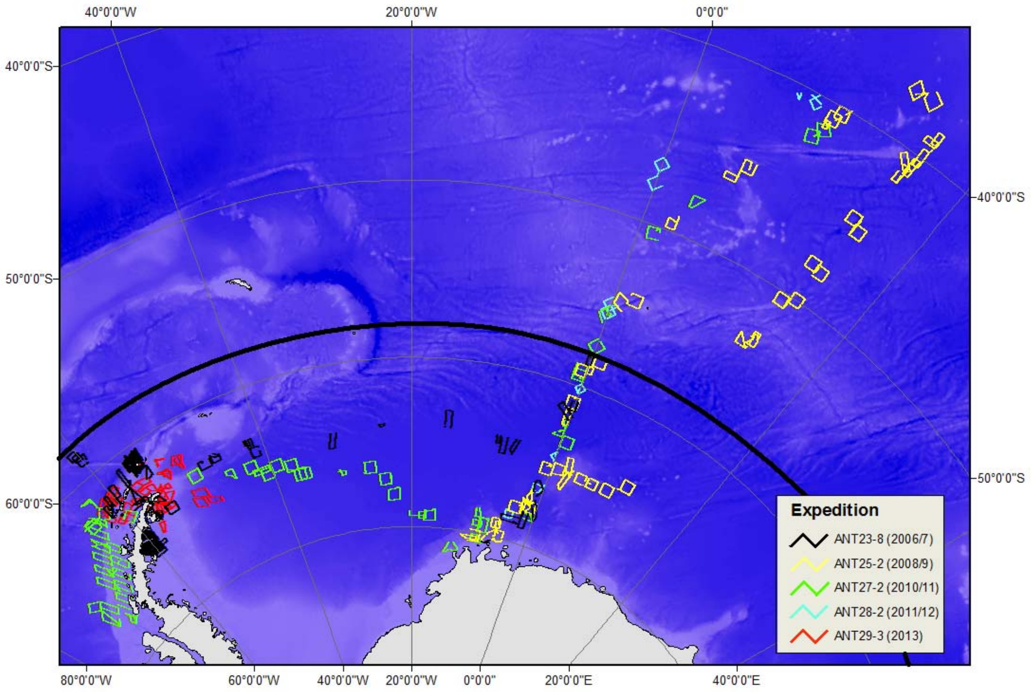


Figure 2: Tracks of all helicopter flights conducted during the aerial surveys of five *Polarstern* expeditions between 2006 and 2013. For the analysis of minke whale data, only data recorded south of 58°S (indicated by thick black line) were included.

Analysis

Although aerial surveys were commenced early en route to the Antarctic, only data collected south of 58°S were considered in the analysis, as the area north of this latitude cannot be attributed to the Southern Ocean. Distance to the marginal ice edge, as defined by a smoothed line bounding the 15 % ice concentration margin, was derived post survey for each data point from satellite remote sensing data. Daily 6.25 km resolution images of ice concentration, recorded by the **A**dvanced **M**icrowave **S**canning **R**adiometer for **E**OS (AMSR-E) satellite sensor (published by the Institute of Environmental Physics, University of Bremen, (http://www.iup.uni-bremen.de/seaice/amsredata/), were used to estimate the position of the ice edge for each survey day. Built-In 'Spatial Analyst' functions in ArcGIS 9.3.1 (Environmental Systems Research Institute, Inc., Redlands, California, 2009) were used to select the largest polygon of contiguous raster pixels featuring at least 15 % ice concentration, defining the outermost edge, and then smoothing it using the ‘‘Boundary Clean’’ function with default parameters. Finally, the "Near" function was used to calculate the distance to the closest ice edge for each 4 s interval data point and all cetacean sightings of the respective day, differentiating between distances within and out of the ice. Additionally, the ice coverage at each survey point was gathered from the same source.

Distance sampling (DS) methods were used to estimate the probability of detection as a function of distance from the trackline (Buckland et al 2001). The collected sighting data were analysed using the software package 'mrds' (Laake et al. 2013) in R Version 3.0.1 (R Core Team 2013). Finally, a multiple covariate *distance sampling* (MCDS) model framework was used to estimate the detection function (Marques and Buckland 2004), with the assumption that detection at the trackline is certain (i.e. $g(0) = 1$). Covariates tested in the MCDS component, in addition to perpendicular distance, included sighting condition, sea state, group size and a measure of local sea ice concentration (ice concentration judged by the observers, and classified as: 0-9% ice coverage = "no ice" and 10-100% = "ice". Ice concentration was included to test for evidence that increasing complexity in the visual field may decrease the probability that a sighting is made. Half-normal and hazard-rate forms of the detection function were tested and Akaike’s information criterion (AIC; Akaike 1974) was consulted in selecting a best set of models. Perpendicular distances were truncated to exclude the furthest 10% of detections (Buckland et al 2001). Detection functions were modelled using all minke whale sightings, including *B. bonaerensis*, *B. acutorostrata* and sightings that could not be clearly identified as either of them, and such that were defined as 'minke-like'. Only data from the left side (collected by the left and front observers) were used for detection function modelling, since, as mentioned above, the right side could not be fully covered by the observers. Furthermore, only sightings from good or moderate sighting conditions were included for fitting the detection function. In order to ensure adequate sample size, the sightings and all their associated covariates were pooled from all survey years to estimate a single detection function.

