PRELIMINARY ANALYSIS OF MINKE WHALE SIGHTING DATA FROM 2009/10 AERIAL SURVEY OFF EAST ANTARCTICA

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Abstract

An aerial survey targeting Antarctic minke whales (*Balaenoptera bonaerensis*) was undertaken in the austral 2009/10 austral summer in east Antarctica. This recent survey repeated a similar survey design (location and transect direction and spacing) to that of a smaller-scale aerial survey in the 2008/09 austral summer. In addition, the recent survey also extended effort both further west across pack-ice around the Shackleton Ice Shelf and Davis Sea and north of the ice edge and into open water. Both aerial surveys were double-platform and conducted using CASA-212 aircraft.

A basic MRDS analysis yielded estimates of relative densities for areas within both aerial surveys. In the Vincennes Bay area, relative density of minke whales in December 2008 was around 10 times that of densities observed in December 2009. There was also an intra-season increase in relative density of minke whales in Vincennes Bay: estimated relative density of minke whales in the Vincennes Bay in late January- early February 2010 was 2-4 times higher than in December 2009 (based on point estimates). Densities of minke whales were higher in the north of the Davis Sea as compared to the south. It may be that pack-ice dynamics and the relative position of the shelf-break (krill habitat) are influencing inter- and intra-summer densities of minke whales across the aerial survey study area.

Introduction

With the aim of studying the abundance and distribution of Antarctic minke whales (*Balaenoptera bonaerensis*) in pack-ice in east Antarctica, aerial surveys (double-platform) were undertaken in the austral summers of 2008/09 and 2009/10. The survey in the 2008/09 summer was considered a 'pilot' and focussed on the Vincennes Bay polynya in December 2008. Survey effort in the austral summer of 2009/10 started in December 2009 and largely repeated the survey design from the first year, but also targeted areas around the Shackleton Ice Shelf and the Davis Sea, and finished with more effort over the Vincennes Bay polynya in late January and early February 2010. These aerial surveys are fully described in Kelly *et al.* (2009; SC/61/IA3) and Kelly *et al.* (2010; SC/62/IA8), respectively.

This short note presents a preliminary analysis of minke whale sighting data from these aerial surveys. We have produced basic estimates of relative densities in order to begin exploring abundance and distribution of minke whales within pack-ice both between and within the 2008/09 and 2009/10 austral summers in east Antarctica. These are, however, preliminary results and we intend to undertake a full analysis in the coming year.

Methods

The following is a summarised description of materials and methods; more details on survey protocols are given in Kelly *et al*. (2010; SC/62/IA8).

Survey protocols

The survey platform was CASA-212(400) fixed-wing aircraft. On-effort flying altitude was 228m (750ft) and speed was 204 km hr^{-1} (110 knots). On board were four observers (two per side of aircraft), a flight leader (A. Hodgson; seated at the left-rear) and two pilots. The survey was double-platform; the front and back observers were isolated visually with a thick curtain and were not able to hear one another through the intercom system. Observers were encouraged to search ahead and as close to the track line as the small-flat windows allowed (aircraft windows were square in shape, with a width of 280 mm, height of 270 mm and 330 mm between diagonal rounded corners). The observations themselves consisted of cue counting and angle of declination when animals are perpendicular, or abeam, to the observer (using a *Suunto* inclinometer). Perpendicular distance out to animal(s) was calculated using angle of declination and flying height (but no correction for curvature of the earth or aircraft drift angle was applied). Other information recorded included species; group size (minimum, maximum and best estimate); cue type; number of animals at surface when perpendicular; direction of travel; and any behavioural features of the animal(s). The flight leader also made a number of whale observations on the left of the aircraft, particularly if the left-side observers failed to detect the animals. Flight leader observations, however, are not presented here. Other than during an observer training phase at the start of each survey, no attempt was made to loop back and re-sight observations to confirm species or group sizes.

