# Consideration of an abundance estimation method of Antarctic minke whales within sea ice field using the IWC IDCR-SOWER data

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ABSTRACT

An abundance estimation method of Antarctic minke whales within sea ice field is considered in this study. Data obtained in Area IV in CPIII (1994/95 and 1998/99) by the IWC IDCR-SOWER are used as a case study. Two levels of GAM based spatial distribution models are considered in this paper. Firstly, probability of occurrence of Antarctic minke whales is estimated. Abundance of Antarctic minke whales given the probability is then estimated. Actual abundance of whales is product of the two levels. Because availability of environmental data as covariates of the models are limited in the period of the IDCR-SOWER especially within sea ice filed, only distance from shelf break and seafloor depth are considered. Because abundance of humpback whales increased from CPII to CPIII in Area IV, it is included as a potential covariate. Longitude is also used as a covariate because the environmental covariates used in this analysis might not capture longitudinal heterogeneity. Abundance of Antarctic minke whales in the surveyed area is firstly estimated using the GAMs. Abundance of Antarctic minke whales within the sea ice filed is then estimated by using the surveyed area models. Abundance of humpback whales are also estimated in a same manner. Depth and abundance of humpback whales are selected in the first level of Antarctic minke whale model. Longitude, distance from shelf break and abundance of humpback whales are selected in the second level of Antarctic minke whale model. Abundance of Antarctic minke whales in the surveyed area is estimated as 23,100 individuals. Exact relationship between sea ice concentrations (IC) and abundance of Antarctic minke whales can not be estimated by the IDCR-SOWER data. However, it can be assumed that it is decreased as IC increased. In this analysis, it is assumed that abundance of Antarctic minke whales is decreased as functions of 1-(IC/100)^2, 1-IC/100 and 1-(IC/100)^0.5. Abundance of Antarctic minke whales within the sea ice field according to these functions are 11,300, 8,900 and 6,700 animals, respectively while 21,100 animals are estimated within sea ice field if the abundance is unaffected by IC. This is just a preliminary excise and the results are not conclusive. Nevertheless, the results of this study indicate abundance of humpback whales could affect the abundance of Antarctic minke whales. Consideration of environmental factors as well as distribution of other whales in open sea is necessary to estimate abundance of Antarctic minke whales in sea ice field. The results imply that abundance estimation within sea ice field only using recent aerial surveys could not be sufficient to estimate abundance within sea ice field in the period of the IDCR-SOWER. Incorporation of data obtained in sea ice field obtained by recent aerial surveys and the past IDCR/SOWER is required even if the goal is to obtain rough abundance estimates in sea ice field in the period of the IDCR-SOWER.

## INTRODUCTION

The International Whaling Commission (IWC) has conducted sighting surveys to assess the abundance of the Antarctic minke whale (*Balaenoptera bonaerensis*) since 1978/79 in the Antarctic in austral summer. The names of the cruises were firstly the International Decade of Cetacean Research programme (IDCR, from 1978/79 to 1995/96) and then the Southern Ocean Whale and Ecosystem Research programme (SOWER, from 1996/97 to 2009/10). These cruises covered three circumpolar surveys for the purpose of comprehensive assessments (Matsuoka, *et al.*, 2003): 1978/79-1983/84 (CPI), 1984/85-1990/91 (CPII) and 1991/92-2003/2004 (CPIII).

Abundance estimates based on the IWC standard method revealed that an appreciable difference of abundance between CPII and CPIII (Branch, 2006; Branch and Butterworth, 2001). The reasons of the difference have been investigated by the Scientific Committee of the IWC (IWC/SC) since 2001 (IWC, 2002a). Last year, the IWC/SC agreed abundance estimates of CPII and CPIII in the surveyed area (IWC, 2013). The agreed abundance estimates took account of a) probability of observing animals on the trackline, g(0), (b) school size distribution, (c) proportion of schools classified as like-minke and (d) trackline design. However, it was noted that no conclusion on whether (and if so to what extent) these numbers indicate a real decline in abundance of Antarctic minke whales between the periods of the two surveys (IWC, 2013).

Change in sea ice characteristics such as its extent and configuration has been considered as one of the influential factors on the difference since early years (IWC, 2002b; IWC, 2003; Murase and Bravington, 2012). Last year, high priority was given for further work examining reasons for the differences between estimates from CPII and CPIII (IWC, 2013). Increases in abundance of large baleen whales such as humpback whales in the two periods were reported in some of the IWC management area. It was indicated that expansion of distribution area of large baleen whales could affect the spatial distribution of Antarctic minke whales (Murase *et al.*, 2011b). It has not been investigated how changes in spatial distribution of large whales in the surveyed area affected the abundance of Antarctic minke whales within the sea ice field. In this paper, an abundance estimation method of Antarctic minke whales within sea ice field is considered.

