AN AERIAL SURVEY FOR ANTARCTIC MINKE WHALES IN SEA ICE OFF EAST ANTARCTICA: A PILOT STUDY

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Abstract

Following on from test flights undertaken in January, 2008, a pilot aerial survey for Antarctic minke whales (*Balaenoptera bonaerensis*) was conducted within the sea-ice zone in Vincennes Bay, east East Antarctica, throughout a 20 day period in December, 2008. The survey was completed using a fixed-wing aircraft (a CASA-212 400) flying from a base at Casey station (66° 17`S, 110° 32`E). The survey was double-platform, with two observers on each side of the aircraft. To augment observer data, video, infrared and photographic equipment were placed in the bottom of the aircraft fuselage to record the presence of whales in the area under the aircraft inaccessible to the observers and also recorded sea ice information.

The survey area was rectangular in shape with a northern extent along latitude of 64° 47` S down to the coast; a western boundary 105° 52` E longitude and an eastern boundary at 113° 15` E longitude; with a total area of 60,600 km^2. Line transects were parallel at 10 nautical mile spacing and orientated north-south. Exceeding a planned total transect length of 3,000km, the survey covered 6,293km on effort (a number of transects were repeated) in 41 hours of flying (over nine days). Around 76 Antarctic minke whales were observed, in 53 sightings, with group size ranging from one to four. Using mark recapture distance sampling to estimate a detection function and a simple estimate of availability, a design-base estimate of minke whale abundance in the aerial survey area is 1,220 (CV=0.18). This is a preliminary estimate, based on highly simplified estimation methods. When compared a minke whale abundance estimate from the most recent adjacent IWC-SOWER cruise (2007/08), animal density appears to be higher in pack ice. However, as both estimates are preliminary, based on simple analysis methods, this comparison is probably not valid. It can be concluded, however, that if the austral summer of 2008/09 is an average year, there does seem to be evidence that minke whales are feeding in pack ice in detectable numbers in one section of East Antarctica.

After completion of both test flights and a pilot study, the utility of the CASA-212 aircraft for aerial survey studies of minke whales in Antarctica has been demonstrated. A larger-scale aerial survey, extending from Vincennes Bay, across the north of the Shackleton Ice Shelf and into the east of the Davis Sea, is planned for the 2009/10 austral summer.

Introduction

In 1978/79, under the direction of the International Whaling Commission, the first of what would eventually be three decade-long Antarctic circumpolar surveys for whales commenced; commonly referred to as CPI (i.e., circumpolar), CPII and CPIII, respectively. These ship-based line-transect surveys, known first as IDCR (International Decade of Cetacean Research) then SOWER (Southern Ocean Ecosystem and Research), traversed up to 60º of longitude each austral summer; moving between 60ºS and an operationally safe ice edge (vessels did not have ice-strengthened hulls). A result from the IDCR/SOWER surveys that is of particular interest is an apparent decrease in the total number of Antarctic minke whales (*Balaenoptera bonaerensis*; hereafter minke whales) between CPII (1985/86-1990/91) and CPIII (1991/92-2003/04) (Branch 2006), which were derived using 'standard methods' outlined by Branch and Butterworth (2001); CPI is not directly comparable owing to substantial differences in survey method. Although new abundance estimates, using novel analysis techniques, will be presented to IWC-SC this year (e.g., Okamura and Kitakado (2009), Bravington and Hedley (2009)), it is likely that the conclusion of an overall decrease in total minke whale abundance from CPII to CPIII is going to stand.

A number of possible explanations for this apparent decline in abundance have been mooted; see (Branch 2007) for details. One compelling hypothesis is changes in the position of the ice edge in concert with changes in the relative proportion of minke whales in pack ice may have decreased the number of animals available to be counted between CPII and CPII (Branch 2007). This suggested effect was deemed 'uncertain', but 'potentially large' (Branch 2007). It is well accepted that minke whales are pagophilic (ice-loving), with short and thin bodies to manoeuvre within narrow leads in pack ice and a rigid rostrum to break through thin ice layers to enable breathing (Ainley *et al.* 2003; Ainley *et al.* 2007). However, relatively little is known about the specific pack ice habitat preferences of minke whales. Furthermore, if the proportion of the total minke whale population that is residing in summer pack ice can be estimated, this information could be used to correct abundance and trend estimates from IDCR/SOWER (or similar) surveys.

With the aim of estimating the proportion of minke whales in pack ice over summer, an Australian fixed-wing aerial survey programme, based in East Antarctica, was devised and scheduled for the 2007/08 season (see Hedley *et al.* (2007)). The estimated number of minke whales in the aerial survey area was to be compared against an estimate derived from a concurrent SOWER survey undertaken in the waters north of the ice edge (see Ensor *et al.* (2008)). However, this aerial survey was cancelled due to the failure of a flight service between Hobart, Australia and the Antarctic continent, which prevented the timely arrival of the observing team. Fortunately, test flights were still able to occur in January, 2008: strengthening the case for the usefulness of fixed-wing aerial survey method for observing minke whales in pack ice (Kelly *et al.* 2008). Following on from these test flights, a small-scale aerial survey targeting minke whales was undertaken in December, 2008, in east Antarctica. The joint aims of this short note are to a) describe this small-scale aerial survey for minke whales conducted in Vincennes Bay in December, 2008; and, b) to present the results of preliminary analyses from the aerial survey and to compare these with basic abundance estimates from the most recent IWC-SOWER voyage adjacent to the aerial survey area (2007/08 cruise). The process used to derive the abundance estimate for the aerial survey has been highly simplified for expediency; the aim was never to produce an abundance estimate that is in any way definitive or final. Instead, in presenting the abundances and comparisons now we aim to provide a first idea of the magnitudes that might be expected from a more thorough and robust analysis effort in concert with a larger survey area.

Methods

Study area

The aerial survey was based at Vincennes Bay (66° 24’S 110° 18’E) in East Antarctica. The primary driver for locating the aerial survey in Vincennes Bay is the location of the Australian Antarctic Division’s skiway at Casey station (66° 17’S, 110° 32’E). Fortunately, there are two nearby polynyas—Vincennes Bay and the Cape Poinsett polynya (65° 34’S 113° 38’E)—which provide open water and, potentially, feeding opportunities for minke whales (Arrigo and van Dijken 2003). Both Vincennes Bay and the Cape Poinsett polynya are ‘shelf polynyas’, features which are formed by prevailing katabatic winds, and are almost guaranteed to reappear each austral summer (Barber and Massom 2007). However, neither polynyas are regarded as being particularly productive compared to others in East Antarctica (Strutton *et al.* 2000; Arrigo and van Dijken 2003).

The aerial survey area was rectangular in shape with a northern extent along latitude of 64° 47` S down to the coast; a western boundary 105° 52’ E longitude and an eastern boundary at 113° 15’ E longitude; with a total area of 60,600 km^2; see *Figure 1*. The location of the western boundary of the survey area was based on aircraft flying range (approximately 1100km or 600nm). The location of the northern boundary was placed to include ocean/pack ice north of the shelf break (1000m bathymetric contour); an area considered to be rich in Antarctic krill (Nicol *et al.* 2000). All of Vincennes Bay and the western half of the Cape Poinsett polynya were included in the survey area.

