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Changes in minke whale distributions in the Southern Ocean

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This study explores the various relationships between distance from the sea ice edge and minke whale density distribution by means of a circumpolar spatial analysis. For almost 30 years, the International Whaling Commission (IWC) has conducted whale surveys in the Southern Ocean during austral summer months under the IWC/IDCR-SOWER programme. This has resulted in three circumpolar sets of surveys, with over 21,000 minke whale sightings. We used these sightings in spatial models of line transect data based on generalised additive models (GAMs). The GAMs assumed an overdispersed Poisson error structure and log-link. Model selection was based on maximisation of explained deviance and minimising the Generalised Cross Validation (GCV) score, while excluding GAMs that generated extreme and unlikely minke whale densities. The GAMs were fitted independently by survey area and year. Selected GAMs included combinations of the following covariates: closest distance of sighting to sea ice edge, closest distance of sighting to either the Southern Antarctic Circumpolar Current Front (SACCF) or the Southern Boundary of the Antarctic Circumpolar Current (SBACC), bathymetric depth and distance from the shelf edge, Optimally Interpolated Sea Surface Temperature (OISST) and latitude. Minke whale densities did not show a consistent relationship with distance from the sea ice edge over the years, suggesting variability in minke whale distribution between years. For most of the regions within the Southern Ocean, mean predicted Antarctic minke whale densities were lowest for the most recent surveys. We plan to investigate if the declining trend in Antarctic minke whale density was accompanied by changes in the sea ice environment, such as changes in total sea ice extent, melt area or quality.

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INTRODUCTION

Antarctic minke whales (*Balaenoptera bonaerensis*) reside in the Southern Ocean mainly during austral summer months. Within these months, the animals are primarily foraging on Antarctic krill (*Euphausia superba*) (Kawamura 1994). Antarctic minke whales can be found across a wide latitudinal range within the Southern Ocean. They have been sighted in both the pack ice region (e.g. Ensor 1989, Ribic 1991, van Franeker 1992, Thiele and Gill 1999, Thiele *et al.* 2002) and open ocean (e.g. Kasamatsu *et al*. 2000, Thiele *et al.*2000, Murase *et al.* 2002, Friedlaender 2006).

The International Whaling Commission (IWC) has conducted visual cetacean surveys in the Southern Ocean for almost 30 years under the IDCR (International Decade of Cetacean Research) and SOWER (Southern Ocean Whale and Ecosystem Research) programmes. The design for these surveys was optimised for the detection of cetaceans, notably Antarctic minke whales. From analysis of IWC/IDCR-SOWER sightings, it became clear that Antarctic minke whale distribution in open waters during austral summer is dependent on the location of the sea ice edge. Kasamatsu *et al* (1988, 2000) reported higher encounter rates of Antarctic minke whales closer to the sea ice edge at a circumpolar scale. This is in line with findings based on sightings obtained during other surveys. For instance, Thiele *et al*. (2000) reported relatively high sighting rates of Antarctic minke whales within close range of the sea ice edge. A more complex picture formed through a study of Murase *et al*. (2002) based on a survey within the 35ºE-145ºW region during the 1998/1999 and 1999/2000 seasons. During this survey, Antarctic minke whales were concentrated in areas where the sea ice edge and continental slope coincided.

In the last decade, spatial models have been developed for baleen whale densities in several parts of the Southern Ocean. Hedley *et al*. (1999) developed new techniques for spatial modelling based on line transect data and applied them to IWC/SOWER sightings data in the 0-40ºE region of the Southern Ocean. Only distance from the sea ice edge was used as an explanatory variable in this study, along latitude and longitude as geographic variables. Friedlaender *et al.* (2006) developed spatial models based on pooled minke and humpback whale sightings collected in waters off the Western Antarctic Peninsula in the autumn of 2001 and 2002 under the SO GLOBEC programme. These spatial models suggested that baleen whale distribution was influenced by distance from the sea ice edge, together with bathymetric slope and zooplankton acoustic volume between 25-100m.