## MATERIALS AND METHODS

Data obtained in Area IV in CPIII (1994/95 and 1998/99) by the IWC IDCR-SOWER are used. Standard data set prepared by Burt (2004) is used as data of sighting effort and sighting of Antarctic minke whales. Like minke whales are not considered. Increase rate of Humpback whales (*Megaptera novaeangliae*) in Area IV between the two periods was statistically significant (Branch, 2011; Matsuoka *et al.*, 2011). Because of this reason, Primary sighting data of humpback whales corresponding to the standard effort data are extracted from the IWC Database-Estimation System Software (DESS) (Strindberg and Burt, 2000) in this analysis to see the effect on Antarctic minke whales. The surveyed and sea ice field is divided into 30x30 km grid cells in the South Pole Lambert azimuthal equal area projection with central meridian at 100°E and latitude of origin at 65°S (1,970 and 564 grid cells, respectively). The effort data were divided into 1 km segments and then aggregated in the grid cells. The sighting data were also aggregated in the grid cells. To estimate density of whales in each grid cell, effective search width (esw) and mean school size (E(s)) were estimated based on the multiple-covariate distance sampling (MCDS) method (Thomas et al., 2010). Initially, activity code, cue, latitude, vessel and year are used as covariates in MCDS. Truncation distance for Antarctic minke and humpback whales are 1.5 (2.8km) and 3.0 (5.6km) n.miles, respectively. All sightings of each species are used to estimate esw while only sightings with confirmed school sizes are used to estimate E(s).

ETOPO1 Global Relief Model (Amante and Eakins, 2009) is used as seafloor depth. Original resolution of ETOPO1 is 1x1 arc minute grid cell. The location of the shelf break (800m isobath) is identified by using this data. Mean depth in each 30x30 km grid cell and distance between the shelf break and each grid cell are calculated using a geographic information system (GIS), ArcGIS version 10.0 (ESRI, Redlands, CA, USA). Satellite-derived sea ice data, the DMSP SSM/I Daily and Monthly Polar Gridded Bootstrap Sea Ice Concentrations (Comiso, 1990), is used to obtain sea ice concentrations at the time of the survey (Murase et al., 2011a). Because original resolution of SSM/I data is 25x25 km grid cell, slightly larger grid cell size (30x30 km) is chosen for spatial distribution model.

Two levels of GAM based spatial distribution models are considered in this paper as in the cases of Murase et al (2009; 2013). Firstly, probability of occurrence of Antarctic minke whales in grid cells is estimated. Abundance of Antarctic minke whales given the probability is then estimated. Actual abundance of whales is product of the two levels. Because availability of environmental data as covariates of the models are limited in the period of the IDCR-SOWER especially within sea ice filed, only distance from shelf break and seafloor depth are considered. Because abundance of humpback whales increased from CPII to CPIII in Area IV, it is included as a potential covariate. Longitude is also used as a covariate because the environmental covariates used in this analysis might not capture longitudinal heterogeneity. A spatial smoother using GAM having a binomial error distribution with the logistic link function was assumed for the first stratum modeling. GAM with a Gamma error distribution with the log link function was used for the second stratum modeling. Smoothness parameters were estimated with the generalized cross-validation (GCV). For these analyses, the mgcv package (Wood, 2006) version 1.7-16 of R software (version 2.15.0; R Development Core Team, 2012) was used. According to Wood (2001), a covariate with the largest p-value was discarded in each step until the lowest GCV scores were reached. Shapes of the functional forms for the all covariates were also plotted by using the package. Abundance of Antarctic minke whales in the surveyed area was firstly estimated using the GAMs. Abundance of Antarctic minke whales within sea ice filed is then estimated by using the models in the surveyed area. Abundance of humpback whales is also estimated in same manner. Exact relationship between sea ice concentrations (IC) and abundance of Antarctic minke whales can not be estimated by the IDCR-SOWER data. However, it can be assumed that it is decreased as IC increased in general sense. In this analysis, it is assumed that abundance of Antarctic minke whales is decreased as functions of 1-(IC/100)^2, 1-IC/100 and 1-(IC/100)^0.5. It is assumed that abundance of humpback whales within sea ice field is not affected by IC.