A density surface modelling approach was used to produce predictions on how the density of minke whales varied over space, and with some environmental covariates. Note that these density and abundance estimates are not corrected for availability bias (sensu Marsh and Sinclair 1989) and *g(0)*. The count method, as described by Hedley and Buckland (2004), in combination with spatial generalised additive models (GAMs), was used to estimate trend in densities of minke whales across the study area. The response variable was the number of animals per ‘segment’ of transect, where the segment length was selected to ensure relative homogeneity in sighting conditions within a single segment. A segment length of 50 km was selected in order to balance between over-dispersion in the number of animals sighted and having too much heterogeneity in density within a single segment. Effort with sighting conditions less than ‘moderate’ in quality were removed from the analysis. An offset variable was incorporated in the model to account for changes in estimated probabilities of detection within each segment, which ultimately manifest in differences in effective search areas of the segments. The offset, or the logarithm of the effective search area, was estimated using the MCDS model described above.

The modelling for the density surfaces was undertaken in R (R Development Core Team, 2014) using the *mgcv* package when fitting GAMs (mgcv v1.7-28; Wood 2006, 2011). A Tweedie distribution (Jørgensen 1987) was used to model the count data. Variance from the detection function fitting was propagated through the GAMs, at the segment level, to the ultimate abundance estimates via a random effects method described in Williams et al. (2011b). Variables tested for inclusion in the spatial model included smooths of longitude, sea ice concentration (AMSR-E, SSMI and AMSR2, corresponding to date of survey) and distance from the putative sea ice edge (approximately 15%, as derived from the satellite data for each survey day as described above), across the survey area. Year was also included in the spatial models as a linear term. Effort beyond 500 km of the sea ice edge was removed from the GAM analysis. Furthermore, effort from the West Antarctica Peninsula region was also removed as it is not generally an ice dominated area and analyses focused on minke whale relationships to ice.

Densities were compared for three selected areas: Neumayer (NM), Weddell Sea (WS) and East Antarctic Peninsula (EAP) (Figure 3). These areas were chosen as they were visited during more than one survey and provided a data base for temporal comparisons. The area of Neumayer was visited during four of the expeditions (ANT23-8 (2006/07), ANT25-2 (2008/09), ANT27-2(2010/11) and ANT28-2 (2011/12), each time during the month of December, providing the opportunity for inter-annual comparisons between the four years. The Weddell Sea area was crossed during two expeditions (ANT23-8 (2006/07) and ANT27-2 (2010/11), both times in the end of December / beginning of January, and areas east of the Antarctic Peninsula were targeted during two surveys (ANT 23-8 (2006/07), ANT29-3 (2013)) in January and February, respectively. Predictions of minke whale densities were conducted for selected dates of the survey periods, meeting approximately the middle of the corresponding effort periods. Accordingly, for NM density surfaces were predicted for 15th December 2006, 15th December 2008, 15th December 2011 and 14th December 2010, for WS for 18th December 2006 and 30th December 2010 and for the EAP for 15th January 2007 and 14th February 2013.

