TEXTE
03/2016

Collection and Analysis of Data on Occurrence, Distribution and Abundance of Cetaceans in the Southern Ocean Following International Standards

For our Environment

Umwelt Bundesamt

TEXTE 03/2016

Environmental Research of the
Federal Ministry for the
Environment, Nature Conservation,
Building and Nuclear Safety

Project No. (FKZ) 3708 91 101-2
Report No. (UBA-FB) 002170/E

Collection and Analysis of Data on Occurrence, Distribution and Abundance of Cetaceans in the Southern Ocean Following International Standards

by

Dr. Helena Herr, Sacha Viquerat, Linn Sophia Lehnert, Prof. Dr. Ursula Siebert
Institut für Terrestrische und Aquatische Wildtierforschung (ITAW)
Stiftung Tierärztliche Hochschule Hannover (TiHo), Büsum, Germany

On behalf of the German Environment Agency

Imprint

Publisher:
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
info@umweltbundesamt.de
Internet: www.umweltbundesamt.de

/umweltbundesamt.de
/umweltbundesamt

Study performed by:
Institut für Terrestrische und Aquatische Wildtierforschung
(ITAW) Stiftung Tierärztliche Hochschule Hannover (TiHo)
Werftstr. 6
25761 Büsum, Germany

Study completed in:
January 2014

Edited by:
Section II 2.8 Protection of the Arctic and Antarctic
Dr. Wiebke Schwarzbach

Publication as pdf:
http://www.umweltbundesamt.de/publikationen/collection-analysis-of-data-on-occurrence

ISSN 1862-4804

Dessau-Roßlau, January 2016

The Project underlying this report was supported with funding from the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear safety under project number FKZ 3708 91 101-2. The responsibility for the content of this publication lies with the author(s).

Contents

Figures

Tables

Abbreviations and Acronyms

AAS	"Antarctic Sound" stratum
AIC	Akaike information criterion
ΔAIC	Difference of the AIC value to the lowest AIC value of all models compared
AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research
AUG	Act on implementation of the Protocol on Environmental Protection to the Antarctic Treaty
CI	confidence interval
CV	coefficient of variation
CCAMLR	Commission for the Conservation of Antarctic Living Resources
esw	effective strip half-width
ft	foot/feet (10 ft = 3.048 m)
GAM	generalised additive model
GAMM	generalised additive mixed model
GLM	generalised linear model
g(x)	probability (mass) function
g(0)	value of the probability function at the transect line
IR	infrared
IFAW	International Fund for Animal Welfare
ITAW	Institute for Terrestrial and Aquatic Wildlife Research
IWC	International Whaling Commission
kn	knot (1 kn = 0.514 m/s)
NM	"Neumayer" stratum
SA	"South Africa" stratum
SE	standard error
nm	nautical mile (DIN 1301: 1852 m)
TiHo	University of Veterinary Medicine Hannover, Foundation
UBA	Federal Environmental Agency
Walog	whale sighting logging system onboard RV Polarstern, allowing nautical officers to log whale sighting information
WAP	"Western Antarctic Peninsula" stratum
WS	"Weddell Sea" stratum

Technical Terms

abundance	Total number of animals in a defined area.
Aikaike information criterion (AIC)	Applied statistics criterion for selection of a model. Assessment of the estimated model's goodness of fit for the available empirical data (sample) and the model's complexity based on the number of parameters.
availability error	Distance sampling error resulting from the observer's inability to see all animals because some may not be "available" (e.g. while diving).
Big Eyes	Tripod-mounted high-performance binoculars (15x30) with excellent light-gathering qualities.
binomial test	Group of statistical tests to review hypotheses for characteristics capable of assuming exactly two discrete forms (success or failure).
confidence interval	Describes the interval comprising a particular quantity (in percentage) of all possible results. Typically, this interval is given as a reference to 95%, i.e. 95% of all possible values are contained within the given interval.
covariate	Explanatory variable analysed to minimise a model's variability.
Cramér-von Mises test	Statistical test to assess a hypothesis for any difference between two empirically observed distributions.
cue counting	A survey method recording each sighting cue, i.e. in the context of a cetacean survey each sighting of a body part, blow, etc.
detection function	The detection function indicates the probability of an observer's, or observer team's, ability to detect an animal at any distance from the transect and is determined by complex numerical procedures.
density	The frequency of a species' occurrence relative to the area, as local density in respect of the immediate area of effort, shown as animals per km^2.
effort	Distance searched in observation modus.
encounter rate	Number of group sightings per kilometre of effort, shown as sightings per km.
esw	Effective strip half-width. Distance from the transect line at which the observer (team) sees and misses equal numbers of animals. For a survey in which both sides of the transect line are observed, double esw describes the transect strip actually observed.
fixed effects	Effects generated by covariates, i.e. constant influences from measured experimental variables. In contrast to random effects.
GAM	Generalised additive model. An additive model does not assume a linear relationship between response variable and the variable(s) considered. It can be used to model complex relationships. Generalisation refers to free selection of the family of error distribution within the model, allowing accurate modelling of non-normally distributed errors.
GAMM	Expansion of a GAM (see above) by adding a mixed effect model (see below).
GLM	Generalised linear model. Generalisation of the classic linear regression model used in regression analysis. Compared to classic linear models requiring Gaussian error distribution, a GLM permits any error distribution (including normal, binomial, poisson, gamma, Tweedie, and inverse Gaussian).

half normal	Description of a distribution underlying the detection function. Since all sightings are “folded to one side” for distance sampling analysis, a bell-shaped, half-normal / Gaussian distribution is used for modelling.
hazard rate	Description of a distribution underlying the detection function. Alternative to the half-normal distribution which may provide a better model for strongly sloping data.
initial sighting	First sighting of an animal / a group during a track.
key	Function underlying the detection function (here: half-normal or hazard rate).
line transect	Section of a line running as directly as possible between a defined start point and a defined endpoint. In the context of distance sampling, a line transect describes the line along which sightings are / were recorded, in contrast to a strip transect. A line transect does not have a predetermined width. Width is determined empirically after data collection as the (double) esw.
modelling	Description of a response variable using explanatory variables, which permits broader and more general statements about the influence of the explanatory variables and information regarding uncertainty of a result.
mixed effect model	A statistical model comprising both fixed and random effects. Effects generated by measured covariates are known as fixed effects, while those generated by test design are known as random effects.
observer error	Error during distance sampling resulting from animals possibly missed by observers.
random effects	Effects generated by test design, explaining the variance of an individual measured variable, e.g. fluctuations when repeatedly recording a measured variable within the same experiment.
right truncation	Clipping of sighting data beyond a certain distance. Sightings recorded beyond this distance are excluded from the analysis as so-called outliers to retain the modelling quality of the detection function. Incidental sightings at atypically long distances are excluded from the analysis in the distance sampling method.
strip transect	A transect line of predetermined width to confine observation to a strip.
track	Tracking of an animal / a group of animals through recording repeat sightings.
tracking	Dedicated attempt to obtain one or several tracks of one animal / a group of animals. After the initial sighting, an effort is made to record as many repeat sightings of the same group as possible. To detect animals early and at great distance from the vessel, powerful optical equipment (typically Big Eyes) is required to obtain the longest possible track.
z-test	Also known as Gaussian test. The z-test identifies a group of hypothesis tests with standard normal test value under the zero hypothesis and examines hypotheses based on sampling means as to the expected values of the sampling totality.

Kurzbeschreibung

Während der antarktischen Sommer der Jahre 2008 (ANT25-2) und 2010 (ANT27-2) wurden parallel verschiedene Methoden zur Erfassung von Walen in der Antarktis vom Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI), sowie dem Institut für Terrestrische und Aquatische Wildtierforschung (ITAW) von Bord des FS Polarstern aus durchgeführt. Im Rahmen des vorliegenden Projekts führte das ITAW schiffsbasierte (Krähennest) und fluggestützte (Helikopter) *Distance Sampling* Surveys durch und unternahm eine *Tracking*studie. In einem parallel zu diesem ausgeführten Projekt erprobte das AWI ein Kamerasystem zur automatisierten Blasdetektion von Walen im Infrarotbereich (IR) und analysierte die systematisch vom nautischen Personal erfassten, opportunistischen Walsichtungsdaten der Brücke (Walog). Neben einer Kenntniserweiterung über das Vorkommen von Walen und deren Dichteverteilung in der Antarktis sollten die Erfassungen einem Methodenvergleich dienen, einer Einschätzung der Qualität der Daten und die Methoden auf ihre Anwendbarkeit in einem Mitigationskontext evaluiert werden. Des Weiteren wurde ein Konzept für "Biologische Begleituntersuchungen" auf Reisen in die Antarktis erstellt, um künftige Datenerhebungen optimieren und vereinheitlichen zu können.

Der Gesamtaufwand der Helikoptersurveys betrug 28 273 km und es wurden 268 Walsichtungen mit insgesamt 753 Individuen erfasst. Der Gesamtaufwand des Krähennestsurveys betrug 2 885 km und es wurden 105 Sichtungen mit insgesamt 198 Individuen beobachtet. Buckelwale *(Megaptera novaeangliae)* stellten die von beiden Methoden am häufigsten beobachtete Walart dar, gefolgt von Antarktischen Zwergwalen *(Balaenoptera bonaerensis)*. Robuste Minimalschätzungen der Dichte konnten in 5 a posteriori definierten Strata für Großwale allgemein, Antarktische Zwergwale sowie Buckelwale ermittelt werden. Hohe Großwaldichten traten auf der Westseite der Antarktischen Halbinsel auf, während Zwergwale im Weddellmeer in erhöhten Dichten vorkamen. Westlich der Antarktischen Halbinsel erreichte der Helikoptersurvey eine repräsentative Abdeckung eines umgrenzten Gebiets und erlaubte die Abschätzung von Minimalabundanzen für Buckel,- Finn,- und Antarktische Zwergwale. Für das Gebiet von 322 303 km^2 Größe wurden Abundanzen von 3 960 [95% Konfidenzintervall: 2 396 – 6 523] Buckelwalen, 200 [33 – 1 065] Finnwalen sowie 3 228 [832 – 12 280] Zwergwalen ermittelt.

Während des schiffsbasierten *Distance Samplings* konnten *Tracks* von 11 Buckelwal- und 4 Zwergwalegruppen aufgezeichnet werden. Eine Modellierungen mittels generalisierter additiver Modelle (GAMs) deutete auf eine Tendenz zur Annäherung von Buckelwalen auf das Schiff zu, während das Verhalten der Zwergwale erratisch schien und sich nicht eindeutig einer gerichteten Bewegung zuweisen ließ.

Der Methodenvergleich beider *Distance Sampling* Methoden ergab, dass sich die unterschiedlichen jeweils vom Helikopter- und Krähennestsurvey ermittelten *Encounter rates* und Dichten nur in Ausnahmefällen statistisch voneinander unterscheiden. Helikoptersurveys erwiesen sich zudem als sehr effiziente Erfassungsmethode in der Antarktis. Ihre Ergebnisse waren im Vergleich mit denen des Krähennestsurveys mit einem kleineren Fehler assoziiert und sind damit als robuster erachten. Der Vergleich zwischen gezielten Walbeobachtungen aus dem Krähennest und den opportunistischen Walerfassungen der Brücke des FS Polarstern bezogen auf gleiche Beobachtungszeiträume zeigte, dass 22,45% [95% Konfidenzintervall: 15,98% - 30,06] der Sichtungen des *Distance Sampling* Teams im Krähennest auch von der Brücke gesehen wurden. Umgekehrt registrierte das Krähennestteam 64,10% [47,18% - 78,80%] der Brückensichtungen. Innerhalb der parallelen Beobachtungszeiträume wurden 89,06% [82,33% - 93,89%] aller Brücken- und Krähennestsichtungen vom *Distance Sampling* Team gestellt. 22 von 53 Sichtungen aus dem Krähennest konnten von der IR Kamera detektiert werden, die Analysen ergaben eine

Erfolgsquote der IR Kamera von 41,51% [28,14% - 55,87%]. Ein Vergleich der Anzahl der von der IR Kamera detektierten Wale, die den Krähennestbeobachtern entgingen, war nicht möglich, da sich die unspezifischen Blasdetektionen der IR Kamera bislang nicht auf Individuenbasis aggregieren lassen.

Die Ergebnisse des Projekts weisen die spezifische Eignung der verschiedenen Methoden für unterschiedliche Anwendungsbereiche nach. Es konnte gezeigt werden, dass *Distance Sampling* Surveys einen guten Beitrag zur Kenntniserweiterung über das Walvorkommen in der Antarktis liefern können. Insbesondere die Ergebnisse des Helikoptersurveys belegen die Durchführbarkeit design-basierter Line-transect *Distance Sampling* Surveys im Rahmen von Biologischen Begleituntersuchungen in der Antarktis, die zu gebietsspezifischen Dichten und Abundanzen führen. Daher sollten die Bestrebungen dahin gehen, den Aufwand gezielter Walerfassungssurveys auf Reisen in die Antarktis zu maximieren. Im Kontext der Mitigation von seismischen Untersuchungen ermöglicht die IR Kamera rund um die Uhr Waldetektionen, auch nachts und bei Wetterbedingungen, die einen dedizierten Walsurvey unmöglich machen würden. Sofern es die Sichtungsbedingungen jedoch gestatten, sind dedizierte Walbeobachter wahrscheinlich besser in der Lage, alle Wale in der Umgebung zu detektieren und eine sichere Mitigation zu gewährleisten. Als idealer Mitigationsansatz wurde ein komplementärer Einsatz beider Methoden identifiziert.

Abstract

Multiple methods to observe cetaceans in Antarctic waters were concurrently conducted during two expeditions of RV Polarstern in the Antarctic summers of 2008/9 (ANT25-2) and 2010/11 (ANT27-2). The Institute for Terrestrial and Aquatic Wildlife Research (ITAW) conducted aerial (helicopter) as well as ship-board (crow's nest) distance sampling Surveys and a Tracking study. Concurrently, the Alfred-Wegener-Institute, Helmholtz Centre for Polar and Marine Research (AWI) tested an infrared camera for the automated detection of whale blows and additionally evaluated opportunistic cetacean sighting data logged by the bridge personnel of RV Polarstern (WALOG). Besides providing data contributing to the knowledge on cetacean distribution and their density in the Southern Ocean, all methods were to be evaluated for their use with respect to mitigation efforts that will be a requirement for future seismic investigations potentially conducted from board of the research vessel. Additionally, a concept for biological monitoring on opportunistic platforms was developed in order to optimise and standardise future cetacean assessments in the Antarctic.

A total length of 28,273 km was covered on-effort by aerial surveys, recording 268 sightings of 753 individuals. 2,885 km were surveyed from the crow's nest and 105 sightings comprising 198 individuals were logged. In both survey methods, Humpback whales *(Megaptera novaeangliae)* represented the most observed species, followed by Antarctic minke whales *(Balaenoptera bonaerensis)*. Robust density estimates of large whales in general, Antarctic minke whales and humpback whales were obtained for 5 a-posteriori defined strata. High densities of large whales were identified on the west side of the Antarctic, while Antarctic minke whales dominated in the Weddell Sea. The helicopter survey achieved a representative coverage of a defined survey area on the western side of the Antarctic Peninsula, allowing for the estimation of minimal abundances of humpback, fin and Antarctic minke whales. The abundance of humpback whales was estimated at 3,960 [95% CI: 2.396 – 6.523], of fin whales at 200 [33 – 1.065] and of Antarctic minke whales at 228 [832 – 12,280] within a 322,303 km^2 area.

11 humpback whale and 4 Antarctic minke whale groups were successfully tracked. The tracks were analysed by means of a GAM and revealed a tendency in humpback whales for approaching the ship. Antarctic minke whales did not show any distinct behavioural pattern.

The comparison of methods proved that differences in encounter rates and density estimates obtained by ship-board and aerial surveys were not significantly different from each other. Helicopter surveys were shown to be very efficient in the Antarctic environment and estimates obtained by the method were more robust and associated with better error statistics than those of the crow's nest surveys. Comparing the crow's nest sightings with the sightings made by the bridge personnel during crow's nest effort periods revealed that 22.45% [95% CI: 15.98% - 30.06] of the sightings of the distance sampling team were also recorded by the bridge. Vice versa the crow's nest detected 64.10% [47.18% - 78.80%] of the sightings logged in by the bridge during the same time span. The crow’s nest observers contributed 89.06% [82.33% - 93.89%] of all observations recorded on board during the crow's nest on effort time (excluding duplicates recorded by crow's nest and bridge).

During concurrent effort times of IR camera and distance sampling survey, 22 of 53 sightings from the crow's nest were detected by the camera, identified by matching blows. The success rate of the camera was judged at 41.51% [28.14% - 55.87%]. A reciprocal comparison, analysing how many animals detected by the camera remained undetected by the crow's nest observers was not possible, as unspecific blow detections of the camera cannot yet be aggregated to reflect cetacean individuals present in the area.

Altogether, the results of this project highlight the specific areas of application for the respective methods. Distance sampling surveys were shown to provide valuable data for density and abundance estimation contributing to knowledge on cetacean distribution in Antarctic waters. Especially the helicopter surveys demonstrated, that design-based line-transect surveys can be conducted from platforms of opportunity and lead to area based density and abundance estimates. Distance sampling efforts during expeditions to the Antarctic should therefore be intensified in order to assess robust baseline data and as a stepping stone to further modelling. The IR camera provides a very useful tool for mitigation, as it detects whales around the clock and is relatively independent from weather and light conditions, which often render dedicated cetacean surveys impossible. As long as sighting conditions allow, however, dedicated cetacean observers probably provide a safer means for detecting animals present in the vicinity of the ship. This concerns smaller species with inconspicuous blows in particular. Finally, a complementary application of both dedicated cetacean survey and IR camera would potentially provide the best conditions for a thorough mitigation during seismic investigations.

1 Introduction

Scientific knowledge on occurrence, spatial distribution and habitat use of cetaceans in the Antarctic is important to evaluate possible effects of human intervention in the biosphere of these animals. Whales are particularly sensitive to acoustic interference because they depend on their highly developed sense of hearing for communication, orientation and hunting (Richardson et al. 1995). Seismic investigations thus have considerable potential to interfere with these essential activities (Gordon et al. 2003). Scientific investigations in the Antarctic, including the deployment of seismic methods, are subject to a permitting process under Germany's Act Implementing the Protocol of Environmental Protection to the Antarctic Treaty (AUG). According to the AUG, all potential effects of a planned intervention on protected resources must be reviewed, and a permit may be granted only if no negative changes in distribution, abundance and productivity of the animals and their populations are expected. Such determinations must be based on reliable data on the protected resources, in this case on distribution, density and habitat use of whales. As well, the same information is urgently needed to implement management goals for optimal protection of these animals in their natural habitat. This includes, for example, the current development of proposed protected areas in the Antarctic by the Commission for the Conservation of Antarctic Living Resources (CCAMLR) and the ongoing discussion within the International Whaling Commission (IWC) regarding Japanese scientific whaling and associated catch quotas. Both would benefit from reliable distribution and abundance data to plan meaningful placement of conservation measures and to better estimate anthropogenic influences on populations.

Compared to other maritime areas, knowledge on cetacean abundance in the Antarctic is extremely scarce. To date there are hardly any reliable abundance estimates or detailed information on distribution and density of cetacean species in the Southern Ocean. The most comprehensive data on cetacean abundance in the Antarctic currently available stem from three circumpolar surveys conducted under the auspices of IWC from 1979 to 2004 (Ensor et al. 2007). These surveys aimed to establish abundance figures for Antarctic cetacean species to assess their state of conservation after decades of exploitation through commercial whaling. For logistical reasons, however, these ship-board surveys of cetaceans were limited to ice-free waters between 60°S and the pack ice edge. No data were collected from ice-covered waters (Ensor et al. 2007). Even during the Antarctic summer, however, the Antarctic continent is surrounded by approximately 3 to 4 million km^2 of sea ice of varying density and concentration (Gloersen et al. 1993), representing a productive and dynamic habitat for many cetacean species in the Southern Ocean. The investigations did not cover this kind of habitat. Furthermore, different data collection methods were used during the three circumpolar surveys, with the effect that observed differences in the abundance estimates currently do not lend themselves to unambiguous interpretation (e.g. Branch 2007). IWC is currently unable to provide abundance estimates for most of the Antarctic cetacean species (Leaper et al. 2008).

The present project, together with the concurrent project, conducted by the Alfred Wegener Institute, Helmholtz Centre for Polar and Maritime Research (AWI), entitled "Implementation of the Monitoring Agreement between AWI and UBA for the Protection of Cetaceans" (FKZ 3708 91 10 1), aims to narrow the knowledge gap on habitat use of cetaceans in the Antarctic and to create a foundation for decision-making in permitting processes. Methods for the collection of cetacean data will be compared to guide future data collection, to evaluate existing data sets, and to generate comparable data sets in the future. This project is comprised of the following tasks:

a) One of the project’s aims was the collection and analysis of whale sighting data according to internationally recognised standards to determine spatial distribution patterns, local densities and abundances of cetaceans in the Antarctic. To this end, surveys of whales on-board the research icebreaker Polarstern were planned to enable collection of data also from ice-covered maritime areas.

b) Additionally, examination of possible behavioural reactions of whales (approach or avoidance behaviour) to the RV Polarstern was planned to assess potential disruption of whales by vessels and to better appreciate possible errors in ship-board data collection.

c) Another aim was a comparison of methods to assess efficiency and applicability of different survey methods. On the one hand, the sighting methods used in this project (crow’s nest survey, helicopter survey and tracking) were to be compared. On the other hand, the comparison of methods was aimed at a determination of efficiency of the infrared-assisted, automated whale detection procedure tested in the concurrent AWI project described above. Finally, the comparison of data was to serve a validation of whale sightings systematically logged by bridge personnel (WALOG). WALOG is a whale data collection system on-board the RV Polarstern used by nautical officers to record the position and additional information regarding whale sightings.

d) Finally, a concept for concomitant biological investigations in the Antarctic (Konzept für "Biologische Begleituntersuchungen in der Antarktis") was to be developed to provide sponsors as well as scientists a decision-making basis for the design of supporting investigations.

2 Planning and Execution of the Project (Materials and Methods)

Data of whale sightings were collected during two trips[1] of the German research icebreaker Polarstern from December 2008 to January 2009 (ANT25-2) and from November 2010 to February 2011 (ANT27-2) using different data collection methods. Distance sampling surveys were conducted from two different observation platforms: ship-board from the crow's nest, a platform on the mast of the RV Polarstern at approximately 28 m above sea level, as well as aerially from the RV's own helicopters (BO 105). To investigate the behaviour of whales vis-à-vis the vessel, tracking observations were conducted from the crow's nest. Figure 1 illustrates the routes of both expeditions.

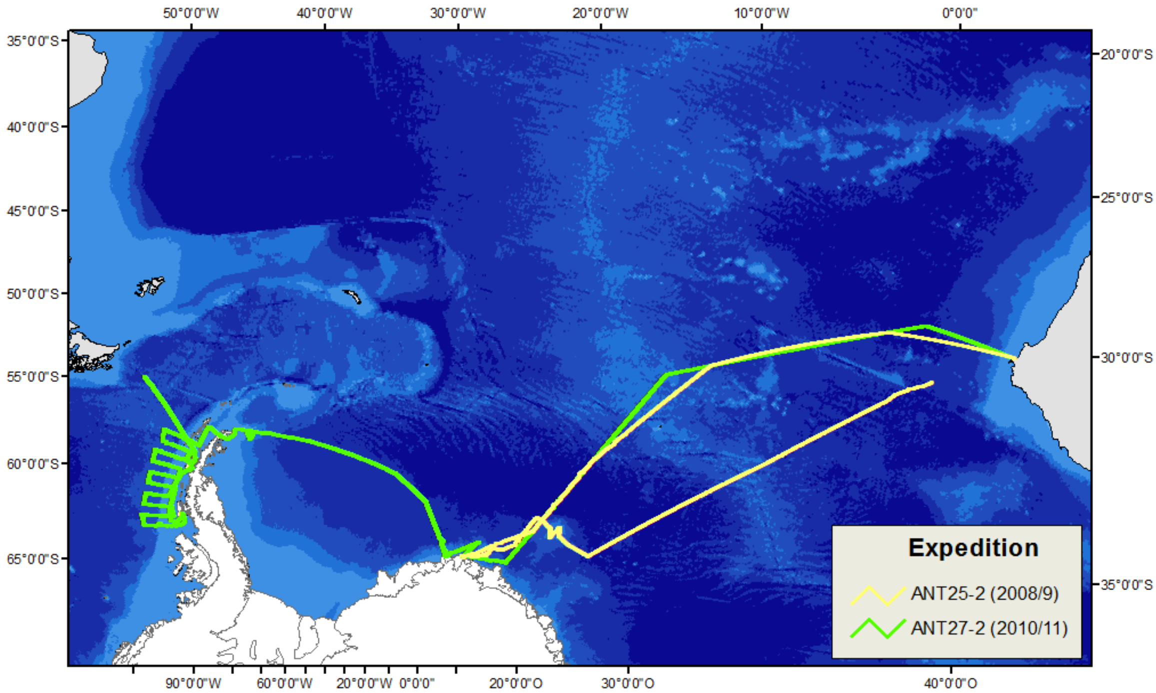

Figure 1: Routes of the Polarstern expeditions ANT25-2 (2008/2009) und ANT27-2 (2010/2011)

The theoretical background of the sighting methods used as well as their practical application during the expeditions are explained below. The evaluation method, detailed questions regarding data comparison, and the aims for the developed concept are also described.