Survey protocols

The survey platform was a CASA-212(400) fixed-wing aircraft. On-effort flying altitude was 213m (700ft) and speed was 204 km hr^{-1} (110 knots). Flights went ahead only if wind speed at the skiway/station (with some extrapolation to wider survey area given by Bureau of Meteorology forecasters) was less than 22.2 km hr^{-1} (12 knots) and the cloud deck was higher than 244m (800ft).

On board were four observers (two per side of aircraft), a flight leader (D. Pike; 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. Observations where recorded onto time-stamped MP3 format files. Observers were encouraged to search ahead and as close to the trackline as possible. The observations themselves consisted of cue counting and angle of declination when animals are perpendicular, or abeam, to the observer (using a *Suunto* inclinometer). The time at which an observer sees a whale ahead is noted, followed by any time the animal cues. Cues were not recorded after the animals had moved past abeam. Cues were also not recorded if the group size was large (applied to killer whale observations only). At abeam, angle of declination of groups was measured at the centre of the group. Perpendicular distance out to animals 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. However, these data are not presented here. Other than during an observer training phase at the start of the aerial 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 and incidental information such as the presence of birds or seals. GPS data, altitude and flying speed were continuously recorded on the aircraft's data logger. There was also a video/digital stills/infrared 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 sea ice information. This system is mentioned here for completion, but as analysis of the video/photographic data is only partially completed, these are not included in this paper.

A systematic parallel line transect design was produced in *Distance* (Thomas *et al.* 2006), with transects at 10 nautical mile spacing and orientated north-south. A single stratum was specified; with an area of fast ice, both upon and north of Petersen Bank (65° 45'S 109° 55'E), removed from this stratum.

Analysis

Aerial survey

A preliminary and very basic estimate of minke whale abundance in the Vincennes Bay region was derived using the double-platform observation data from our aerial survey. These data were corrected for animals missed on the trackline due to 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* 5 (release 2) (Thomas *et al.* 2006) 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.

Only minke whale observations from systematically located north-south transects were included in this abundance estimate for Vincennes Bay. The analysis included perpendicular distances only as the quality of the cue observation data is yet to be decided. Effort was removed from the analysis when Beaufort sea state was greater than four. 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 213m, this equates to a distance of 113m from the trackline that cannot be searched. This distance, therefore, becomes the left truncation distance by default. A right truncation distance was set at 1000m.

We are reasonably confident there was no animal response to the aircraft at the survey height of 213m and a speed of 204 km hr^{-1}, so point-independence (i.e., observations are only assumed independent at the trackline) 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 and group size) were fitted and model selection was via minimising the Akaike information criterion (AIC) (Akaike 1974). A design-based abundance estimate was derived using a Horvitz-Thompson like estimator which incorporated 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)). Instead of using cue counting to estimate animal availability, an estimate of 30 seconds out of a minute (or 1/2) was derived from observer experience from the aerial survey (assumption based on tendency to be able to see animals underwater, which is discussed below). Availability was applied as a straight multiplier with no variance.

IWC-SOWER 200708 cruise

The most recent IWC-SOWER voyage adjacent to the aerial survey area is the 2007/08 cruise (area covered by cruise given in *Figure 1*). A basic minke abundance estimate for the IWC-SOWER 2007/08 cruise is being presented to the IWC Scientific Committee this year by Burt and Ensor (2009). Using observations from the BT-option 2 mode, Burt and Ensor (2009) derived a simple mark-recapture estimate of minke whale abundance across both north and south stratum. For more details on the IWC-SOWER 2007/08 cruise, please consult Ensor *et al.* (2008) and Burt and Ensor (2009).

Results

Between 11 and 31 December, 2008, nine days of flying were available (specifically, 11-13; 15-16; and 28-31 December). The long gap in the middle of the survey was due to a persistent blizzard. Based on prevailing weather conditions, it is estimated that approximately one day in two is available for flying in December in the Vincennes Bay region. At the beginning of the aerial survey, Vincennes Bay (excluding fast ice over Petersen Bank) was almost free of any significant areas of ice (*Figure 2*), but a large patch of highly variable pack ice remained in the north-west corner. However, during an extended high wind/blizzard period between 17 and 27 December, easterly winds pushed pack ice in the north-west into a condensed patch in the far west of the survey area (*Figure 3*). The coverage of sea ice along the coastline between 80º and 140 º E greatly decreased over the duration of the aerial survey.

Exceeding a planned total transect length of around 3,000km (1620 nm), the survey covered 6,293km (3398nm) on-effort (a number of transects were repeated) in 40 hours of flying; see *Figure 4*. On a number of occasions, survey effort was also allocated during some of the longer transit flying. The approximate percentage of sighting quality during the entire survey was 62.2%, 27.6%, 9.9% and 0.3% for sightability of good, fair, poor or none, respectively.

A total of 76 minke whales were observed in 53 sightings. Despite the fact that species identification was found to be a problem with the CASA-212 aircraft (discussion below), species identification was assumed reasonable for the purposes of the analysis presented here. Overall sightings are given in *Figure 4* and individual sightings, along with group sizes and prevailing sea ice conditions (as indicated by AMRS-E sea ice data[1]), for each flying day are presented in *Figures 5.A-5.I*. Maximum minke whale group size was four, with the majority being of size one; *Figure 6*. A further 27 animals in 12 sightings of unknown species were also observed, but these are not considered here. A notable feature of this survey was the large number of killer whales observed (approximately 372). Discussion of these killer whale observations is given in Kelly *et al.* (2009a).

The percentages of cues which first brought the animal(s) to the attention of the observers were: body and blow, 32.1%; underwater, 30.2%; blow only, 20.8%; not recorded, 11.3%; and body only 5.6%. When minke whales came abeam, around 53% were underwater (includes groups were some individuals were still above the surface at abeam).

The front (or primary) observers saw 40 sightings; the back (or secondary) observers saw 36 sightings; with 23 sightings observed by both the primary and secondary observers, see *Figure 7*. Mean group size was 1.44 (se = 0.1). 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 with a constant and a mark-recapture model specified with distance and group size; fitted detection function given in *Figure 8*. The distance and group size parameter estimates behaved as expected: detection probability decreasing with distance and increasing with group size (data not shown). The mean detection probability at distance 0m (i.e., p(0)) for the primary observer was 0.82 (CV=0.08) and pooled probability of detection was 0.964 (CV=0.03). Using the availability estimate of 0.5 (based loosely on the ability to view animals underwater), the total abundance of minke whales in the aerial survey area is estimated to be 1,220 (CV=0.18). This corresponds to a density of 0.02 animals per km^2.

The abundance estimate of minke whales in the most recent adjacent SOWER survey area (2007/08) was calculated by (Burt and Ensor 2009) to be 1,123 animals (CV=0.44). With a total survey area of 279,362km^2, this corresponds to a density of 0.004 animals per km^2.