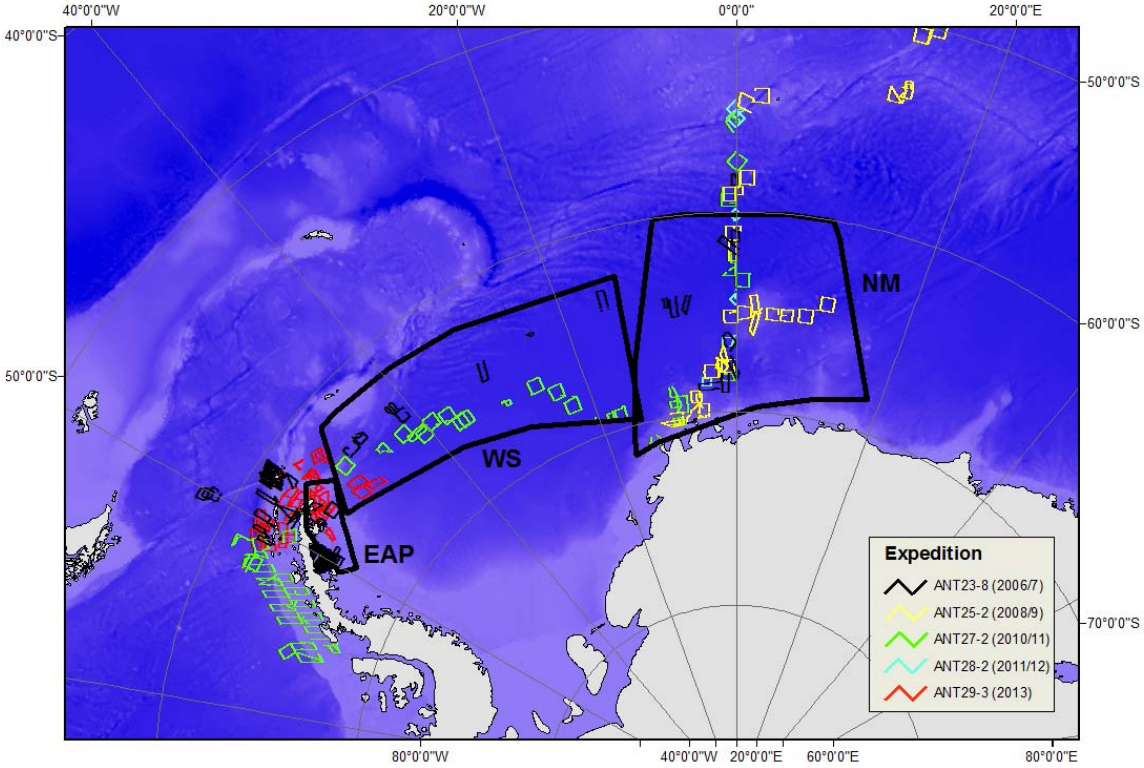


Figure 3: Areas for which density predictions were compared; EAP (East Antarctic Peninsula), WS (Weddell Sea), NM (Neumayer). Projection: South Polar Stereographic.

RESULTS

During five expeditions, 40,985 km of track lines were covered on effort by the helicopter surveys south of 58°S (Table 1). Flights were conducted on 106 survey days, with concentration of effort in December and January. Altogether 157 minke whale pods (288 individuals) were recorded. Observations by the left sided observers (i.e. front observer and left rear observer combined) provided 120 sightings of minke whale groups, comprising a total of 217 animals (Table 2). Positions of all minke whale sightings are given in Figure 4**Figure 4**. While 65 % of all effort was conducted in areas out of the 15% MIZ, 74 % of all minke groups were sighted out of the MIZ, and 81 % of all sighted individuals occurred out of the ice, corresponding to larger group sizes of 2.06 (SD +/- 0.66) animals / group compared to an average group size of 1.33 (SD +/- 0.13) animals / group within the MIZ (Figure 5). During the expedition ANT28-2 in 2011/12, technical problems led to comparably little effort and resulted in no sightings of minke whales at all (Table 2). Therefore, effort data from this survey was excluded from further analysis.

Table 1: Distribution of all effort south of 58°S over months, including effort under sighting conditions good, moderate and poor.

month	survey days	effort [km]
December	47	18,299
January	40	15,637
February	13	4,763
March	6	2,286
Sum	**106**	**40,985**