## RESULTS AND DISCUSSION

Sighing positions of humpback and Antarctic minke whales with respect to sea ice and seafloor depth are shown in Figs. 1 and 2. Sea state and year, and cue are selected as covariates to estimate esw and E(s) of humpback whales. Estimated esw and E(s) of humpback whales are 1.46 n.miles (2.7km; CV=12.4%) and 2.07 animals (CV=7.2%). Activity code, cue and year are selected as covariates to estimate esw and E(s) of Antarctic minke whales. Estimated esw and E(s) of Antarctic minke whales are 0.61 n.miles (1.1km; CV=7.9%) and 1.65 animals (CV=8.3%). A total of 478 grid cells was used in the modeling. Among them, 97 and 103 grid cells were treated as presence of humpback and Antarctic minke whales. Selected GAMs are summarized in Table 1.

Longitude and distance from the shelf break (linear term) are selected in both the first and second levels of humpback whale models. The shapes of the functional forms for the selected covariates are shown in Figs. 3 and 4. Abundance of humpback whales in the surveyed area and the sea ice field are estimated as 36,300 and 2,000 animals, respectively. Estimated spatial distribution of humpback whales in the surveyed area and within the sea ice field are shown in Fig. 5.

Depth and abundance of humpback whales are selected in the first level of Antarctic minke whale model. Longitude, distance from shelf break and abundance of humpback whales are selected in the second level of Antarctic minke whale model. The shapes of the functional forms for the selected covariates are shown in Figs. 6 and 7. Abundance of Antarctic minke whales in the surveyed area is estimated as 23,100 individuals. Estimated spatial distribution of Antarctic minke whales in the surveyed is shown in Fig. 8. Abundance estimates of Antarctic minke whales in the sea ice field assuming abundance of Antarctic minke whales is decreased as functions of 1-(IC/100)^2, 1-IC/100 and 1-(IC/100)^0.5 (Fig. 9) are 11,300, 8,900, 6,700 animals, respectively while 21,100 animals are estimated within sea ice filed if the abundance is unaffected by IC. Estimated spatial distribution of Antarctic minke whales in the sea ice field based on these assumptions is shown in Fig. 10.

This is just a preliminary excise and the results are not conclusive. Nevertheless, the results of this study indicate abundance of humpback whales could affect the abundance of Antarctic minke whales. The results imply that abundance estimation within sea ice field only using recent aerial surveys could not be sufficient to estimate abundance within sea ice field in the period of the IDCR-SOWER. Consideration of environmental factors as well as distribution of other whales in open sea is necessary to estimate abundance of Antarctic minke whales in sea ice field. Several cetacean sighting surveys were conducted in the sea ice field (Kelly *et al.*, 2008; 2009; 2010; Scheidat *et al.*, 2011) and abundance estimation methods using these data have been considered (Kelly *et al.*, 2012). Incorporation of data obtained by the recent sea ice field surveys and the past IDCR/SOWER is required even if the goal is to obtain rough abundance estimates in sea ice field in the period of the IDCR-SOWER.

The estimated abundances of humpback and Antarctic minke whales in the surveyed area in this study are overestimated in comparison with the estimates by the IWC standard method as reported in Branch (2006) and Branch 2011. In addition, probability of observing Antarctic minke whales on the trackline, g(0), is assumed 1 in this study. These aspects should be considered further in the future research.

## ACKNOWLEDGEMENT

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Table 1. Selected GAM-based, spatial distribution models for humpback and Antarctic minke whales. Approximate significance levels (P-value) and effective degrees of freedom (edf) are shown for each of the covariates.

| | Humpback whales | | | | Antarctic minke whales | | | |
|---|---|---|---|---|---|---|---|---|
| | 1st | | 2nd | | 1st | | 2nd | |
| Family | Binomial | | Gamma | | Binomial | | Gamma | |
| Link function | Logit | | log | | Logit | | log | |
| Adjusted $R^2$ | 0.20 | | 0.16 | | 0.15 | | 0.12 | |
| Deviance explained (%) | 22.1% | | 45.3% | | 14.4% | | 38.7% | |
| GCV score | 0.82 | | 0.86 | | 0.94 | | 0.64 | |
| | edf | p-value | edf | p-value | edf | p-value | edf | p-value |
| *Covariates* | | | | | | | | |
| Longitude | 7.91 | <0.01 | 8.73 | <0.01 | - | - | 3.00 | <0.01 |
| Distance from shelf break | (used in linear term) | | (used in linear term) | | - | - | 4.57 | <0.01 |
| Seafloor depth | - | - | - | - | 6.76 | <0.01 | - | - |
| Abundance of humpback whales | - | - | - | - | 4.05 | <.001 | 4.81 | 0.02 |