Discussion

Comparative abundance estimates

As the process to derive preliminary minke whale abundance estimate for the Vincennes Bay area presented here was highly simplified, there are a number of caveats that accompany the estimate. So, what is wrong with our minke whale abundance estimate from the aerial survey from last December? Let us count the ways. First, it is believed there may have been some issues with species identification (i.e., confusing larger killer whales for minke whales), especially early in the survey as observers were gaining experience. The analysis presented here has assumed that all minke whale sightings were in fact minke whales. Unfortunately, there is limited scope to introduce a policy of circling back on sightings to confirm species identification. The CASA-212 aircraft is substantially larger than those traditionally used in aerial surveys for cetaceans, resulting in longer turn around times and distances, and attempts to do so often resulted in entirely missing the targeted animals. We are

[1] http://www.iup.uni-bremen.de:8084/amsr/amsre.html

currently investigating increasing the number of digital stills cameras in the aircraft to cover more water, particularly corresponding to where observers are looking (current system has digital stills camera looking straight down resulting in a relatively small footprint directly beneath aircraft). There may also be some scope to estimate the robustness of the ultimate minke whale estimate to species identification error.

Second, there was an improper treatment of the sightability covariate used may not fully describe conditions, as only values for the left side of the aircraft were applied used in this analysis. Splitting sightings into their proper aircraft side will allow more valid analysis of the effect of the heterogeneity in sighting conditions to be incorporated into modelling of the detection function.

Third, further analysis of the cue counting data is required so it was not used to estimate animal availability. Instead, the availability applied in this analysis was based on nothing more than observer 'gut feeling' and the length of time observed minke whales seemed to at or near the surface during survey effort; it is probable that availability was overestimated, resulting in a relative underestimate of abundance. However, we do believe there is some merit to assuming Antarctic minke whales are easily seen near the surface owing to the large number of sightings that were underwater for most or all of the duration of the individual sightings. Antarctic minke whales are larger and do seem to be more visible from the air than their Northern Hemisphere counterparts, so analyses of common minke whale availability, such as that outlined in Heide-Jørgensen *et al.* (2009), might not be so helpful. However, if a proper availability estimate—to which was attached a standard error and degrees-of-freedom—was applied, it is likely that the CV of the aerial survey estimate will be far greater than that reported here.

As stressed in the introduction, the process used to derive the abundance estimate for the aerial survey has been highly simplified for expediency; the aim was never to produce an abundance estimate that is in any way definitive or final. Instead, in presenting the abundances and comparisons now we aim to provide a first idea of the magnitudes that might be expected from a more thorough and robust analysis effort in concert with a larger survey area. At face value, it would seem that the density of minke whales in pack ice is five times that observed in open water (i.e., 0.02 compared 0.004 minke whales per square kilometre). However, that comparison is made on flawed abundance estimates, made at differing times over the summer period and in completely different years. There is still a long way to go to being able to attribute the decrease in abundance from CPII to CPIII to a higher or perhaps increasing presence of minke whales in inaccessible pack ice. In summary, all we can say at this time is if the austral summer of 2008/09 is an average year, that there does seem to be evidence that minke whales are feeding in pack ice in detectable numbers in one section of East Antarctica.

Into the future

After completion of both test flights (Kelly *et al.* 2008) and a pilot study, the utility of the CASA-212 aircraft for aerial survey studies of minke whales in Antarctica has been demonstrated. Despite problems with small, flat windows, a large number of minke whales were still sighted. Buoyed by the success of this pilot survey, a larger-scale aerial survey, extending from Vincennes Bay, across the north of the Shackleton Ice Shelf and into the east of the Davis Sea, is planned for the 2009/10 austral summer (see Kelly *et al.* (2009b) for further details).

There is a large amount of video and photographic data still remaining to be analysed from this pilot survey. We are planning an analysis of the utility of angled high-definition video cameras to act as a third platform, in addition to an analysis of sea ice/habitat data derived from digital stills images. A great deal of analysis remains to be completed on species identification and availability issues before we can attempt a more robust abundance estimate of minke whales from either this pilot study or future aerial surveys in East Antarctica.

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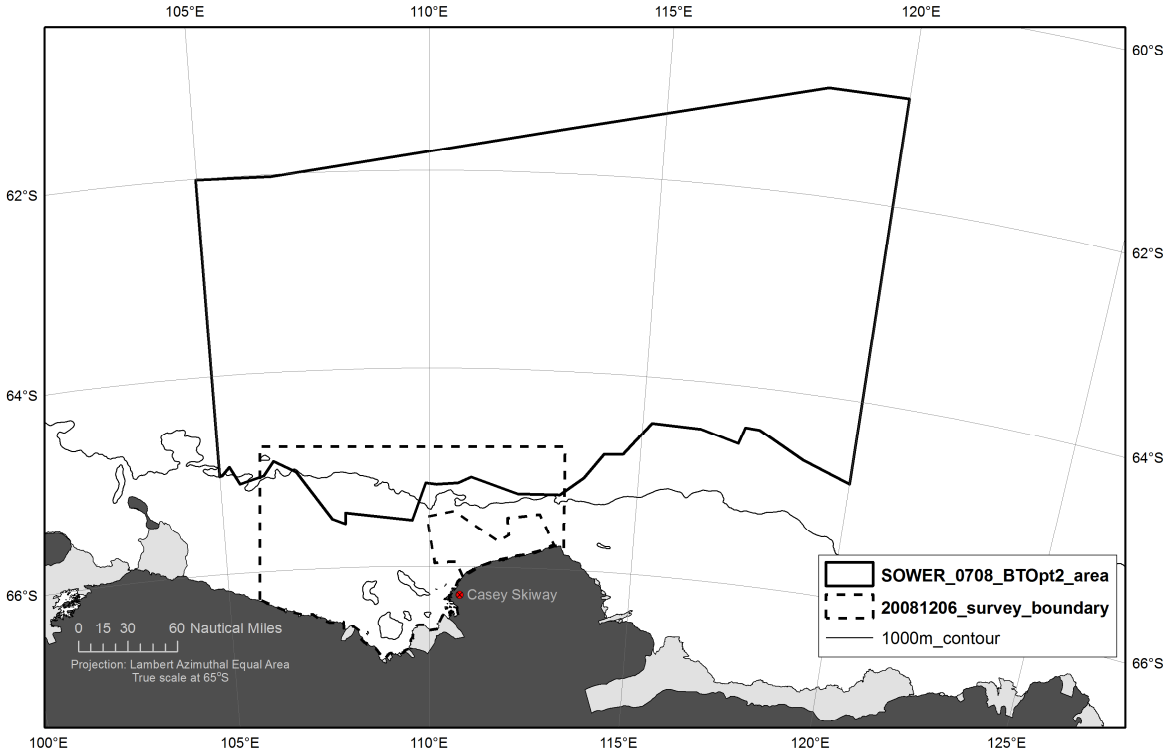

Figure 1 Aerial survey area (in dashed line) and the SOWER 2007/08 BT-option mode 2 area (thicker solid black line; north and south strata not indicated on this map). Shelf-break (1000m bathymetry contour) also included for interest.