There is a need to characterise the physical habitat for Antarctic minke whales in the Southern Ocean in order to understand associate long-term changes in minke whale density with the environment. From the independent studies stated above, it is not clear which factors determine the variability in Antarctic minke whale distribution and density at a circumpolar scale during austral summer. The IWC/IDCR-SOWER dataset is the only circumpolar whale sightings dataset for the Southern Ocean that allows for a long-term circumpolar analysis of variability in minke whale density. We have developed spatial models at a circumpolar scale using the methodology developed by Hedley *et al.* (1999) using IWC/IDCR-SOWER sightings. We hypothesised that Antarctic minke whale distribution is primarily determined by the distribution of krill, its main prey. However, krill was not sampled during the IWC/IDCR-SOWER cruises. Instead, we used remote sensing variables which are likely to be related to krill distribution. Examples are variables related to sea ice (Nicol *et al.* 2006), bathymetry (Pauly *et al.* 2000, Atkinson *et al.*, *in press*), sea surface temperature (Pauly *et al.* 2000) and fronts associated with the Antarctic Circumpolar Current (ACC) (Murphy *et al.* 2004).

MATERIALS AND METHODS

Study area and effort

The IWC has divided the Southern Ocean into six management Areas, ranging from 50 to 70 longitudinal degrees. Since 1978/79, the IWC has conducted annual surveys in which 2-4 vessels took part, focusing on one particular management Area per survey. Sometimes Areas were revisited, if the Area could not be sufficiently surveyed in the previous year. The development of spatial models for the 1978/79-1980/81 could not be justified, due to a lack of remote sensing data for these seasons. Therefore, we developed spatial models based on line transect data from the 1981/82-2004/05 IWC/IDCR-SOWER surveys. General information about these surveys is displayed in table 1. Total area coverage range from 0.690 million km^2 (2001/02 survey) to 3.305 million km^2 (1985/1986). Primary effort was at a minimum of 4,991 km for the 2000/2001 survey, while a maximum of 32,678km primary effort was reached during the 1985/86 survey.

Whale sightings and g(0) estimation

We selected only "definitely minke whale" sightings, codes as "04" under IWC classification rules. These sightings were exclusively obtained under primary effort, in both closing and passing mode (Branch and Butterworth 2001). Only the first sighting of every pair/triplet of non-simultaneous "definite"("D") duplicates was included in the analysis. Duplicates marked as possible duplicate ("P"), remotely possible duplicate ("R") and "uncertain" ("U") were considered as separate sightings.

We estimated g(0), the probability of sighting a whale group on the transect line, using Mark Recapture Distance Sampling (MRDS) analysis methods, as implemented in Distance V5.0 release 2 (Thomas *et al*. (2006). We fitted detection functions that assumed point independence (Laake and Borchers 2004) using only Antarctic minke whale sightings obtained during Independent Observer (IO) mode. The g(0) values could only directly be estimated for surveys since 1985/86, as IO sightings were only collected for these surveys. The g(0) values were independently estimated per vessel for each survey season. IO sightings data were pooled over several surveys in the same Area if the number of IO sightings for a vessel for a particular survey was lower than 60 (Buckland *et al*. 2001, p. 240) or if the detection function did not provide a good fit. The estimated g(0) values were clearly smaller than 1 for the vessels that took part in the surveys conducted since 1985/86. Therefore, we abandoned the g(0) = 1 assumption as well for the surveys between 1981/82 and 1984/85 that were not supported by IO sightings data. For the vessels that also took part in the later surveys (labelled as "SM1"and "SM2"), we fitted detection functions using all IO sightings data that had been collected on that vessel in the particular Area during the 1985/1986 – 2004/05 surveys. Vessels which had only been used in the 1981/82 – 1984/85 seasons (i.e. that did not survey under IO mode) had g(0) values assigned to them which were averages of the g(0) values for the other vessels that had collected IO data in the same Area over the years.