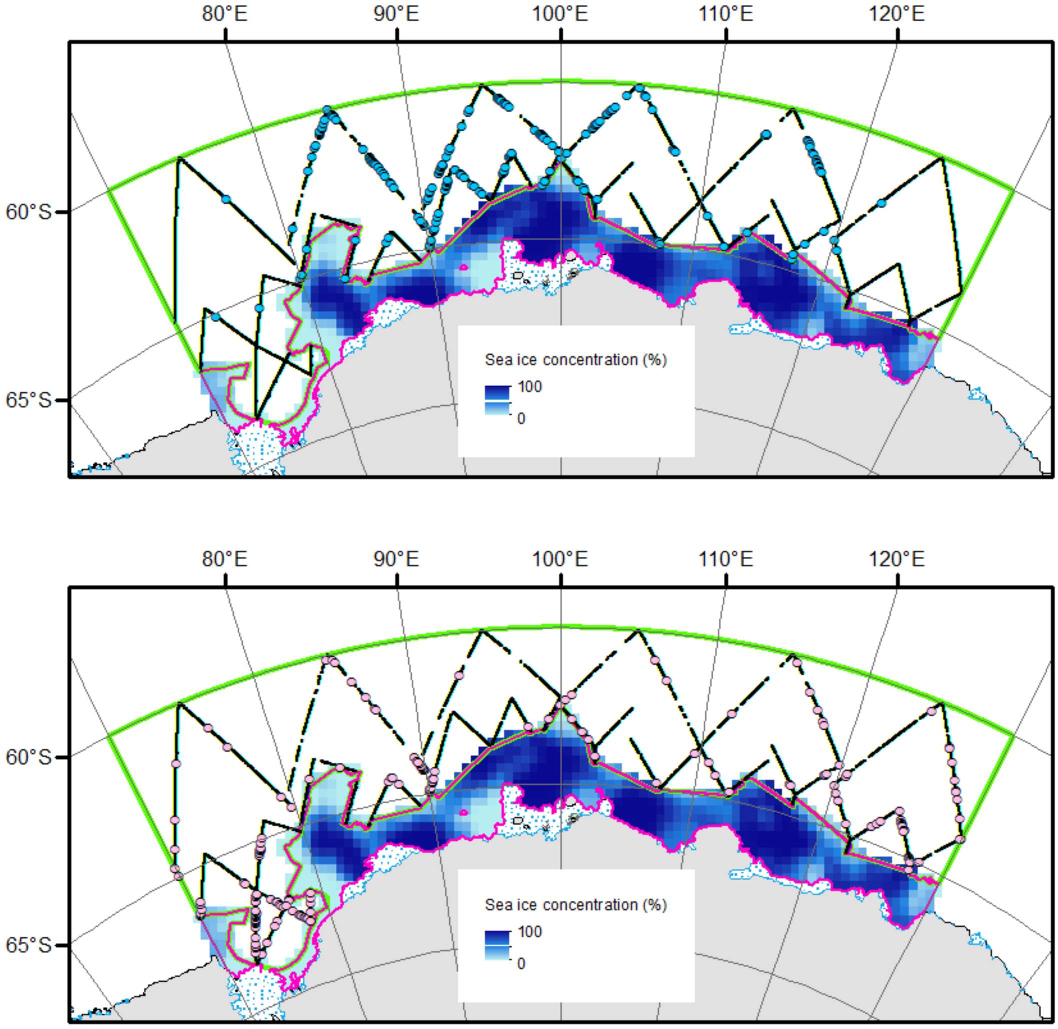



Fig. 1. Sighting positions of humpback (top) and Antarctic minke whales (bottom). Sea ice concentrations at the time of the survey are also shown. Sky blue and pink circles represent sighting positions of humpback and Antarctic minke whales. Black, green and purple lines represent the sighting effort, surveyed area, and sea ice field, respectively.