2.1 Sighting methods

2.1.1 Distance sampling surveys

2.1.1.1 Line-transect distance sampling

Distance sampling is an internationally recognised and established method to estimate abundance and density of wild animal populations (Buckland et al. 2001). A special form of

[1] The data comparisons performed utilised additional sighting data from a third Polarstern expedition (ANT28-2, 2011/2012), which was, however, not undertaken as part of this project and therefore not described and analysed in detail.

distance sampling, called line-transect distance sampling, is now the established method to collect data from marine mammals. The basic assumption of this method is that (a) not all animals will be recorded and (b) the probability of an animal's sighting decreases with increasing distance to the transect (Buckland et al. 2001). In the line-transect distance sampling method, transect lines serve as samples of the survey area. During trips by aircraft or vessel along the transect lines, all sightings of the target species are recorded. Ideally, these transect lines cover the survey area evenly. The most important information recorded is the perpendicular distance x of the recorded animal (or group of animals) from the transect line (Figure 2). Later, these measurements can be used to determine the effectively searched area, the effective strip half-width (*esw*) (Hiby & Lovell 1998, Buckland et al. 2001). For this purpose, the entirety of the measured distances *x* is subjected to a probability function *g(x)*, the so-called detection function. *g(x)* describes the probability of recording a sighting at each distance *x* from the transect line (Figure 2). Environmental factors capable of influencing detection probability are included in the analysis as covariates, and the extent of their impact on modelling is considered to determine how to integrate them in the detection function. The *esw*, together with the length *L* of the covered distance, serves as spatial foundation for the calculation of density in line-transect distance sampling. The *esw* indicates the distance *μ* from the transect line for each side, beyond which the probability of animal sightings is equal to the probability of missing them within this distance (Figure 2).

The effective strip width thus determined represents the area in which effectively all available animals were recorded (animals recorded outside of *μ* were essentially replaced by animals missed by observers within *μ*). The *esw* consequently represents an ideal spatial foundation for density calculations. When *esw* is used as spatial foundation, density *D* is calculated according to formula (1),

$$(1)\hat{D} = \frac{n \cdot s}{2 \cdot esw \cdot L}$$

where *n* = number of sightings, *s* = mean group size, and *L* = total length of the transects. As the *esw* is calculated separately for the left and right observation sides, the complete strip width is thus formed when both *esw* are combined (Evans & Hammond 2004).

Another assumption of line-transect distance sampling is that all animals directly in the transect line (distance from the transect line = 0 m) are definitely recorded, i.e. *g(0)* = 1. As far as marine mammals, in particular whales, are concerned this is not possible because diving animals are invisible to the observer (availability error). If *g(0)* is <1, the determined densities and abundances constitute minimum estimates.

Line-transect distance sampling was the method used in this project both during crow's nest surveys and helicopter surveys.

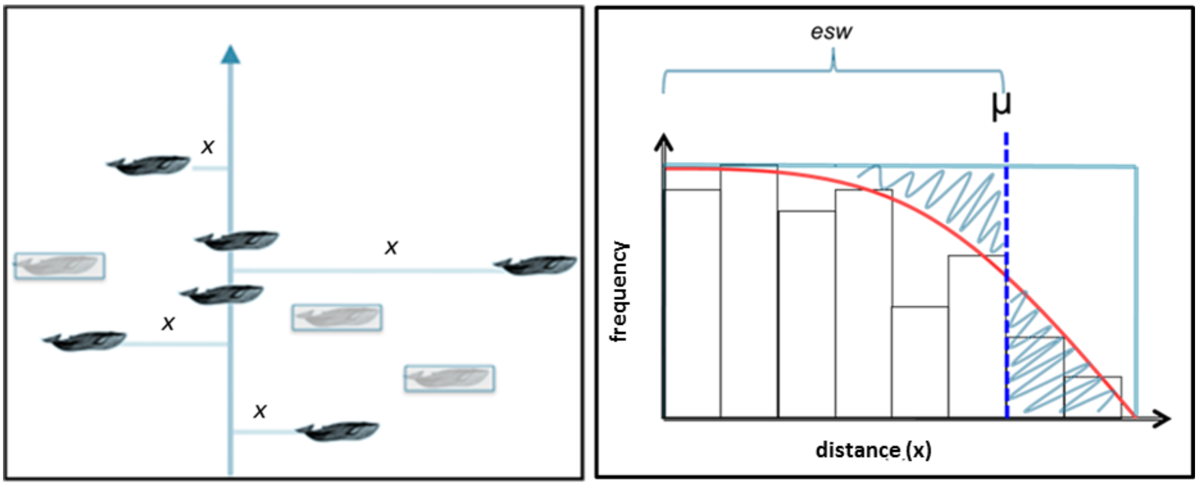

Figure 2: Schematic representation of strip width calculation. Line-transect distance sampling does not use a maximum observation area or a predetermined width of the observation strip. Instead, all animal sightings are recorded, and the observers note the distance *x* from the transect line to the animal for each sighting (left drawing). This method takes into consideration that observers may overlook animals. Transparent animals in the left drawing correspond to animals not recorded. The spatial foundation for density calculations is subsequently determined from the measured distances by fitting a detection function (red graph) to the entirety of the recorded distances (right graph). This graph is used to determine the distance within which the number of animals not recorded equals the number of additional animals recorded outside of it (blue shaded areas). The strip width *(esw)* thus determined corresponds to the unilateral spatial foundation reflecting all animals on this side, on which the density calculation will be based.

2.1.1.2 Crow's nest survey

The ship-board distance sampling survey was conducted from the crow's nest. Each observation shift in the crow's nest was manned by three participants. The first observer was assigned to the left side of the transect, the second observer to the right side, reaching from the baseline straight ahead to 90°athwartship. They observed unaided and used binoculars (Fujinon 7x50) only to verify sightings, to identify species, and to measure distances (using the binoculars' reticle scale). The third person was in charge of data recording. This person was seated in the turret of the crow's nest and operated a GPS unit (Garmin e-Trex) connected to a computer (Panasonic Toughbook) using the software package LOGGER 2000 (IFAW). The observers and data recorder communicated by two-way radio. While the computer was continuously recording GPS positions, the data recorder was entering weather and sighting conditions, along with ongoing updates. The following information was recorded: Sea state (Beaufort), swells, surface solar reflection (angle and intensity), ice cover and subjective assessment of sighting conditions. The observers reported sightings via radio, and the computer programme automatically recorded the GPS position and time once the data recorder had pressed the key. The data recorder also entered the following information communicated by the observer: species, number of individuals, horizontal azimuth angle (relative to the direction of travel), distance to the sighting or reticle in the binoculars, percentage of calves, sighting cue, behaviour and direction of movement (relative to the direction of travel).

Positions of the three team members were usually rotated every half hour to avoid exposing anyone to the same environmental conditions (particularly airstream) for more than half an hour. The observations occurred along the predetermined ship route, uninfluenced by the crow's nest survey. The survey was performed only up to sea state 5 (because whale sightings are no longer reliable at a higher sea state) und from a minimum ship speed of 8 kn (to minimise the likelihood that whales passed the vessel and would be counted twice). Especially icebreaker activities of the vessel often made observations from the crow's nest impossible due to the low travel speed, and poor weather conditions considerably reduced the observation periods.

2.1.1.3 Helicopter survey

The two helicopters type BO 105 on-board served as observation platform for the aerial distance sampling surveys. The helicopters were flown at a constant cruising altitude of approx. 600 ft (approx. 183 m) and constant travel speed of 90-100 kn (approx. 160 km/h). The observer team was comprised of three individuals: One observer each was seated at the left and right windows behind the pilot. They observed the areas to the left and right of the transect, approximately from an inclination angle of 60° (this corresponds to a distance of 105 m from the transect line), as the area directly below the helicopter (90°- 60°) cannot be visualised from the flat windows. The front observer was seated to the left of the pilot and observed the left area directly below the helicopter (90°- 60°) (helicopters have a front window reaching down to the floor). This assignment of tasks allowed the complete observation of the left transect side and the observation of the right side beginning at 60°. For this reason, the subsequent determination of the strip width was based solely on sightings on the left side. One observer was also responsible for data recording. This was the front observer during the ANT25-2 expedition. For the ANT27-2 expedition this task was assigned to the right observer, whose sightings would not be included in the determination of strip width and missed sightings resulting from the additional effort would be more tolerable than had they been missed by the front observer. The observers, data recorder and pilot communicated over an intercommunications system.

The data recorder operated a laptop (Panasonic Toughbook) connected to a GPS unit (Garmin e-Trex). The software programme VOR (Conversation Research Ltd.) continuously recorded GPS positions, and the data recorder continuously entered current weather and sighting conditions. The following information was continuously recorded: sea state, ice cover, cloud cover, solar reflection (angle and intensity) and the observer's subjective assessments of sighting conditions. The data recorder entered all whale sightings directly into the computer, which automatically stored sighting positions and times. The data recorder added the following information for each sighting: species, group size, angle of inclination, percentage of calves, behaviour, direction of movement (relative to direction of air travel), location above or below surface, sighting cue, and possible reactions to the helicopter. The angle of inclination permits subsequent calculation of the sighting's perpendicular distance to the transect line using formula (2) (Figure 3).

$$(2)\ x = r \cdot tan\ (90° - \alpha)$$

r = constant/known cruising altitude, α = angle of inclination.

As a rule, the two observers in the rear reported any sightings and measurements of the angle of inclination at exactly the time when the sighting was at a right angle to the transect. The front observer was facing forward and thus could not report any sightings made at a right angle. Therefore, the front observer provided the corresponding horizontal azimuth angle of the sighting relative to the transect, as additional information to the angle of inclination, to allow subsequent calculation of the perpendicular distance of the sighting to the transect.

If the sighting could not be directly identified, or there was uncertainty as to group size, the effort was interrupted and the sighting approached by helicopter until the corresponding information could be obtained. After successful identification, the helicopter was returned to the transect line and the effort continued. This procedure of effort interruption for closer inspection of a sighting is frequently used during marine mammal surveys according to line-transect method and is referred to as closing mode (e.g. Calambokidis & Barlow 2004, Hedley et al. 2004, Strindberg & Buckland 2004).

Flights and transect design generally had to be planned ad hoc and could not follow a predetermined survey design. Flights are subject to permission by trip and ship's command at all times. In addition, weather conditions must meet safety requirements and be suitable for observation. The remaining operations on-board the vessel as well as the use of equipment must permit helicopter flights. For these reasons each flight could be planned with only a few hours' lead time. If conditions for a flight were met, the flights were planned for a maximum distance of approximately 160 nm, the maximum distance established by safety regulations. The underlying transect design of a flight corresponded to a square with an edge length of 40 nm and consisted of four transects. Orientation and length of the individual transects were individually adjusted to the current environmental conditions and other requirements for the flight. During the ANT27-2 expedition the RV Polarstern followed along a transect design on the western side of the Antarctic Peninsula predetermined by a krill survey. As a result of the extended stay in a circumscribed area, it was possible to design and carry out a survey for the corresponding area in advance.

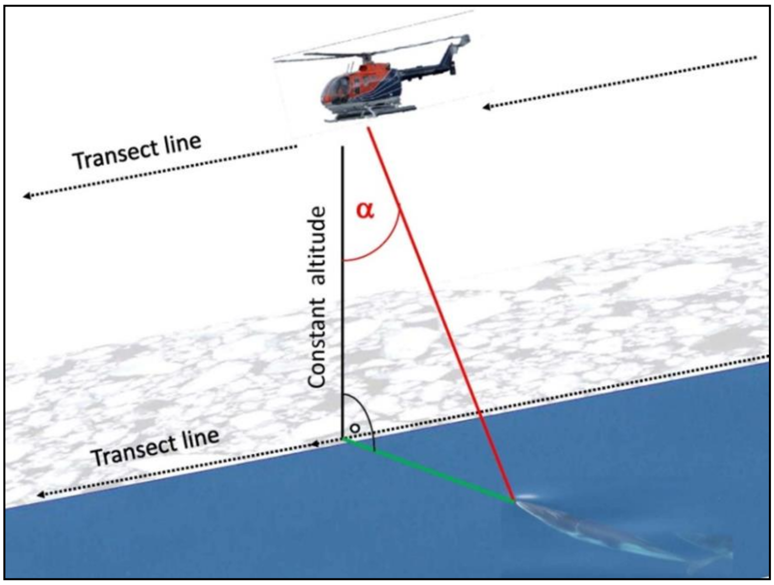

Figure 3: Schematic representation of the calculation of a sighting's distance from the transect line. The perpendicular angle of inclination α is recorded for each sighting. When combined with the known cruising altitude, calculation of the sighting's perpendicular distance from the transect line is possible.

2.1.1.4 Analysis

The collected data were analysed with the software package *distance* (Miller 2013), R Version 3.0.1 (R Core Team 2013). Initially, species-specific detection functions were modelled for all species for which sufficient sighting numbers were available (n~40). As a rule, detection functions are specific to a species and display a strong correlation to size and behaviour of the target species. Smaller, less conspicuous species have a lower probability of discovery as distance to the transect line increases compared to larger species with more surface activity or large blows visible from afar. Buckland et al. (2001) recommend 60-80 sightings as basis for a robust detection function, 40 sightings being the minimum. The recorded environmental and sighting parameters, which may influence detection probability, were included in the analysis as covariates. A determination was made as to the degree of their influence on modelling and consequent integration in the detection function. Once combined with the determined effective strip width *esw*, which describes the computer-calculated width of the area covered by the observer, species-specific densities could then be determined. Of the helicopter survey data only those from the left side (collected by the left and front observers) were used for density calculations since, as mentioned above, the right side could not be fully visualised (thus, the helicopter survey density refers only to the one-sided area $esw \cdot L$).

To determine whale densities the entire area along the routes travelled by the RV Polarstern during the two trips was afterwards divided into five strata.

1) South Africa (SA): the area between South Africa and 60°S
2) Neumayer (NM): the area south of 60°S to the ice shelf edge near Neumayer Station III
3) Weddell Sea (WS): the section along the Weddell Sea
4) Antarctic Sound (AAS)
5) Western Antarctic Peninsula (WAP)

The delineation of strata occurred primarily according to geographic and associated habitat-specific aspects to create the basis for a comparison of results within the research area. The SA stratum comprised the entire area beyond the Southern Ocean covered by the surveys. While the project's focus was on the Antarctic, this area should also be analysed because a considerable part of the effort took place in this maritime area, offering good conditions for a comparison of methods. The WAP stratum comprised the area west of the Antarctic Peninsula, the WS stratum covered the Weddell Sea. The distinction was made to evaluate these two habitats on the two sides of the Antarctic Peninsula separately for their many differences. The comparatively small AAS stratum identifies the Antarctic Sound which occupies a special position as the geographic connection between Weddell Sea and the western side of the Antarctic Peninsula. The NM stratum comprises the area south of 60°S to the ice shelf edge near Neumayer Station III and describes the part of the research area located east of the Weddell Sea. The strata are shown in Figure 4. It was possible to predetermine a survey design for helicopter surveys carried out in the WAP stratum (see below). Favourable weather conditions permitted a representative coverage of the WAP stratum with helicopter flights, enabling an abundance calculation based on flight data. For all other strata only local densities were calculated: The densities thus relate only to the calculated strip width and permit no extrapolation to a larger research area. They are, however, suitable for a comparison of strata.

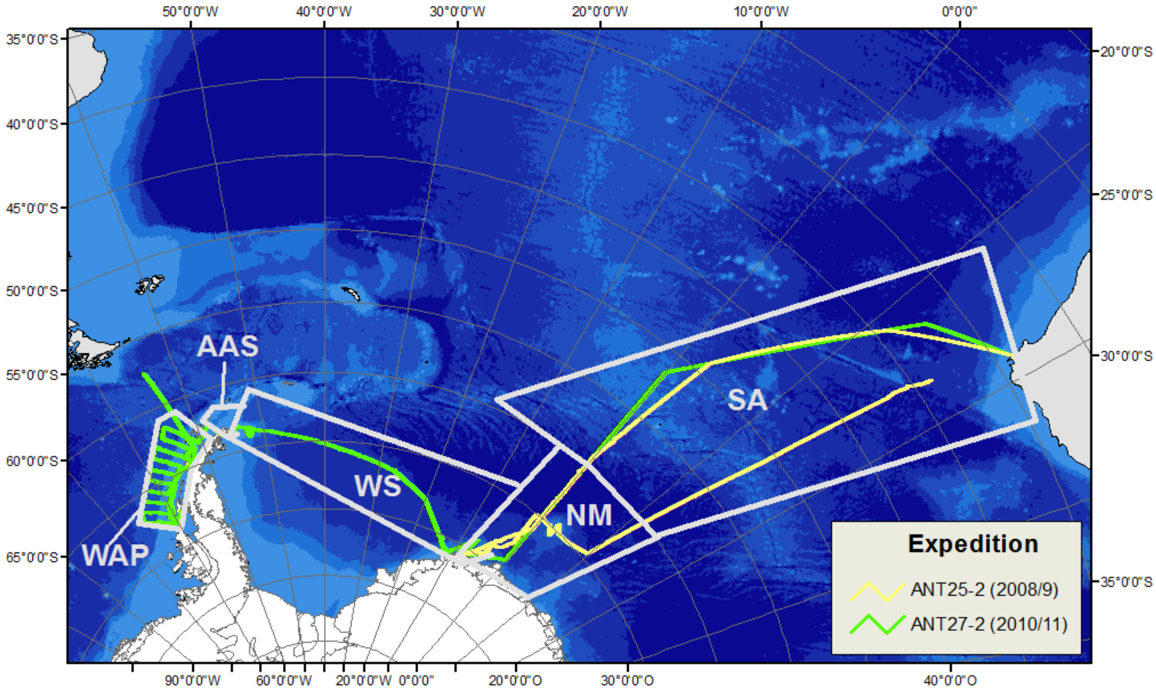

Figure 4: Division of the research area into five strata: South Africa (SA), Neumayer (NM), Weddell Sea (WS), Antarctic Sound (AAS), and Western Antarctic Peninsula (WAP).

2.1.2 Tracking

2.1.2.1 Tracking observations

Tracking is the process of following an individual sighting and recording every repeat sighting. Tracking was performed in addition to or in lieu of distance sampling surveys from the crow's nest. Tracking is possible only under extremely favourable sighting conditions. Heavy swell or ice-breaking make it impossible to steady binoculars sufficient to continuously observe the water surface at required magnification. Whenever sufficiently favourable observation conditions prevailed, a tracker undertook observations using high-performance binoculars, so-called Big Eyes, on adjustable mounts at each side of the crow's nest. The tracker would choose that side for observation which provided more tolerable conditions (i.e. less airstream) and then observe the entire frontal area to the horizon. If a sighting occurred, an observer at his or her side noted time (using a GPS calibrated chronometer), horizontal azimuth angle of the sighting relative to the direction of travel and reticle number (for subsequent distance calculation), sighting cue, species, number of individuals, behaviour, percentage of calves, and direction of movement. The tracker then attempted to follow the sighted animal or group of animals and communicated each repeat sighting for recording. Repeat sightings were recorded for as long as possible and, if possible, at least until the sighting was athwart ship. Data recording was performed manually because the tracker was using both hands on the Big Eyes and unable to operate a radio to communicate data to the data recorder in the turret. Handwritten notes were subsequently digitised and GPS positions supplemented using the calibrated times.

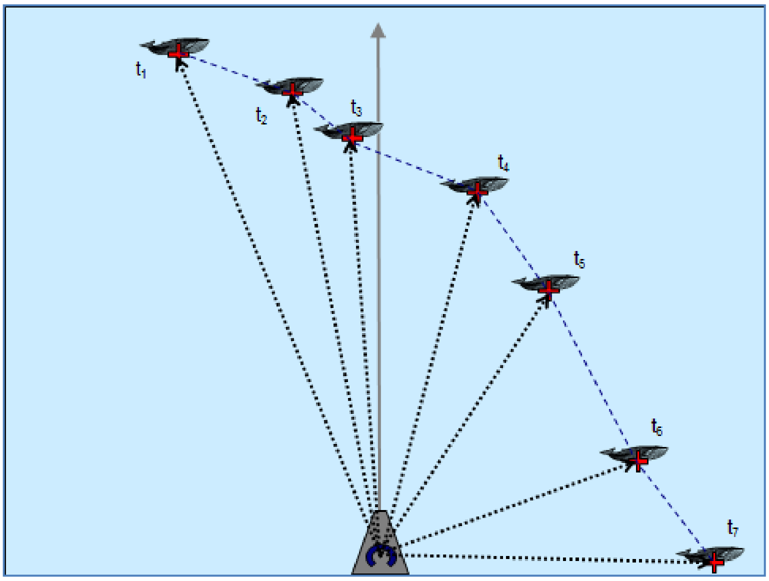

Figure 5: Schematic representation of a tracking event. An animal sighted at time t_1 is re-sighted a total of six more times (t_{2-7}). Each re-sighting time, together with the horizontal angle (relative to the ship's axis) and distance from the ship, is recorded.

2.1.2.2 Analysis

The tracks thus recorded served for analysis of the whales' behaviour vis-à-vis the ship. For this purpose a generalised additive model (GAM) was developed based on tracking data from both surveys. The GAM's aim was to establish whether or not the animals approached or avoided the vessel. In contrast to conventional models, such as generalised linear models (GLM), a GAM does not assume a linear connection between the response variable and the variable under consideration. This allows modelling of complex relationships which would not yield significant results in the context of a GLM. The animals' distance to the vessel was modelled over the course of individual re-sightings against the time elapsed since the initial sighting. To relativise the different initial distances of the sightings, all changes in distance were noted relative to the initial distance, which was assigned a relative distance of 100%. Accordingly, a distance of >100% at a given time after the initial sighting corresponded to a distancing of the sighted animal from the vessel, while a relative distance of <100% indicated an approach to the vessel. As the different sightings of one species constitute sample repetitions in the statistical context, a mixed effect model was added to the GAM, resulting in a generalised additive mixed model (GAMM). The model now also reflects any variance resulting from individual sightings for variance calculation and thus validation of the model when compared to the GAM. This not only increases the model's robustness but permits predictions of flight distances independent of individual identification not possible in a model using sighting numbers as a factor.

Since behaviour vis-à-vis the vessel may vary from species to species, each species is modelled individually.

2.2 Concept for concomitant biological investigations in the Antarctic

Vessels on route to the Antarctic are often used as opportunistic platforms for concomitant biological investigations. Data on cetacean occurrence are collected along the predetermined travel route. While the quantity of data collected is considerable, their quality is generally heterogeneous because different research teams use varying data collection methods and protocols and have different requirements for the qualification of observers and sighting conditions. Comparison of data sets and general analysis of data sets are often impeded or prevented by the use of different data formats, temporal resolution of data sets, information recorded, and precision of the recorded information. To enable comparability of data from these biological investigations, an approach needs to be coordinated and internationally recognised and a consistent, standardised protocol followed. One of the project’s aims was the development of a concept for concomitant biological investigations in the Antarctic (Konzept für "Biologische Begleituntersuchungen in der Antarktis") to provide sponsors as well as scientists a decision-making basis for the design of concomitant investigations. To this end, several different data collection methods were investigated to determine which insights they might provide and which data they suitably collect. This concept would describe appropriate performance of data collection and contain corresponding field guidelines, enabling implementation on-board and describing data collection according to uniform parameters for use by future research teams.

3 Results

3.1 Sighting data collected

3.1.1 Crow's nest survey

During the ANT25-2 and ANT27-2 expeditions of the RV Polarstern, 2,885 km were surveyed from the crow's nest, and 105 sightings comprising 198 individuals were logged in 161 hours of effort (Table 1). The observation sections along the ship route are shown in Figure 6, the distribution of effort among the individual strata in Table 2. The SA and NM strata accounted for the main portion of the effort because they were the only strata covered by both expeditions. Sightings of eight different cetacean species were recorded during crow's nest surveys (Table 3). With 39 sightings and 75 observed individuals, humpback whales (*Megaptera novaeangliae)* were the species most frequently observed from the crow's nest, followed by Antarctic minke whales *(Balaenoptera bonaerensis)*. All other species were observed relatively rarely. 21 sightings were of large whales which could not be further identified. In most cases, this was due to the long distance of the animals from the vessel. A beaked whale could also not be identified as to species. Figure 7 to Figure 10 show the individual sighting positions. Only minke whales and unidentified large whales were observed in the NM and WS strata, humpback whales dominated in the AAS and WAP strata, with some local "hot spots" identified. Another large whale "hot spot" was located in the general vicinity of Bouvet Island (54°25.8′ S, 3°22.8′ O) in the southern part of the SA stratum (Figure 8).