Remote sensing data

Under the IDCR-SOWER programme, survey design was specifically designed to optimise the detection of cetaceans. During the surveys, relatively few abiotic data were collected and krill was not sampled. Therefore, we decided to use only remote sensing datasets for the estimation of potential covariate values. For sea ice concentrations, we used passive microwave remote sensing data on a weekly basis, generated from the Scanning Multichannel Microwave Radiometer (SMMR) onboard the Nimbus-7 satellite and from the Special Sensor Microwave/Imagers (SSM/I) onboard Defense Meteorological Satellite Program (DMSP) satellites F8, F11 and F13. The version 2 sea ice concentration data had a 25 x 25 km resolution (Cavalieri et al., 1996, updated 2006). Bathymetric data were extracted from the General Bathymetric Chart of the Oceans (GEBCO) one-minute dataset (IOC *et al*. 2003). Weekly 9 x 9 km gridded chlorophyll-a concentration data were derived from the NASA Sea-viewing Wide Field-of-view Sensor (SeaWiFS) dataset (http://oceancolor.gsfc.nasa.gov/ SeaWiFS/). Sea surface temperature data were derived from the Optimum Interpolation version 2 Sea Surface Temperature (hereafter OISST) dataset (Reynolds and Smith, 1994; Reynolds et al., 2002). OISST data were provided on weekly one-degree latitude-longitude grids (ftp://ftp.emc.ncep.noaa.gov/cmb/sst/ oisst_v2/). Information on frontal zone positions was derived from two datasets. Firstly, we used long-term positions of the Southern Antarctic Circumpolar Current Front (SACCF) and the Southern Boundary of the ACC (SBACC) as identified by Orsi *et al*. (1995). Secondly, sea surface velocities (SSV) were used based on absolute geostrophic velocities measured by altimetric instruments onboard the Topex/Poseidon, Jason-1, ERS and ENVISAT satellites. SSV data were provided by AVISO on weekly 1/3° x 1/3° Mercator grids.

Spatial models and potential covariates

The Antarctic minke whale sightings served as input for spatial models based on line transect data using generalised additive models (GAMs). We applied the count method developed by Hedley *et al*. (1999), dividing the transect line into equal segments of ten nautical miles.

We estimated minke whale density using a Horvitz-Thompson-like estimator, as the sum of the count of whales on each segment corrected by the estimated g(0)-values. The derived whale density estimates were used as the response variable of GAMs, which assumed an overdispersed quasi-Poisson error structure and logarithmic-link to the predictor variables. These were the environmental and spatial variables.

We fitted the GAMs independently by survey year using the mgcv-package (V1.3-28) of program R, V2.6.0 (R Development Core Team 2007). To avoid overfitting, we constrained the degree of covariate smoothing by using the argument gamma=1.4 within the gam-function of the mgcv-package (Wood 2006, p. 256). We also examined the degree of autocorrelation between segment data by comparing the output of models with and without a spatial autocorrelation structure. Spatial autocorrelation structures were based on euclidean distances between segment midpoints and had an exponential structure (Pinheiro and Bates 2000). The structures were fitted using the generalised additive mixed modeling (GAMM) framework developed by Wood (2006).

Variables considered as potential covariates for the spatial models were: distance from the sea ice edge, defined at 15% sea ice concentration (Tynan and Thiele 2003), bathymetric depth and distance from the shelf edge, defined as the 1000m depth contour, Sea Surface Velocity (SSV) and distances from the SACCF and SBACC, OISST, chlorophyll-a concentration and latitude. We selected the GAMs by maximising explained deviance and minimising the Generalised Cross Validation (GCV) score (Wood 2006), while excluding GAMs that generated extreme minke whale densities.

We used the selected GAMs to create predicted Antarctic minke whale density surfaces for each Area and year. For each surveyed stratum within a survey, we estimated the covariate values for the middle date of the survey period. In order to investigate changes in mean whale densities over time, we identified longitudinal ranges that were surveyed at least three times under the IWC/IDCR-SOWER programme. For each longitudinal range, we calculated overall mean whale density as follows, thereby taking into account heterogeneity between strata (Buckland *et al*. 2001):

$$D_A = \Sigma_v (A_v \text{ x } D_v) / \Sigma_v A_v$$

where: D_A = overall mean whale density for all surveyed strata within an overlapping longitudinal range

D_v = mean whale density for stratum v

A_v = area of stratum v.