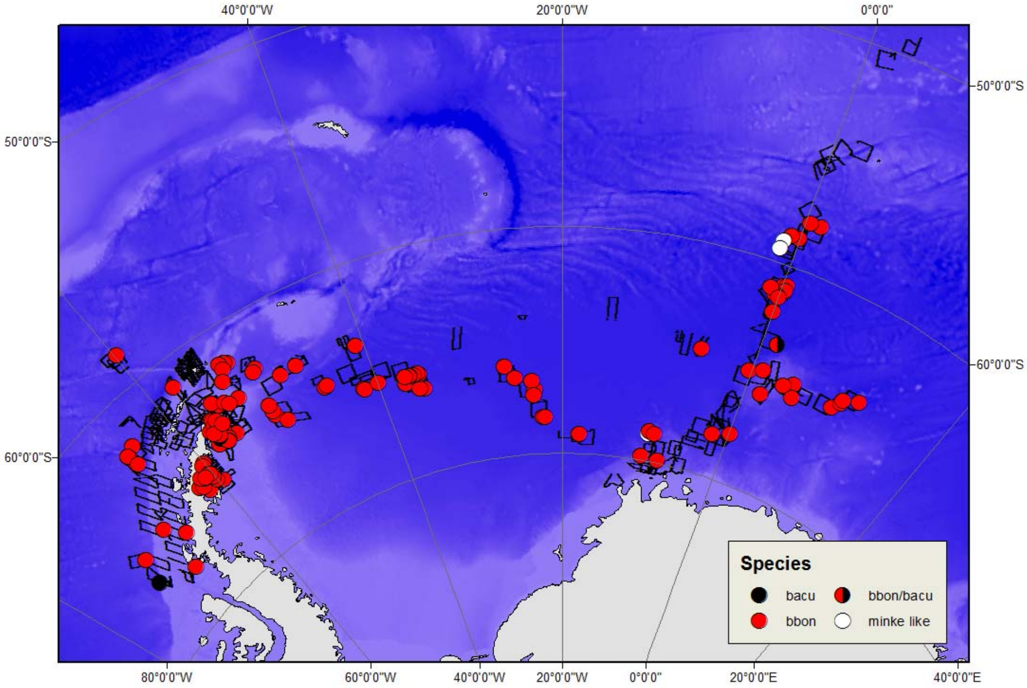


Figure 4: All sighting positions of minke whales recorded during aerial surveys conducted in the course of five *Polarstern* expeditions (see Figures 1 and 2). bacu = *Balaenoptera acutorostrata*, dwarf minke whale; bbon = *B. bonaerensis*, Antarctic minke whale; bbon/bacu = uncertain identification of either *B. acutorostrata* or *B. bonaerensis*; minke like = "minke like" identification of cetacean.

Table 2: Summary of effort and minke sightings for all five *Polarstern* expeditions. Only sightings from left side of the transect line are considered, therefore encounter rates also account for one-sided observations only.

year	**expedition**	**effort [km]**	**# sightings**	**# individuals**	**mean group size** (CV)	**encouter rate [sighting/km]**
2006/07	ANT23-8	13,124	65	132	2.03 (0.61)	0.0050
2008/09	ANT25-2	6,220	11	13	1.18 (0.41)	0.0018
2010/11	ANT27-2	13,213	28	42	1.5 (0.86)	0.0021
2011/12	ANT28-2	776	0	0	-	-
2013	ANT29-3	7,652	16	30	1.88 (0.80)	0.0021
Sum		**40,985**	**120**	**217**	**1.81 (0.72)**	**0.0024**

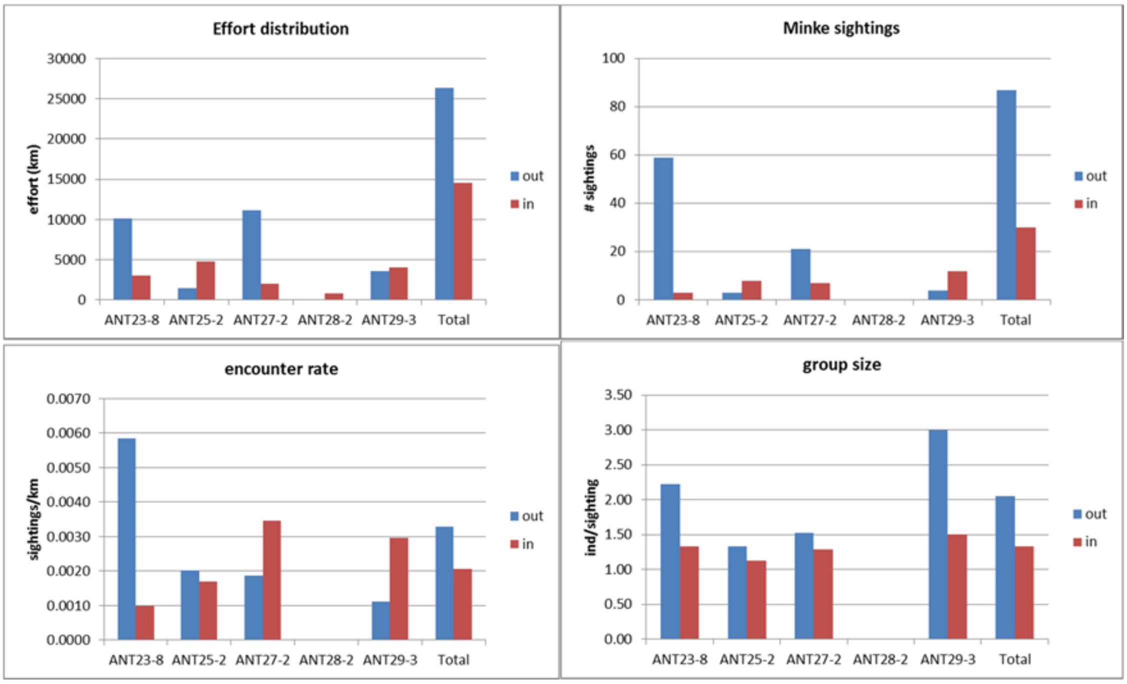


Figure 5: Distribution of effort, minke whale sightings, average group sizes and encounter rates between areas within ("in", red) the 15% ice coverage zone and without ("out", blue).