The flight leader recorded variables that potentially influence the quality of observations, such as Beaufort sea state, glare, cloud cover and type, and an overall sightability score (a four-level compound variable detailing the overall quality of sighting conditions), at the start of each transect and each time these variables changed; and also continuously observed environmental covariates such as concentration of pack ice. GPS data, altitude and flying speed were continuously recorded on the aircraft's data logger. There was also a video/digital stills camera system located in the base of the aircraft. These cameras recorded the presence of whales in the area under the aircraft inaccessible to the observers and also recorded ice information.

Survey design and analysis

There was a single stratum for the 2008/09 aerial survey, covering the Vincennes Bay polynya, and the parallel and systematically located transects were orientated north-south and spaced at 10 nm; this stratum is referred to as CA12008. The 2009/10 aerial survey was conducted in three phases, consisting of several strata. The first phase repeated a survey design (but not the exact transects) from the 2008/09 summer period, based in and around Vincennes Bay; there was one stratum in this phase and both the phase and the stratum are referred to as CA1. The second phase, referred to BH1, moved survey effort over to the Shackleton Ice Shelf and the Davis Sea. This second phase contained four strata: Davis Sea South (DSS); Davis Sea North (DSN); Shackleton polynya (SCN); and SOWER-follow stratum (SWF), see Figure 1. Equal-spaced zigzag transects were used in the second phase due to low fuel availability. The final phase, referred to as CA2, repeated the CA1 phase (again, transect locations were re-randomised), but also extended transects around 40 nm north of the sea ice boundary. Again, parallel and systematically located transects, which were north-south orientated and spaced at 10 nm, where used. Unfortunately, there was uneven coverage in the final phase, so two new strata were produced after the survey had finished, which split the planned survey area east and west: CA2E (east) and CA2W (east). A full description of the survey strata are given in Kelly *et al*. (2009; SC/61/IA3) and Kelly *et al*. (2010; SC/62/IA8).

Preliminary and very basic estimates of the relative densities of Antarctic minke whales within the survey strata were derived using the double-platform observation data from both aerial surveys. These data were corrected for animals missed on the track-line (due to small flat aircraft windows) using mark-recapture distance sampling (MRDS) (after Borchers *et al.* (1998) and Borchers *et al.* (2006)). This analysis was completed using *Distance* 6 (release 2) (Thomas *et al.* 2009) with the MRDS engine. The status of duplicate sightings was decided using time abeam and the angle of declination and no error has been attached to this process at this time. A small number of 'like' minke whale sightings were pooled with the minke whale sightings for this analysis.

Effort was removed from the analysis when Beaufort sea state was greater than 4. For simplicity, after aircraft side-wise duplicate sightings were assigned, the front observers and back observers were pooled, respectively; so, effectively, there were only two observers in the analysis.

With a combination of aircraft skis and small, flat windows, the maximum declination (from the horizon) that could effectively (and comfortably) be searched was around 62°. At a survey flying height of 228 m, this equates to a distance of 121 m from the track-line that cannot be searched. This distance, therefore, becomes the left truncation distance by default. A right truncation distance was set at 1,200 m. By being isolated both visually and audially, front and back observers are truly independent. And while the aircraft frame starts to taper towards the front near where the front observers sit, but we don't believe this provides a substantial increase in sighting area. We are reasonably confident there was no animal response to the aircraft at the survey height and speed, so point-independence (i.e., observations are only assumed independent at the track-line) is appropriate.

Models with various permutations of detection function shape (i.e., half-normal versus hazard-rate), and variables which may affect scaling of the distance sampling and mark-recapture model components (i.e., distance, sightability, group size and sea ice concentration[1]) were fitted and model selection was via minimising the Akaike information criterion (AIC) (Akaike 1974). As pack-ice concentration changed so frequently, transects were split into (approximately) 10 second segments, within which ice concentrations and other environmental covariates are assumed to be homogenous. A design-based (relative) density estimate was derived for each stratum, incorporating the probability of detection for each sighting, as estimated from the detection function (Borchers *et al*. 1998), and total transect length. The variance of the estimated density was based on the empirical variance, (as presented in Innes *et al.* (2002)).

Results

Coverage

Achieved effort (as achieved stratum boundaries) is shown in Figure 1 and summarised in Table 1. More details about coverage of each survey are given in Kelly *et al*. (2009; SC/61/IA3) and Kelly *et al*. (2010; SC/62/IA8).