PRELIMINARY ANALYSIS

Whale sightings and g(0) estimation

For the various sightings, Table 1 gives an overview of total numbers of Antarctic minke whale sightings made under primary effort. Mean school size per km primary effort ranged from 0.025 (Area III) to 0.0522 (Area V). Mean number of Antarctic minke whale sightings per km primary effort per Area ranged from 0.057 (Area III) to 0.134 (Area II). G(0) values varied per vessel and ranged from 0.514 (SE=0.052) to 0.891 (SE=0.036). See Table 2 for a more comprehensive overview of g(0) values.

Spatial models and selected covariates

We decided not to implement autocorrelation structures in our spatial models, as autocorrelation coefficients never exceeded 0.01 and were not statistically significant. Instead, we developed simple GAMs, which output is given in Table 3. Explained deviances were high, being 24.5% at their smallest (1982/83 survey, Area I) and 66.8% (2000/2001 survey, Area VI) at their largest.

We were not able to fit a good spatial model for the 2001/2002 survey in Area V. Therefore, we excluded this survey from the analysis of variability in mean Antarctic minke whale densities within a particular longitudinal range over the years. For all other surveys, we were able to develop good spatial models based on remote sensing data.

Seven out of nine potential covariates were included in at least one of the selected GAMs. Only SSV and chlorophyll-a concentration were not included in the models. Distance from the sea ice edge (icedist), OISST and latitude were most often included in the models (respectively 20, 19 and 19 times out of 24 models). On the other hand, distance from the shelf edge (1000m-dist) was selected as an explanatory variable for only two GAMs. Table 3 gives an overview of the relationships between the selected covariates and their effect on Antarctic minke whale density for the various spatial models. Spatial models that included icedist as a covariate showed mostly a negative effect of icedist on Antarctic minke whale density. In other words, these models suggested that Antarctic minke whale densities tended to be higher close to the sea ice edge for those surveys. Similarly, most spatial models indicated a negative relationship between density and OISST, as they showed higher Antarctic minke whale densities in colder waters. Although both icedist and OISST showed a predominantly negative relationship with density, spatial models showed variability in these qualitative relationships. Some of the models showed an unexpected positive relationship between icedist and its effect on Antarctic minke whale densities (see for instance the output for the 1987/88 (Area III) and 1998/99 (Area IV) surveys.

Either distance from the SACCF (SACCFdist) or distance from the SBACC (SBACCdist) was included in 21 out of 24 spatial models. However, neither SACCFdist nor SBACCdist showed a dominant relationship with its effect on Antarctic minke whale density. We also did not find dominant relationships between the two bathymetric explanatory variables (i.e. depth and distance from the shelf edge)

Relatively high Antarctic minke whale densities were predominantly found close to the sea ice edge (Figure 1). These results seemed to contradict the non-negative relationships between icedist and its effect on whale density for a number of surveys. However, the predicted Antarctic minke whale densities are combinations of the different additive effects related to the various covariates. For instance, a positive icedist-density effect relationship was probably mitigated by the strong negative OISST-density effect for the 1998/99 survey. As the waters close to the sea ice edge are relatively cold, the 1998/99 model also predicted higher whale densities close to the sea ice edge. As OISST is highly negatively correlated to sea ice extent (Forcada *et al*. 2006), a negative OISST-density effect relationship can be interpreted as a positive association between minke whale density and sea ice extent.

Table 4 shows mean Antarctic minke whale densities, grouped by overlapping longitudinal range, for the various surveys. For most regions, predicted mean densities were lowest for the most recent surveys. This is in line with preliminary abundance estimates for the SOWER surveys (Branch 2005). The decline in whale densities is also displayed by figures 1-3. Regions with relatively high whale densities were most common for the surveys undertaken between 1981/82 and 1987/88 (Figure 1) and least common for surveys undertaken between 1996/97 and 1997/98. Furthermore, apart from the Ross Sea sector (Area V), regions characterised by relatively high predicted Antarctic minke whale densities showed wider latitudinal bands for the earliest set of surveys (Figure 1) than for the most recent surveys (Figure 3).