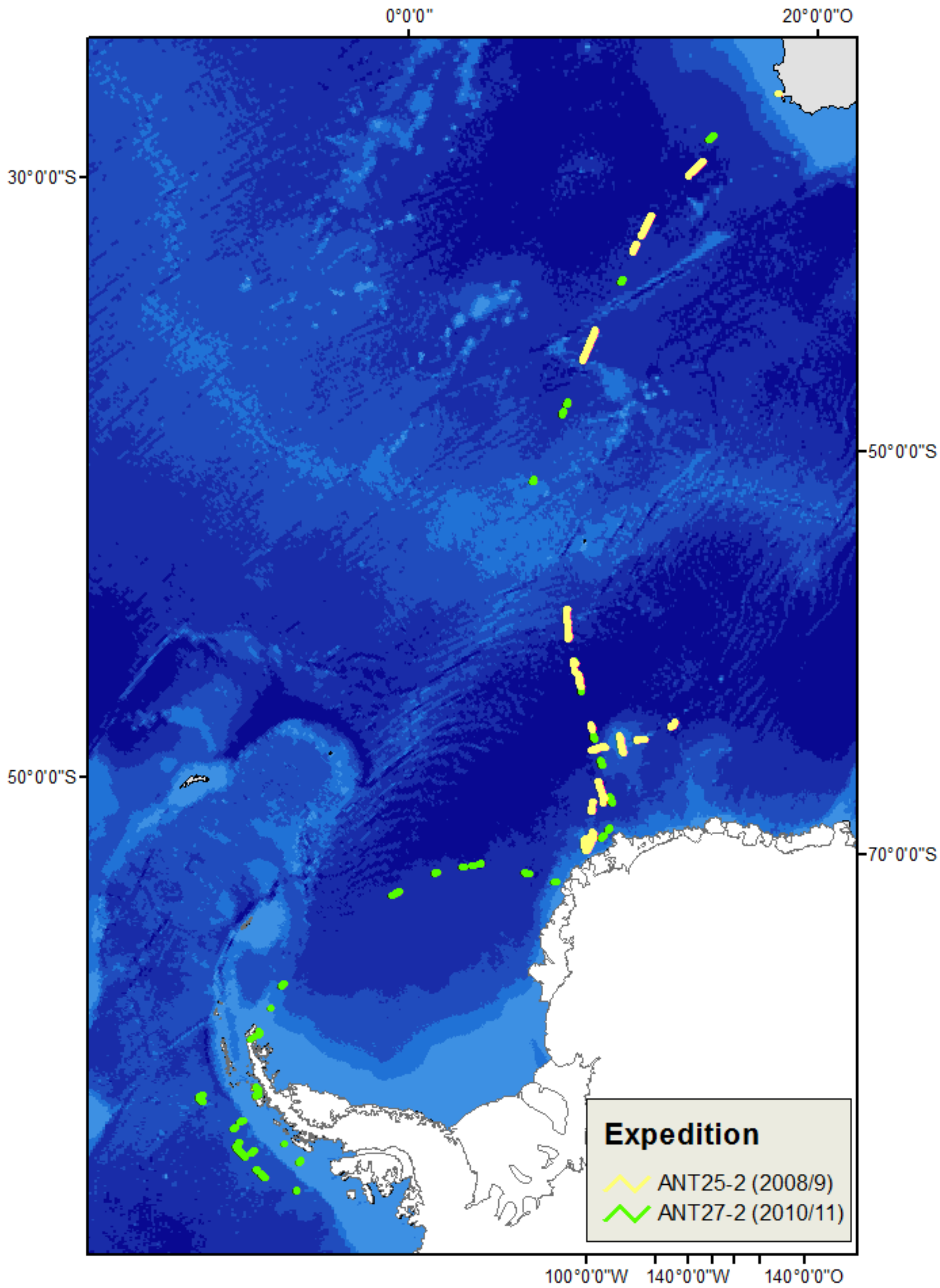

Figure 6: Sections of the ANT25-2 and ANT27-2 expeditions where crow's nest efforts were conducted.

Table 1: Search efforts and number of recorded sightings and individuals from crow's nest surveys conducted during ANT25-2 and ANT27-2 expeditions of RV Polarstern.

Expedition	Section searched (km)	Sightings	Individuals
ANT25-2	2008	56	124
ANT27-2	877	49	74
Total	**2885**	**105**	**198**

Table 2: Distribution of effort in the crow's nest surveys during ANT25-2 and ANT27-2 expeditions of RV Polarstern between individual strata.

Stratum	ANT25-2 effort (km)	ANT27-2 effort (km)	Total effort (km)
SA	1,080	104	1,184
NM	928	212	1,140
WS	0	190	190
AAS	0	38	38
WAP	0	333	333
Total	**2,008**	**877**	**2,885**

Table 3: Cetacean species recorded in crow's nest surveys during ANT25-2 and ANT27-2 expeditions of the RV Polarstern with numbers of sightings and individuals.

Cetacean species	ANT25-2		ANT27-2		Total	
	Sightings	Individuals	Sightings	Individuals	Sightings	Individuals
Southern bottlenose whale *(Hyperoodon planifrons)*	-	-	1	2	1	2
Humpback whales *(Megaptera novaeangliae)*	14	36	25	39	39	75
Antarctic minke whale *(Balaenoptera bonaerensis)*	22	28	8	11	30	39
Unidentified large whale	8	13	13	13	21	26
Fin whale *(Balaenoptera physalus)*	5	10	1	2	6	12
Killer whale *(Orcinus orca)*	1	6	-	-	1	6
Sperm whale *(Physeter macrocephalus)*	4	29	-	-	4	29
Sei whale *(Balaenoptera borealis)*	1	1	-	-	1	1
Unidentified beaked whale	1	1	-	-	1	1
Hourglass dolphin *(Lagenorhynchus cruciger)*	-	-	1	7	1	7
Total	**56**	**124**	**49**	**74**	**105**	**198**

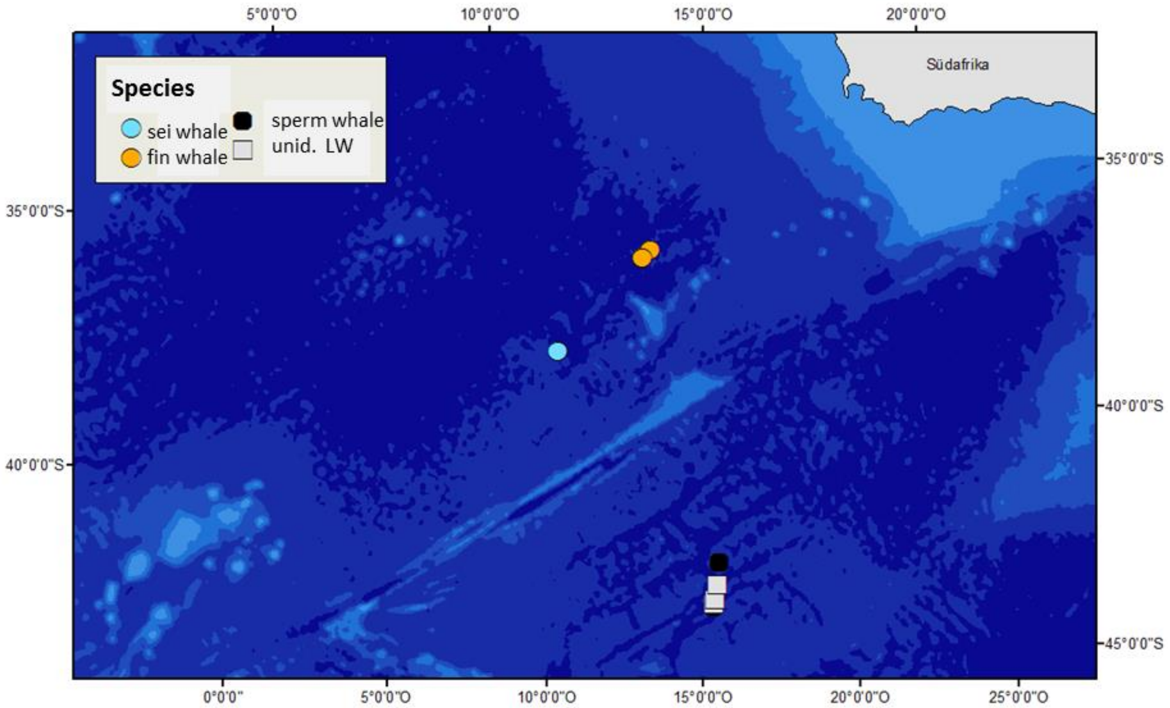

Figure 7: Geographic positions of all cetacean sightings in the northern part of the SA stratum (between South Africa and 45°S), recorded in the crow's nest surveys during RV Polarstern's ANT25-2 and ANT27-2 expeditions. LW = large whale.

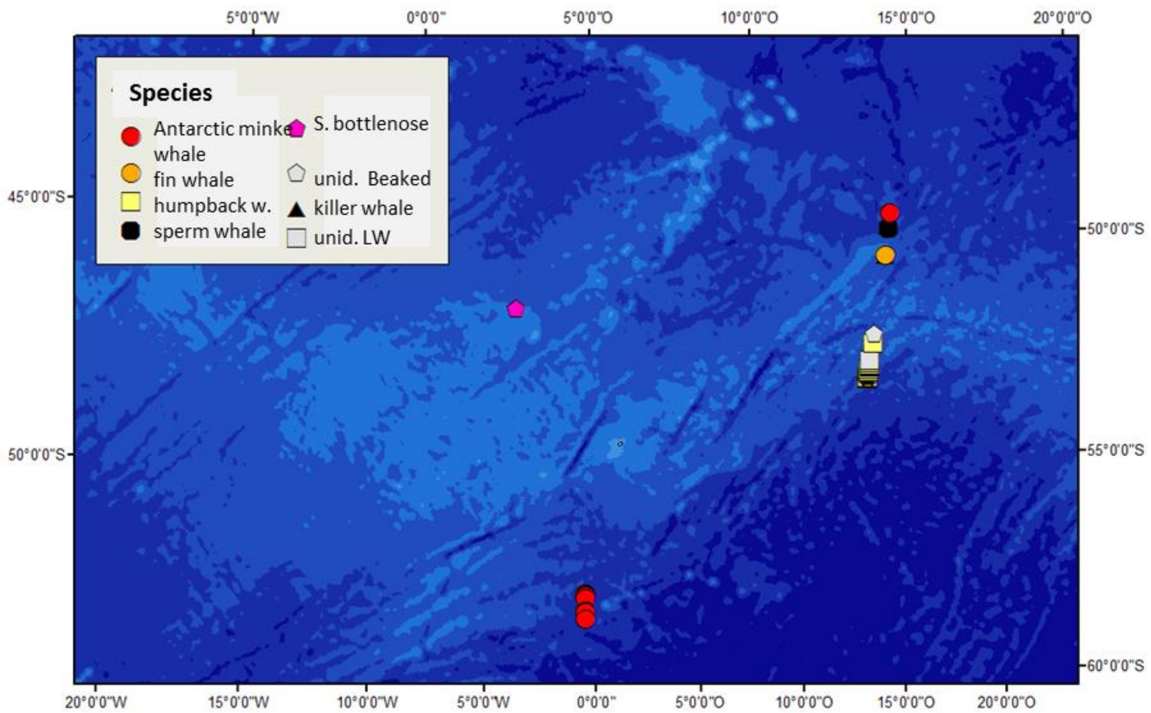

Figure 8: Geographic positions of all cetacean sightings in the southern part of the SA stratum (between 45°S and 60°S), recorded in the crow's nest surveys during RV Polarstern's ANT25-2 and ANT27-2 expeditions.

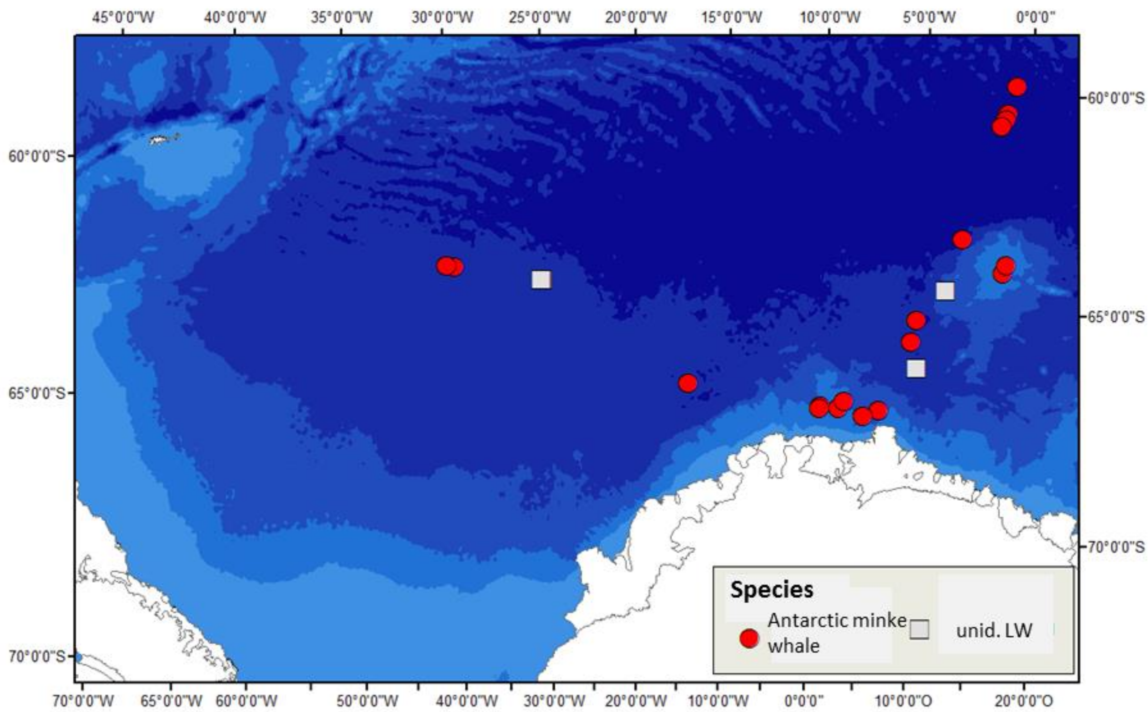

Figure 9: Geographic positions of all cetacean sightings in the NM and WS strata, recorded in the crow's nest surveys during RV Polarstern's ANT25-2 and ANT27-2 expeditions.

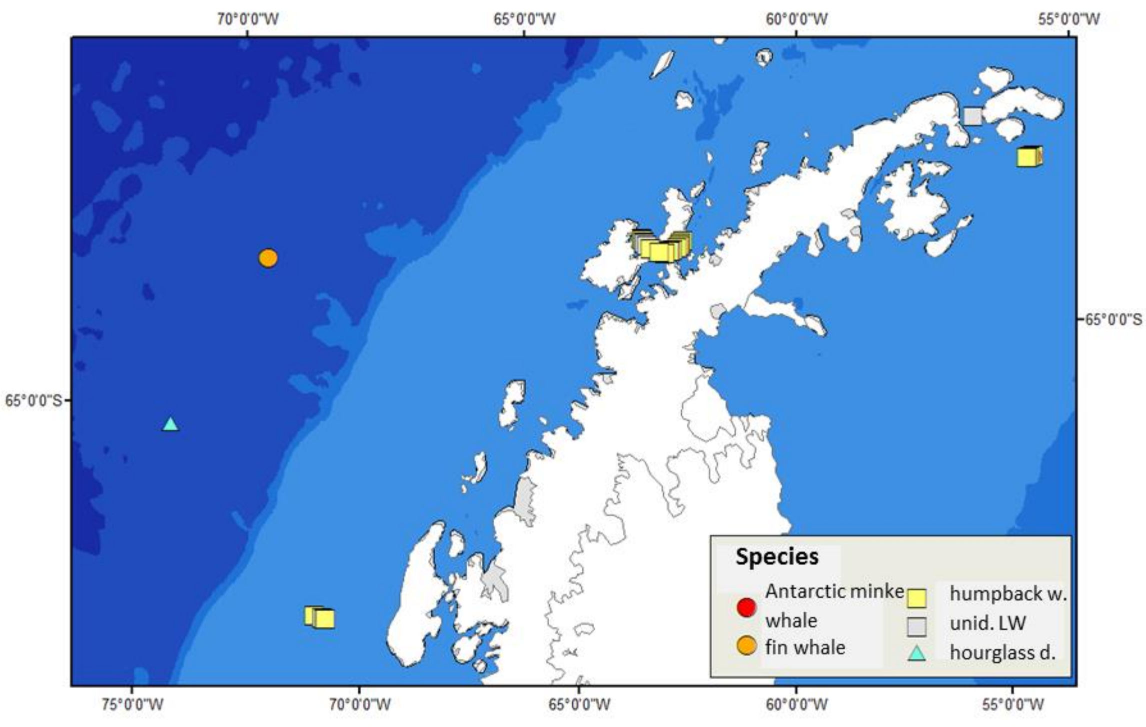

Figure 10: Geographic positions of all cetacean sightings in the AAS and WAP strata, recorded in the crow's nest surveys during RV Polarstern's ANT25-2 and ANT27-2 expeditions.

3.1.1.1 Distance analysis

Since a sufficiently large sighting number (n~40) is required to model a detection function, it was not possible to adjust a detection function to each observed cetacean species individually.

For this reason, a joint detection function for all observed large whales (sperm whales, unidentified large whales as well as all baleen whales except minke whales) was modelled and, separately, a detection function for Antarctic minke whales. Minke whales display considerably less conspicuous behaviour than the larger baleen whale species, are smaller and have a smaller blow. Thus, it is likely that their detection probability and *esw* are different from those for large whales. The number of sightings of other identified smaller species (e.g. dolphins) was insufficient to model a separate detection function. Selection of the best model in each case was based on the lowest AIC value (Akaike information criterion, e.g. Akaike 1974, Bozdogan 1987, Anderson et al. 1994), a selection criterion to measure a model's goodness of fit.

The best model for large whales proved to be a "half normal" function. The detection function did not include any of the collected sighting or environmental parameters as additional covariates (cf. chapter 2.1.1.4) because the model containing "distance to transect line" as the only variable (basic distance sampling model) achieved the best results ($g_{1,}$ Table 4). Figure 11 shows a graphic representation of the detection function for all large whales. It is based on a total of 53 sightings with a data cut-off beyond 2,000 m (right truncation at 2,000 m). This resulted in the exclusion of 12 of the original 65 sightings beyond this distance as outliers to preserve modelling quality. The Cramér-von Mises test for assessment of the detection function's quality showed that the function did not deviate significantly from the expected value (p=0.95; uniformly weighted). The *esw* corresponding to the detection function was measured to be 1,031 m.

Table 4: All tested function models and corresponding AIC values for modelling the detection function for all large whales observed in the crow's nest surveys. Model g_1 was identied as the best model, a half-normal function without inclusion of additional covariables. Key = the distribution underlying the detection function, covariable = the covariable used in modelling the detection function, AIC = Akaike information criterion, ΔAIC = difference in the AIC to the lowest AIC. Models listed without AIC values did not converge.

Model	Key	Covariate	AIC	ΔAIC
g_1	half normal	-	784.55	0.00
g_2	half normal	Subjective sighting conditions	785.72	1.17
g_3	half normal	Cloud cover	-	-
g_4	half normal	Ice cover	786.63	2.08
g_5	half normal	Sighting cue	-	-
g_6	half normal	Observer	787.01	2.46
g_7	half normal	Solar reflection	-	-
g_8	half normal	Sea state	-	-

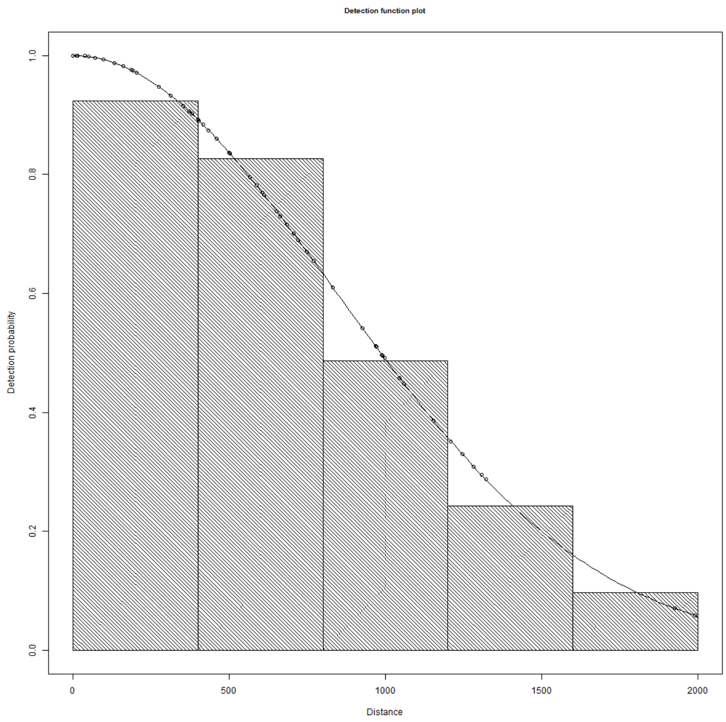

Figure 11: Graphic representation of the detection function for all large whales recorded in crow's nest surveys. The detection probability is shown against distances (in m), a further element shown is a scaled histogramme of observations in the individual distance classes used to test the detection function. A right truncation at 2,000 m was applied.

A half-normal function without inclusion of additional covariates (g_1) was identified as the best model for minke whales. Only the models including covariates "subjective sighting conditions" (g_2) and "ice cover" (g_4) converged (Table 5). Sample size was too small for all other covariates to cover all stages of the covariates in a statistically meaningful way. Figure 12 shows the detection function for minke whales based on 35 sightings. Right truncation at 800 m resulted in exclusion of 4 of the original 39 sightings beyond this distance as outliers to preserve modelling quality. The Cramér-von Mises test for assessment of the detection function's goodness showed that the function did not deviate significantly from the expected value (p=0.06). The *esw* corresponding to the detection function was measured to be 467 m.

Table 5: All tested function models and corresponding AIC values for modelling the detection function for minke whales observed in the crow's nest surveys. Model g_1 was identied as the best model, a half-normal function without inclusion of additional covariables. Key = the distribution underlying the detection function, covariable = the covariable used in modelling the detection function, AIC = Akaike information criterion, ΔAIC = difference in the AIC to the lowest AIC. Models without AIC values did not converge.

Model	Key	Covariate	AIC	ΔAIC
g_1	half normal	-	355.39	0.00
g_2	half normal	Subjective sighting conditions	360.50	5.11
g_3	half normal	Cloud cover	-	-
g_4	half normal	Ice cover	361.10	5.71
g_5	half normal	Sighting cue	-	-
g_6	half normal	Observer	-	-
g_7	half normal	Solar reflection	-	-
g_8	half normal	Sea state	-	-

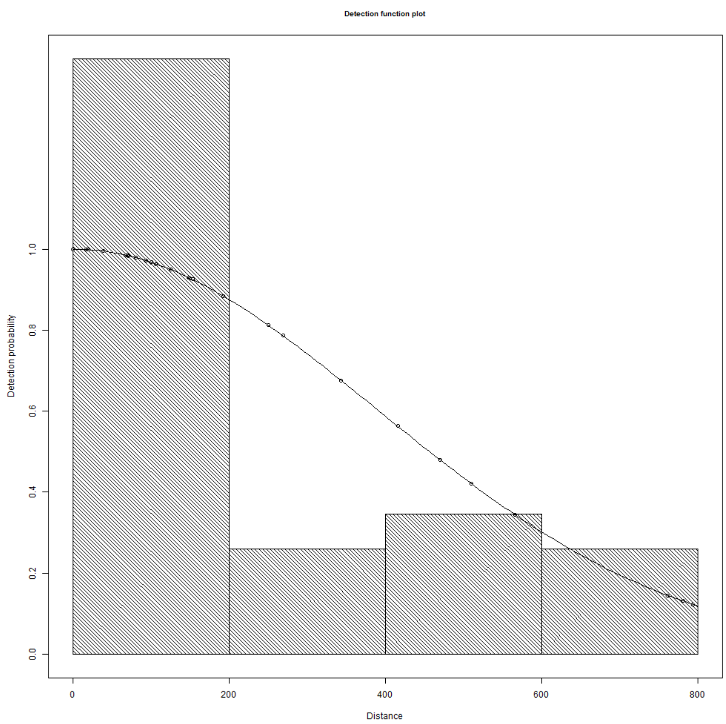

Figure 12: Graphic representation of the detection function for minke whales recorded in crow's nest surveys. The detection probability is shown against distances (in m), a further element shown is a scaled histogramme of observations in the individual distance classes used to test the detection function. A right truncation at 800 m was applied.

The adjusted detection function was used as a means to determine species- or group-specific densities for each stratum. In addition to the density of large whales in general, the local density specific to humpback whales was determined in each stratum by applying the detection function for large whales to the sightings of humpback whales. Because the number of sightings was too small to determine a separate detection function for humpback whales, their densities were calculated based on the detection function for all large whales. It can be assumed that the detection functions for different large whale species are similar. The determined encounter rates and densities for large whales in general are shown in Table 6, for humpback whales in Table 7, and for minke whales in Table 8.

Table 6: Listing of the encounter rates (sighting/km) and local densities (individuals/km^2) determined in each stratum for large whales generally, based on crow's nest surveys. SE = standard error, CV = coefficient of variation, CI = 95% confidence interval.

Area	Encounter rate [sight./km]	Encounter $rate_{SE}$	Encounter $rate_{CV}$	Density [animals/km^2]	$Density_{SE}$	$Density_{CV}$	$Density_{CI}$
SA	0.0135	0.0079	58.75%	0.0225	0.0122	54.12%	0.008 - 0.0636
NM	0.0018	0.0012	69.75%	0.0009	0.0006	70.54%	0.0002 - 0.0031
WS	0.0210	0.0211	100%	0.0102	0.0103	100%	0.0015 - 0.0673
AAS	0.1566	0.0134	08.56%	0.1519	0.0311	20.47%	0.0915 - 0.2522
WAP	0.0752	0.0377	50.11%	0.0496	0.0248	50.06%	0.0185 - 0.1332

Table 7: Listing of the encounter rates (sighting/km) and local densities (individuals/km^2) determined in each stratum for humpback whales, based on the detection function for large whales in crow's nest surveys. SE = standard error, CV = coefficient of variation, CI = 95% confidence interval.