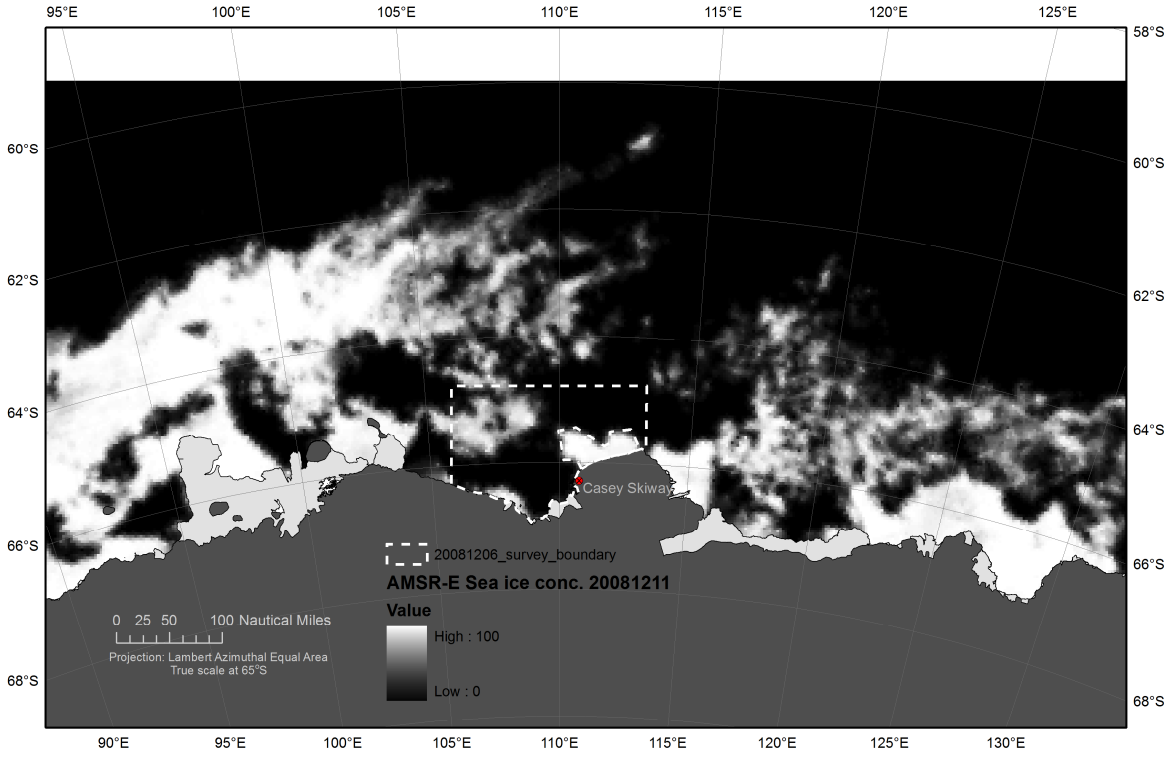

Figure 2 Large-scale concentrations of pack ice on 11 December, 2008, with aerial survey boundary.

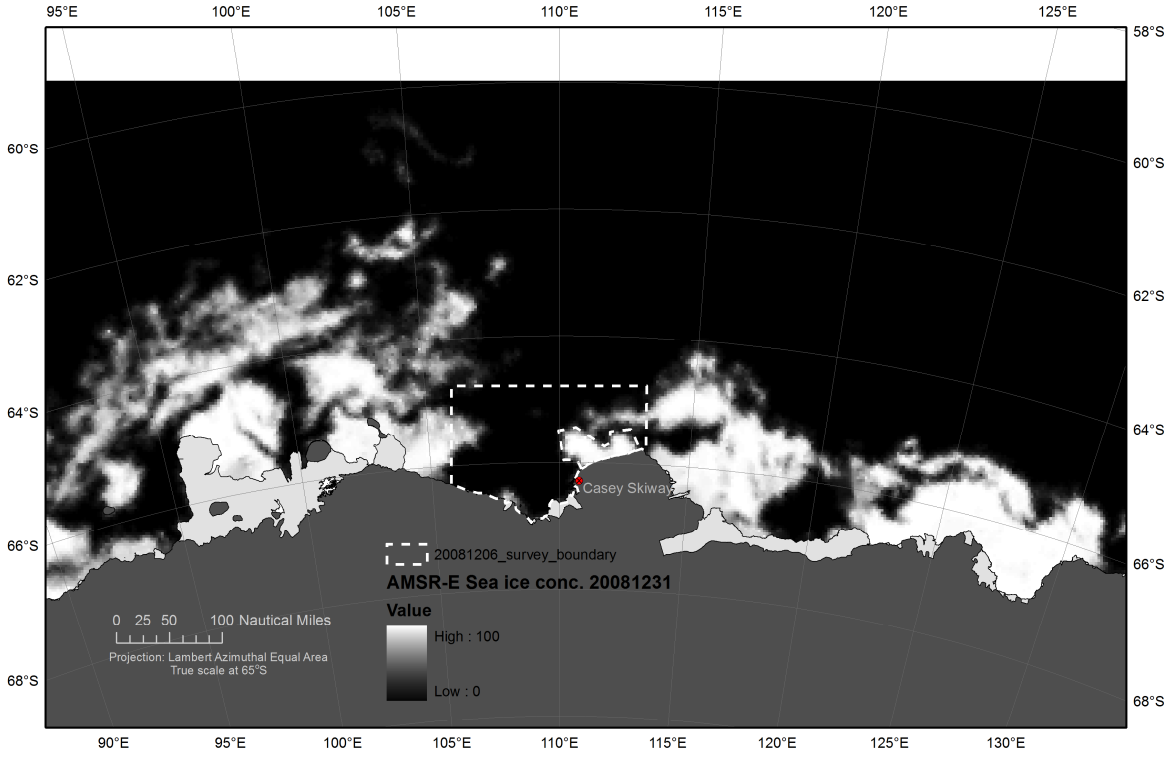

Figure 3 Large-scale concentrations of pack ice on 31 December, 2008, with aerial survey boundary.

Figure 4 Aerial survey transect lines (light grey lines) and minke whale observations for entire survey period. Size of triangle proportional to group size (between one and four animals). Edge of survey area in dash black line. Bathymetric contours also included: 500m (——), 1000m (.....) and 2000m (- - -).