We plan to investigate if the declining trend in Antarctic minke whale densities was accompanied by changes in the sea ice environment, which were not captured by the covariates we considered for the spatial models. Examples are changes in total sea ice extent, melt area and quality. In this way, we hope to understand if and how sea ice related changes have had an impact on Antarctic minke whale densities, which is crucial for any scenario analysis of Antarctic minke whale densities in the Southern Ocean.

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TABLES

Table 1 Survey and Antarctic minke whale sighting information for the various surveys, grouped per IWC Area. Sighting information refers to sightings made during primary effort and Independent Observer (IO) mode. Schools and sightings are standardised per km primary effort.

IWC Area	**Survey season**	**Survey period**	**Area size (10^6 km^2)**	**Primary effort (km)**	**IO effort (km)**	**# schools**	**# schools/ effort**	**# sightings**	**# sightings/ effort**
Area I (120-60°W)	1982/83	1 Jan – 18 Feb 1983	1.099	16,953	n/a	974	0.057	2599	0.153
	1989/90	28 Dec 1989 – 15 Feb 1990	1.473	12,766	6,389	538	0.042	1147	0.090
	1993/94	29 Dec 1993 – 13 Feb 1994	2.290	10,425	5,291	236	0.023	503	0.048
	1999/2000	12 Jan 1999 – 14 Feb 2000	0.776	4,934	2,197	42	0.009	84	0.017
Area II (60°W-0)	1981/82	26 Dec 1981 – 8 Feb 1982	1.078	24,091	n/a	1053	0.044	2941	0.122
	1986/87	25 Dec 1986 – 9 Feb 1987	1.699	29,315	8,190	1053	0.036	3875	0.132
	1996/97	13 Jan – 17 Feb 1997	1.479	7,324	3,776	168	0.023	354	0.048
	1997/98	16 Jan – 15 Feb 1998	1.053	5,873	2,982	116	0.020	253	0.043
Area III (0-70°E)	1987/88	20 Dec 1987 – 27 Jan 1988	1.645	10,705	2,753	332	0.031	775	0.072
	1992/93	25 Dec 1992 – 2 Feb 1993	1.527	12,380	6,065	349	0.028	834	0.067
	1994/95	12 Jan – 27 Feb 1995	1.470	6,817	3,421	145	0.021	318	0.047
	2004/05	10 Jan – 27 Feb 2005	0.720	6,128	2,559	114	0.019	256	0.042
Area IV (70-130°E)	1984/85	28 Dec 1984 – 21 Feb 1985	1.105	16,990	n/a	536	0.032	1204	0.071
	1988/89	28 Dec 1988 – 12 Feb 1989	1.622	15,283	5,195	570	0.037	1541	0.101
	1998/99	20 Jan – 23 Feb 1999	1.329	8,388	4,526	98	0.012	190	0.023

Area V (130°E-170°W)	1985/86	22 Dec 1985 – 20 Feb 1986	3.305	32,678	8,817	1717	0.053	4644	0.142
	1991/92	27 Dec 1991 – 12 Feb 1992	1.522	9,293	4,221	606	0.065	1522	0.164
	2001/02	25 Dec 2001 – 13 Feb 2002	0.690	4,991	3,695	81	0.071	188	0.165
	2002/03	22 Dec 2002 – 26 Feb 2003	1.653	10,740	4,439	200	0.019	465	0.043
	2003/04	21 Dec 2002– 1 March 2003	1.446	10,236	3,952	541	0.053	1598	0.156
Area VI (170-120°W)	1983/84	3 Jan – 18 Feb 1984	2.516	24,871	n/a	772	0.031	1791	0.072
	1990/91	2 Jan – 13 Feb 1991	1.912	8,628	4,626	186	0.022	401	0.046
	1995/96	10 Jan – 24 Feb 1996	1.531	8,041	3,700	190	0.024	340	0.042
	2000/2001	8 Jan – 22 Feb 2001	1.553	5,376	1,911	137	0.025	378	0.070

Table 2 Overview of estimated g(0) values, detection probabilities for sighting an Antarctic minke whale group on the survey line. Estimation was based on Independent Observer (IO) data. All models assumed point independence. As the estimated g(0) for vessel K27 (1985/86 season) was very low, we decided to use the mean value of g(0)s for vessels SM1 and SM2 instead. The g(0) estimates for both vessels that surveyed during the 2004/2005 season were almost 1, so we decided to use IO sightings collected during the 1992/93 and 1994/95 seasons instead.