Area	Encounter rate [sight./km]	Encounter $rate_{SE}$	Encounter $rate_{CV}$	Density [animals/km^2]	$Density_{SE}$	$Density_{CV}$	$Density_{CI}$
SA	0.0076	0.0074	96.79%	0.0078	0.0076	97.36%	0.0015 - 0.0416
NM	0	0	0%	0	0	0%	0 - 0
WS	0	0	0%	0	0	0%	0 - 0
AAS	0.1305	0.0395	30.24%	0.1392	0.0446	32.01%	0.0572 - 0.3387
WAP	0.0602	0.0322	53.55%	0.0409	0.0228	55.84%	0.0137 - 0.1214

Table 8: Listing of the encounter rates (sighting/km) and local densities (individuals/km^2) determined in each stratum for minke whales, based on crow's nest surveys. SE = standard error, CV = coefficient of variation, CI = 95% confidence interval.

Area	Encounter rate [sight./km]	Encounter $rate_{SE}$	Encounter $rate_{CV}$	Density [animals/km^2]	$Density_{SE}$	$Density_{CV}$	$Density_{CI}$
SA	0.0059	0.0049	83.34%	0.0063	0.0053	84.20%	0.0014 - 0.0284
NM	0.0140	0.0032	23.10%	0.0197	0.0069	34.75%	0.01 - 0.039
WS	0.0158	0.0089	56.70%	0.0281	0.0192	68.35%	0.007 - 0.1128
AAS	0.0261	0.0079	30.24%	0.0559	0.0182	32.53%	0.0232 - 0.1347
WAP	0	0	0%	0	0	0%	0 - 0

The highest density of large whales was observed in the AAS stratum, followed by the WAP and SA strata. No large whales were observed in the NM and WS strata, and the densities and encounter rates were correspondingly low. Humpback whales represented the majority of large whale sightings and reflected the same distribution pattern across all strata. The highest densities of minke whales were observed in the AAS, WS and NM strata. No minke whales were registered in the WAP stratum during the crow's nest surveys, while the observed density in the SA stratum was very low. It is typical of marine mammal surveys that standard errors and coefficients of variation are high and confidence intervals wide.

3.1.2 Helicopter survey

Helicopter surveys during the ANT25-2 and ANT-27-2 expeditions of the RV Polarstern covered 28,273 km over a total flight time of 232 h in observation modus ("on effort"). 268 sightings comprising 753 whales were recorded (Table 9). Figure 13 provides an overview of the geographic distribution of the effort and shows the helicopter routes flown. The SA and NM strata account for the largest effort (i.e. the highest number of kilometres flown) because only those strata where sampled during both expeditions. However, a similar effort was achieved in the WS and WAP strata during the ANT27-2 expedition alone. Sightings of 14 different cetacean species were recorded (Table 11). With 98 sightings and 215 observed individuals, humpback whales represented the species most frequently observed, followed by Antarctic minke whales with 63 sightings and 86 animals observed. Fin whales (*Balaenoptera physalus*) were recorded in 22 sightings with 57 individuals. All other species were observed relatively rarely. Species could not be determined in 45 sightings. Even application of the closing mode did not allow for identification of all sightings as not every sighting could be inspected due to time constraints, particularly those at great distance. Often, animals were diving again before they could be identified.

Table 9: Search effort and number of recorded sightings and individuals from helicopter surveys conducted during ANT25-2 and ANT27-2 expeditions of RV Polarstern.

Expedition	Effort (km)	Sightings	Individuals
ANT25-2	13,417	115	383
ANT27-2	14,856	153	370
Total	**28,273**	**268**	**753**

Table 10: Distribution of effort among individual strata in the helicopter surveys of both expeditions.

Stratum	ANT25-2 effort (km)	ANT27-2 effort (km)	Total effort (km)
SA	7,985	2,265	10,250
NM	5,432	1,962	7,394
WS	0	4,542	4,542
AAS	0	119	119
WAP	0	5,968	5,968
Total	**13,417**	**14,856**	**28,273**

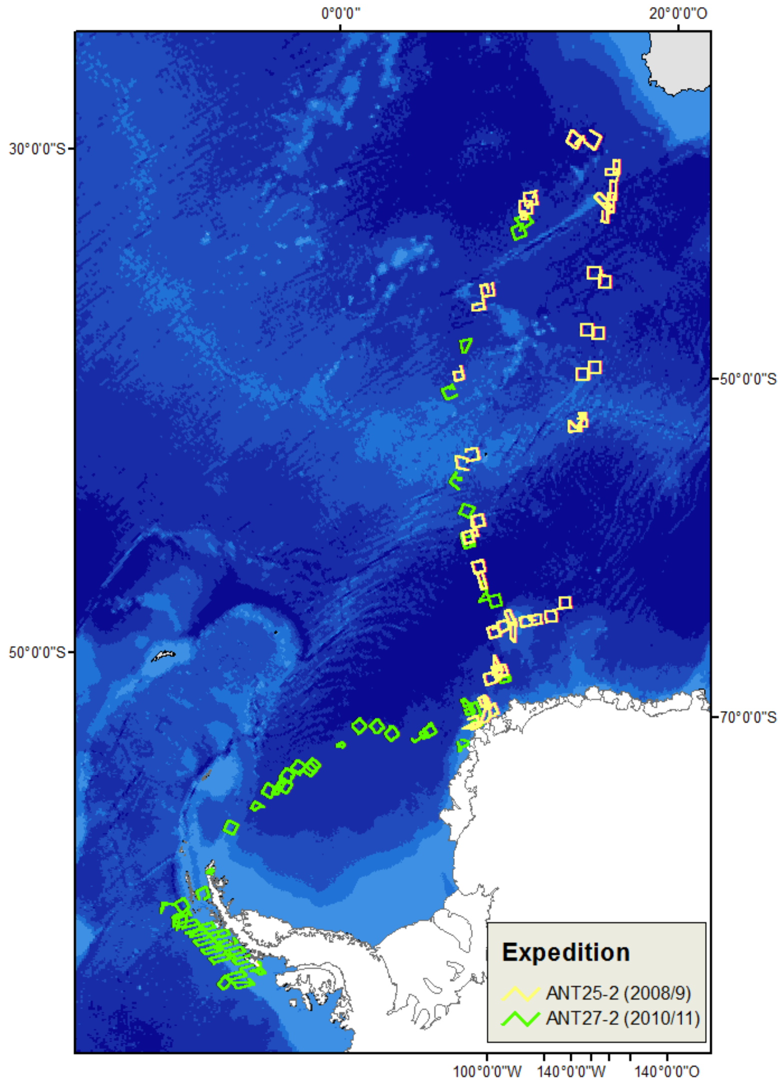

Figure 13: All helicopter flights performed during ANT25-2 and ANT27-2 expeditions of RV Polarstern.

Figure 14 through Figure 17 show the distribution of sightings in the research area for both expeditions side by side. While a range of species and many large whales were observed in the SA and WAP strata, only minke whales (*Balaenoptera bonarensis* / *B. acutorostrata*) and killer whales (*Orcinus orca*) could be identified in the NM and WS strata. The WAP stratum had a particularly high number of humpback whales. Near Bouvet Island in the southern region of the SA stratum, several “hot spots” with large numbers of humpback and fin whale sighings were noted, at one “hot spot” also an increased number of minke whales (Figure 15). An unusual sighting was a blue whale (*Balaenoptera musculus*) in the WAP stratum.

Table 11: Cetacean species recorded in helicopter surveys during ANT25-2 and ANT27-2 expeditions of RV Polarstern with numbers of sightings and individuals.

Cetacean species	ANT25-2		ANT27-2		Total	
	Sightings	Individuals	Sightings	Individuals	Sightings	Individuals
Antarctic minke whale *(Balaenoptera bonaerensis)*	23	27	40	59	63	86
Minke whale *(Balaenoptera acutorostrata)*	-	-	1	2	1	2
Minke whale or Antarctic minke whale	-	-	1	6	1	6
Blue whale *(Balaenoptera musculus)*	-	-	1	1	1	1
Fin whale *(Balaenoptera physalus)*	16	49	5	8	21	57
Sei whale *(Balaenoptera borealis)*	2	5	4	31	6	36
Humpback whales *(Megaptera novaeangliae)*	40	103	58	112	98	215
Southern right whale *(Eubalaena australis)*	1	2	-	-	1	2
Sperm whale *(Physeter macrocephalus)*	6	15	-	-	6	15
Killer whale *(Orcinus orca)*	2	5	4	64	6	69
Rough-toothed dolphin *(Steno bredanensis)*	3	143			3	143
Hourglass dolphin *(Lagenorhynchus cruciger)*	-	-	1	3	1	3
Long-finned pilot whale *(Globicephalus melas)*	-	-	1	13	1	13
Antarctic minke whale *(Hyperoodon planifrons)*	3	7	8	13	11	20
Layard's beaked whale *(Mesoplodon layardii)*	1	3	2	13	3	16
Unidentified large whale	13	19	20	30	33	49
Unidentified small whale	1	1	-	-	1	1
Unidentified dolphin	-	-	1	4	1	4
Unidentified beaked whale	-	-	4	9	4	9
Probably minke whale	1	1	2	2	3	3
Small whale or seal	3	3	-	-	3	3
Total	**115**	**383**	**153**	370	**268**	**753**

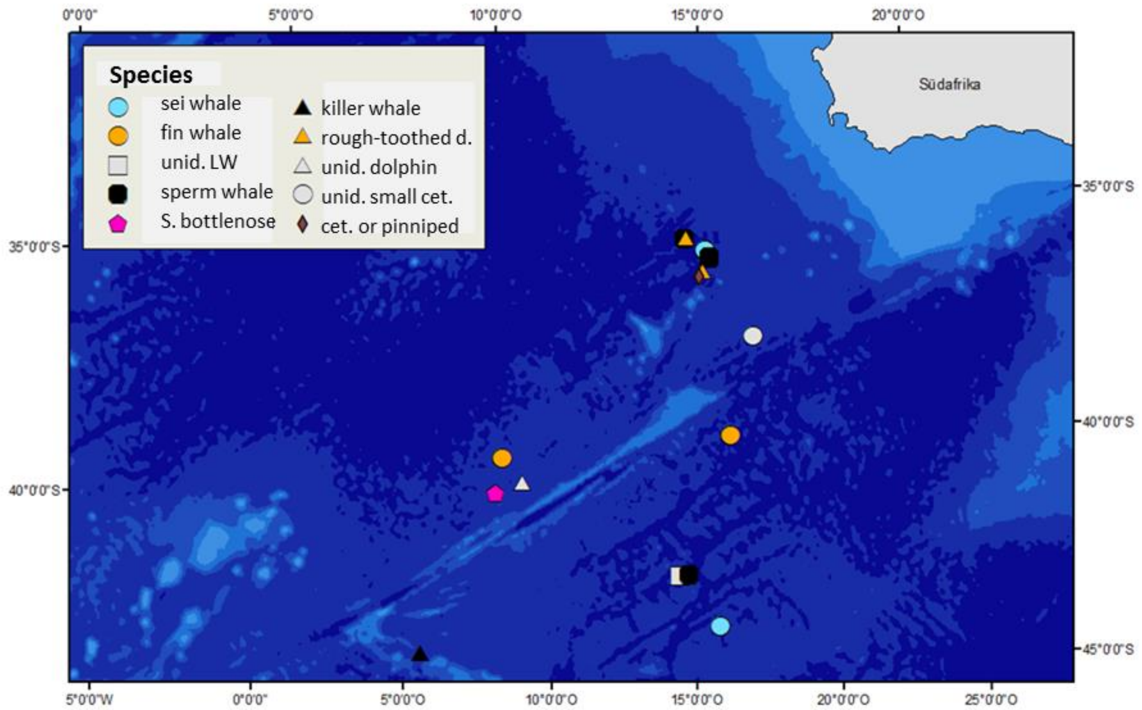

Figure 14: Geographic positions of all cetacean sightings in the northern part of the SA stratum (between South Africa and 45°S), recorded in the helicopter surveys during ANT25-2 and ANT27-2 expeditions of RV Polarstern.

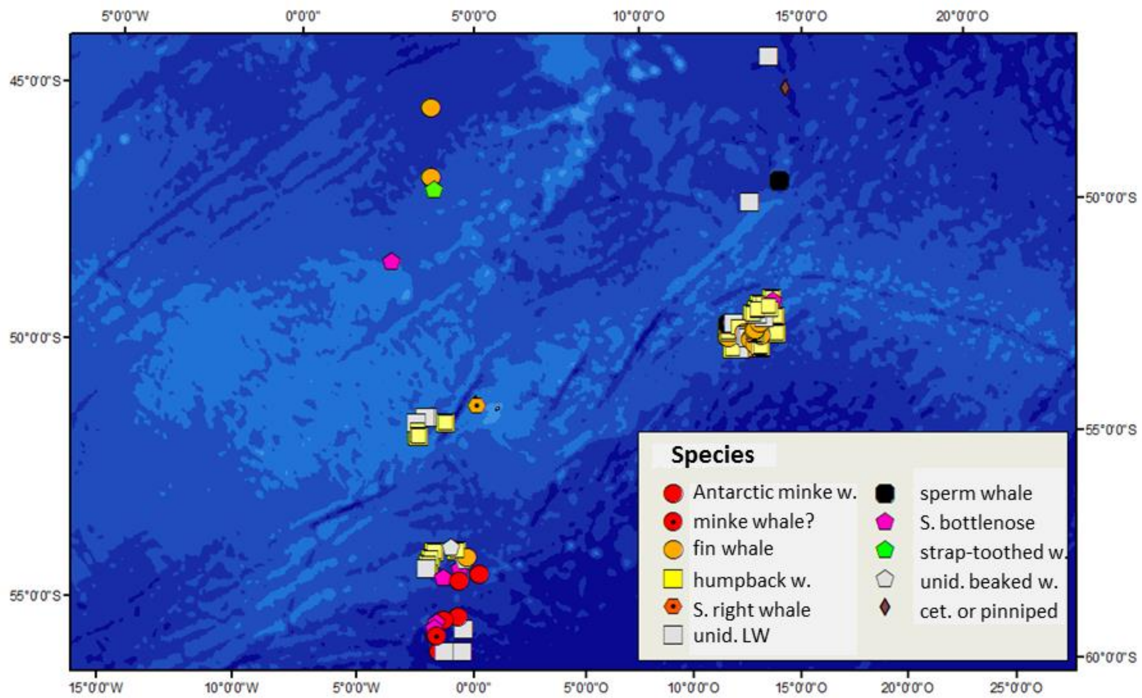

Figure 15: Geographic positions of all cetacean sightings in the southern part of stratum SA (between 45°S and 60°S), recorded in the helicopter surveys during RV Polarstern's ANT25-2 and ANT27-2 expeditions.

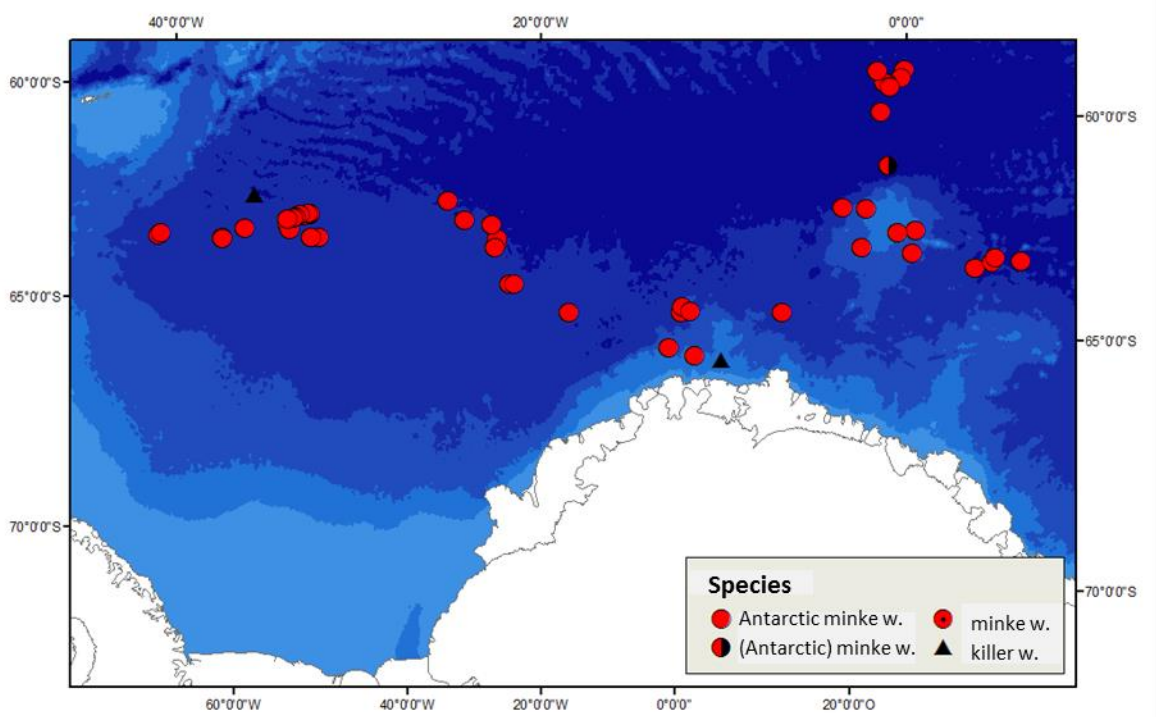

Figure 16: Geographic positions of all cetacean sightings in the NM and WS strata, recorded in the helicopter surveys during RV Polarstern's ANT25-2 and ANT27-2 expeditions.

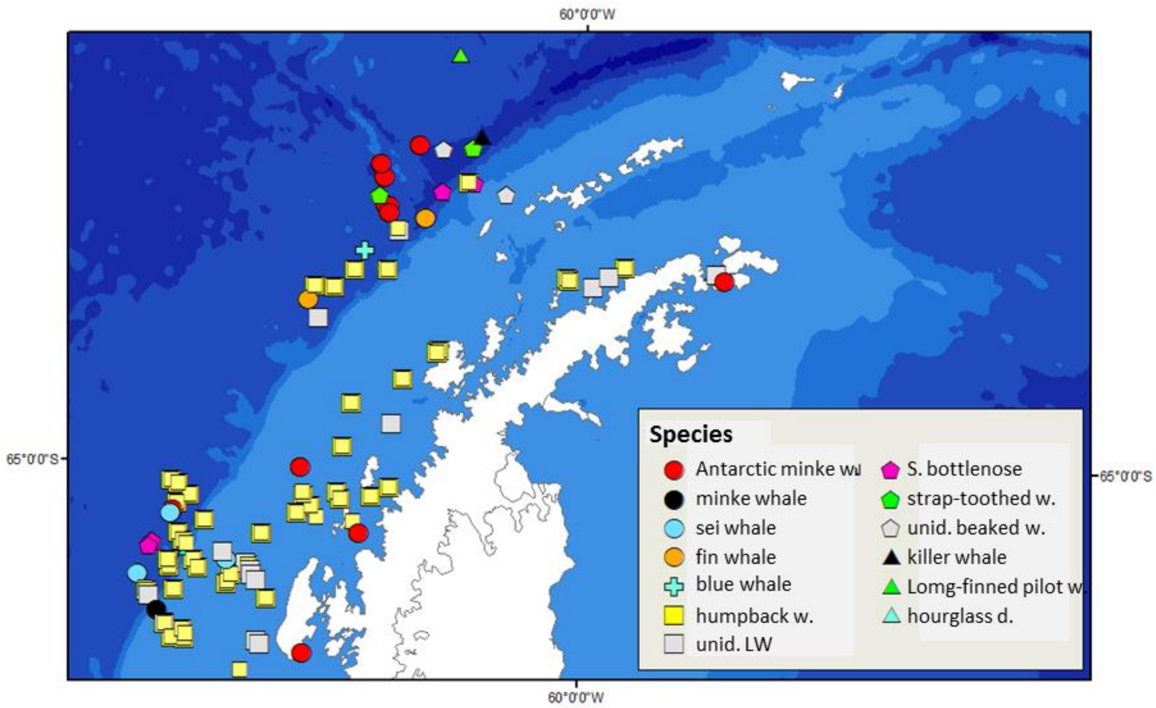

Figure 17: Geographic positions of all cetacean sightings in the AAS and WAP strata, recorded in the helicopter surveys during RV Polarstern's ANT25-2 and ANT27-2 expeditions.

3.1.2.1 Distance analysis

Only sightings on the left side (left and front observers) were used for modelling the detection function as only the left strip could be observed completely (see above). This led to a reduction of the total sighting number by 90 sightings to 178 sightings, which were then used to model the detection function. Since a sufficiently large sighting number (n~40) is required to model a detection function, it was not possible to adjust a detection function to each observed species individually. For this reason, and as done earlier in the analysis of crow's nest data, a joint detection function for all observed large whales was determined, as well as a separate detection function for minke whales (Antarctic and northern minke whales, sightings of "minke whale-like" animals as well as undetermined minke whales), because these cetaceans are smaller and display considerably less conspicuous behaviour. As in the crow's nest surveys, the number of sightings of smaller toothed whales was insufficient to model a detection function. The selection of the best model in each case was again based on the lowest AIC value.

The best model for large whales proved to be a "half normal" function. The detection function did not include any additional covariates because the model containing "distance to transect line" as the only variable (basic distance sampling model) achieved the best results (g_2, Table 12). Figure 18 shows a graphic representation of the detection function for all large whales. It is based on a total of 83 sightings. A right truncation at 2,000 m was applied. This resulted in the exclusion of 4 sightings beyond this distance from the analysis to preserve modelling quality. The Cramér-von Mises test for assessment of the detection function's quality showed that the function did not deviate significantly from the expected value (p=0.16; uniformly weighted). The *esw* corresponding to the detection function was measured to be 818 m.

Table 12: All tested function models and corresponding AIC values for modelling the detection function for all large whales observed in the helicopter surveys. Model g_2 was identied as the best model, a half-normal function without inclusion of additional covariables. Key = the distribution underlying the detection function, covariable = the covariable used in modelling the detection function, AIC = Akaike information criterion, ΔAIC = difference in the AIC to the lowest AIC.

Model	Key	Covariate	AIC	ΔAIC
g_1	hazard rate	-	1199.99	3.50
g_2	half normal	-	1196.48	0.00
g_3	half normal	Subjective sighting conditions	1197.36	0.88
g_4	half normal	Cloud cover	1197.96	1.48
g_5	half normal	Ice cover	1198.16	1.68
g_6	half normal	Sighting cue	1199.19	2.70
g_7	half normal	Observer	1199.36	2.88
g_8	half normal	Solar reflection	1199.64	3.15
g_9	half normal	Sea state	1201.86	5.37

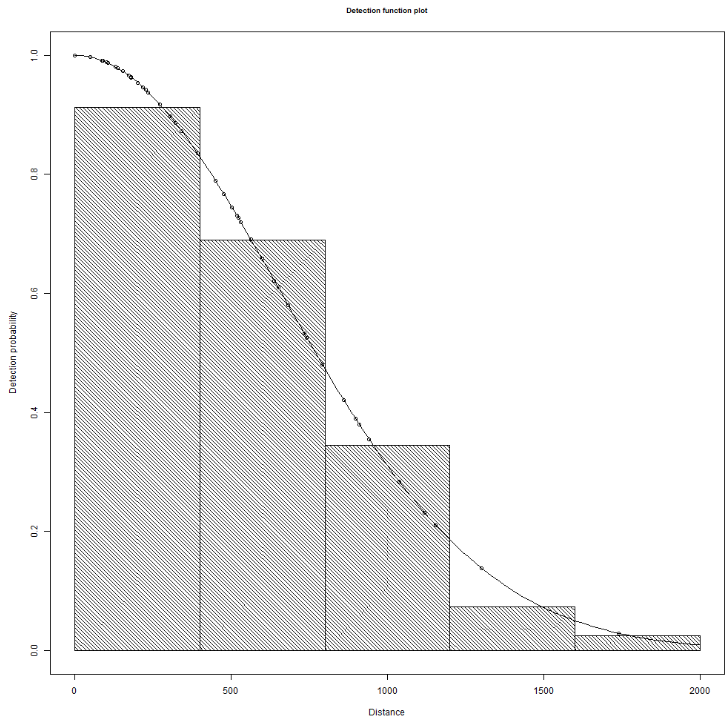

Figure 18: Graphic representation of the detection function for all large whales recorded in helicopter surveys. The detection probability is shown against distances (in m), a further element shown is a scaled histogramme of observations in the individual distance classes used to test the detection function. A right truncation at 2,000 m was applied.

A half-normal function incorporating sea states as covariates (g_9) was identified as the best model for minke whales. None of the models converged when cloud cover (g_4), ice cover (g_5) or observer (g_6, Table 13) was incorporated as a covariate. This is on account of the low number of sightings which did not permit a statistically meaningful use of the covariables' increments. Figure 19 shows the detection function for minke whales. A right truncation at 1,000 m was applied, which excluded 6 sightings beyond this distance to preserve modelling quality. The Cramér-von Mises test for assessment of the detection function's quality showed that the function did not deviate significantly from the expected value (p=0.74). The *esw* corresponding to the detection function was measured to be 453 m.

Table 13: All tested function models and corresponding AIC values for modelling the detection function for all minke whales observed in the helicopter surveys. Model g_9 was identied as the best model, a half-normal function incorporating sea states as covariables. Key = the distribution underlying the detection function, covariable = the covariable used in modelling the detection function, AIC = Akaike information criterion, ΔAIC = difference in the AIC to the lowest AIC.