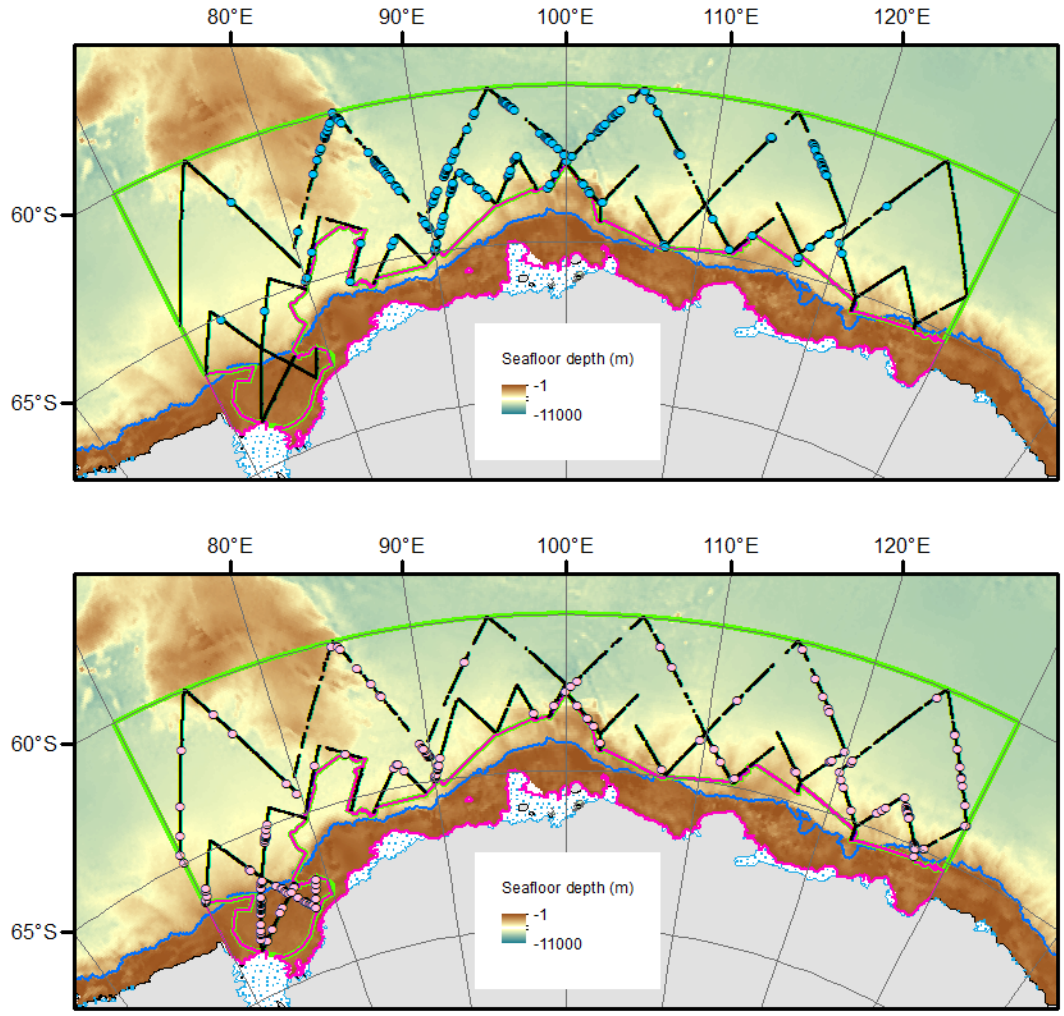



Fig. 1. Sighting positions of humpback (top) and Antarctic minke whales (bottom). Seafloor depth is also shown. Sky blue and pink circles represent sighting positions of humpback and Antarctic minke whales. Black, blue, green and purple lines represent the sighting effort, shelf break (800m isobath), surveyed area, and sea ice field, respectively.

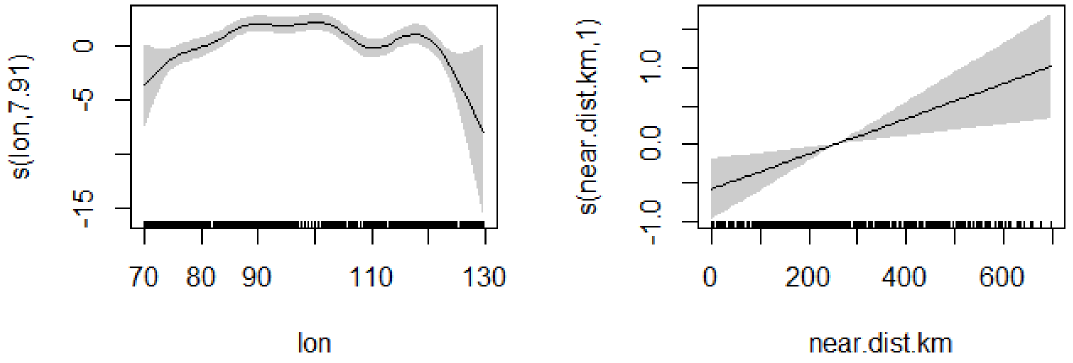



Fig. 3. Smoothed fits of selected covariate modeling the probability of occurrences of humpback whales. Tick marks on the x-axis are observed data points. The shaded areas indicate the 95% confidence bounds. Lon: longitude, near.dist.km: distance from the shelf break. The graph of the near.dist.km is shown for illustrative purpose as this covariate is used as a linear term.