Detection function

Detection distances were right-truncated at 945 m for fitting the detection function. Comparing the AIC from all permutations of the detection functions and potential scaling variables identified a half-normal detection function with a *distance sampling* model scaled by a linear combination of group size (binned as: group size of 1; group size of 2-7) and sighting condition score (1 = moderate, 2 = good) as the most effective model. Detection distances and the resultant detection function are given in Figure 6. The estimated mean detection probability between track-line and the truncation distance was 0.71 (CV = 0.09). Effective strip widths, depending on binned group sizes and sighting conditions are given in Table 3. Going from group size of 1 to 2+ increased the effective strip width an average of around 330 m; moving between a sighting condition score of moderate to good increased the effective strip width by an average of 80 m.

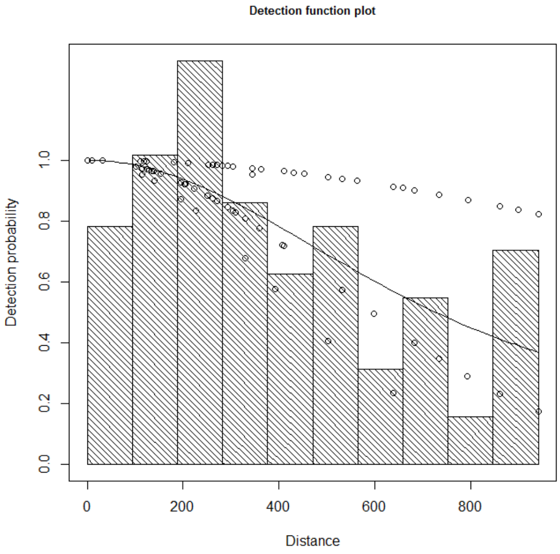


Figure 6: MCDS detection function fit — a half normal function scaled by a linear combination of group size (two bins: 1, 2-7) and a sighting condition score (moderate and good). Circles are the probability of detection for each sighting given its perpendicular distance and other covariate values; solid line is the fitted detection model.

Table 3: Effective strip widths (m) for the combination of sighting condition and binned group size

sighting condition	**group size = 1**	**group size = 2-7**
'moderate'	463	840
'good	593	883

A spatial model comprising a combination of smoother of longitude, distance to the ice edge, and ice concentration was selected as the best GAM to describe the distribution of densities in the survey region, assuming a Tweedie distribution with a power variance value of 1.3 (see

Figure 7). The survey year term was also statistically significant and was retained in the model. The GAM results suggest that minke whale densities are much higher in the west part of the Weddell Sea as compared to regions closer to 0°E; this is reflected in the distribution of sightings. The smooth of distance from the ice edge (negative values are inside ice areas) suggests a peak in minke whale densities at or slightly outside the ice edge, and a decrease in density when heading further into the open water. Although there is an increase of uncertainty around estimates of density inside ice areas, the GAM is indicating the density of minke whales to remain fairly constant with distance to the sea ice edge (

Figure 7).

Predictions of minke whale densities across each stratum and dates as described above, are given in Figure 8, Figure 9 and Figure 10. Predictions are associated with daily satellite sea ice data and are relevant to the particular day sea ice data was derived for. The coordinates of the prediction grid correspond to the grids points of the AMSR-E sea ice data, which are spaced at 6.25 km intervals. The associated abundance and density estimates (uncorrected for *g(0)* and availability bias) are provided in Table 4.

The NM stratum, which has been surveyed in the middle of December during three different years shows little variation in predicted densities between the years (Figure 8, Table 4). However, predictions for NM are associated with high CVs. Stratum WS, surveyed for the first time in December 2006 and a second time in December 2010 on the other hand shows interesting variation between the two years, with higher densities distributed over a much larger area in 2006 compared to 2010, and abundances (uncorrected) ranging from around 15,000 (CV 0.34) in 2006 down to around 6,513 (CV 0.32) animals in 2010 (Figure 9, Table 4). Likewise, differences between the two years stratum EAP was surveyed are also remarkable (Figure 10, Table 4).

Spatial comparisons of densities between the three strata during the same years revealed evident differences, e.g. for Dec 2006 a density of 2.54×10^{-3} [95% CI 1.27×10^{-3}, 5.11×10^{-3}] was predicted for in NM compared to densities of 1.24×10^{-2} [7.88×10^{-3}, 1.97×10^{-2}] in WS and 3.40×10^{-2} [2.54×10^{-2}, 4.56×10^{-2}] in EAP (EAP in January 2007).