Model	Key	Covariate	AIC	ΔAIC
g_1	hazard rate	-	437.98	4.63
g_2	half normal	-	437.48	4.13
g_3	half normal	Subjective sighting conditions	438.80	5.45
g_4	half normal	Cloud cover	-	-
g_5	half normal	Ice cover	-	-
g_6	half normal	Sighting cue	439.17	5.82
g_7	half normal	Observer	-	-
g_8	half normal	Solar reflection	439.54	6.19
g_9	half normal	Sea state	433.35	0.00

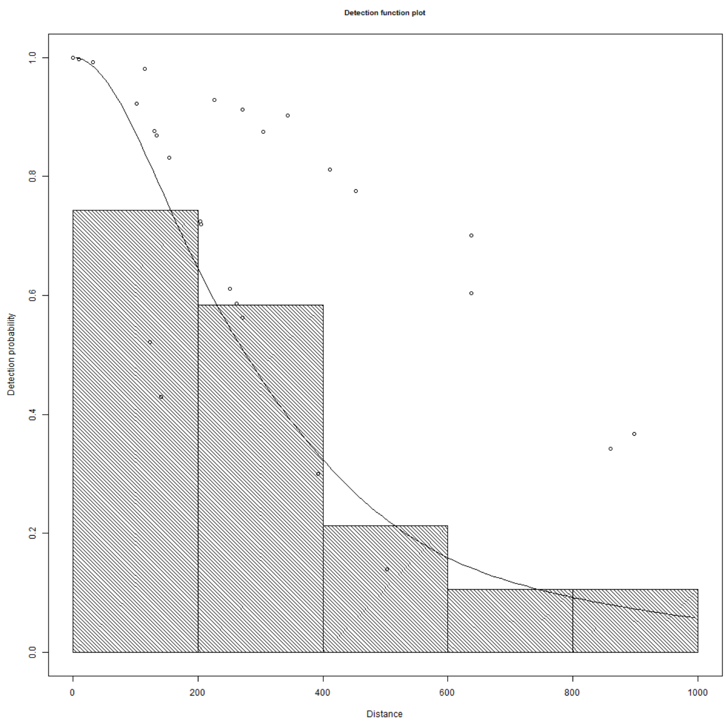

Figure 19: Graphic representation of the detection function for all minke whales recorded in helicopter surveys showing the mean (solid line) and for the individual increments of the incorporated covariable "sea state" (dots). The detection probability is shown against distances (in m), a further element shown is a scaled histogramme of observations in the individual distance classes used to test the detection function. A right truncation at 1,000 m was applied.

The adjusted detection function was used as a means to determine species- or group-specific densities for each stratum. The detection function for large whales was also applied to humpback und fin whale sightings to preserve species-specific densities. For other large whale species, the number of sightings was too low to apply this procedure. The encounter rates and local densities for large whales, fin whales and humpback whales are shown in Table 14 through Table 16, and for minke whales in Table 17. The encounter rates represent the total of all sightings from both observer sides per section. Densities, however, refer to the esw and are based on the determined detection function, which is derived solely on sightings on the left side. The encounter rates thus allow an intuitive comparison with studies that do not present any density calculations, while densities presented in this project represent a value corrected by area and sighting probability. The highest density of large whales was calculated for the WAP stratum with 0.0149 animals/km^2 [95% confidence interval: 0.0094 – 0.0237], followed by the SA stratum with 0.0134 animals/km^2 [0.0071 – 0.0252]. No large whales were observed in the NM and WS strata. The density of humpback whales was very close to that of large whales, fin whales were encountered at noticeably lower densities. With 0.0265 animals/km^2 [0.0023 – 0.2997] minke whale density was highest in the AAS and WS strata (0.0115 animals/km^2 [0.0048 – 0.0275]), and lowest in the SA stratum (0.0007 animals/km^2 [0.0002 – 0.0027]).

Table 14: Listing of the encounter rates (sightings/km) and local densities (individuals/km^2) determined in each stratum for large whales, based on helicopter surveys. SE = standard error, CV = coefficient of variation, CI = 95% confidence interval.

Area	Encounter rate [sight./km]	Encounter $rate_{SE}$	Encounter $rate_{CV}$	Density [animals/km^2]	$Density_{SE}$	$Density_{CV}$	$Density_{CI}$
SA	0.0077	0.0019	25.23%	0.0134	0.0044	32.97%	0.0071 - 0.0252
NM	0	0	0%	0	0	0%	0
WS	0	0	0%	0	0	0%	0
AAS	0.0084	0.0080	94.95%	0.0103	0.0098	95.35%	0.0011 - 0.0945
WAP	0.0116	0.0021	18.30%	0.0149	0.0035	23.51%	0.0094 - 0.0237

Table 15: Listing of the encounter rates (sightings/km) and local densities (individuals/km^2) determined in each stratum for humpback whales, based on helicopter surveys. SE = standard error, CV = coefficient of variation, CI = 95% confidence interval.

Area	Encounter rate [sight./km]	Encounter $rate_{SE}$	Encounter $rate_{CV}$	Density [animals/ km^2]	$Density_{SE}$	$Density_{CV}$	$Density_{CI}$
SA	0.0041	0.0012	28.26%	0.0076	0.0027	34.76%	0.0039 - 0.0149
NM	0	0	0%	0	0	0%	0
WS	0	0	0%	0	0	0%	0
AAS	0	0	0%	0	0	0%	0
WAP	0.0084	0.0016	19.35%	0.0119	0.0031	25.78%	0.0072 - 0.0196

Table 16: Listing of the encounter rates (sightings/km) and local densities (individuals/km^2) determined in each stratum for fin whales, based on helicopter surveys. SE = standard error, CV = coefficient of variation, CI = 95% confidence interval.

Area	Encounter rate [sight./km]	Encounter rate$_{SE}$	Encounter rate$_{CV}$	Density [animals/km^2]	Density$_{SE}$	Density$_{CV}$	Density$_{CI}$
SA	0.0018	0.0007	40.77%	0.0037	0.0020	55.27%	0.0013 - 0.0102
NM	0	0	0%	0	0	0%	0
WS	0	0	0%	0	0	0%	0
AAS	0	0	0%	0	0	0%	0
WAP	0.0003	0.0002	69.00%	0.0006	0.0006	99.45%	0.0001 - 0.0032

Table 17: Listing of the encounter rates (sightings/km) and local densities (individuals/km^2) determined in each stratum for minke whales, based on helicopter surveys. SE = standard error, CV = coefficient of variation, CI = 95% confidence interval.

Area	Encounter rate [sight./km]	Encounter rate$_{SE}$	Encounter rate$_{CV}$	Density [animals/km^2]	Density$_{SE}$	Density$_{CV}$	Density$_{CI}$
SA	0.0006	0.0003	46.52%	0.0007	0.0005	74.20%	0.0002 - 0.0027
NM	0.0030	0.0007	21.97%	0.0029	0.0012	41.34%	0.0013 - 0.0064
WS	0.0053	0.0015	28.01%	0.0115	0.0053	46.09%	0.0048 - 0.0275
AAS	0.0084	0.0092	109.01%	0.0265	0.0294	110.78%	0.0023 - 0.2997
WAP	0.0017	0.0006	33.19%	0.0097	0.0073	75.73%	0.0025 - 0.0369

Sufficiently representative coverage of a helicopter survey area defined a posteriori was achieved for the WAP stratum (Figure 20), allowing abundance estimates for fin and humpback whales, for large whales generally, and for minke whales. The calculated abundances for the WAP stratum, which is 322,303 km^2 in size, are shown in Table 18.

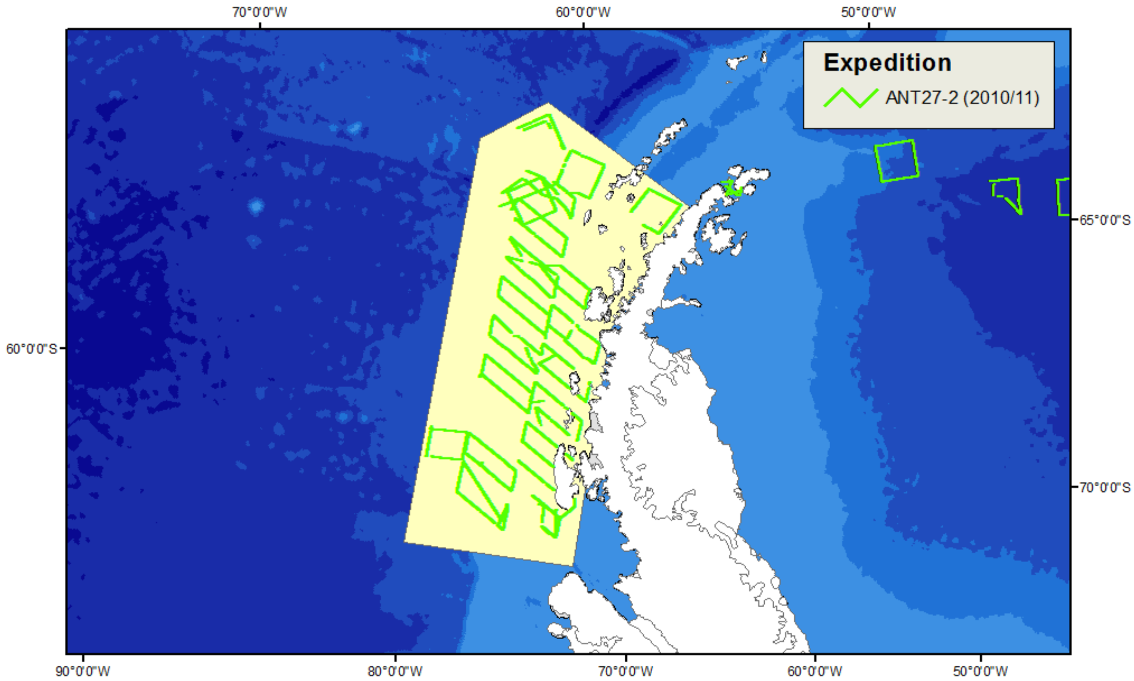

Figure 20: The WAP stratum and its coverage by helicopter surveys during ANT27-2 expedition of RV Polarstern. Abundances for large, humpback, fin and minke whales were estimated for this stratum.

While estimated abundances for humpback and minke whales are similar, the confidence interval associated with minke whale abundance was considerably larger than the one associated with humpback whales. This is on account of more even distribution of sighting distances for humpback whales in the WAP stratum than was the case with minke whales (see also Figure 18 in comparison to Figure 19). The resulting variance directly influences the quality of the detection function, leading in the case of minke whales to a rather high coefficient of variation of 75.73% in the WAP stratum (in contrast to the comparatively lower coefficient of variation of 25.78% for humpback whales). The estimation of humpback whale abundance may thus be considered more robust.

Table 18: Abundances of large whales generally, humpback, fin and minke whales in the WAP stratum (322,303 km^2), based on densities calculated from helicopter survey data. The values are rounded to the next integer. CI = 95% confidence intervall.

Species	Abundance	$Abundance_{CI}$
Large whales	4959	3128 – 7887
Humpback whales	3960	2396 – 6523
Finback whales	200	33 - 1065
Minke whales	3228	832 – 12280

3.1.3 Tracking

Demands on sighting conditions for the successful performance or tracking are high. Tracking observations can be recorded only during very favourable conditions. Heavy swell or the vessel's movements from ice-breaking can make it impossible to steady binoculars sufficient to continuously observe the water surface at required magnification. Such conditions prevailed on only 7 survey days. On these days 19 whale groups from four different species were successfully tracked. Table 19 shows all successful tracks, i.e. all tracks with at least one re-sighting. Figure 21 shows these tracks as a graph.

Table 19: Listing of all tracks with at least two sightings of the same group. The time and geographic position (lat = latitude; lon = longitude) of the first sighting, the species, group size and number of recorded sightings are indicated for each track.

Survey	Date/time	lat	lon	Species	Group size	No. of sightings
ANT25-2	08/12/2008 05:04:13	-39.5291	11.0802	Sei whale	1	2
ANT25-2	12/12/2008 05:43:03	-57.6809	0.5794	Minke whale	1	6
ANT25-2	12/12/2008 05:57:03	-57.7325	0.5463	Minke whale	1	5
ANT25-2	12/12/2008 09:57:57	-58.2089	0.3467	Minke whale	1	4
ANT25-2	13/12/2008 15:17:53	-61.4102	-0.0500	Minke whale	1	2
ANT25-2	29/12/2008 12:56:47	-53.2918	13.5928	Humpback whales	2	6
ANT25-2	29/12/2008 13:02:37	-53.2769	13.5971	Humpback whales	2	8
ANT25-2	29/12/2008 13:27:27	-53.2137	13.6151	Humpback whales	4	4
ANT25-2	30/12/2008 10:22:27	-50.8050	14.2867	Killer whale	1	13
ANT27-2	20/01/2011 16:43:00	-66.3239	-68.4598	Humpback whales	1	2
ANT27-2	20/01/2011 16:47:36	-66.3328	-68.4836	Humpback whales	1	2
ANT27-2	20/01/2011 17:04:02	-66.3642	-68.5677	Humpback whales	2	5
ANT27-2	20/01/2011 17:04:42	-66.3654	-68.5710	Humpback whales	k. A.	5
ANT27-2	20/01/2011 17:14:46	-66.3846	-68.6216	Unid. Large whales	1	3
ANT27-2	20/01/2011 17:31:07	-66.4152	-68.7036	Humpback whales	1	2
ANT27-2	20/01/2011 17:31:40	-66.4162	-68.7063	Humpback whales	1	2
ANT27-2	20/01/2011 17:39:44	-66.4312	-68.7476	Humpback whales	2	23
ANT27-2	20/01/2011 18:30:49	-66.5280	-69.0070	Humpback whales	1	22

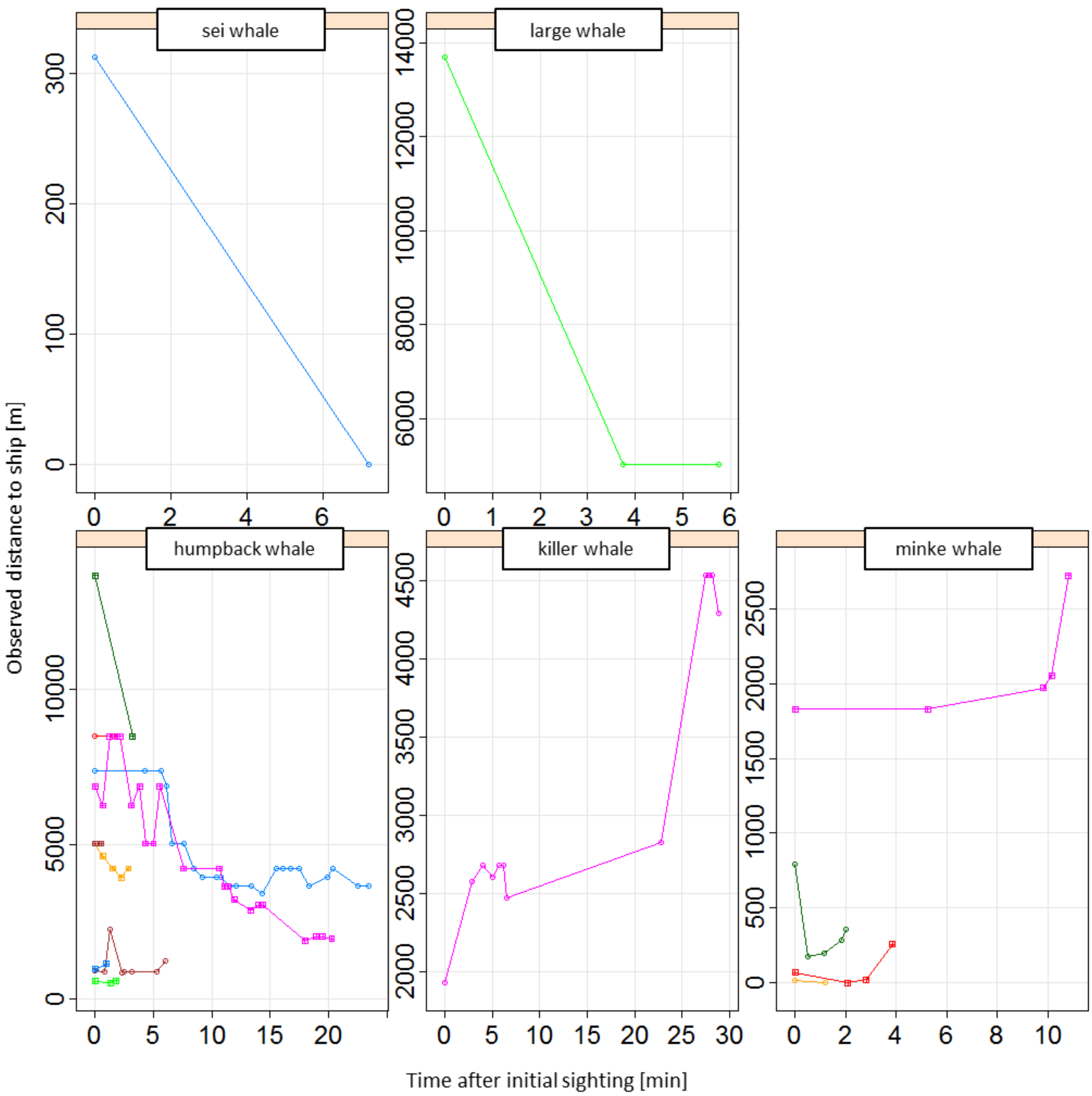

Figure 21: Graphic representation of all tracks according to species: Sei whale, unidentified large whale, humpback whale, killer whale, and minke wale. The chronology of the absolute distance to the vessel of each individual by species is shown. Each point marks a recorded sighting (beginning with the initial sighting), the line represents the interpolated path of the individual between two successive sightings.

Due to the low sample value, an analysis using GAMM was possible only for minke whales (4 tracks) and humpback whales (11 tracks). For all other cetacean species, the number of tracks was insufficient. To harmonise the different distances of the tracks to the vessel, an animal's distance to the vessel at the beginning of the track recording was defined as initial distance (subsequently referred to as initial sighting).

The spatial representation of the tracks indicates an approaching behaviour of the humpback whales in the direction of the vessel (Figure 22). Modelling underscores a clear, gradual approach of the humpback whales to the vessel (Figure 23). The mixed effect model (cf. chapter 2.1.2.2) identified only the time elapsed since the initial sighting as relevant ($p<0.001$). The "overshooting" of the initial distance at the time of initial sighting should be considered an artefact of the model and does not influence its power (Figure 23). In contrast, the movement of minke whales seems to be random. Both the representation of minke whale behaviour (Figure 22) and its modelling (Figure 24) show no discernable pattern in the distance to the vessel over time. It should be noted, however, that this analysis as a whole is based on a small sample. The analysis of humpback whale behaviour is based on eleven tracks, of minke whale behaviour on only four. In addition, it should be noted that robustness of the model for minke whales collapses 650 s after initial sighting (see Figure 24) and does no longer allow meaningful prediction beyond this time span.

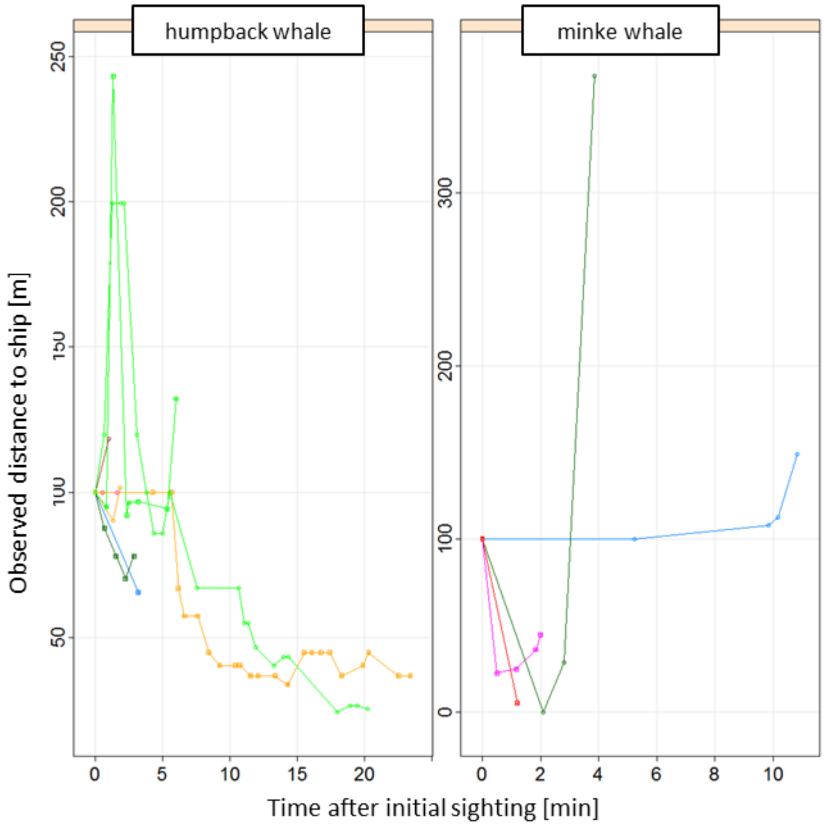

Figure 22: All humpback and minke whale tracks. The distance of each re-sighting is shown relative to the distance of the initial sighting. The initial sighing is assumed at a relative distance of 100%. A re-sighting at a distance of >100% corresponds to a larger distance from the vessel, a relative distance of <100% corresponds to an approach.

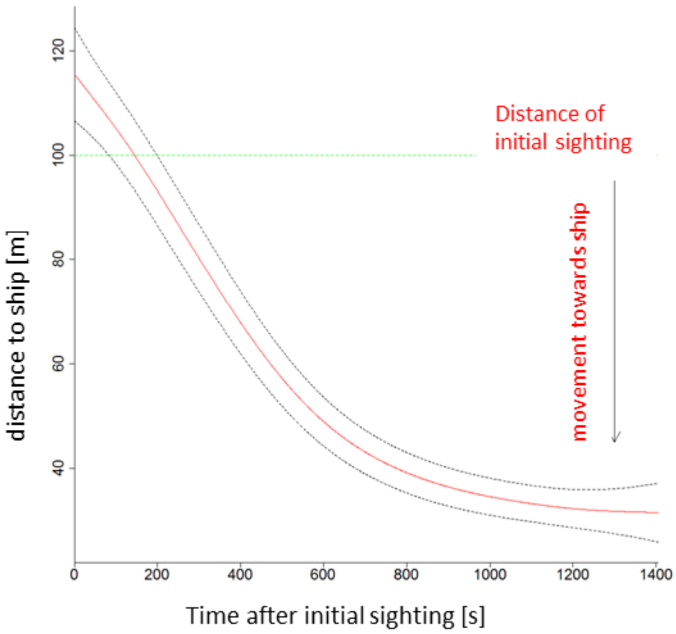

Figure 23: Modelling of humpback whale behaviour vis-à-vis the vessel using a GAMM. The predicted change in distance of a humpback whale to the vessel is shown relative to the initial distance of the sighting. The decrease in relative distance to the vessel indicates an approach to the vessel. The deviation is indicated by black dotted lines and is based on the calculated variance of sighting distances as well as the variance between individual tracking events of individual humpback whales (as mixed effect model).

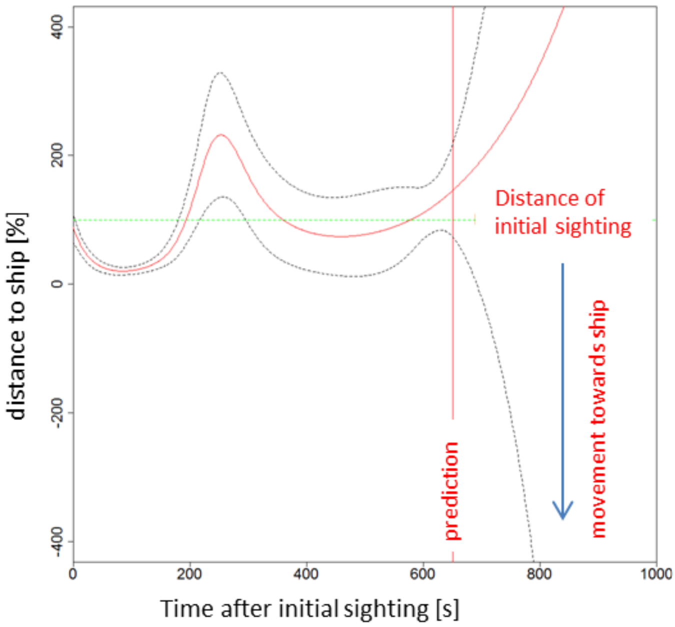

Figure 24: Modelling of minke whale behaviour vis-à-vis the vessel using a GAMM. The predicted change in distance of a minke whale to the vessel is shown relative to the initial distance of the sighting. The decrease in relative distance to the vessel indicates an approach to the vessel. The deviation is indicated by black dotted lines and is based on the calculated variance of sighting distances as well as the variance between individual tracking events of individual minke whales (as mixed effect model). The model's robustness extends only to approximately 650 s, after which the model collapses due to small sample size.

3.1.4 Discussion of the results and their contribution to scientific knowledge on occurrence, distribution and abundance of cetaceans in the Antarctic

Results of the distance sampling surveys show a heterogeneous distribution of cetacean species in the Antarctic. The ice-rich waters of the Weddell Sea are dominated by minke whales, while a much more diverse spectrum of species inhabits the ice-free waters west of the Artic Peninsula, where many large whales, particularly humpback whales, are encountered.