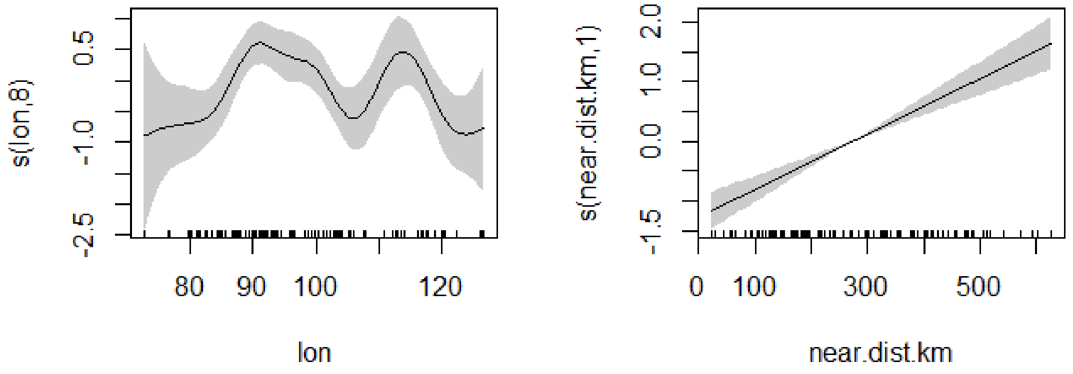



Fig. 4. Smoothed fits of selected covariate modeling the abundance of humpback whales given presence. Tick marks on the x-axis are observed data points. The shaded areas indicate the 95% confidence bounds. Lon: longitude, near.dist.km: distance from the shelf break. The graph of the near.dist.km is shown as illustrative purpose as this covariate is used as a linear term.

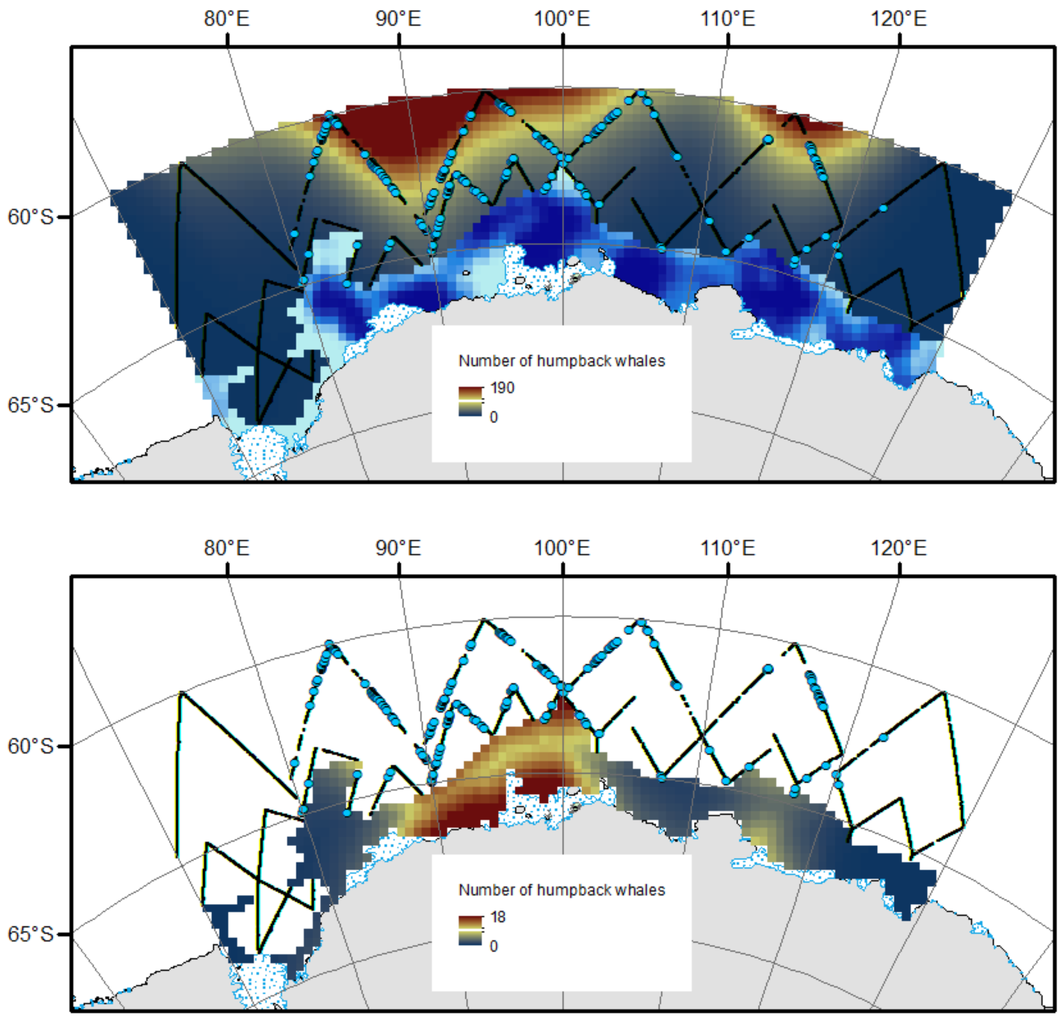



Fig. 5. Estimated spatial distribution of humpback whales in the surveyed area (top) and within the sea ice field (bottom). It is assumed that abundance of humpback whales within the sea ice field is unaffected by sea ice concentrations. Note difference of scales of color bars in the figure.