IWC Area	Survey Season	Vessel	G(0) ± SE	IWC Area	Survey Season	Vessel	G(0) ± SE	IWC Area	Survey Season	Vessel	G(0) ± SE
Area I	1982/83	SM1	0.832 ± 0.040	**Area III**	1987/88	SM1	0.800 ± 0.058	**Area V (cont.)**	1991/92	SM1	0.678 ± 0.052
		SM2	0.737 ± 0.039			SM2	0.590 ± 0.063			SM2	0.618 ± 0.069
		V34	0.785 ± 0.028		1992/93	SM1	0.800 ± 0.058		2001/02	SM1	0.772 ± 0.040
	1989/90	SM1	0.613 ± 0.077			SM2	0.825 ± 0.040			SM2	0.683 ± 0.060
		SM2	0.744 ± 0.043		1994/95	SM1	0.702 ± 0.085		2002/03	SM1	0.772 ± 0.040
	1993/94	SM1	0.808 ± 0.044			SM2	0.723 ± 0.072			SM2	0.683 ± 0.060
		SM2	0.664 ± 0.080		2004/05	SM1	0.800 ± 0.058		2003/04	SM1	0.891 ± 0.036
	2000/2001	SM1	0.832 ± 0.040			SM2	0.801 ± 0.037			SM2	0.844 ± 0.042
		SM2	0.737 ± 0.039	**Area IV**	1984/85	SM1	0.517 ± 0.072	**Area VI**	1983/84	SM1	0.736 ± 0.059
Area II	1981/82	SM1	0.639 ± 0.044			SM2	0.593 ± 0.064			SM2	0.738 ± 0.069
		SM2	0.832 ± 0.070			K27	0.555 ± 0.048			K27	0.737 ± 0.045
		V34	0.739 ± 0.033			V34	0.555 ± 0.048			V34	0.737 ± 0.045
	1986/87	SM1	0.514 ± 0.052		1988/89	SM1	0.517 ± 0.072		1990/91	SM1	0.736 ± 0.059
		SM2	0.832 ± 0.070			SM2	0.593 ± 0.064			SM2	0.738 ± 0.069
		K27	0.746 ± 0.055		1998/99	SM1	0.517 ± 0.072		1995/96	SM1	0.736 ± 0.059
		V34	0.746 ± 0.055			SM2	0.593 ± 0.064			SM2	0.738 ± 0.069
	1996/97	SM1	0.775 ± 0.076	**Area V**	1985/86	SM1	0.517 ± 0.046		2000/2001	SM1	0.736 ± 0.059
		SM2	0.782 ± 0.088			SM2	0.599 ± 0.046				
	1997/98	SM1	0.775 ± 0.076			K27	0.558 ± 0.033			SM2	0.738 ± 0.069
		SM2	0.782 ± 0.088			V36	0.558 ± 0.033				

Table 3 Model output for the various surveys, grouped per IWC Area. The covariate columns show the relationships between a specific covariate and the effect of the specific covariate on Antarctic minke whale density. Abbreviations of the covariates: icedist = distance from the sea ice edge (defined at 15% sea ice concentration), OISST = Optimally Interpolated Sea Surface Temperature, 1000m-dist = distance from the shelf edge (defined at 1000m depth), SACCFdist = distance from the Southern Antarctic Circumpolar Current Front (SACCF), SBACCdist = distance from the Southern Boundary of the Antarctic Circumpolar Current (SBACC). Legend for the relationship characterisations: **—** = negative, + = positive, 0 = no clear signal, U = minimum effect on density in middle of covariate range, n = maximum effect on density in middle of covariate range, NL = complex non-linear relationship, NS = covariate non-significant, thus not included in model.