The densities determined represent basic data which many be used for comparison with future surveys and between strata. Robust minimum density estimates are available for large whales in general (sperm whales, unidentified large whales as well as all baleen whales except minke whales), humpback whales and Antarctic minke whales in each stratum (summary of results in Table 20 through Table 22).

Table 20: Results of the line-transect distance sampling method relating to all large whales (sperm whales, unidentified large whales, as well as all baleen whales except minke whales); CV = coefficient of variation

	Vessel				Helicopter			
Area	Encounter rate [sight./km^2]	Encounter rate$_{CV}$	Density [animals/km^2]	Density$_{CV}$	Encounter rate [sight./km^2]	Encounter rate$_{CV}$	Density [animals/km^2]	Density$_{CV}$
SA	0.0135	58.75	0.0225	54.12	0.0077	25.23	0.0134	32.97
NM	0.0018	69.75	0.0009	70.54	0.0000	0	0	0
WS	0.0210	100.21	0.0102	100.75	0.0000	0	0	0
AAS	0.1566	8.56	0.1519	20.47	0.0084	94.95	0.0103	95.35
WAP	0.0752	50.11	0.0496	50.06	0.0116	18.30	0.0149	23.51

Table 21: Results of the line-transect distance sampling method relating to humpback whales; CV = coefficient of variation

	Vessel				Helicopter			
Area	Encounter rate [sight./km^2]	Encounter rate$_{CV}$	Density [animals/km^2]	Density$_{CV}$	Encounter rate [sight./km^2]	Encounter rate$_{CV}$	Density [animals/km^2]	Density$_{CV}$
SA	0.0076	96.79	0.0078	97.36	0.0041	28.26	0.0076	34.76
NM	0.0000	0	0	0	0.0000	0	0	0
WS	0.0000	0	0	0	0.0000	0	0	0
AAS	0.1305	30.24	0.1392	32.01	0.0000	0	0	0
WAP	0.0602	53.55	0.0409	55.84	0.0084	19.35	0.0119	25.78

Table 22: Results of the line-transect distance sampling method relating to all minke whales; CV = coefficient of variation

	Vessel				Helicopter			
Area	Encounter rate [sight./km^2]	Encounter rate$_{CV}$	Density [animals/km^2]	Density$_{CV}$	Encounter rate [sight./km^2]	Encounter rate$_{CV}$	Density [animals/km^2]	Density$_{CV}$
SA	0.0059	83.34	0.0063	8.42	0.0006	46.52	0.0007	7.42
NM	0.0140	23.10	0.0197	34.75	0.0030	21.97	0.0029	41.34
WS	0.0158	56.70	0.0281	68.35	0.0053	28.01	0.0115	46.09
AAS	0.0261	30.24	0.0559	32.53	0.0084	109.01	0.0265	110.78
WAP	0	0	0	0	0.0017	33.19	0.0097	75.73

Encounter rates of the crow's nest surveys increase in all three groups in a southerly and westerly direction (SA, NM, WS, AAS, WAP) and mostly peak in the AAS stratum. Only humpback whales are completely absent in the NM and WS strata. Encounter rates of the helicopter surveys indicate a similar trend, however, no humpback whales were recorded in the NM, WS or AAS strata.

The results confirm the subjective impression of humpback whale dominance on the western side of the Antarctic Peninsula, at least in respect of the encouter rates, (cf. Figure 10 and Figure 17). The much narrower strip width on which the minke whale sightings are based, however, puts this difference of densities in perspective. In that case, they are similar and statistically not distinguishable (Table 20 through Table 22).

To assess the results' contribution to current scientific knowledge on occurrence and distribution of cetaceans in the Antarctic, it is worthwhile to look at other studies. Most ship-board surveys follow a multitude of different survey methods. Published data on cetacean densities mostly originate from surveys based on strip transects (often connected to sea bird surveys, e.g. Joiris 1991, Ainley et al. 2007). The underlying relationship to area thus does not correspond to the one determined through distance sampling, and the derived densities cannot be compared to the present data without qualification. The esw for large whales (1,004 m) and minke whales (466 m) determined in the crow's nest surveys are very different from one another and suggest that a uniform relationship to area (such as 800 m in Ainley et al. 2007) is not appropriate for all species. Kasamatsu et al. (2000) used strip transects to determine minke whale densities in the Bellingshausen and Amundsen Seas of 0.003 - 0.15 animals/km^2, where the observation area was not limited and reached to the horizon. Observations in comparable strata during the present project resulted in densities of 0.0281 [95% CI: 0.0070 – 0.1128] in the Weddell Sea (WS stratum) and 0.0197 [0.0100 – 0.0390] animals/km^2 in the NM stratum. Thus, the results fall into the lower range of the values determined by Kasamatsu et al. (2000).

Encounter rates of various surveys can be compared almost immediately in the case of ship-board surveys. It should be noted, however, that in some cases observations took place only on one side of the vessel, in some cases on both sides, and the number of observers also varied accordingly, which affected the number of sightings. For comparison purposes, it is therefore advisable to halve encounter rates from bilateral observations (such as in this project) to arrive at a basis for comparison (see Table 23). Comparison data for encounter rates from different surveys in the Antarctic are available only for Antarctic minke whales.

Table 23: Halved encounter rates for minke whales from the crow's nest surveys of ANT25-2 and ANT27-2 expeditions of the RV Polarstern in comparison with other unilateral cetacean surveys.

Area	Encounter rate [sight./km^2]	Encounter rate$_{SE}$	Encounter rate$_{CV}$
SA	0.0030	0.0025	41.67
NM	0.0070	0.0016	11.55
WS	0.0079	0.0045	28.35
AAS	0.0131	0.0040	15.12
WAP	0	0	0

Ainley et al. (1985) determined an encounter rate of 0.0241 sightings/km^2 for the Amundsen and Bellingshausen Seas, Ainley et al. (2007) a rate of 0.0114 sightings/km^2 for the same area. These areas are located south of the WAP stratum, in which no minke whales were recorded from the vessel ().

Few other surveys can be found in the literature presenting data with which those from the helicopter survey could be compared. Gutt et al. (2009) used the same survey method to determine densities of Antarctic minke whales between 0.007 and 0.073 animals/km^2 near the Larsen Ice Shelf in the Weddell Sea. The helicopter surveys analysed in the present study yielded densities for the Weddell Sea which overlap with the lower range of those estimates (0.0115 animals/km^2 [0.0048 – 0.0275]). Kelly et al. (2009) conducted aerial surveys of minke whales in the Eastern Antarctic and arrived at densities of 0.02 animals /km^2, which is similar to the results of the present study as well.

Densities determined in this project are based on an underlying area determined empirically from the collected data. They reflect animal densities for the areas covered, which are adjusted for effort and probability of detection. Therefore, they present a more robust evidence base than encounter rates, which are lacking correction of area and of probability of detection unknown in advance and probably influenced by covariates. They are also more reliable than data from strip transect surveys based on a predetermined area which, consequently, do not take probability of detection into consideration (see, for example, Ainley at al. 2007). As in estimates based solely on encounter rates or strip transects, densities determined in this project are limited to the area actually searched (i.e. local density). To determine densities and related abundances for a defined research area, either a predetermined survey must be conducted, covering the corresponding area throughout with transect lines in a representative manner, or modelling procedures be used (e.g. Forney 1995, Hedley & Buckland 2004).

Furthermore, the determined densities and abundances should be considered minimum estimates because no correction could be applied for (a) diving animals which are “not available” (so-called availability bias, Marsh & Sinclair 1989) and (b) animals on the transect line overlooked by the observer (so-called perception bias) (cf. Buckland et al. 2001), and it should be assumed that g(0) is <1 (cf. Chapter 2.1.1.1). A g(0) correction is possible only if surveys are conducted using redundant platforms, i.e. the same observation section is searched independently by two observers. This requires two consecutively arranged observation platforms, visually and acoustically separated from each other, (in helicopter surveys, for example, two seat rows or one helicopter flying behind another) to determine the percentage of animals overlooked. Logistically, this was not possible during the surveys conducted. In spite of these limitations, the densities determined in the course of this project serve as a reliable measure to compare the occurrence of cetaceans between strata. The estimated values for the WAP stratum can be assumed as robust minimum abundances.

Analysis of the tracking data provided initial indications that the vessel as observation platform exerts influence on sighting rates and that the number of observed animals is likely not independent of the vessel’s presence. Different species reacted differently so that no general conclusion about the vessel’s effect can be drawn. In the case of humpback whales there seems to be a tendency among animals to approach the vessel, leading to a higher sighting rate and thus to an overestimation of density. As regards minke whales, no clear behavioural pattern was discernible, neither an approach to the vessel nor avoidance in reaction to the vessel. However, the sample size for minke whales during tracking was very small. Ainley et al. (2007) described flight behaviour of minke whales in open waters with little ice cover vis-à-vis the vessel, based on the observers’ impressions. However, in deeper pack ice they observed that this reaction of the animals was absent. The small sample size unfortunately did not permit separate analysis of observations in areas with different ice cover. This correlation to ice cover may, however, lead to the ambiguous results regarding minke whale behaviour. A more thorough investigation of this connection in the future is desirable, though tracking is very difficult under heavy ice conditions. It is doubtful that a representative analysis of minke whale behaviour in all types of ice cover is even possible by means of tracking.

3.1.5 Summary

Helicopter and crow's nest surveys according to the line-transect distance sampling method were used to determine local cetacean densities for five different strata in Antarctic waters. In addition to local densities for large whales as a group (sperm whales, unidentified large whales as well as all baleen whales except minke whales), species-specific densities could be estimated for humpback, fin and Antarctic minke whales. High densities of large whales were encountered on the western side of the Antarctic Peninsula (WAP stratum) and in the Antarctic Sound (AAS stratum). Minke whales were observed at higher densities in the Weddell Sea (WS stratum). On the western side of the Antarctic Peninsula (WAP stratum), a representative coverage of a partial area achieved with helicopter surveys allowed the estimation of minimum abundances for the three above-mentioned species. Abundances for this 322,303 km^2 large area were determined to be 3,960 [95% confidence interval: 2,396 – 6,523] for humpback whales, 200 [33 – 1,065] for fin whales, and 3,228 [832 – 12,280] for minke whales.

Tracking observations yielded initial insight into the behaviour of humpback and minke whales vis-à-vis the RV Polarstern: Humpback whales displayed a tendency to approach the vessel, while the behaviour of minke whales appeared to be more erratic, and an unambiguous direction of movement could not be identified. Behavioural reactions of the animals towards the vessel violate a central assumption (no responsive movement) of line-transect distance sampling (Buckland et al. 2001) and can lead to over- or underestimation of densities. This may be one explanation, in addition to different survey speeds during the helicopter and crow's nest surveys, of the observed differences in density.

3.2 Comparison of different observation methods

3.2.1 Crow's nest vs. helicopter

Crow's nest and helicopter surveys were conducted according to the line-transect distance sampling method and arrived at different results regarding encounter rates and densities for individual cetacean species (Table 6 - Table 8, and Table 14 - Table 17). Overall, crow's nest surveys yielded higher values than helicopter surveys. They do, however, also show higher standard errors. Dawson et al. (2008) noted higher encounter rates in ship-board surveys compared to aerial surveys. Due to the much slower travel speed during ship-board surveys compared to aerial surveys, whales have more time to surface in the field of observation and be noticed by observers (Dawson et al. 2008, Kelly et al. 2012). Consequently, more whales are recorded in a section searched at comparatively slower speeds during ship-board surveys than during aerial surveys. Thus, ship-board surveys achieve higher encounter rates. Encounter rates, however, do not take the searched area into consideration, they refer only to the section searched (in kilometres) irrespective of strip width and prevailing sighting conditions. It may be possible that a considerably higher sighting number also refers to a considerably larger strip width covered, and the determined densities may in fact be much more similar. The analyses of distance sampling resulted in different effective strip widths (*esw*) for large whales depending on the survey method. Helicopter surveys covered a smaller strip of 818 m, while the *esw* in crow's nest surveys was 1,031 m. Overall, the density estimates are associated with relatively wide confidence intervals. To compare two densities for statistically significant differences in the context of the distance sampling method, comparison using a z-test is recommended (Buckland et al. 2001). The z-test, using the confidence intervals of two values, verifies the hypothesis of whether or not they originate in the same underlying set and thus differ statistically. To perform the test it was assumed that the densities derived from both helicopter and crow's nest surveys were nearly normally distributed and sample size sufficient (Buckland et al. 2001). This led to the results of two-sided z-tests shown in Table 24 through Table 27.

Table 24: Results of the two-sided test with 5% significance level for large whale encounter rates per stratum based on helicopter and crow's nest sightings. Asterisks indicate significance level (*** = 0.001, ** = 0.01, * = 0.05, .= 0.1).

Stratum	Ship		Helicopter		Test statistic		
	Encounter rate [sight./km]	Encounter $rate_{SE}$	Encounter rate [sight./km]	Encounter $rate_{SE}$	z-score	p-value	Significance
SA	0.0135	0.0079	0.0077	0.0019	0.7138	0.4753	
NM	0.0018	0.0012	0	0	1.5	0.1336	
WS	0.0210	0.0211	0	0	0.9953	0.3196	
AAS	0.1566	0.0134	0.0084	0.0080	9.4961	0	***
WAP	0.0752	0.0377	0.0116	0.0021	1.6844	0.0921	.

Table 25: Results of the two-sided test with 5% significance level for minke whale encounter rates per stratum based on helicopter and crow's nest sightings. Asterisks indicate significance level (*** = 0.001, ** = 0.01, * = 0.05, .= 0.1).

Stratum	Ship		Helicopter		Test statistic		
	Encounter rate [sight./km]	Encounter $rate_{SE}$	Encounter rate [sight./km]	Encounter $rate_{SE}$	z-score	p-value	Significance
SA	0.0059	0.0049	0.0006	0.0003	1.0796	0.2803	
NM	0.0140	0.0032	0.0030	0.0007	3.3581	0.0008	***
WS	0.0158	0.0089	0.0053	0.0015	1.1634	0.2447	
AAS	0.0261	0.0079	0.0084	0.0092	1.4596	0.1444	
WAP	0	0	0.0017	0.0006	-2.8333	0.0046	**

Table 26: Results of the two-sided test with 5% significance level for large whale densities per stratum based on helicopter and crow's nest sightings. Asterisks indicate significance level (*** = 0.001, ** = 0.01, * = 0.05, .= 0.1).

Stratum	Ship		Helicopter		Test statistic		
	Density [Ind./km²]	$Density_{SE}$	Density [Ind./km²]	$Density_{SE}$	z-score	p-value	Significance
SA	0.0225	0.0122	0.0134	0.0044	0.7017	0.4829	
NM	0.0009	0.0006	0	0	1.5	0.1336	
WS	0.0102	0.0103	0	0	0.9903	0.3220	
AAS	0.1519	0.0311	0.0103	0.0098	4.3426	<0.0001	***
WAP	0.0496	0.0248	0.0149	0.0035	1.3855	0.1659	

Table 27: Results of the two sided test with 5% significance level for minke whale densities per stratum based on helicopter and crow's nest sightings. Asterisks indicate significance level (*** = 0.001, ** = 0.01, * = 0.05, .= 0.1).

Stratum	Ship		Helicopter		Test statistic		
	Density [Ind./km²]	$Density_{SE}$	Density [Ind./km²]	$Density_{SE}$	z-score	p-value	Significance
SA	0.0063	0.0053	0.0007	0.0005	1.0519	0.2928	
NM	0.0197	0.0069	0.0029	0.0012	2.3988	0.0164	*
WS	0.0281	0.0192	0.0115	0.0053	0.8334	0.4046	
AAS	0.0559	0.0182	0.0265	0.0294	0.8503	0.3952	
WAP	0	0	0.0097	0.0073	-1.3288	0.1839	

Significant differences between encounter rates determined through the different methods were revealed for large whales in the AAS and WAP strata, and for minke whales in the NM and WAP strata. Significant differences between densities determined through the different methods existed for large whales only in the AAS stratum and for minke whales in the NM stratum.

These results show that encounter rates determined through different methods differ from each other statistically only in a few cases, and the densities determined can be separated statistically only in isolated cases. The discussed advantage of higher encounter rates in ship-board surveys compared to aerial surveys is thus relegated to a position of less concern.

At the same time, helicopter surveys provide the advantage over crow's nest surveys that a much larger distance can be covered in the same time and, despite the lower encounter rate, a large number of sightings can be achieved faster. In an effort of 161 h over 2,885 km the crow's nest surveys recorded 105 sightings, or 0.65 sightings per hour of effort. The helicopter survey, in contrast, recorded 268 sightings in an effort of 232 h over 28,273 km, or 1.16 sightings per hour of effort. Because the analysis of distance sampling data requires a minimum number of sightings, maximising the number of sightings, particularly near the transect line, is important. The encounter rate is of secondary importance.

The previously mentioned influence observers may be exerting on whales - in the present case avoidance or approaching of the vessel by whales – may be playing a significant role in the qualitative differences between the two survey methods. It should be assumed that due to the high travel speed during helicopter surveys no impairment of observed densities, resulting from the mentioned effects such as avoidance or approaching, occurs, while the influence of this effect, which is difficult to measure, may be more significant in crow's nest surveys, as the tracking observations indicate.

Meaningful cetacean surveys can be conducted only under favourable weather conditions because probability of detection is strongly diminished in inclement weather, and the power of data (i.e. reliability of the results) thus considerably reduced. Extreme and changeable weather conditions prevail in the Antarctic, sometimes providing only short breaks for cetacean surveys. Aerial surveys enable more effective use of these short windows of opportunity (in respect of coverage and distance travelled, as well as number of sightings) than crow's nest surveys, which are restricted to the location of the vessel.

The closing mode during helicopter surveys ensures the quality of species identification, especially in cases of more distant sightings or species which are difficult to identify, such as beaked whales. This is reflected in sightings of 14 different species in helicopter surveys, compared to 8 different species in crow's nest surveys. 21% of crow's nest sightings were not identified (22 of 105 sightings), 16.8% of helicopter sightings (45 of 268) were not identified at the species level.

Helicopter surveys also allow a survey design independent of the vessel's direction of travel, compared to crow's nest surveys on-board the vessel. For example, a stay in the WAP stratum was used to develop and execute a systematic survey with representative coverage of the area. Thus, abundances could be determined for an area 322,303 km² in size. Only a survey design with sufficient coverage of a given area can generate reliable figures on a species' abundance. This was never possible during crow's nest surveys because they were confined to the vessel's course.

Results of the helicopter surveys distinguish themselves, compared to results from crow's nest surveys with comparable densities and encounter rates, by smaller coefficients of variation (than the crow's nest survey results); there were a few exceptions, mostly in the AAS stratum. Coefficients of variation constitute an important criterion for planning future surveys and for analysis of temporal trends (see Buckland et al. 2001). Statistical significance of the z-test (typically used in the context of distance sampling) for comparison of density values and encounter rates (such as shown above) is closely coupled to the associated coefficient of variation (Wade & DeMaster 1999, Plumptre 2000). Small coefficients of variation thus allow increasing the requirements of a statistic test (such as a z-test) so that a coincidental significant difference between two values becomes highly improbable. The smaller the coefficient of variation, the higher the significance of the results from statistic tests to compare two values. Therefore, the coefficient of variation should be as low as possible to determine differences between results with any statistical significance. When analysing the distance travelled and the resulting coefficient of variation of the encounter rates from helicopter and crow's nest surveys in each stratum, the high efficiency of helicopter surveys is impressive (as illustrated for minke whales in Figure 25 and Figure 26). The relatively high effort achieved with helicopter surveys led to low coefficients of variation, while differences between strata are relatively evenly distributed (Figure 25). In contrast, the coefficients of variation calculated for minke whale encounter rates in crow's nest surveys (Figure 26) show more significant differences between strata with considerably lower effort. Based on the assumption of Buckland et al. (2001), it is possible to determine the likely coefficient of variation of a subsequent study using a previous study if the coefficient of variation and the associated effort are known (formula 3, see Buckland et al. 2001, p. 241).

$$(3) VK_{erw} = VK_{vorh} \cdot \sqrt{\left(\frac{L_{vorh}}{L_{erw}}\right)}$$

with VK_{erw} = expected coefficient of variation, VK_{vorh} = previous coefficient of variation, L_{erw} = expected (planned) effort, and L_{vorh} = previous (realised) effort.

Figure 25 and Figure 26 show graphs of the expected coefficient of variation for each stratum. The diagrams indicate the effort necessary to achieve the minimum coefficient of variation for a surveyed species. Examples of the lowest coefficients of variation actually achieved for each species are shown in the figures as a green line. It becomes obvious that an enormous increase in effort would be necessary for crow's nest surveys to achieve a small improvement in the coefficient of variation (Figure 25 and Figure 26). Helicopter surveys are already in the flat part of the graph with the effort achieved during ANT25-2 and ANT27-2 expeditions of RV Polarstern; they reached an area of comparably low coefficients of variation. With an average coverage of 121.9 km/h during helicopter surveys, an improvement of the coefficient of variation through increased effort could be achieved much more efficiently compared to a coverage of only 17.9 km/h in crow's nest surveys.

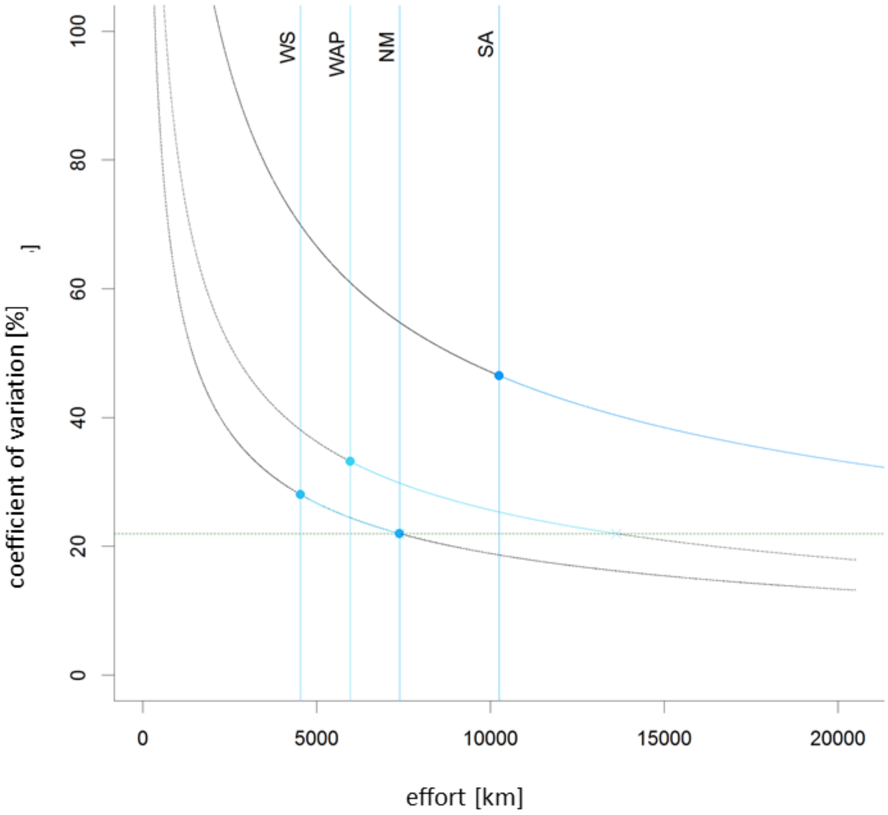

Figure 25: Extrapolation of the coefficient of variation for encounter rates in minke whale surveys based on helicopter surveys per stratum; coloured dots mark the measured value in each stratum, the graph indicates the extrapolation of the coefficient of variation; the horizonal green (dotted) line marks the lowest coefficient of variation actually achieved; consequently, to achieve a coefficient of variation of 21.97 actually measured in the NM stratum, an increase in effort in the WS stratum by approximately 2,500 km would be necessary.