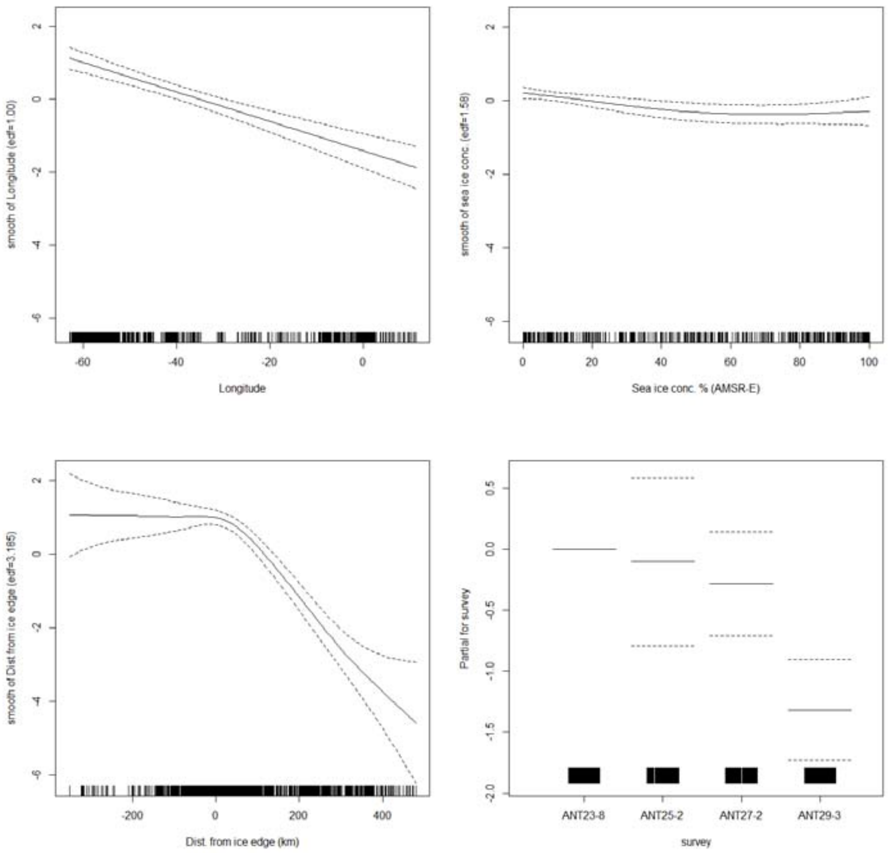
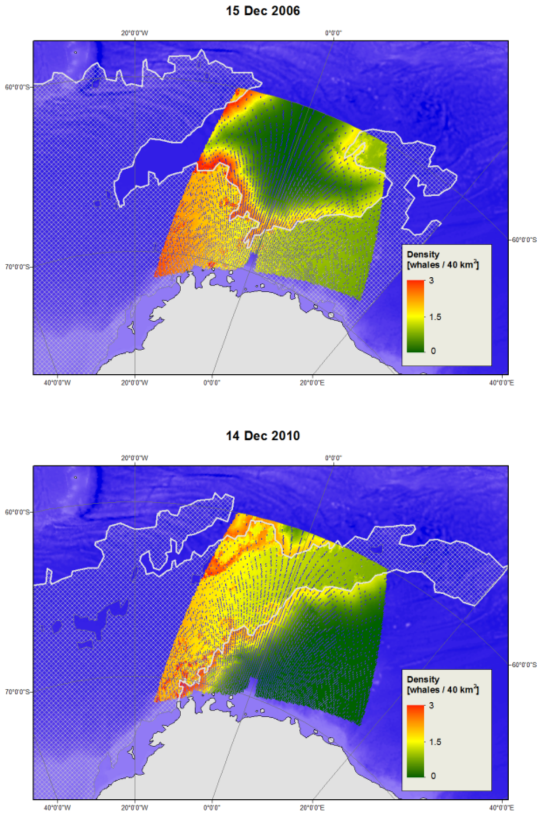