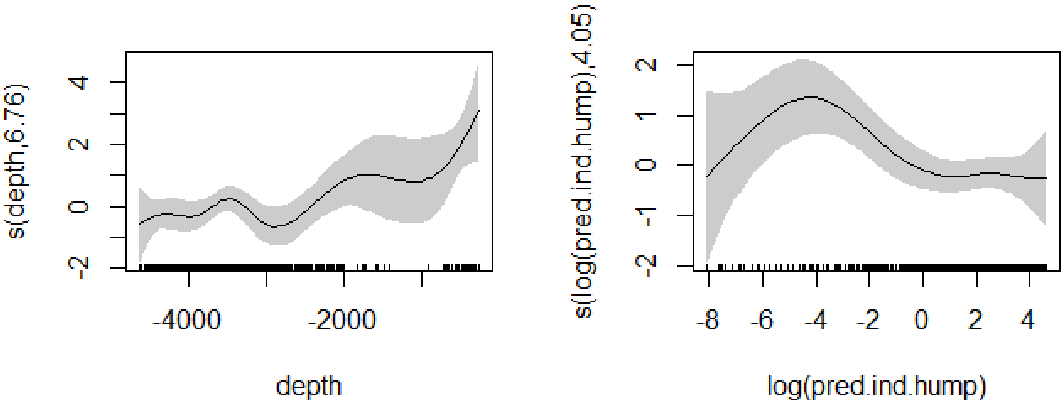



Fig. 6. Smoothed fits of selected covariate modeling the probability of occurrences of Antarctic minke whales. Tick marks on the x-axis are observed data points. The shaded areas indicate the 95% confidence bounds. Depth: seafloor depth (m), log(pred.ind.hump); natural logarithm of estimated abundance of humpback whales.