[1] Sea ice concentration along track was estimated using stills taken with a vertically orientated digital camera (mounted in the based of the fuselage of the aircraft; image footprint approximate 153 m x 102 m (at a flying altitude of 228 m)). An automatic classification algorithm was developed to take still images and estimate the percentage of sea ice coverage in each image, as well as information on ice pan size and numbers. Images were pre-processed to allow for the survey's differing light conditions and then normalised to provide the greatest light contrast. Each pixel of these adjusted images was then classified as either 'ice' or 'water' based on the pixel's intensity in the red spectrum. An analysis of 'clumps' in the images provided a description of ice pan size and number.

For MRDS analysis, estimated sea ice concentration was summarised into following bins: 0-5%; 5-30%; 30-60%; 60-90%; and 90-100%.

Table 1 Details of the 2009/10 aerial survey strata and transects

Stratum	Stratum area (nm2) - realised	Phase	Start and end date	Total Transect Length (nm) – achieved*
Casey 1 2008 (CA12008)	17 668.1	CA12008	11 Dec – 31 Dec 2008	3 397.7
Casey 1 (CA1)	16 238.3	CA1	16 Dec – 27 Dec 2009	1 470.2
Davis Sea South (DSS)	5 181.3	BH01	29 Dec – 30 Dec 2009	552.9
Davis Sea North (DSN)	4 627.4	BH01	30 Dec – 31 Dec 2009	393.6
Shackleton Polynya (SCN)	3 396.7	BH01	31 Dec 2009 – 9 Jan 2010	277.9
SOWER follow (SWF)	1 081.6	BH01	16 Jan – 16 Jan 2010	96.7
Casey 2 (CA2)	24 917.8	CA2	17 Jan – 5 Feb 2010	
CA2-East (CA2E)	5 567.8	CA2	5 Feb – 5 Feb 2010	317.4
CA2-West (CA2W)	19 466.1	CA2	17 Jan – 5 Feb 2010	1 814.9
Totals	55 559.2~			4 923.8

~Total realised survey area, minus overlapping areas, is 34 159.9 nm^2.
*Does not include observer break/rest periods.

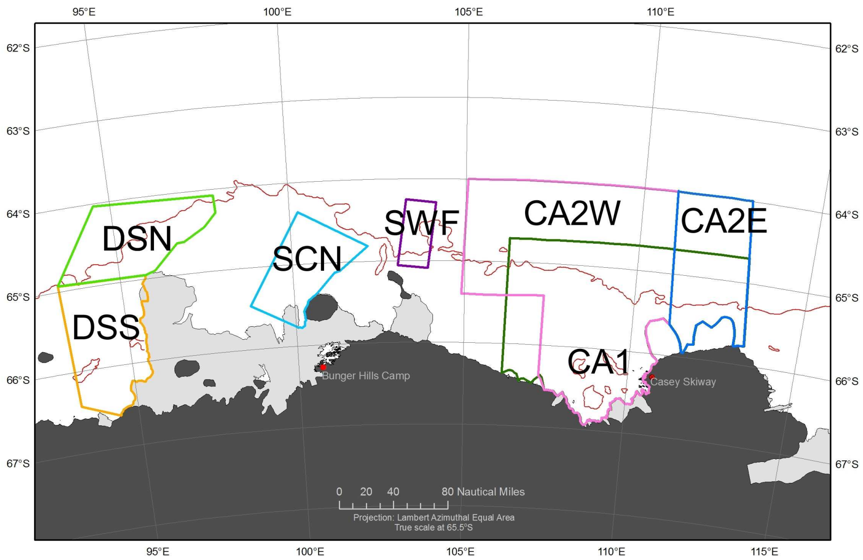

Figure 1 The single stratum of the CA1 phase (Vincennes Bay) is in dark green; strata within the BH1 phase (Shackleton Ice Shelf and Davis Sea): Davis Sea South (DSS) given in yellow, Davis Sea North (DSN) in bright green, Shackleton polynya (SCN) in aqua, and SOWER-follow stratum (SWF) in purple; strata within the CA2 phase (Vincennes Bay): western stratum (CA2W) given in pink and the eastern stratum (CA2E) in blue. Continuous red line is the 1000m bathymetric contour. See Kelly *et al*. (2009; SC/61/IA3) for map of CA12008 stratum.