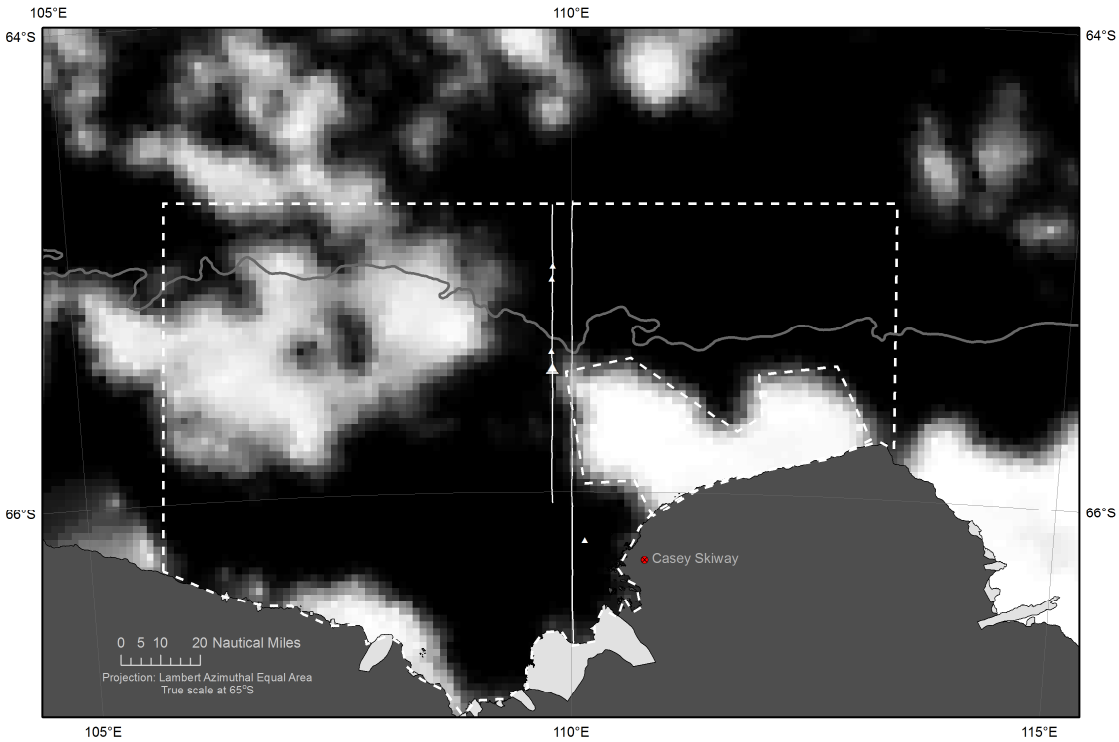

Figure 5.A Minke whale observations on 11 December, 2008; size of triangle proportional to group size (between 1 and 4 animals). Edge of survey area is the white dashed line; solid white line is survey effort (transects); paler grey line 1000m bathymetric contour. Sea ice concentration from daily AMSR-E data; black indicates open water, scaling to white, indicating 100% ice coverage.

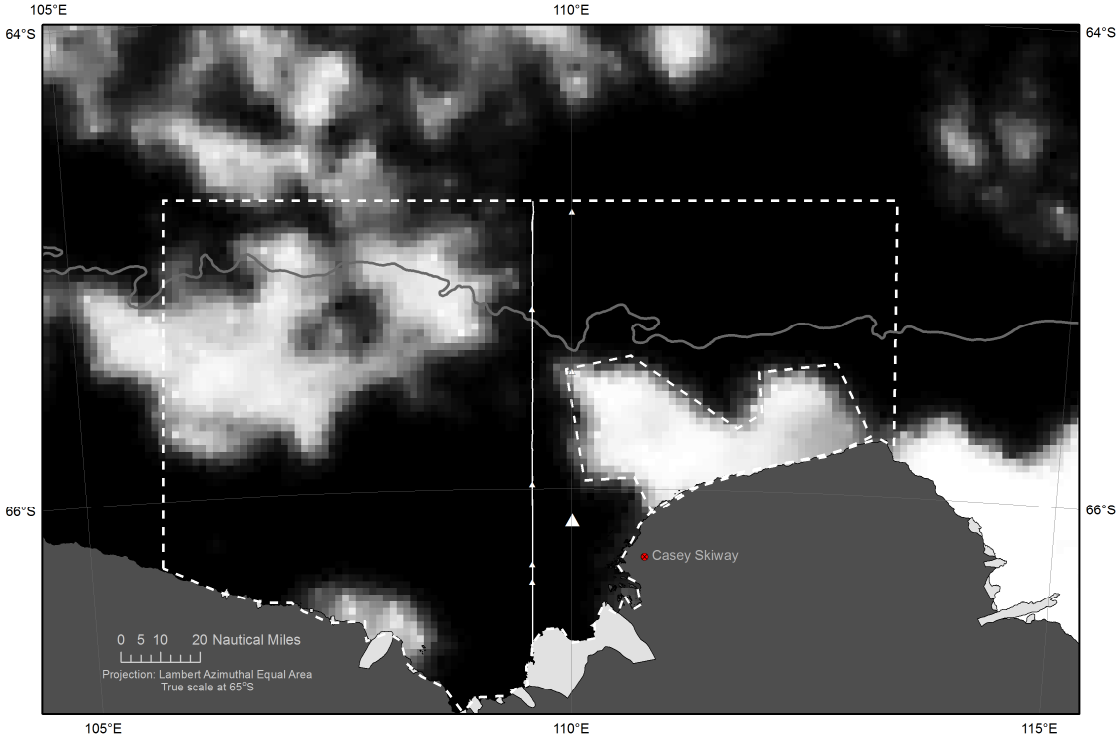

Figure 5.B Minke whale observations on 12 December, 2008.

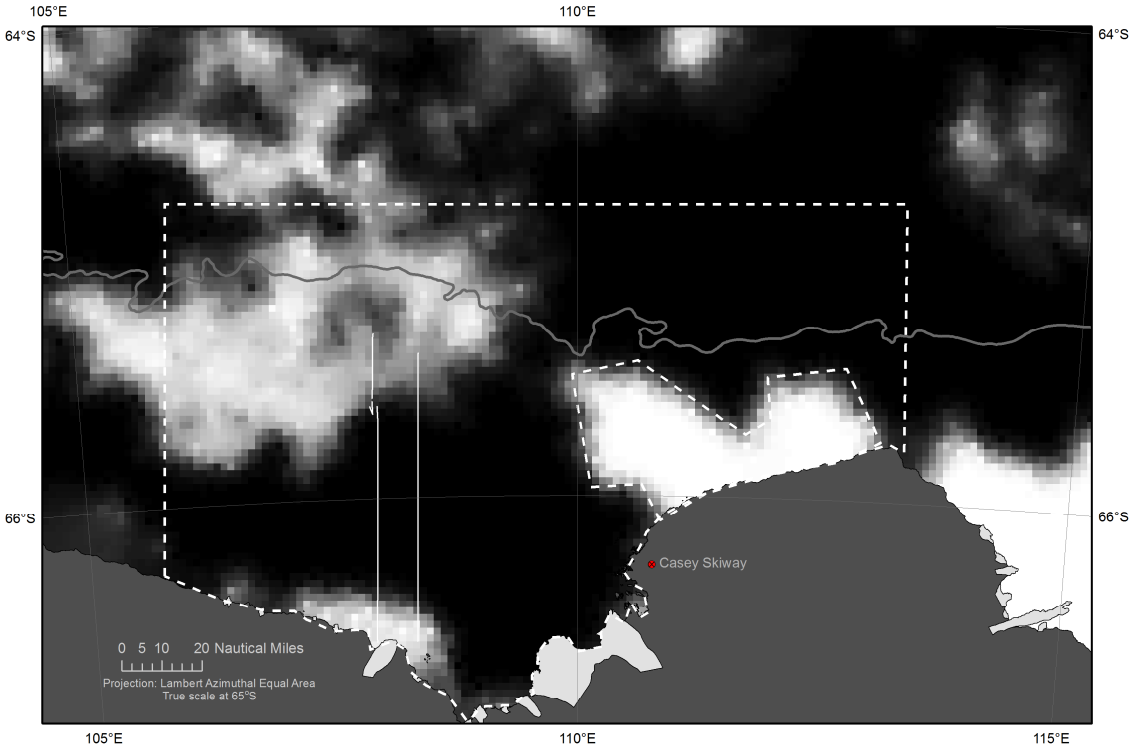

Figure 5.C Minke whale observations on 13 December, 2008. No minke whale observations.