IWC Area	**Survey season**	**Explained Deviance (%)**	**Covariates**					
			Icedist	**OISST**	**depth**	**1000m-dist**	**SACCF-dist**	**SBACC-dist**
Area I (120-60°W)	1982/83	24.5	—	—	+	NS	NS	NS
	1989/90	27.1	NS	—	NS	NS	NS	N
	1993/94	47.1	U	NL	NS	NS	NS	U
	1999/2000	55.8	NS	—	0	NS	NS	NS
Area II (60°W-0)	1981/82	40.2	—	—	NS	NS	NS	+
	1986/87	43.8	0	0	+	NS	NS	0/—
	1996/97	44.0	—	0	NS	NS	NS	0
	1997/98	61.2	+/n	NL	N	NS	NS	+
Area III (0-70°E)	1987/88	49.6	+	0	NS	NS	—	NS
	1992/93	41.6	NL	NS	NS	NS	+	NS
	1994/95	55.2	NL	—	NS	0	NL	NS
	2004/05	44.6	—	—	0	NS	+	NS
Area IV (70-130°E)	1984/85	41.4	—	—	—	NS	NS	—
	1988/89	44.3	—	0/+	—	NS	0	NS
	1998/99	55.1	+	—	NS	NS	N	NS
Area V (130°E-170°W)	1985/86	31.7	—	NL	0	NS	NL	NS
	1991/92	38.3	NS	NS	NS	NS	NS	0/—
	2001/02	NS	NS	NS	NS	NS	NS	NS
	2002/03	32.5	—	0	NS	NS	NS	0
	2003/04	47.7	—	NS	NS	NS	+/n	NS

Area VI (170-120°W)	1983/84	29.3	0/+	NS	n	0/+	+	NS
	1990/91	25.6	NL	—	NS	NS	—/n	NS
	1995/96	34.4	+/n	0	—	NS	NS	NL
	2000/2001	66.8	—/0	u	NS	NS	NS	—

Table 4 Mean whale densities for various surveys undertaken within overlapping longitudinal ranges

IWC Area	Longitudinal range	Survey season	Overall mean density (D_A)
Area I (120-60°W)	**110 - 60ºW**	1982/83	2.27
		1989/90	1.60
		1993/94	0.65
	80- 60ºW	1982/83	1.96
		1989/90	1.09
		1993/94	0.97
		1999/2000	0.46
Area II (60°W-0)	**60-25ºW**	1981/82	2.52
		1986/87	2.30
		1997/98	2.62
	30ºW-0	1981/82	1.39
		1986/87	5.43
		1996/97	0.84
Area III (0-70°E)	**0-40ºE**	1987/88	2.86
		1992/93	0.89
		2004/05	0.85
Area IV (70-130°E)	**80-100ºE**	1984/85	1.58
		1988/89	1.57
		1998/99	1.22
Area V (130°E-170°W)	**165ºE-170ºW**	1985/86	3.98
		1991/92	5.84
		2003/04	2.30
Area VI (170-120°W)	**170-140ºW**	1983/84	1.38
		1990/91	0.70
		1995/96	1.00

FIGURES

Figure 1 Predicted mean Antarctic minke whale densities in the Southern Ocean at a circumpolar scale for the 1981/82 – 1987/88 seasons