Sightings

Combined minke and 'like' minke sightings, by observer and strata are given in Table 2. See Kelly *et al*. (2009; SC/61/IA3) for further details of minke whale sightings in the 2008/09 aerial survey (i.e., CA12008). Sighting information below largely repeated from Kelly *et al*. (2010; SC/62/IA8). (Duplicated sightings are also displayed in the top row of Figure 4.)

Table 2 Numbers of minke whale and 'like' minke whale sightings within each stratum, for both primary (front) and secondary (back) observers; total number of individual animals given in brackets.

Stratum	Primary observer	Secondary observer	Both	Total
CA12008	38 (59)	36 (53)	23 (37)	51 (75)
CA1	2 (3)	1 (2)	1 (2)	2 (3)
DSS	3 (4)	2 (2)	2 (2)	3 (4)
DSN	3 (5)	1 (1)	1 (1)	3 (5)
SCN	2 (2)	2 (2)	1 (1)	3 (3)
SWF	3 (9)	2 (8)	2 (8)	3 (9)
CA2W	7 (7)	5 (5)	2 (2)	10 (10)
CA2E	1(1)			1 (1)
Total	59 (90)	49 (73)	32 (53)	76 (110)

The distributions of minke whale group-sizes for both survey years are given in Figure 2. Sightings of single animals are by far the most common across both survey years. Mean group size, with standard error, by stratum is given in Table 3.

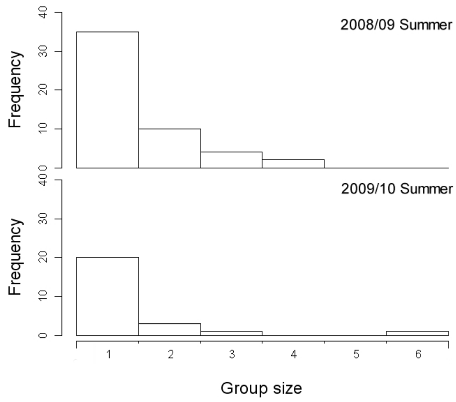

Figure 2 Distribution of group-sizes of minke whale sightings across all survey phases, for both the 2008/09 and 2009/10 aerial surveys.

Table 3 Mean group size by stratum, with standard error.

Stratum	Mean group-size	Stand. error group-size
CA12008	1.37	0.06
CA1	1.45	0.40
DSS	1.30	0.22
DSN	1.53	0.09
SCN	1.00	0.07
SWF	2.32	0.96
CA2W	1.00	0.08
CA2E	1.00	
Overall	1.32	0.08

Distance Analysis

Comparing the AIC from all permutations of the detection functions and potential scaling variables, the most promising combination was a hazard-rate detection function with a distance sample model scaled by group-size and binned sea ice concentration; and a mark-recapture model specified by distance and group-size; fitted detection function given in Figure 4. The estimated mean detection probability at the track-line for the primary observer was 0.83 (CV = 0.06) and pooled probability of detection was 0.97 (CV = 0.02). The distance and group-size parameter estimates behaved as expected: detection probability decreasing with distance and increasing with group-size (data not shown). Estimated detection probability also increased slightly with the binned sea ice concentration variable (data not shown). This is curious as, generally speaking, the ability to see minke whales decreases with increasing ice concentration. However, the addition of the binned ice concentration variable only improved model fit by a small amount and, so, its slightly positive parameter estimate may be a spurious result.