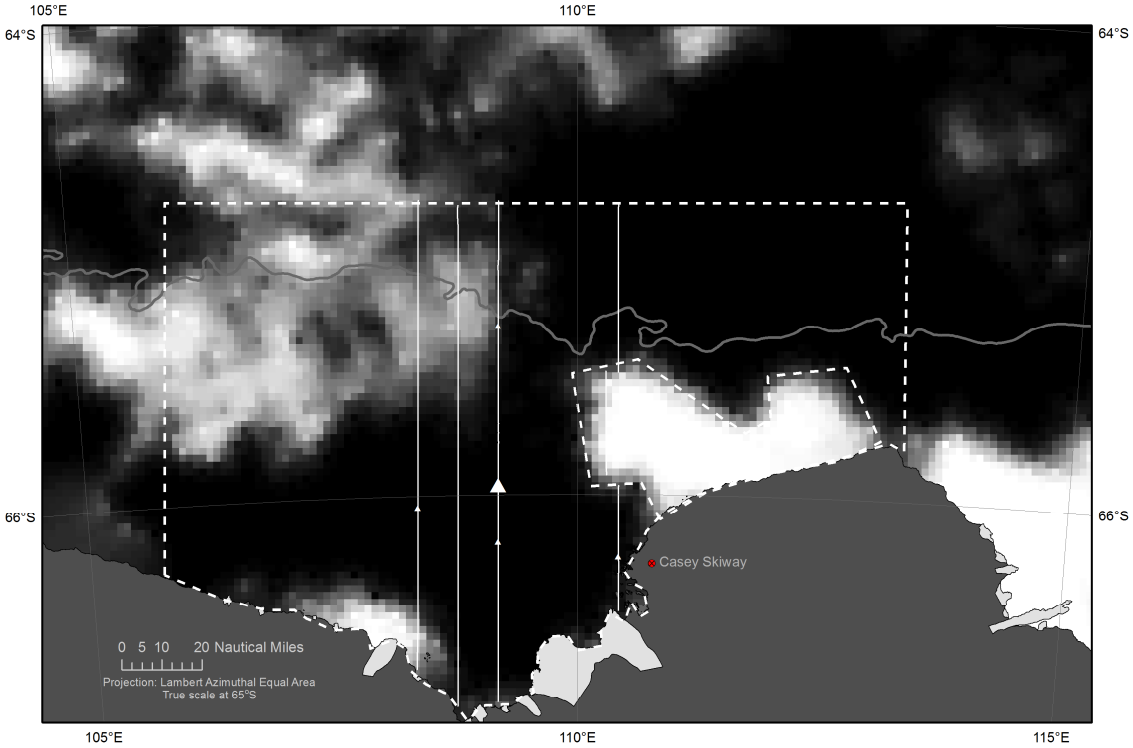

Figure 5.D Minke whale observations on 15 December, 2008.

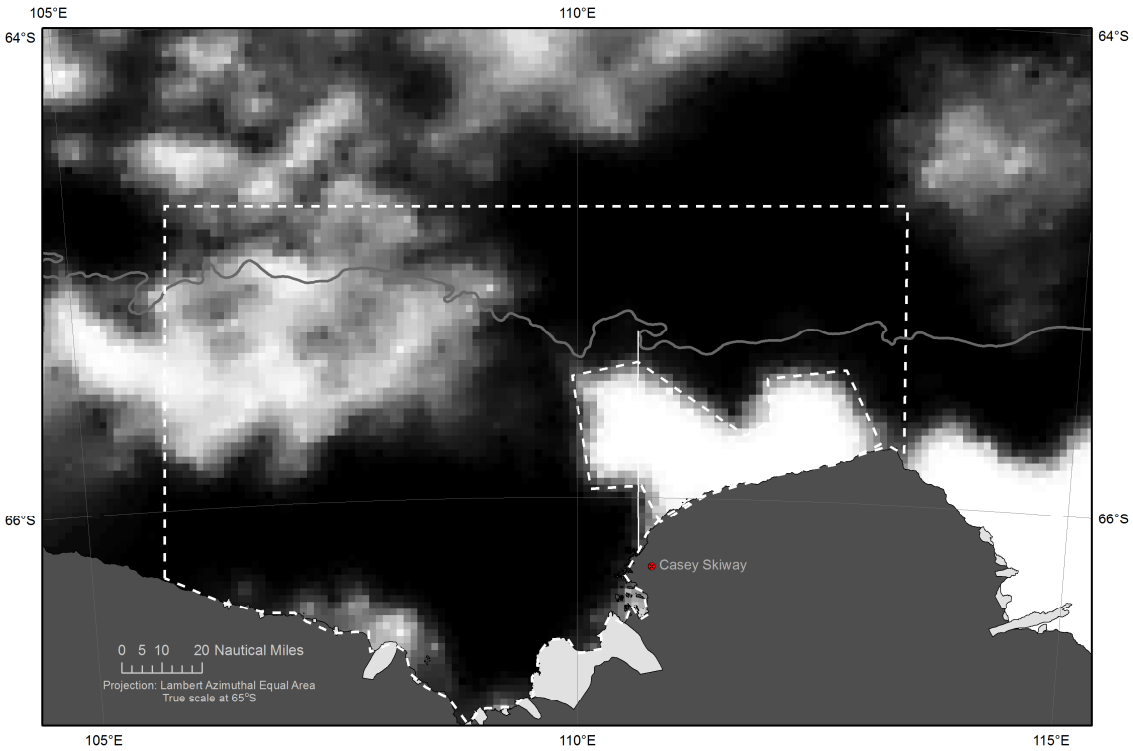

Figure 5.E Minke whale observations on 16 December, 2008. Flying on this day was aborted due to bad weather; with no minke whales observed.