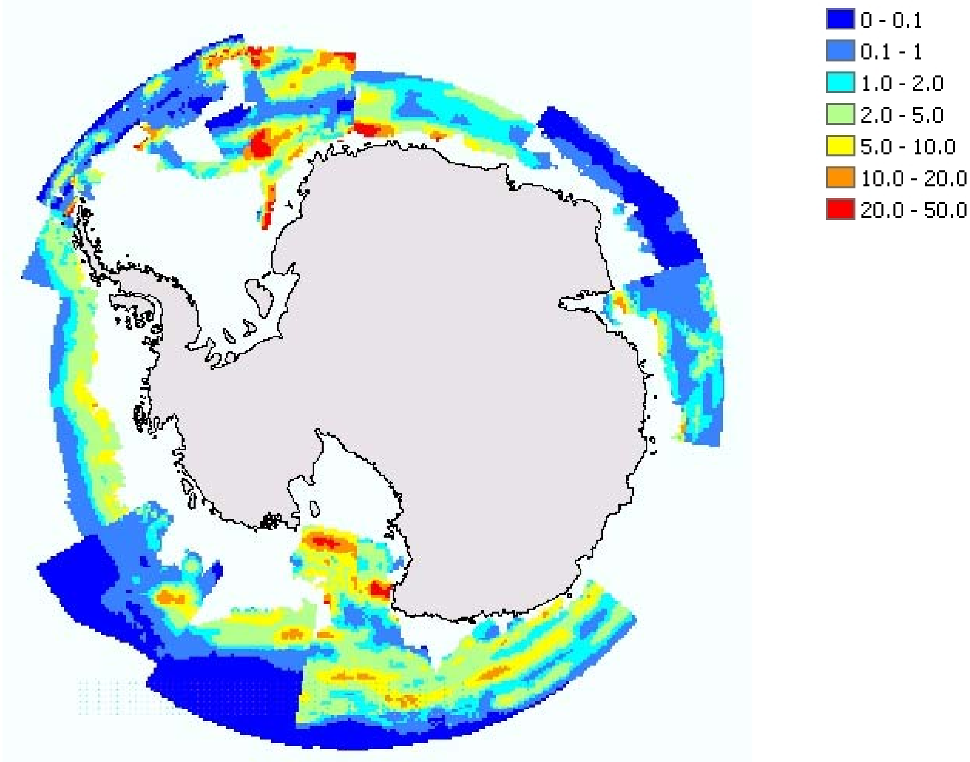

Figure 2 Predicted mean Antarctic minke whale densities in the Southern Ocean at a circumpolar scale for the 1988/89– 1997/98 seasons

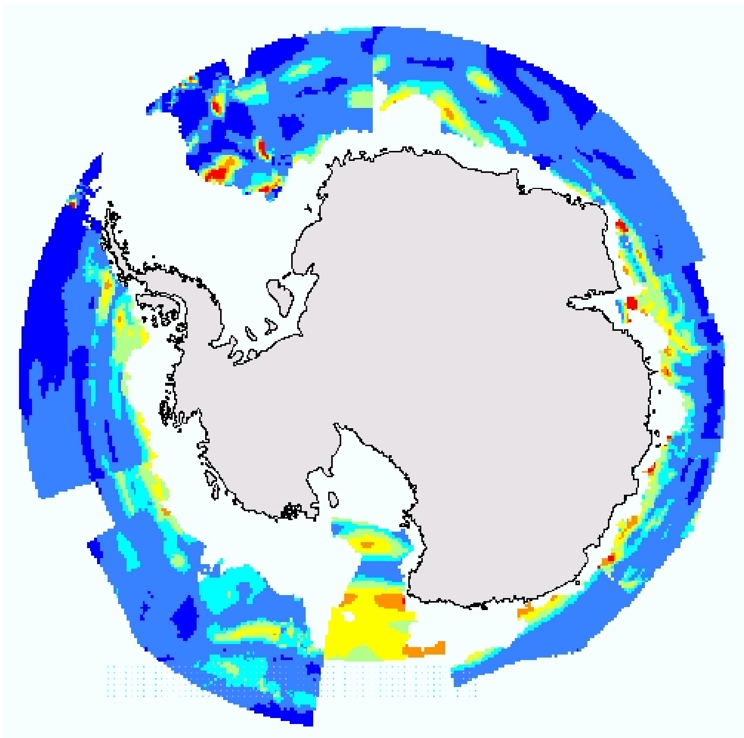

Figure 3 Predicted mean Antarctic minke whale densities in the Southern Ocean at a circumpolar scale for the 1997/98– 2004/05 seasons