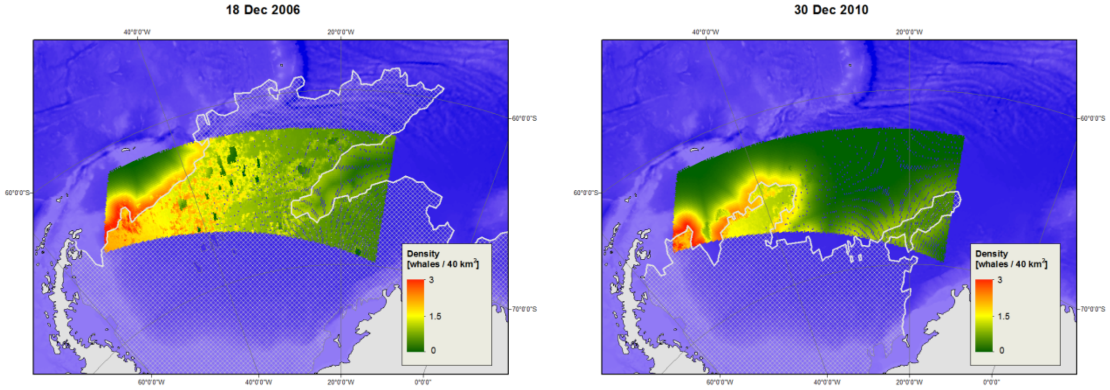
Figure 7: Effect of longitude (upper left), sea ice concentration (AMSR-E satellite) (upper right), and distance from ice edge (lower left) on minke whale abundance, as modelled with GAMs. The y axis in these plots is on the scale of the log-link function of minke whale abundance. The effect of survey season is given in lower right plot. The rug ticks at the bottom indicate reasonable coverage of longitudes between 15°E and 65° W, good coverage across all sea ice concentrations and in distances to the 15% ice-edge between 400 km to the outside and 200 km into the 15% marginal ice zone (negative numbers).


15 Dec 2006

15 Dec 2008

14 Dec 2010

Figure 8: Predictions of minke whale densities across the NM stratum for three given dates of sea ice concentration. Outlined in white is the 15% ice margin for each date as derived from satellite data. Ice data are only displayed up to 20° E. Raster resolution 0.1 decimal degree.


18 Dec 2006

30 Dec 2010

Figure 9: Predictions of minke whale densities across the WS stratum for two given dates of sea ice concentration. Outlined in white is the 15% ice margin for each date as derived from satellite data. Raster resolution is 0.1.

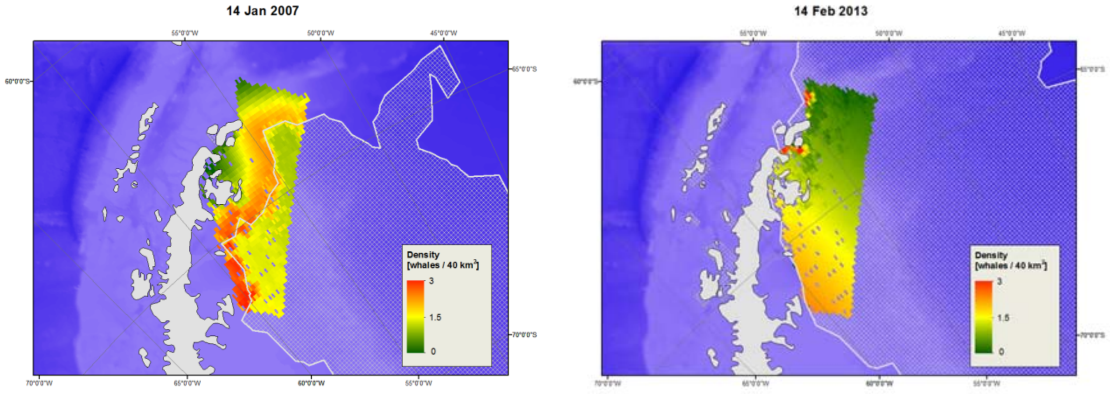


Figure 10: Predictions of minke whale densities across the EAP stratum for two given dates of sea ice concentration. Outlined in white is the 15% ice margin for each date as derived from satellite data. Raster resolution is 0.1.

Table 4: Estimates of abundance (with CVs) and densities (with 95% CI) of Antarctic minke whales for selected strata and for dates representing approximately the midpoint of the associated survey effort (uncorrected for *g(0)* and availability bias). Prediction regions: NM = Neumayer, WS = Weddell Sea, EAP = East Antarctic Peninsula.

Prediction region	**Dates**	**Area of prediction grid [km^2]**	**Uncorrected abundance (CV)**	**Mean uncorrected density--animals per 40 km^2 (95% CI)**
NM	15. Dec. 2006	1 382 070	3522 (0.53)	2.54×10^{-3} (1.27×10^{-3}, 5.11×10^{-3})
NM	15. Dec. 2008	1 382 070	4016 (3.26)	2.91×10^{-3} (3.23×10^{-4}, 2.61×10^{-3})
NM	14. Dec 2010	1 382 070	2668 (0.41)	1.93×10^{-3} (1.10×10^{-3}, 3.36×10^{-3})
WS	18. Dec 2006	1 201 953	15001 (0.34)	1.24×10^{-2} (7.88×10^{-3}, 1.97×10^{-2})
WS	30. Dec. 2010	1 201 953	6513 (0.32)	5.42×10^{-3} (3.51×10^{-3}, 8.35×10^{-3})
EAP	14. Jan. 2007	82 578	2811 (0.21)	3.40×10^{-2} (2.54×10^{-2}, 4.56×10^{-2})
EAP	14. Feb. 2013	82 578	684 (0.65)	8.28×10^{-3} (3.60×10^{-3}, 1.90×10^{-2})

As the selected detection function contained group size as a variable, variance from estimating school size was propagated through to the ultimate abundance estimates using the delta method.