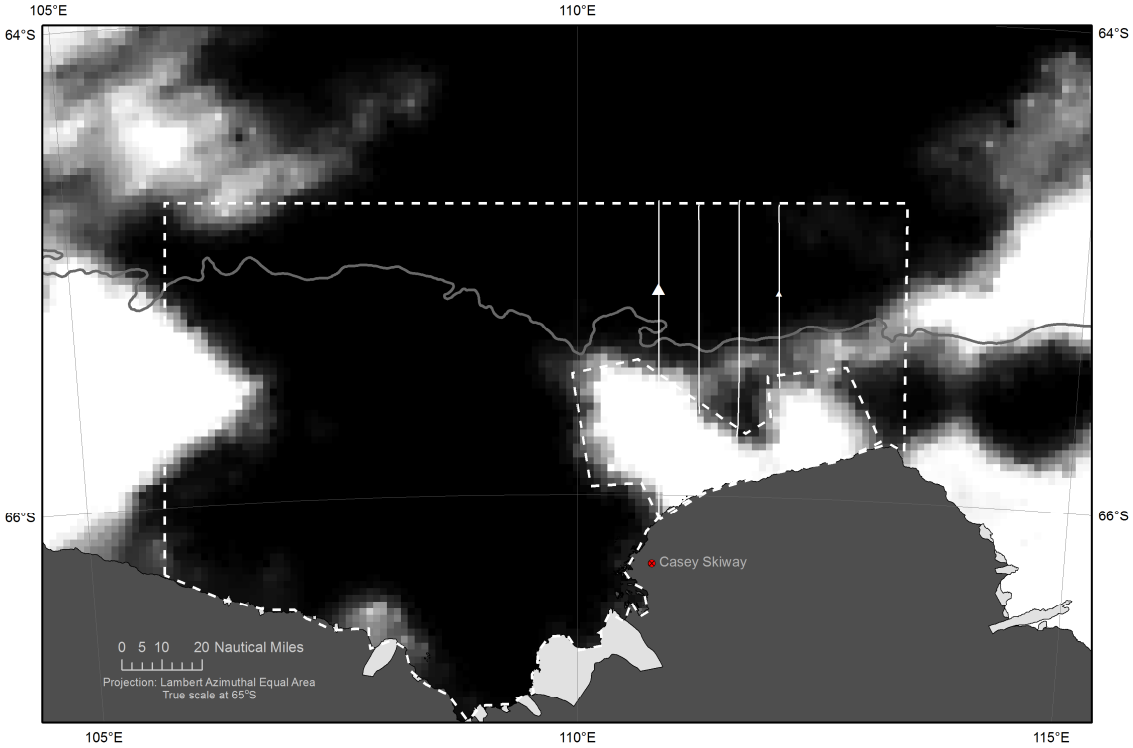

Figure 5.F Minke whale observations on 28 December, 2008.

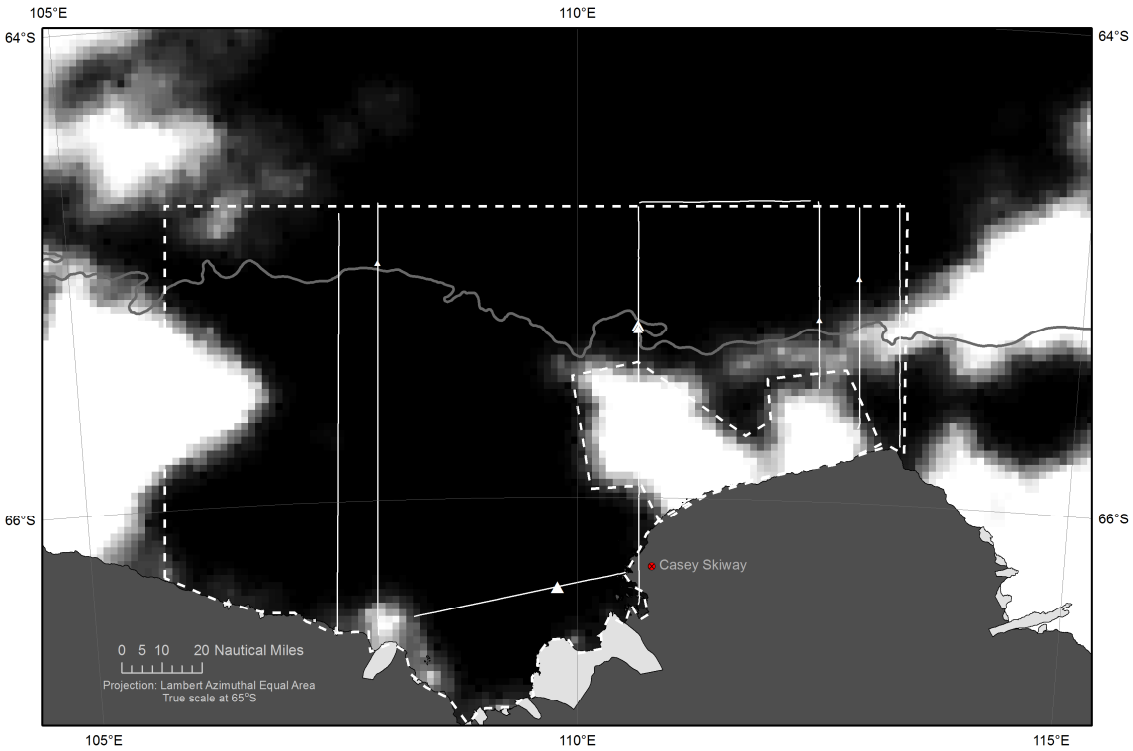

Figure 5.G Minke whale observations on 29 December, 2008.

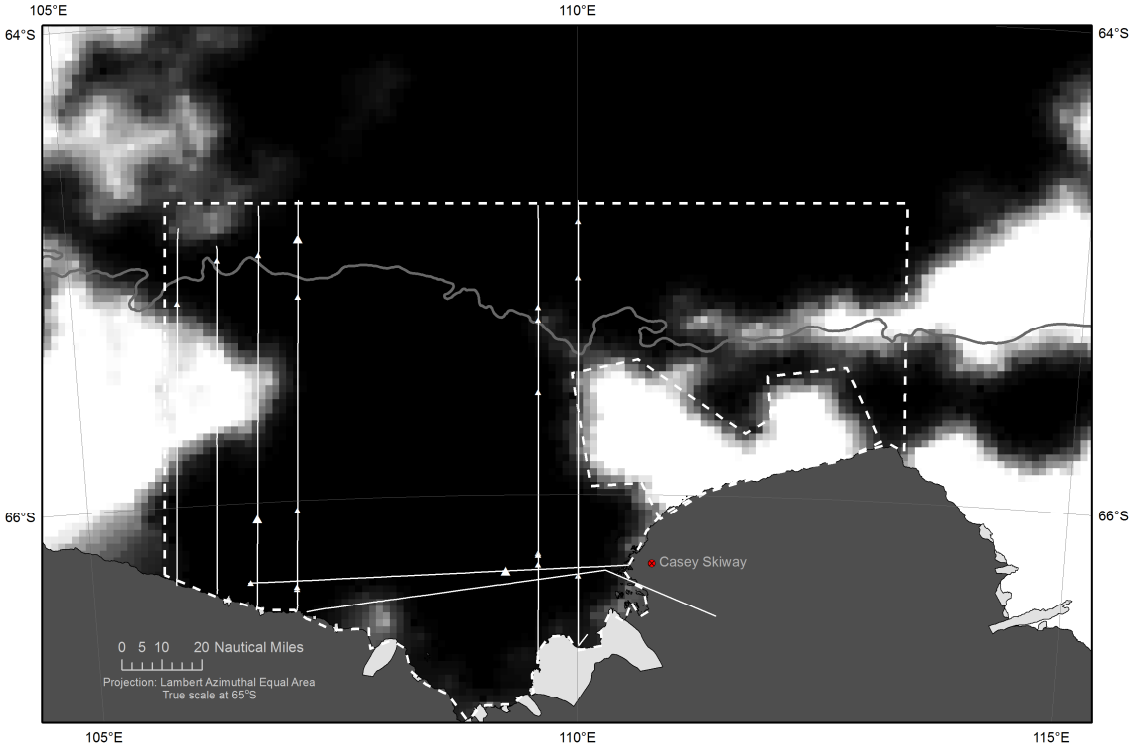

Figure 5.H Minke whale observations on 30 December, 2008.