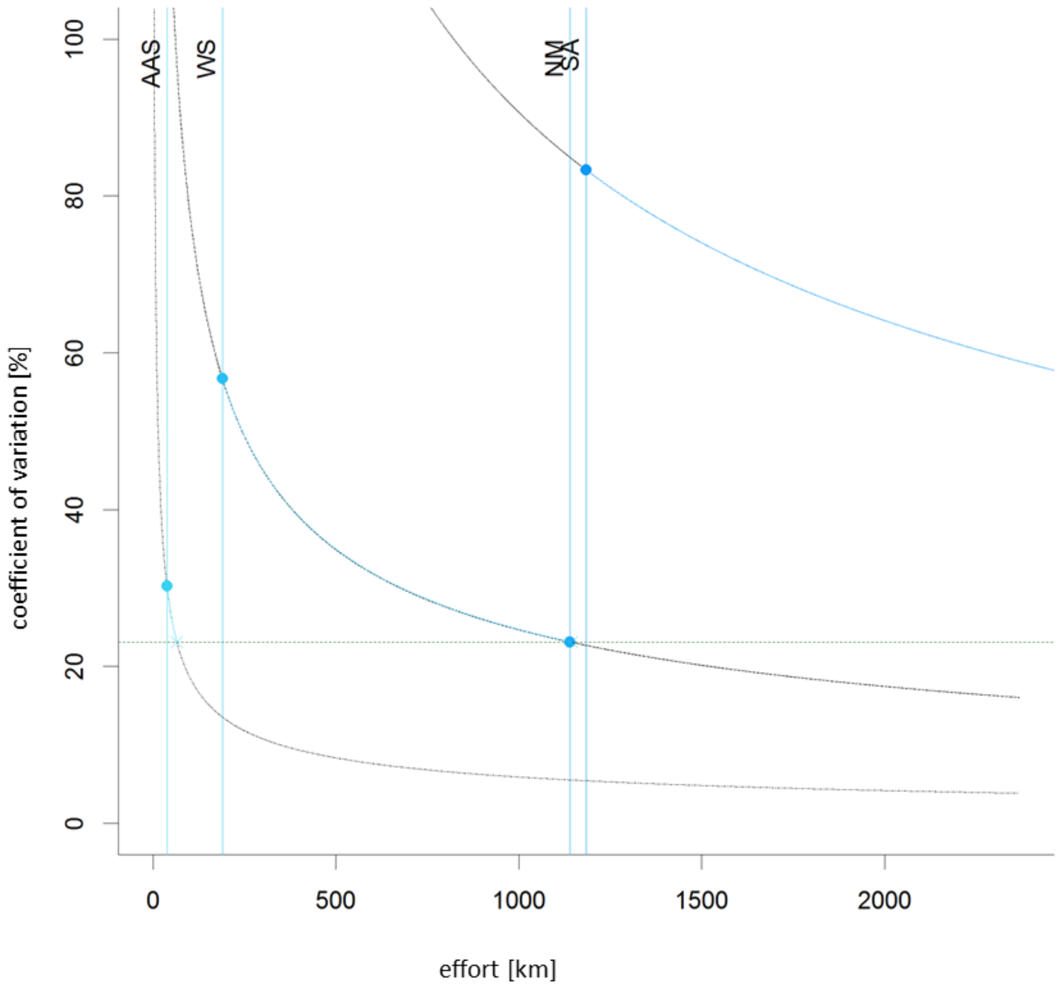

Figure 26: Extrapolation of the coefficient of variation for encounter rates in minke whale surveys based on crow's nest surveys per stratum; coloured dots mark the measured value in each stratum, the graph indicates the extrapolation of the coefficient of variation; the green line marks the lowest coefficient of variation actually achieved; consequently, to achieve a coefficient of variation of 23.10 actually measured in the NM stratum, an increase in effort in the WS stratum by approximately 800 km would be necessary.

3.2.2 Crow's nest vs. WALOG

Sightings during crow's nest surveys and sightings of bridge personnel (WALOG sightings) were compared to determine if a team of trained whale observers arrives at a different sighting figure when conducting focused cetacean surveys. It can be assumed that nautical personnel, due other unrelated obligations, spend less time on intensive whale observations than a dedicated whale observation team. A statistical analysis was used to determine the percentage of sightings recorded in a focused cetacean survey that is also recorded by nautical officers and, conversely, whether sightings by nautical officers were missed by the observation team.

A bidirectional comparison of recorded sightings was used for this analysis. By comparing crow's nest sightings with bridge sightings as sighting parameter, and vice versa, it was possible to determine the success rate of the respective observation method. A binomial test was used to determine the success rate of each observation method based on the assumption that the alternative method predetermines the number of sightings to be achieved. Data sets were limited to overlapping survey periods within a time buffer of ± 30 minutes by the observation period predetermined by the focused cetacean survey (crow's nest survey) because bridge personnel was assumed to be "on effort" per definition. Each sighting was manually compared with those of the alternative method within the time interval predetermined by sighting time to verify or falsify matching sightings recorded by both observation methods. A minor temporal difference between the predetermined sighting and at least one sighting of the alternative method, as well as the temporally isolated grouping of a sighting with a compatible sighting of the alternative method, were considered strong criteria for matching sightings. An additional weak criterion for a possible match was the recorded species, grouped as large whales (humpback, sei, fin, sperm, and unidentified large whales), medium-size whales (minke, killer, and southern bottleneck whales), and small whales (hourglass dolphins and unidentified small whales) to counter possible identification errors at the species level. An additional comparison was performed at the species level for minke whales and humpback whales. A further weak criterion for assessment of a sighting match was group size, which is, however, dependent on diving behaviour of individual group members and thus can vary more over time than species identification; it is thus a less suitable criterion.

The results showed that crow's nest observations recorded an average 64.10% [95% confidence interval: 47.18% - 78.80%] of all bridge sightings (Table 10), while bridge personnel discovered only 22.45% [15.98% - 30.06%] of all crow's nest sightings (Table 11). The results did not differ significantly between cetacean groups and species. The strongest match between both survey methods was for large whales, particularly humpback whales. The 100% match for minke whales with bridge observations as the predetermined value is based on one single sighting.

Table 28: Results of a binomial test to determine the success rate of each observation method. The results are shown based on bridge sightings also observed from the crow's nest. Cetacean species were additionally analysed in groups to counter possible identification errors and to analyse individual cetacean species with sufficient sample size in more detail. Large whales: humpback, sei, fin, sperm, and unknown large whale; medium-size whales: minke, killer, and southern bottlenose whale; small whales: hourglas dolphin and unknown small whale. Minke whales include *B. bonaerensis* and *B. acutorostrata*, CI = 95% confidence interval.

Group	Success rate	CI	Matches	Reference values	Reference
Large whales	69.23%	48.21%- 85.67%	18	26	Bridge
Medium-size whales	55.56%	21.2%- 86.3%	5	9	Bridge
Small whales	50.00%	6.76%- 93.24%	2	4	Bridge
Humpback whales	65.00%	40.78%- 84.61%	13	20	Bridge
Minke whales	100.00%	2.5%- 100%	1	1	Bridge
Other whales	61.11%	35.75%- 82.7%	11	18	Bridge
Total	**64.10%**	**47.18%- 78.8%**	**25**	**39**	**Bridge**

Table 29: Results of a binomial test to determine the success rate of each observation method. The results are shown based on crow's nest sightings also observed from the bridge. Cetacean species were additionally analysed in groups to counter possible identification errors and to analyse individual cetacean species with sufficient sample size in more detail. Large whales: humpback, sei, fin, sperm, and unknown large whale; medium-size whales: minke, killer, and southern bottlenose whale; small whales: hourglas dolphin and unknown small whale. Minke whales include *B. bonaerensis* and *B. acutorostrata*, CI = 95% confidence interval.

Group	Success rate	CI	Matches	Reference values	Reference
Large whales	27.27%	18.32%- 37.81%	24	88	Crow's nest
Medium-size whales	15.79%	7.48%- 27.87%	9	57	Crow's nest
Small whales	0%	0%- 84.19%	0	2	Crow's nest
Humpback whales	27.78%	16.46%- 41.64%	15	54	Crow's nest
Minke whales	20.93%	10.04%- 36.04%	9	43	Crow's nest
Other whales	18.00%	08.58%- 31.44%	9	50	Crow's nest
Total	**22.45%**	**15.98%- 30.06%**	**33**	**147**	**Crow's nest**

To assess which percentage each of the two methods contributed to the total of all sightings recorded during the same time period, any duplicates (i.e. sightings recorded by both methods) were removed from the data set. The remaining quantity of sightings recorded only once was assumed as 100% of available sightings, and the percentage attributable to each method was determined (Table 30 and Table 31). This process revealed a significant difference in the number of recorded sightings between dedicated whale observers and bridge personnel within the same observation period (Table 30). In all cetacean groups observers in the crow's nest contributed the largest percentage to the total of sightings. This is particularly striking for the groups of large whales and medium-size whales. Here, the percentage of crow's nest sightings is 88.89% [79.28% – 95.08%] of all large whale sightings and 92.31% [84.46% - 97.86%] of medium-size whale sightings. For comparison, the bridge personnel contributed 11.11% [4.92% - 20.72%] and 7.69% [2.14% - 18.54%] of the respective sightings (Table 31).

Table 30: Sightings recorded by only one method (bridge or crow's nest) within the same observation period. Any sightings recorded with both methods (duplicates) are omitted. Cetacean species were additionally analysed in groups to counter possible identification errors and to analyse individual cetacean species with sufficient sample size in more detail. Large whales: humpback, sei, fin, sperm, and unknown large whale; medium-size whales: minke, killer, and southern bottlenose whale; small whales: hourglas dolphin and unknown small whale. Minke whales include *B. bonaerensis* and *B. acutorostrata*.

Group	Bridge sightings	Crow's nest sighting	Total
Large whales	8	64	72
Medium-size whales	4	48	52
Small whales	2	2	4
Humpback whales	7	39	46
Minke whales	0	34	34
Other whales	7	41	48
Total	**14**	**114**	**128**

Table 31: Results of a binomial test to determine the success rate of each observation methods based on total sightings, each of which was recorded by only one method (bridge or crow's nest) within the same observation period. Any sightings recorded with both methods (duplicates) are omitted. Cetacean species were additionally analysed in groups to counter possible identification errors and to analyse individual cetacean species with sufficient sample size in more detail. Large whales: humpback, sei, fin, sperm, and unknown large whale; medium-size whales: minke, killer, and southern bottlenose whale; small whales: hourglas dolphin and unknown small whale. Minke whales include *B. bonaerensis* and *B. acutorostrata*. Percentage$_{Bridge}$: percentage of total sightings from bridge sightings; Percentage$_{Crow's\ nest}$: percentage of total sightings from crow's nest sightings; CI = 95% confidence interval of the respective method.

Group	Percentage$_{Bridge}$	CI$_{Bridge}$	Percentage$_{Crow's\ nest}$	CI$_{Crow's\ nest}$
Large whales	11.11%	4.92%- 20.72%	88.89%	79.28%- 95.08%
Medium-size whales	7.69%	2.14%- 18.54%	92.31%	81.46%- 97.86%
Small whales	50%	6.76%- 93.24%	50%	6.76%- 93.24%
Humpback whales	15.22%	6.34%- 28.87%	84.78%	71.13%- 93.66%
Minke whales	0%	0%- 10.28%	100%	89.72%- 100%
Other whales	14.58%	6.07%- 27.76%	85.42%	72.24%- 93.93%
Total	**10.94%**	**6.11%- 17.67%**	**89.06%**	**82.33%- 93.89%**

The viewer of the results should take into account that the effort of bridge personnel, when compared to the crow's nest, is heterogeneous. Nautical personnel on the bridge are often joined by other persons, sometimes even bird observers, who purposely search the ocean surface. These individuals can alert nautical personnel to sightings and contribute to species identification. At other times, a nautical officer may be working alone and must tend to other tasks beside focused observation of whales. WALOG data thus do not allow control of effort. The probability of detection of whales in the vicinity of the vessel is likely to be significantly dependent on the number of persons present on the bridge as well as their primary occupation at a given moment. Additionally, bridge personnel presumably have comparatively little control over possible re-sightings. A whale observer can ensure that a sighting is not recorded in duplicate if he or she observes continuously. It is thus possible that repeat sightings of the same animal were registered among the WALOG sightings, which were correctly identified as such by crow's nest observers and recorded only once. Additionally, WALOG data were selected with a time buffer of 30 minutes around the observation times in the crow's nest and thus cover a longer observation period than the crow's nest data. Bridge sightings may therefore include sightings from the one-hour buffer around crow's nest observation time that were not available to crow's nest observers if the whale remained in the vessel's vicinity only briefly. This implies an even higher success rate of the crow's nest sightings than the rate determined. These results solely serve as a benchmark for qualitative assessment of the effectiveness of the two methods compared.

3.2.3 Crow's nest vs. IR

In a concurrent research project conducted by AWI, an infrared (IR) camera capable of detecting the thermic signature of whale blows was tested (cf. Zitterbart et al. 2013). The camera's ability to detect all or at least a large number of all cetaceans present, but at a minimum those detected by focused cetacean observations, must be established before it can be deployed for mitigation purposes such as during seismic investigations. To assess their accuracy, IR camera detections were compared to those in crow's nest surveys recorded during the same time periods. The IR camera was not yet in use during the ANT25-2 expedition. Therefore, data from the ANT27-2 expedition were supplemented by sighting data from a crow's nest survey conducted by ITAW during a subsequent expedition (ANT28-2 (2011/2012)) when the camera was deployed.

To compare crow's nest and IR camera detection data, only data sets originating from corresponding effort periods (including a 30 minute buffer) were used, i.e. only those data were considered which had been collected while both methods were deployed concurrently, buffered by 30 minutes before and after each unit of effort. The success rate of the IR camera was compared directly to successful detections by the crow's nest observers: For each crow's nest sighting it was determined whether the corresponding animal or animal group was represented in the IR camera's data set with at least one blow detection. Due to the unspecific detection of each individual blow by the IR camera (and, consequently, a large number of detections associated with an individual or single group) and the lack of information about group size and species, assessing whether each camera detection corresponds to an observer detection would not make sense. Observers record each animal only once when it is first noticed, while the IR camera records multiple sightings of the same animal by default. A two-sided comparison, such as for crow's nest vs. WALOG data, will not be possible until camera detection can be aggregated and compiled by individual.

To analyse for matches between IR camera detections and crow's nest sightings, the exact positions of all recorded events were first calculated. Both the IR database and the crow's nest database add only the vessel's position to each sighting or detection record. This position is, of course different from the animal's exact location. However, in both visual surveys and IR camera detections the horizontal angle between the vessel and sighting as well as the radial distance are recorded. The Haversine formula (4) is used to determine the spatial components of a sighting or detection. Thus, the exact position of a sighting with known distance from and angle to the vessel can be calculated.

$$(4)\begin{pmatrix}\varphi_2\\ \lambda_2\end{pmatrix} = \begin{pmatrix} asin\left(sin(\varphi_1)\cdot cos\left(\frac{d}{R_E}\right) + cos(\varphi_1)\cdot sin\left(\frac{d}{R_E}\right)\cdot cos(\delta)\right) \\ \lambda_1 + atan2\left(cos\left(\frac{d}{R_E}\right) - sin(\varphi_1)\cdot sin(\varphi_2), sin(\delta)\cdot sin\left(\frac{d}{R_E}\right)\cdot cos(\varphi_1)\right)\end{pmatrix}$$

φ_1 represents the longitude of the vessel's position, φ_2 the sighting's longitude to be calculated, λ_1 the vessel's latitude to be calculated, λ_2 the sighting's latitude to be calculated, δ the horizontal angle of the sighting relative to the vessel's direction of travel, d the radial distance to the sighting, and R_E the mean radius of Earth (here assumed to be 6,371 km). All angles are given in radians. *atan2* is defined in (5).

$$(5)\ atan2(y,x) := \begin{cases} arctan\left(\frac{y}{x}\right) & x > 0 \\ arctan\left(\frac{y}{x}\right) + \pi & y \geq 0, x < 0 \\ arctan\left(\frac{y}{x}\right) - \pi & y < 0, x < 0 \\ +\frac{\pi}{2} & y > 0, x = 0 \\ -\frac{\pi}{2} & y < 0, x = 0 \\ nicht\ definiert & y = 0, x = 0 \end{cases}$$

The available distances, the horizontal angle to the vessel's axis, and the vessel's position at the time of the sighting were used to determine the animals' positions at the time of sighting or detection. Because both the measured distance and the measured angle are associated with an individual error, the probability of the animals being present in the vicinity of the determined position was also calculated. The distal probability was determined by increasing or decreasing the distance in sighting direction by the error of distance measuring. The lateral component of probability resulted from the width of the measured angle to the sighting ± of the error of the specified angle. Due to a lack of precise angle error and in consideration of the qualitative character of the sightings' representation, the angle was set at ± 5°.

The convex hull of the calculated points of probability was then used to calculate a polygon representing the actual position of an observation with a 95% probability (see shaded areas in Figure 27 and Figure 28). To validate the IR camera's detections through visual observations from the crow's nest, each crow's nest sighting was represented along with all IR camera detections within a 60 minute window around the sighting (for examples see Figure 27 and Figure 28). Any possible matches between an IR camera detection and an observer sighting identified through this process were subsequently manually reviewed for overlap and proximity of the probabilities and general plausibility, and finally verified or falsified as matched sighting (Table 32). A total of 53 crow's nest sightings from concurrent observation periods of both methods were available and used for this review. For 22 of these sightings IR detections could be verified as described above (Table 33).

A success rate for IR camera detections was determined from the quantity of matches between IR camera detections and the total of observer detections using a binomial test (Table 33).

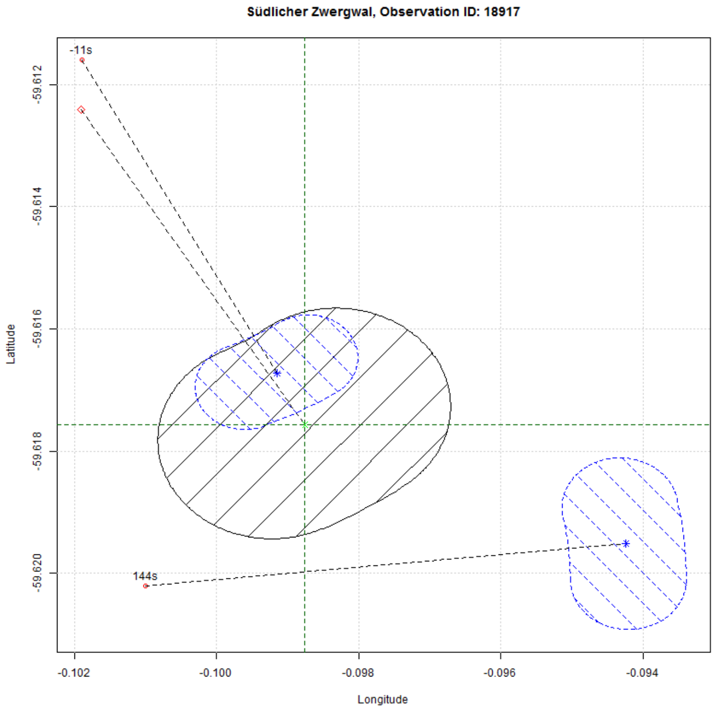

Figure 27: Example of a clear match between a crow’s nest sighting and an IR camera detection within the related 60 minute interval. The vessel’s position at the time of the crow’s nest sighting and IR camera detection is marked in red. The dotted lines indicate direction and distance of the sighting (green cross) or IR detection (blue asterisk). The ship icon at the time of the crow's nest sighting indicates the species, which, in this case, is a southern minke whale (red rhombus). The shaded areas of probability around the sighting and detection positions are dependent on the error of distance measurement as well as the error of angle measurement. The relative time difference between IR detection and crow’s nest sighting is indicated in seconds above the vessel’s position. In this example it was possible to clearly associate an IR detection recorded 11 s earlier to a crow’s nest sighting.

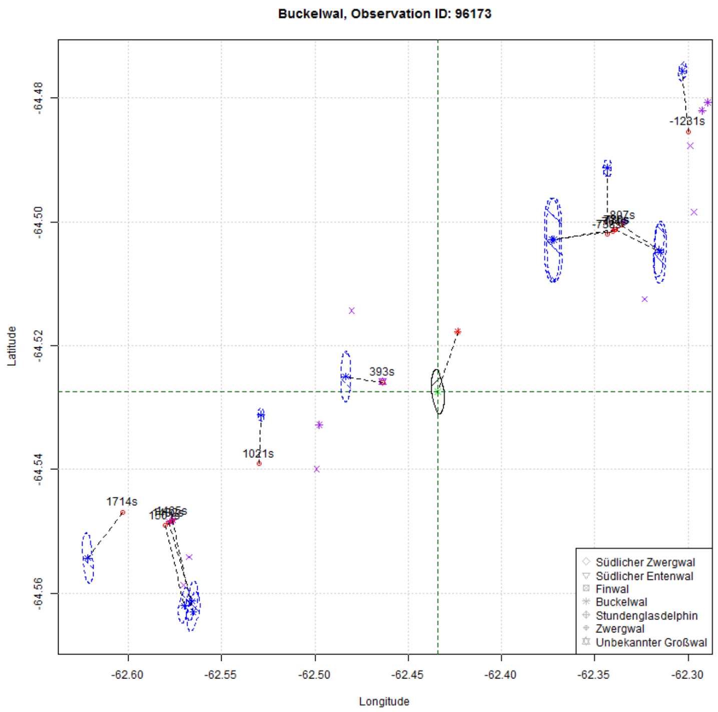

Figure 28: Example of a failed match between a crow's nest sighting and all IR camera detections within the related 60 minute interval. The vessel's position at the time of the crow's nest sighting and IR camera detection is marked in red. The dotted lines indicate direction and distance of the sighting (green cross) or IR detection (blue asterisk). Additional crow's nest sightings during this time period are represented in violet. The ship icon at the time of the crow's nest sighting indicates the observed species according to the legend. The shaded areas of probability around the sighting and detection positions are dependent on the error of distance measurement as well as the error of angle measurement. The relative time difference between IR detection and crow's nest sighting is indicated in seconds above the vessel's position. An IR detection could not be associated with any crow's nest sighting in this example.

Table 32: Extraction of the first 28 of 53 results of manual analysis of the graphic representation of IR detections. ID = unambiguous identification number of crow's nest sighting; unixtime = time of crow's nest sighting in seconds since 01/01/1970 00:00:00 UTC; survey = trip; group size = group size observed from the crow's nest; distance [m] = distance to the sighting in meters; sighting angle = angle of the sighting relative to the vessel's direction of travel; vessel direction = vessel's direction of travel; match = assessment of a match between IR camera detection and crow's nest sighting; negative = not detected by the IR camera; probable = probably detected by the IR camera; positive = detected by the IR camera.

ID	unixtime	Survey	Latitude	Longitude	Species	Group size	Distance [m]	Sighting angle	Vessel direction	Match
15396	1291700000	ANTXXVII2	-50.8703	0.6774	South. bottlenose whale	2	300	345	206.2	Negative
18917	1323767684	ANTXXVIII2	-59.6124	-0.1019	Ant. minke whale	2	600	346	176.8	Positive
21428	1323779051	ANTXXVIII2	-60.0558	-0.0986	Unid. large whale	1	500	320	64.6	Probable
21820	1323780745	ANTXXVIII2	-60.1126	-0.0790	Unid. large whale	1	100	30	207.1	Probable
26917	1292221384	ANTXXVII2	-61.2929	0.0010	Ant. minke whale	1	400	350	179.7	Negative
30336	1324019947	ANTXXVIII2	-67.3576	-2.1689	Ant. minke whale	1	1100	300	223.4	Positive
31977	1324044363	ANTXXVIII2	-68.1431	-3.1069	Unid. large whale	1	1500	5	0	Negative
33268	1292440448	ANTXXVII2	-64.4158	-0.0178	Ant. minke whale	1	500	340	174.6	Probable
35698	1292503858	ANTXXVII2	-65.8105	0.0593	Unid. large whale	1	1000	355	171.9	Negative
39125	1324715743	ANTXXVIII2	-68.9533	-0.1407	Ant. minke whale	1	150	345	308.3	Positive
39716	1324722196	ANTXXVIII2	-68.7215	-0.2649	Ant. minke whale	1	850	90	352.6	Negative
40120	1325082128	ANTXXVIII2	0	0	Unid. large whale	1	800	60	0	Negative
40356	1325084648	ANTXXVIII2	-58.4650	0.0051	Ant. minke whale	1	100	5	333.2	Positive
40689	1292666911	ANTXXVII2	-67.9431	-0.0010	Unid. large whale	1	350	290	179.5	Negative
43241	1292764757	ANTXXVII2	-69.2849	-1.5742	Ant. minke whale	1	300	75	232.6	Negative
43774	1292774204	ANTXXVII2	-69.5442	-2.5770	Ant. minke whale	1	600	20	218.8	Negative
56756	1293375068	ANTXXVII2	-69.5785	-15.9715	Ant. minke whale	1	200	295	316.9	Positive
63099	1293600444	ANTXXVII2	-66.8260	-26.0767	Unid. large whale	1	1000	330	296.8	Negative
63262	1293601098	ANTXXVII2	-66.8108	-26.1530	Unid. large whale	1	500	45	297.1	Negative
63351	1293601463	ANTXXVII2	-66.8021	-26.1949	Unid. large whale	1	100	170	296.4	Negative
63396	1293601643	ANTXXVII2	-66.7981	-26.2159	Unid. large whale	1	400	300	295.5	Negative
66358	1293718657	ANTXXVII2	-66.1232	-31.7272	Ant. minke whale	1	120	350	284.0	Negative
81815	1294478358	ANTXXVII2	-63.6772	-55.4741	Humpback whale	2	500	30	249.5	Probable
81962	1294478953	ANTXXVII2	-63.6891	-55.5287	Ant. minke whale	2	600	35	247.1	Probable
82154	1294479750	ANTXXVII2	-63.7027	-55.5921	Humpback whale	3	250	50	241.6	Positive
83805	1294494663	ANTXXVII2	-63.3901	-56.6771	Unid. large whale	1	800	280	323.6	Probable
93332	1294919678	ANTXXVII2	-64.4174	-63.0242	Humpback whale	1	150	300	142.0	Probable
93369	1294919817	ANTXXVII2	-64.4222	-63.0144	Humpback whale	1	150	80	138.2	Positive

Results of the binomial test show clearly that the IR camera detected an average 41.51% of all aggregated cetacean species [95% confidence interval: 28.14% - 55.87%] observed in crow's nest sightings when the best-case scenario assumed that all doubtful (i.e. 'probable') detections are attributed to positive detections (Table 33). Because crow's nest sightings always include species identification, it was possible to determine the success rate for different whale groups. Due to small sample size, this analysis was possible only for humpback whales, unidentified whales and a group comprised of all remaining cetacean species detected from the crow's nest.

Table 33: Results of the binomial test to determine the IR camera's success rate. The results are shown in relation to crow's nest sightings; CI = 95% confidence interval.