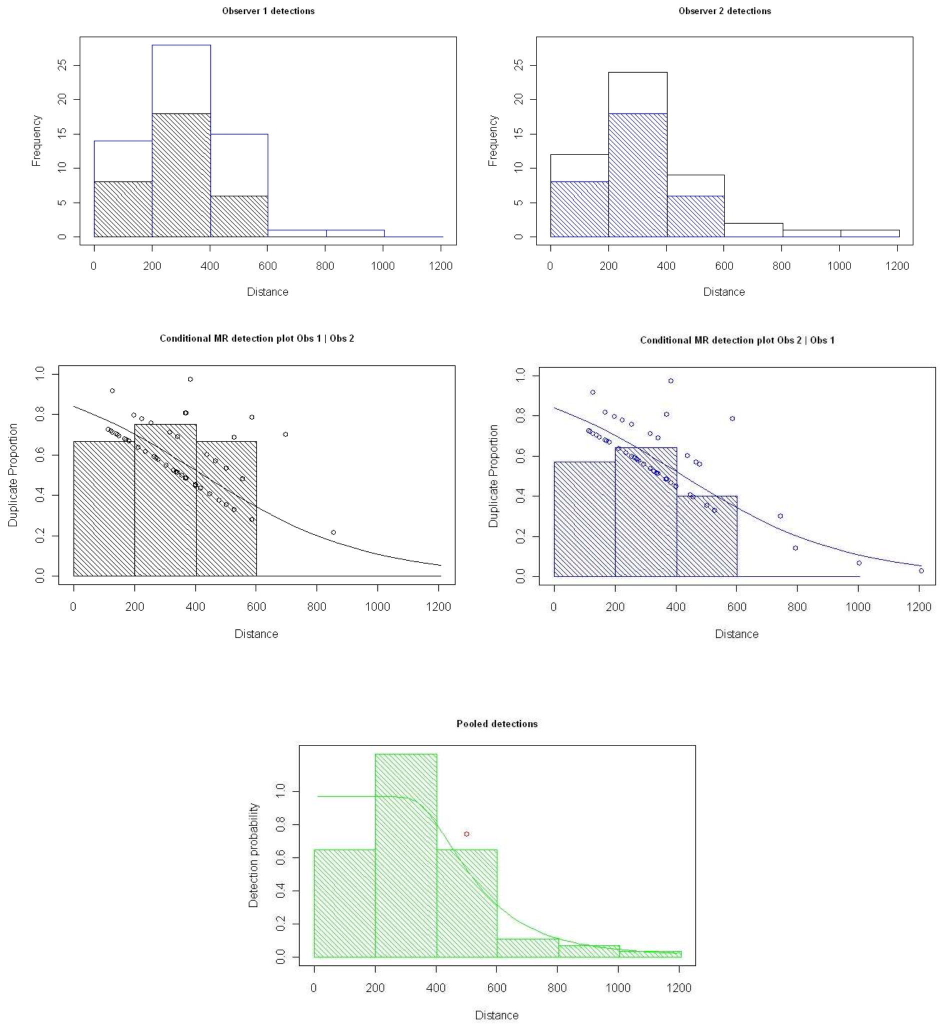

Figure 3 Conditional detection functions for the 'primary' and 'secondary' observers. Plots in top row show proportion of sightings by one observer duplicated by the other (filled sections of bars). Plots in middle row show MRDS detection functions, with the circles showing the estimated probability of detection for each sighting. Plot in bottom row shows detections pooled across both observers.

Relative Densities

Estimated relative densities of groups and individuals (per km^2) are given in Tables 4 and 5, respectively. Of note is that estimated density of groups (and individuals given mean group size was just above one) in the 2008/09 aerial survey was around ten-times that of the 2009/10 survey in the Vincennes Bay area (i.e., CA12008 vs. CA1; inference based on point estimates). Estimated density of minke whales in the Vincennes Bay in late January- early February 2010 was 2-4 times higher than in December 2009 (again, based on point estimates). Estimated density in the SWF (SOWER-follow) stratum should be treated with care given relatively small stratum area. Estimated minke whale density in the north of the Davis Sea is almost double that estimated in the south of the Davis Sea.