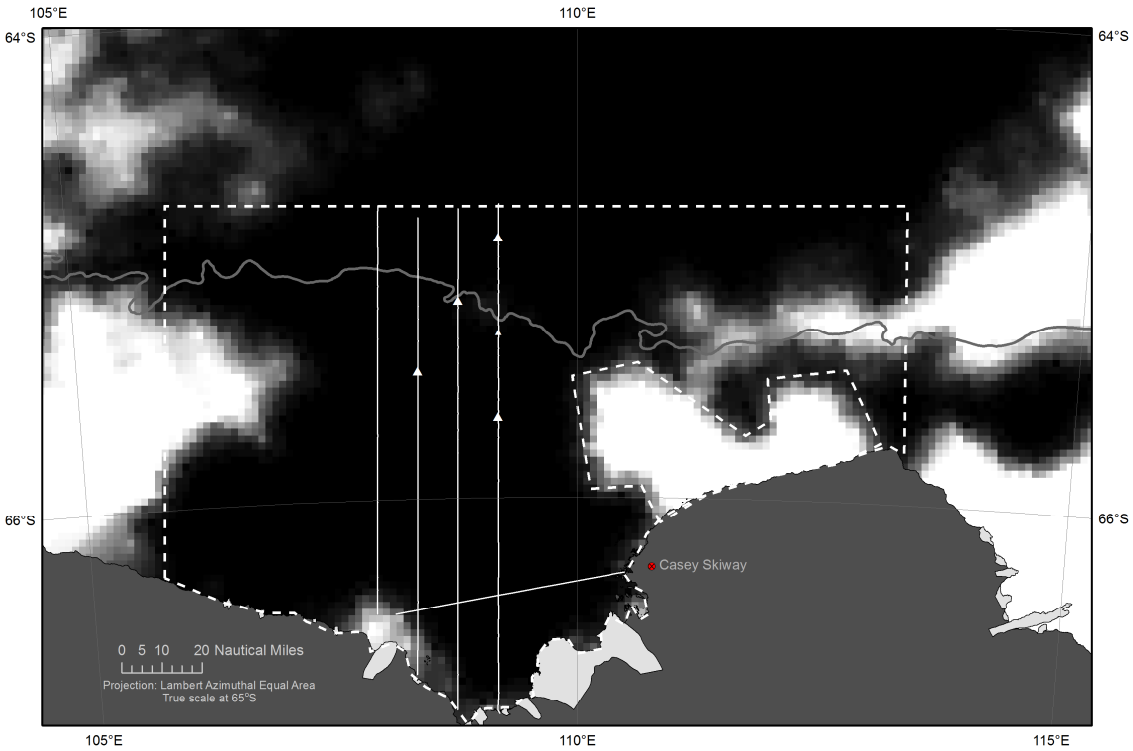

Figure 5.I Minke whale observations on 31 December, 2008.

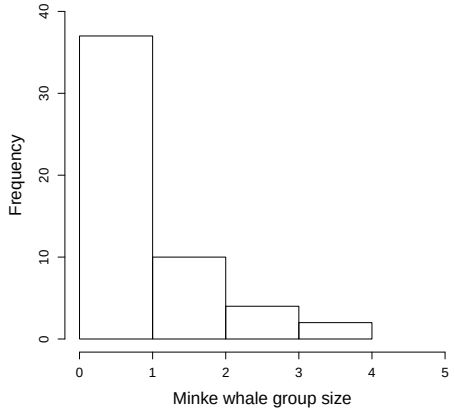

Figure 6 Distribution of group sizes of minke whale sightings in Vincennes Bay, east Antarctica during an aerial survey, December, 2008.

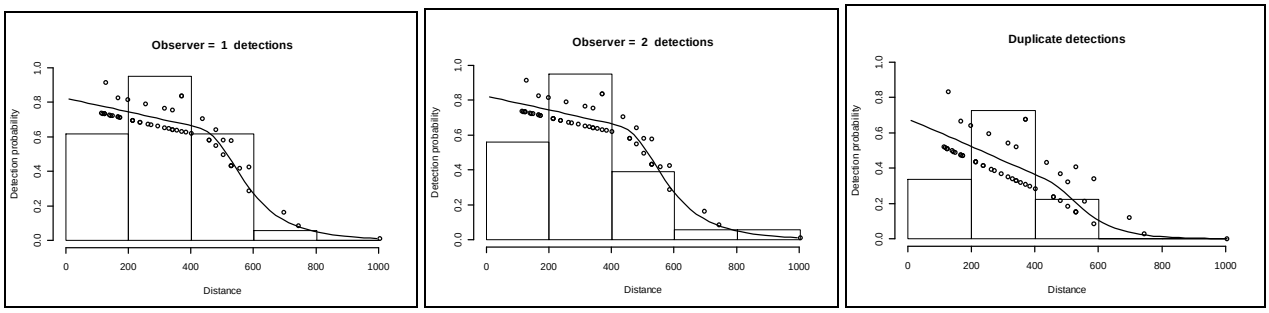

Figure 7 Observer 1 and 2 detections (left and middle) and duplicate detections (right) over distances out to 1000m from the trackline.

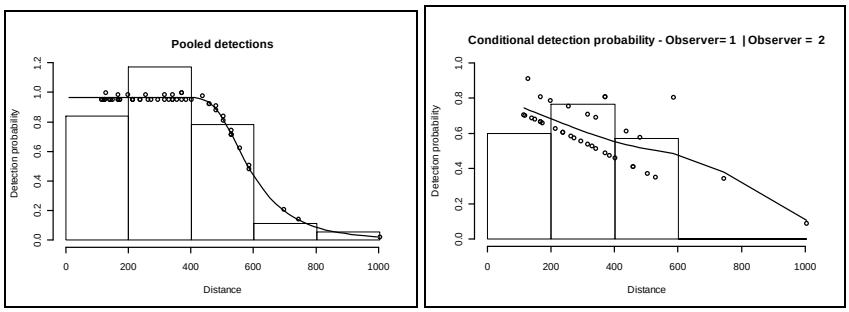

Figure 8 Pooled detections (left) and conditional detection probability.