Group	Success rate	CI	Detections	Reference values
Humpback whales	50.00%	28.22% 71.88%	11	22
Unidentified whales	17.65%	3.80% 43.43%	3	17
Other whales	57.14%	28.86% 82.34%	8	14
Total	**41.51%**	**28.14% 55.87%**	**22**	**53**

The analyses indicate that the IR camera generally detected fewer than half of all sightings recorded from the crow's nest. It was, however, not possible to determine how many animals are included in additional IR camera detections that may not have been recorded by observers. As explained above, the available preparation of IR data does not permit such a comparison. Thus, a broad statement that the camera records only half as many sightings as trained cetacean observers cannot be made. Information about the number of animals recorded with the camera but omitted from crow's nest observations is not available to support such a statement. When assessing the camera's success rate, it must also be considered that the determination of sighting and detection positions is closely related to the precision of distance and angle measurements. Particularly in crow's nest sightings, where both measurements are taken manually, there is an increased (human) error potential which is difficult to assess. Larger errors could lead to a smaller number of matches between sightings and detections and thus result in underestimation of the IR camera's success rate. A validation of angle and distance measurements of crow's nest sightings would be required, which was, however, not possible in this project.

3.2.4 Tracking vs. WALOG

A comparison of tracking observations and WALOG data was aimed at determining the percentage of animals which apparently remained in the vessel's observation area longer, were detected by bridge personnel, and with which temporal difference. Only time segments of the tracks reaching from the first to the last sighting were used for this analysis. This approach was based on the assumption that crow's nest observers tracking with powerful Big Eyes and positioned at a considerably higher platform than the bridge were able to detect sightings earlier than bridge personnel. Because the trackers made a concerted effort to follow the observed animals until they had passed the vessel, a sighting from the bridge after the last tracker sighting is rather unlikely. The analysis was limited to the total number of sightings in one track (in contrast to an analysis of each individual tracker sighting). It was therefore not specific as to whether or not the bridge sighting occurred within the track's time interval (between the first and last sighting) (Table 34). A binomial test (19 reference values, 6 successes) resulted in a success rate of 31.58% [95% confidence interval: 12.58% - 56.55%] for bridge sightings compared to tracker sightings. Compared to results from the earlier comparisons of bridge and crow's nest sightings, this value is slightly higher but indistinguishable due to its wide confidence interval. Species was successfully identified 80% of the time (5 of 6 sightings with matching species identification). Track 1 was the only one of the five matches which could not be correctly identified, the bridge personnel had, however, considered it only a possible minke whale. The remaining matches were identified at least as probable matches by nautical personnel. The time gap between an initial tracker sighting and the corresponding bridge sighting are always more than 120 s, which reflects the smaller observation radius of bridge personnel (see also Figure 29). It should be noted that an instance of long tracking increases the bridge personnel's chances disproportionately to also observe an animal (humpback whale tracks 16 – 19, Table 34).

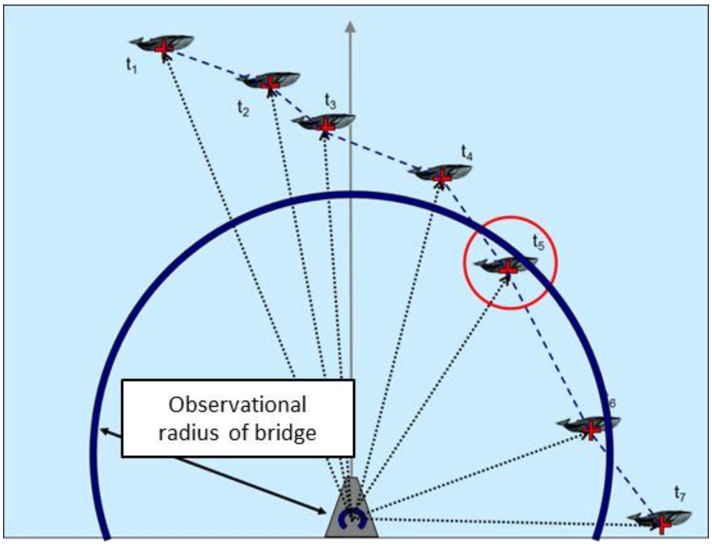

Figure 29: Schematic representation of the comparison between tracker and bridge sightings. WALOG entries are reviewed for the schematically represented track within the time period from first (t_1) to last (t_7) sighting to determine whether a sighting occurred during the same period.

Table 34: Matches between bridge sightings and crow's nest tracker sightings.

ID	Crow's nest		Bridge			
	Species	Group size	Species	Group size	Time difference	Confidence of species identification
1	Sei whale	2	Minke whale	3	407	possible
2	Minke whale	2	not detected	0	0	
3	Minke whale	1	not detected	0	0	
4	Minke whale	2	Minke whale	3	123	definite
5	Minke whale	1	not detected	0	0	
6	Humpback whales	2	not detected	0	0	
7	Humpback whales	2	not detected	0	0	
8	Humpback whales	4	not detected	0	0	
9	Killer whale	5	not detected	0	0	
10	Humpback whales	1	not detected	0	0	
11	Humpback whales	1	not detected	0	0	
12	Humpback whales	1	not detected	0	0	
13	Humpback whales	2	not detected	0	0	
14	Unidentified large whale	1	not detected	0	0	
15	Humpback whales	1	not detected	0	0	
16	Humpback whales	3	Humpback whales	4	448	definite
17	Humpback whales	3	Humpback whales	3	514	definite
18	Humpback whales	3	Humpback whales	3	1124	probable
19	Humpback whales	2	Humpback whales	3	1156	probable

3.2.5 Synopsis of comparison of different sighting methods

A comparison of all observation methods thus analysed shows that each method has a meaningful application for a certain area. Distance sampling surveys are the only option to determine densities that are adjusted for sighting probability and show a true relationship to area. If reliable, comparable density figures are needed, this method must be used. If abundance and density of cetaceans in a certain area should be determined, a representative survey of this area, preferably with a prospective survey design, is also required. The surveys conducted during this project are qualified by the absence of a corrective factor for g(0), i.e. there is no correction of the possibility that a percentage of animals directly in the transect line was not recorded. Without this corrective factor, all estimates are minimum estimates and remain below the actual number of animals. Nonetheless, they represent a robust basis for density comparisons between areas and times, and constitute a reliable measured variable.

When comparing the two observation platforms used, helicopter surveys are the more efficient method because they lead to usable results more quickly with less effort; helicopters can be deployed more flexibly in the changeable weather conditions of the Antarctic. They enable better coverage of an area, have a smaller coefficient of variation than ship-board surveys, and are more efficient for species identification. While they generally achieve a lower encounter rate and density than ship-board surveys, these differences are not statistically significant. A comparison of the sighting methods revealed that densities obtained from aerial and ship-based cetacean surveys varied significantly only in isolated cases.

Ship-board surveys, in contrast, appear to provoke a behavioural reaction of the target species, as revealed by tracking analysis, which violates a basic assumption of distance sampling. Attraction or displacement of animals by the research platform leads to a distortion of results due to over- or underestimation of densities. Still, a dedicated crow's nest survey can achieve meaningful results when these potential errors are taken into consideration. If observations are conducted in the context of mitigation, a helicopter survey does not constitute a viable alternative. It was shown that crow's nest surveys detect a large percentage of cetaceans in the vessel's vicinity, mostly at the species level.

Comparison between observations of a trained cetacean observation team in the crow's nest and those by the nautical personnel on the bridge revealed that bridge personnel detected only approximately 22.45% [95% confidence interval: 15.98% - 30.06%] of the crow's nest sightings within an identical observation period including 30 minute buffers, while the crow's nest team detected 64.10% [47.18% - 78.8%] of bridge sightings. Possible multiple recordings of the same animal or animal group by bridge personnel, as well as the buffered observation period, suggest that the success rate of crow's nest observations may be even higher. Measured against all sightings recorded only once (i.e. excluding duplicates recorded by both methods), the crow's nest contributed approximately 90% of all sightings, while the bridge contributed only 10%. This is not surprising as nautical personnel are primarily occupied with tasks other than cetacean observation. The comparison shows only that observations by bridge personnel are not suitable for mitigation purposes, for example, because the majority of whales in the vessel's vicinity are not recorded. Surveys by nautical personnel do, however, represent a useful data source for habitat models because they are "on effort" continuously, can identify species and group size, and are able to generate considerable data quantities without large additional expense or effort. One must take into consideration, however, that these are opportunistic data lacking any measurement of effort or relationship to area.

The IR camera did detect whales in the vessel's vicinity, however not all animals that a trained observer team was able to detect. A validation of IR camera data by crow's nest data established that the IR camera detected 41.51% [95% confidence interval: 28.14% - 55.87%] of whale groups recorded by crow's nest observers. It was not possible to analyse how many whales the camera detected during the same observation period that were missed by the crow's nest team because individual blow events are not currently aggregated at the individual level, i.e. they are not attributed to individual animals. Considering that cetacean observations by humans are expensive and cannot be conducted around the clock or in all weather conditions, IR camera observation represents a meaningful mitigation approach when no observer team is available. Exclusive use of this method, however, runs the risk of missing a percentage of whales in the area. This is true particularly for most of the small cetacean species that generate small, inconspicuous blows. Here, an observer team has a clear advantage because it can detect animals based on bodies, flukes and other indicators.

3.2.6 Summary

A comparison of all observation methods thus analysed established varying suitability of the methods for different areas of application. Comparison of ship-board and aerial distance sampling surveys showed that these two methods lead to different cetacean densities. These differences are, however, not statistically significant. While aerial surveys generally lead to somewhat lower densities, even if this is not of statistical significance, they provide a multitude of other advantages such as lower coefficients of variation, better coverage of an area in less time, larger numbers of sightings per time unit, and better identification of species. Comparison of crow’s nest and IR camera surveys revealed that the IR camera recorded only 41.51% [95% confidence interval: 28.14% - 55.87%] of the sightings detected by the crow’s nest team. A reverse analysis to determine the percentage of whales detected by the camera but overlooked by the crow’s nest team was not possible for methodological reasons because camera detections can currently not be aggregated at the individual level. Data comparison showed that nautical personnel detected approximately 22.45% [95% confidence interval: 15.98% - 30.06%] of crow’s nest sightings, while the crow’s nest team detected 64.10% [47.18% - 78.8%] of bridge sightings.

3.3 Summary of the *Konzept für "Biologische Begleituntersuchungen in der Antarktis"*

Distance sampling surveys (to the extent possible) are recommended for concomitant biological investigations in the Antarctic. Slightly increased effort compared to strip-transect surveys, the current standard of concomitant biological investigations, allows the collection of more robust data because they can be corrected for effort and sighting probability. Surveys according to a uniform, standardised protocol can generate comparable data available for joint analysis. A concept was developed in this project which describes in detail the advantages and disadvantages of different sighting methods and explains when data collected with a certain method is best used. The concept elucidates the requirements for an observer team and the vessel as an observation platform. Field guidelines for application of the method both in helicopter and crow’s nest surveys were developed according to the recommendation for performance of distance sampling surveys as part of concomitant biological investigations. The concept and the field guidelines are included as appendices (in German only) to this report.

4 Synthesis of results

The distance sampling surveys resulted in density values for large, humpback, fin and minke whales in five different strata. In addition, abundances for one stratum could be estimated. The density values can be used as an index for comparison of cetacean densities between the strata and establish different density distributions of cetaceans in the Antarctic. Accordingly, primarily minke whales are found in ice-covered waters of the Weddell Sea and near Neumayer Station III, while a wider range of species are encountered on the western side of the Antarctic Peninsula where, in addition to minke whales, more large whales, particularly humpback whales, exist. The WAP stratum was used as an example to demonstrate that a sufficient stay of the research vessel in a circumscribed area allows helicopter surveys to be used to determine abundances. Although the abundances, as well as the densities, are minimum values due to the absence of g(0) correction, they represent a useful expansion of existing scientific knowledge on cetacean occurrence in the Antarctic and provide robust data for this circumscribed area.

Both methods, helicopter and crow's nest surveys, generated different encounter rates and densities. The lower encounter rates in aerial surveys are primarily due to higher speed of travel. Analyses of tracking observations additionally provided first signs of approaching behaviour in humpbacks to the vessel. At least for this species, it is possible that approaching behaviour is responsible for a higher detection rate in ship-board than in aerial surveys. Aerial surveys are often suspected of underestimating stocks as a result of lower encounter rates than generated in ship-board surveys, but this doubt was cleared up in this study. While aerial surveys achieved lower encounter rates, the densities determined based on the collected data differed only in few instances to a statistically significant degree from ship-board surveys. Mostly, they were associated with a smaller error and should thus be considered to be more robust. Helicopter surveys also proved to be a very efficient survey method in the Antarctic because they allow researchers to make good use of short windows of favourable survey conditions and record many sightings in a short time. A large number of sightings per kilometre of effort are needed to arrive at robust abundance estimates according to the distance sampling method. Another advantage of helicopter surveys is their ability to leave the vessel's sphere of influence and thus collect data independently of possible approaching behaviour, which was first observed in humpback whales during this study.

A comparison between crow's nest and WALOG data revealed that a dedicated cetacean survey captures at least nine times the number of sightings as bridge personnel does in the same observation period. In a side-by–side comparison of sightings, bridge personnel discovered only approximately one quarter of all sightings recorded by a trained cetacean observation team during a focused survey. This insight highlights the opportunistic character of WALOG recordings. Nautical personnel are primarily occupied with other tasks and cannot dedicate continuous effort to cetacean observation. Consequently, bridge personnel can miss sightings, and duplicate recording of animals may occur. In addition, information on volume of effort is not available. One important advantage is, however, that bridge personnel is "on effort" at all times and potentially able to record sightings around the clock. Thus, more sightings may be recorded during an entire expedition than would be possible in a dedicated cetacean survey. Dedicated cetacean surveys are labour-intensive and have stringent requirements for environmental and sighting conditions to ensure data quality necessary for density and abundance determination. While opportunistic bridge data are unsuitable for density and abundance determinations, they are a useful data source for habitat models because they quite accurately provide species and group size. Thus, considerable data quantities can be generated without much additional cost or effort.

An analysis of the IR camera's efficiency revealed that it detected only approximately half of the sightings recorded by a trained cetacean observation team during a focused survey. It was not possible to analyse how many whales the camera detected during the same observation period that were missed by the crow's nest team because individual blow events are not currently aggregated at the individual level, i.e. they are not attributed to individual animals. Advantages of IR cameras, particularly for mitigation purposes in seismic investigations, are their ability to be in continuous use and functioning at night and during heavy sea states. During poor sightings conditions, and particularly at night, human observers are not an alternative to IR camera systems. During favourable sighting conditions, however, a trained observation team is probably more capable of detecting all whales in the vicinity and ensure mitigation. Particularly smaller cetacean species with inconspicuous blow, such as beaked whales, would be more effectively observed by a cetacean observation team. Beaked whales, because they are one of the deep-diving species, are particularly susceptible to seismic investigations (e.g. Gordon et al. 2003, Cox et al. 2006, Barlow & Gisiner 2006). Considering that cetacean observations by humans are expensive and cannot be conducted around the clock or in all weather conditions, IR camera observation represents a meaningful mitigation approach when no observer team is available. Complementary use of both methods would create ideal conditions for mitigation.

5 Outlook

Distance sampling data collected during this project enabled determination of local cetacean densities. To transfer densities to areas exceeding the immediate observed area, a prospective transect design providing representative coverage of the area under investigation, according to the conventional distance sampling method, is required. If these prerequisites are not available, modelling procedures allow density determinations for larger areas based on distance sampling data. Particularly density surface models (DSM) constitute a suitable (Hedley et al. 2004) method often used in the context of distance sampling (e.g. Katsanevakis 2007, Herr et al. 2009). A subsequent, meaningful step during further analysis of data collected would be the creation of DSM to allow more far-reaching and detailed statements on cetacean densities in the Antarctic. In contrast to the WALOG Data-based habitat suitability model (HSM) created by AWI during a concurrent project, which describes suitability of a habitat for cetaceans, a DSM based on distance sampling data allows the modelling of actual densities. This provides a unique opportunity for making a valuable contribution to scientific knowledge on cetacean distribution, density and, in combination with AWI's habitat suitability models, the effective allocation of suitable habitats in the Atlantic sector of the Southern Ocean.

Particularly the helicopter survey results show that time a in circumscribed area will allow distance sampling surveys based on line-transect designs to be performed in the Antarctic. These systematic surveys can lead to area-specific densities and abundances using conventional analysis of distance sampling. Repeat surveys of the same areas would enable temporal comparisons and investigation of dependency on environmental variables such as ice cover for the same geographic area. Surveys of other maritime areas could provide supplementary abundance and density information and considerably improve coverage of the Antarctic with focused cetacean surveys and thus available information on distribution and density of cetaceans in the Antarctic. Efforts should be aimed at maximising the effort of focused cetacean surveys on expeditions to the Antarctic. Standard concomitant biological investigations should be established to collect systematic distance sampling data according to the developed concept. Compared to the widely used strip-transect surveys currently employed as concomitant investigations, the minor additional cost of dedicated cetacean surveys would yield much more reliable and meaningful data.

Of particular interest for assessing populations in the Antarctic would be the determination of a corrective factor, i.e. determination of the g(0) value, at least for the species most frequently observed, the humpback and Antarctic minke whales. This requires focused (ship-board) double-platform surveys (cf. concept for concomitant biological investigations in the Antarctic, appendix).

A significant opportunity for mitigation is found in the complementary use of a trained cetacean observation team and the IR camera. 24-hour use of the IR camera could ensure continuous whale detection at any time of the day, independently of weather conditions, while the cetacean observation team represents a positive expansion, under suitable conditions, for recording whales in the vicinity. Each method could also be used to validate and evaluate the other method and lead to improvements in both. The camera could be informed by the cetacean observation team about undetected whales in the vicinity, and thus the detection algorithm could be further improved. The cetacean observation team could benefit from the camera's precision of distance and angle measurements and use those for evaluation of manual measurements (cf. Chapter 4.2.3). Different time stamps of sighting events, based on time recording methods not mutually calibrated between the individual methods, prevented unambiguous attribution of individual events, which would allow exact comparison of distance and angle. This would be possible in a future focused study with calibrated time recording.

6 Literature

Ainley, D.G. (1985): The biomass of birds and Mammals in the Ross Sea, Antarctica. IN Siegfried, W.R., Condy, P.R., Laws, R.M. (eds) Antarctic nutrient cycles and food webs. Springer Verlag, Hamburg, Germany.

Ainley, D.G., Dugger, K.M., Toniolo,V., Gaffney, I. (2007): Cetacean occurnce patterns in the Amundsen and Bellingshausen Sea sector, Southern Ocean. Marine Mammal Science 23(2): 287–305.

Akaike, H. (1974): A new look at the statistical model identification. IEEE Transactions on Automatic Control 19 (6): 716 – 723.

Anderson, D. R., Burnham, K. P., and White, G. C. (1994): AIC Model Selection in Overdispersed Capture-Recapture Data. Ecology 75: 1780 – 1793.

Barlow, J., Gisiner, R. (2006): Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. Journal of Cetacean Research and Management 7(3): 239 – 249.

Branch, T.A. (2007): Possible reasons for the appreciable decrease in abundance estimates for Antarctic minke whales from the IWC/SOWER surveys the second and the third circumpolar sets of cruises. Paper SC/59/IA7, International Whaling Commission, Cambridge, UK.

Bozdogan, H. (1987): Model selection and Akaike's Information Criterion (AIC): The general theory and its analytical extensions. Psychometrika 52 (3): 345 – 370.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., Thomas, L. (2001): Introduction to distance sampling. Estimating abundance of biological populations. Oxford University Press, New York.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., Thomas, L. (2004): Advanced distance sampling. Estimating abundance of biological populations. Oxford University Press, New York.

Calambokidis, J., Barlow, J. (2004): Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. Mar. Mamm. Sci. 20(1):63-85.

Cox, T.M., Ragen, T.J., Read, A.J., Vos, E., Baird, R.W., Balcomb, K., Barlow, J., Caldwell, J., Cranford, T., Crum, L., Amico, A.D., Spain, G.D., Fernández, A., Finneran, J., Gentry, R., Gerth, W., Gulland, F., Hildebrandt, J., Houser, D., Hullar, T., Jepson, P.D., Ketten, D., MacLeod, C.D., Miller, P., Moore, S., Mountain, D.C., Palka, D., Ponganis, P., Rommel, S., Rowles, T., Taylor, B., Tyack, P., Wartzok, D., Gisiner, R., Mead, J., Benner, L. (2006): Understanding the impacts of anthropogenic sound on beaked whales. Journal of Cetacean Research and Management 7(3): 177 - 187.

Dawson, S., Wade, P., Slooten, E., Barlow, J. (2008): Design and field methods for sighting surveys of cetaceans in coastal and riverine habitats. Mammal Review 38: 19-49.

Ensor, P., Komiya, H., Beasley, I., Fukutome, K., Tsuda, Y. (2007): 2006-2007 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) cruise: International Whaling Commission, Cambridge, UK: pp. 58

Forney, K. (2000): Environmental Models of Cetacean Abundance: Reducing Uncertainty in Population Trends. Conservation Biology 14 (5):1271-1286.

Gloersen, P., Campbell, W.J., Cavalieri, D.J., Comiso, J.C., Parkinson, C.L., Zwally, H.J. (1993): Satellite passive microwave observations and analysis of Arctic and Antarctic sea ice, 1978-1987. Annals of Glaciology 17: 149-154.

Gordon, J., Gillespie, D., Potter, J., Frantzis, A., Simmonds, M.P., Swift, R., Thompson, D. (2003): A review of the effects of seismic surveys on marine mammals. Marine Technology Society Journal 37(4):16-34.

Gutt, J., Barratt, I., Domack, E., d'Udekem d'Acoz, C., Dimmler, W., Grémare, A., Heilmayer, O., Isla, E., Janussen, D., Jorgensen, E., Kock, K.-H., Lehnert, L.S., López-Gonzáles, P., Langner, S., Linse, K., Manjón-Cabeza, M.E., Meißner, M., Montiel, A., Raes, M., Robert, H., Rose, A., Schepisi, E.S., Saucède, T., Scheidat, M., Schenke, H.-W., Seiler,J., Smith, C. (2010): Biodiversity change after climate-induced ice-shelf collapse in the Antarctic. Deep-Sea Research II 1-2: 74-83.

Hedley, S.L., Buckland, S.T. (2004): Spatial models for Line Transect Sampling. J. Agric. Biol. Environ. Stat. 9(2): 181–199.

Herr, H., Scheidat, M., Lehnert, K., Siebert, U., (2009): Seals at sea: modelling seal distribution in the German bight based on aerial survey data. Marine Biology 15: 811 – 820.

Joiris, C.R. (1991): Spring distribution and ecological role of seabirds and marine mammals in the Weddell Sea, Antarctica. Polar Biology 11:415-424.

Kasamatsu, F., Ensor, P., Joyce, G.G., Kimura, N. (2000): Distribution of minke whales in the Bellingshausen and Amundsen Seas (60°W–120°W), with special reference to environmental/physiographic variables. Fisheries Oceanography 9:214–223.

Katsanevakis, S. (2007): Density surface modelling with line transect sampling as a tool for abundance estimation of marine benthic species: the Pinna nobilis example in a marine lake. Marine Biology 152: 77-85.

Kelly, N., Peel, D., Pike, D., Bravington, M.V., Gales, N. (2009): An aerial survey for Antarctic minke whales in sea ice off east Antarctica: a pilot study. Paper SC/61/IA3, International Whaling Commission, Cambridge, UK.

Kelly, N., Murase, H., Kitikado, T., Kock, K.-H., Williams, R., Feindt-Herr, H., Wallø, L. (2012): Appraisal of methods and data to estimate abundance of Antarctic minke whales within sea ice covered areas of the Southern Ocean. Paper SC/64/IA10, International Whaling Commission, Cambridge, UK.

Leaper, R., Bannister, J., Branch, T.A., Clapham, P.J., Donovan, G.P., Matsuoka, K. Reilly, S., Zerbini, A.N. (2008): A review of abundance, trends and foraging parameters of baleen whales in the Southern Hemisphere. Paper SC/60/EM3, International Whaling Commission, Cambridge, UK.

Marsh, H., Sinclair, D.F. (1989): Correcting for availability bias in strip transect aerial surveys of aquatic fauna. Journal of Wildlife Management 53: 1017-1024.

Miller, D.L. (2013): Distance: A simple way to fit detection functions to distance sampling data and calculate abundance/density for biological populations. R package version 0.7.2. http://CRAN.R-project.org/package=Distance

Plumptre, A.J. (2000): Monitoring mammal populations with line transect techniques in African forests. J. Appl. Ecol. 37: 356–368.

R Core Team (2013): R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Richardson, W.J., Greene, C.R., Malme, C.I., Thomson, D.H. (1995): Marine mammals and noise. Academic Press, San Diego, USA.

Strindberg, S, Buckland, S.T. (2004): Zigzag survey designs in line transect sampling. J. Agric. Biol. Environ. Stat. 9(4): 443–461.

Wade, P.R., DeMaster, D.P. (1999): Determining the optimum interval for abundance surveys. In: G.W. Garner, S.C. Amstrup, J.L. Laake, B.F.J. Manly, L.L. McDonald & D.G. Robertson (Eds), Marine mammal survey and assessment methods (pp. 53–66). A.A. Balkema, Rotterdam.

Zitterbart, D.P., Kindermann, L., Burkhardt, E., Boebel, O. (2013): Automatic Round-the-Clock Detection of Whales for Mitigation from Underwater Noise Impacts. PLOSone 8(8): e71217.