DISCUSSION

Presented here are preliminary analyses of all obtained sighting and effort data on Antarctic minke whales from helicopter surveys in Antarctica between 2006 and 2013. Ship-based helicopter surveys proved to provide valuable data on minke whale occurrence in pack-ice regions that are difficult to survey from ships (compare Kelly et al. 2012). A large amount of survey effort, a third of the total effort and equalling ~15000 km, could be dedicated to areas beyond the 15% sea ice edge collecting data on minke whales from areas of various ice concentrations.

While roughly 35% of all survey effort were spent within the 15 % MIZ, only 26% of all minke sightings occurred within the MIZ, pointing to a slightly higher encounter rate out of the ice than within. This assumption is underlined by the GAM results with the smooth of distance from the ice edge suggesting a peak in minke whale densities at or slightly outside the ice edge, yet at the same time predicting a decrease in density when heading further into the open water. The smooth of sea ice concentration proved not as informative, but that may be due to the smooth of the distance to the ice edge soaking up most of the variation in minke whale densities. Furthermore, the GAM results suggest that minke whale densities are much higher in the west part of the Weddell Sea as compared to regions closer to 0°E; this is also reflected in the distribution of sightings.

Predictions for selected areas and times, based on the helicopter data provide interesting insights into the variability of minke whale densities over time and space and their relationship to sea ice. The temporal comparisons show large differences in predicted (uncorrected) density and abundance between the same months of different years, highly dependent on the prevalent ice situation. Stratum WS featured high predicted minke whale densities distributed over a much larger area in December 2006 than compared to December 2010, resulting in a significantly higher abundance for the stratum in December 2006 than December 2010. In December 2006 much more of the stratum was covered by ice than in December 2010. On the other hand, in the comparably small stratum EAP abundance was predicted much higher for January 2006, when only half the stratum was covered by ice, as compared to February 2013, where, due to an extreme ice-situation (compare NASA 2013) the area was almost completely covered by ice. Predicted density and abundance in stratum NM showed little variance between three investigated survey years. Yet, a notably large CV is associated with the predictions for NM in 2008. This can be attributed to it being an extensive ice year and owing to larger uncertainty for predictions deeper inside the ice (see Figure 7) being propagated through to this CV.

These results give insight into a high variability in minke whale densities related to sea ice parameters, potentially changing quickly over time and space. The uncorrected densities of minke whales within sea ice regions in the Weddell Sea area seem to be very heterogeneous, driven by a longitudinal gradient and a strong relationship to the position of the 15% sea ice edge. Covering the full range of ice concentrations and dedicating effort to both sides of the ice edge, the helicopter survey data provide capacity to predict for patterns of minke whale distribution in and out of the ice, which could be demonstrated in this analysis. As suggested by Kelly et al. (2012) such regional density and abundance estimates could provide an idea of likely boundaries or magnitudes of abundances of minke whales inside and outside of sea ice regions.

However, the obtained abundances and densities could not be corrected for neither perception nor availability bias and therefore have to be considered as minimum estimates. It is clearly important to begin estimating availability bias across a range of sea ice and open water habitats, to allow for corrected abundance estimates fromaerial surveys. An approach that shall be explored in this respect is the 'forward distances' approach developed by Borchers et al. (2013), based on hidden markov models. Thanks to the front observer, who estimates perpendicular distance of a sigthing to the trackline via radial distance and horizontal angle, rather than only the perpendicular declination angle, the helicopter data provide the opportunity to evaluate the forward distances of a large share of sightings. Such an analysis may potentially enable at least an approach to availability bias (Borchers et al. (2013) of minke whales during aerial surveys. Regardless of this it is imperative that funding be allocated to the estimation of availability bias, as without this factor abundance estimates will always miss a large share of the minke whale population.

The presented analyses are a first assessment of the collected data, including only few environmental variables for prediction. During continued analysis other parameters, such as bathymetric data (especially depth and distance to shelf break) are to be added to the models and predictions of abundance. In a commenced cooperation, data from the Australian fixed-wing aerial surveys (Kelly 2009, 2010) and the helicopter data are to be analysed together. The combination of both data sets will offer the opportunity to make inferences on how minke whales occupy areas over the gradient between the open-ocean and dense sea ice, throughout much broader areas of the circum-Antarctic region than just covered by each survey programme alone.

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