Table 4 Estimated relative densities (per km^2) of schools across each stratum

Stratum	Stratum Area (km^2)	Density	CV	Lower 95% CI	Upper 95% CI
CA12008	60600.0	0.0074	0.09	0.0062	0.0088
CA1	55695.8	0.0007	0.72	0.0002	0.0025
DSS	17771.4	0.0028	0.59	0.0010	0.0082
DSN	15871.5	0.0035	0.10	0.0029	0.0043
SCN	11650.4	0.0047	0.61	0.0016	0.0142
SWF	3709.8	0.0128	0.61	0.0042	0.0388
CA2W	66766.9	0.0028	0.33	0.0015	0.0053
CA2E	19097.0	0.0017	1.01	0.0003	0.0090
Total	190562.7	0.0036	0.13	0.0028	0.0047

Table 5 Estimated relative densities (per km^2) for individual animals across each stratum

Stratum	Stratum Area (km^2)	Density	CV	Lower 95% CI	Upper 95% CI
CA12008	60600.0	0.0101	0.10	0.0083	0.0122
CA1	55695.8	0.0010	0.74	0.0003	0.0037
DSS	17771.4	0.0037	0.61	0.0012	0.0110
DSN	15871.5	0.0054	0.12	0.0042	0.0069
SCN	11650.4	0.0047	0.61	0.0016	0.0142
SWF	3709.8	0.0296	0.63	0.0094	0.0928
CA2W	66766.9	0.0028	0.33	0.0015	0.0053
CA2E	19097.0	0.0017	1.01	0.0003	0.0090
Total	190562.7	0.0048	0.13	0.0037	0.0062

Discussion

According to an MRDS analysis on double-platform survey data from an aerial survey over two consecutive summers in east Antarctica, the relative densities of Antarctic minke whales in pack-ice can change considerably both between years (in the same location), within a single summer (in the same location) and across a 20º section of longitude.

In the Vincennes Bay area, relative density of minke whales in December 2008 was around 10 times that of densities observed in December 2009. An obvious difference between the years is the amount of ice sitting within and to the north of Vincennes Bay. By the end of December 2008, Vincennes Bay was largely open (note: but not truly ‘open’ in the sense that an IWC-SOWER vessel could travel through) (Kelly *et al*. 2009; SC/61/IA3). During December 2009, a band of high-concentration ice (on average, 60 nautical miles in north-south extent) sat the north of Vincennes Bay. Perhaps minke whales were not bothering move through this high ice concentration to reach the polynya to the south (although we certainly observed animals in high ice concentrations during both survey seasons). In addition, there had been no substantial recession of ice over the shelf-break (in east Antarctica, this occurs along the 1000 m bathymetric contour) during December 2009, as opposed to December 2008: a process generally considered important in stimulating Antarctic krill growth and development (Nicol *et al*. 2000). It may be that by late 2009, Vincennes Bay only supported modest krill abundances.

There was also an intra-season increase in relative density of minke whales in Vincennes Bay: estimated density of minke whales in the Vincennes Bay in late January- early February 2010 was 2-4 times higher than in December 2009 (based on point estimates). By late January 2010, the thick bridge of ice to the north of the bay had thinned somewhat and the ice edge had receded south around 30 nautical miles; this may have increased access to the polynya and increased ice melt/recession over the shelf-break. These two factors may have increased the relative attractiveness of Vincennes Bay to minke whales over the 2009/10 summer period. It may also be the case that fewer minke whales had migrated that far south by the first phase of the 2009/10 aerial survey, as compared to 4-6 weeks later in the last phase.

As we don’t have repeat surveys over the Davis Sea polynya (either inter- or intra-summer season), it is difficult to begin to interpret the estimated minke whale densities there. Certainly by late December 2009 surrounding pack-ice (to the north and west) had started to thin substantially as compared to earlier in December (see Figures 6 and 7 of Kelly *et al*. (2010; SC/62/IA8)). It may be that the higher density of minke whales in the north of the Davis Sea, as compared to the southern areas, were responding to higher krill abundances forming as ice was melting/receding over the shelf-break in December 2009.

It should be stressed that analyses, and subsequent interpretations, presented in this paper are preliminary. These results are presented here to stimulate discussion as to likely environmental influences and resultant minke whale population movements in east Antarctica. These preliminary analyses point to fluctuating minke whale densities in pack-ice over the summer months and between years and this should be of interest to modellers attempting to estimate minke whale distribution and abundance.

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