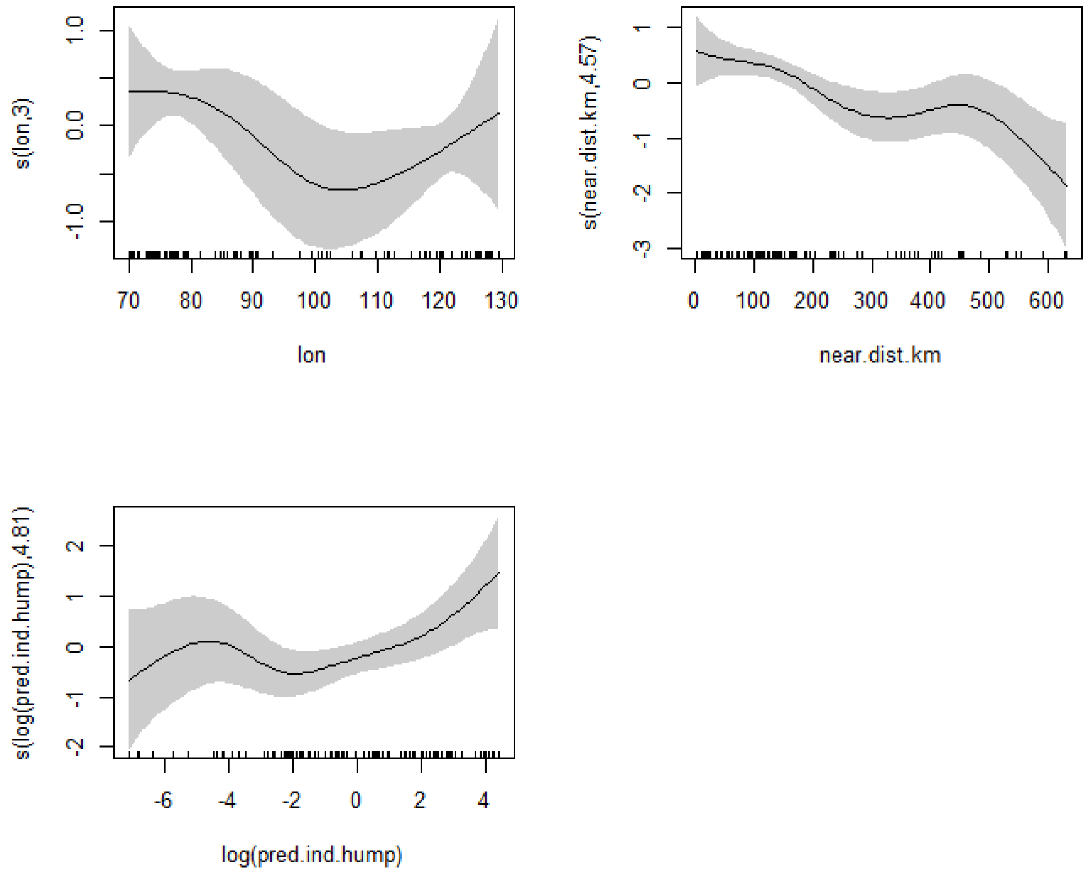



Fig. 7. Smoothed fits of selected covariate modeling the abundance of Antarctic minke whales given presence. Tick marks on the x-axis are observed data points. The shaded areas indicate the 95% confidence bounds. Lon: longitude, near.dist.km: distance from the shelf break, log(pred.ind.hump); natural logarithm of estimated abundance of humpback whales.

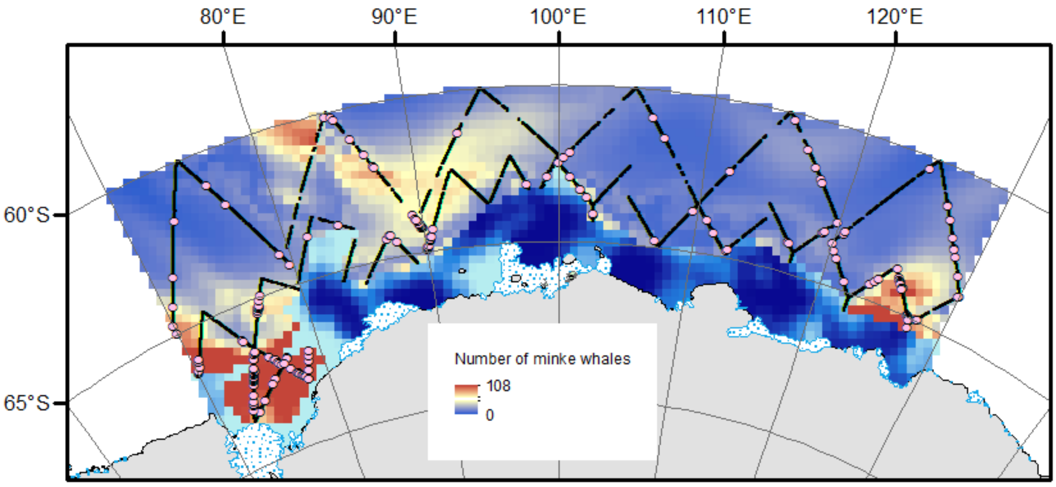



Fig. 8. Estimated spatial distribution of Antarctic minke whales in the surveyed area.

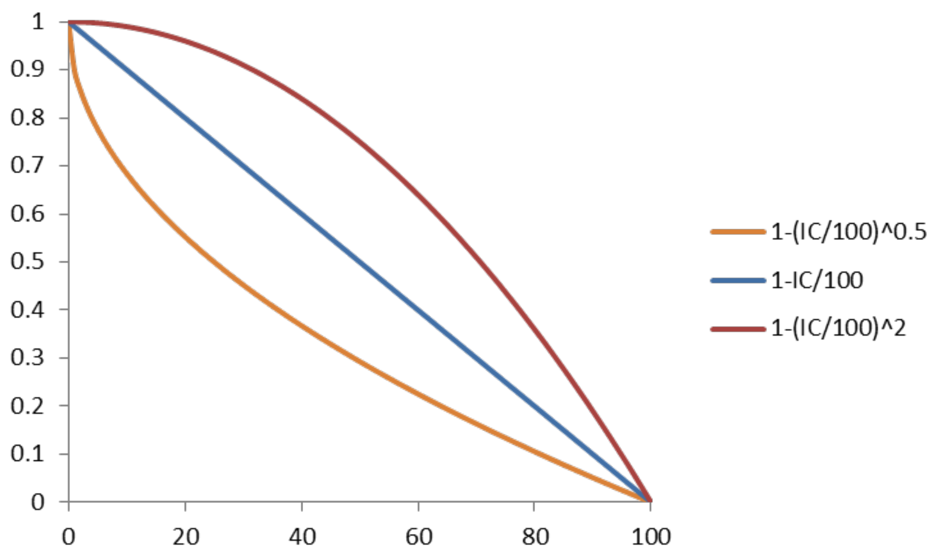
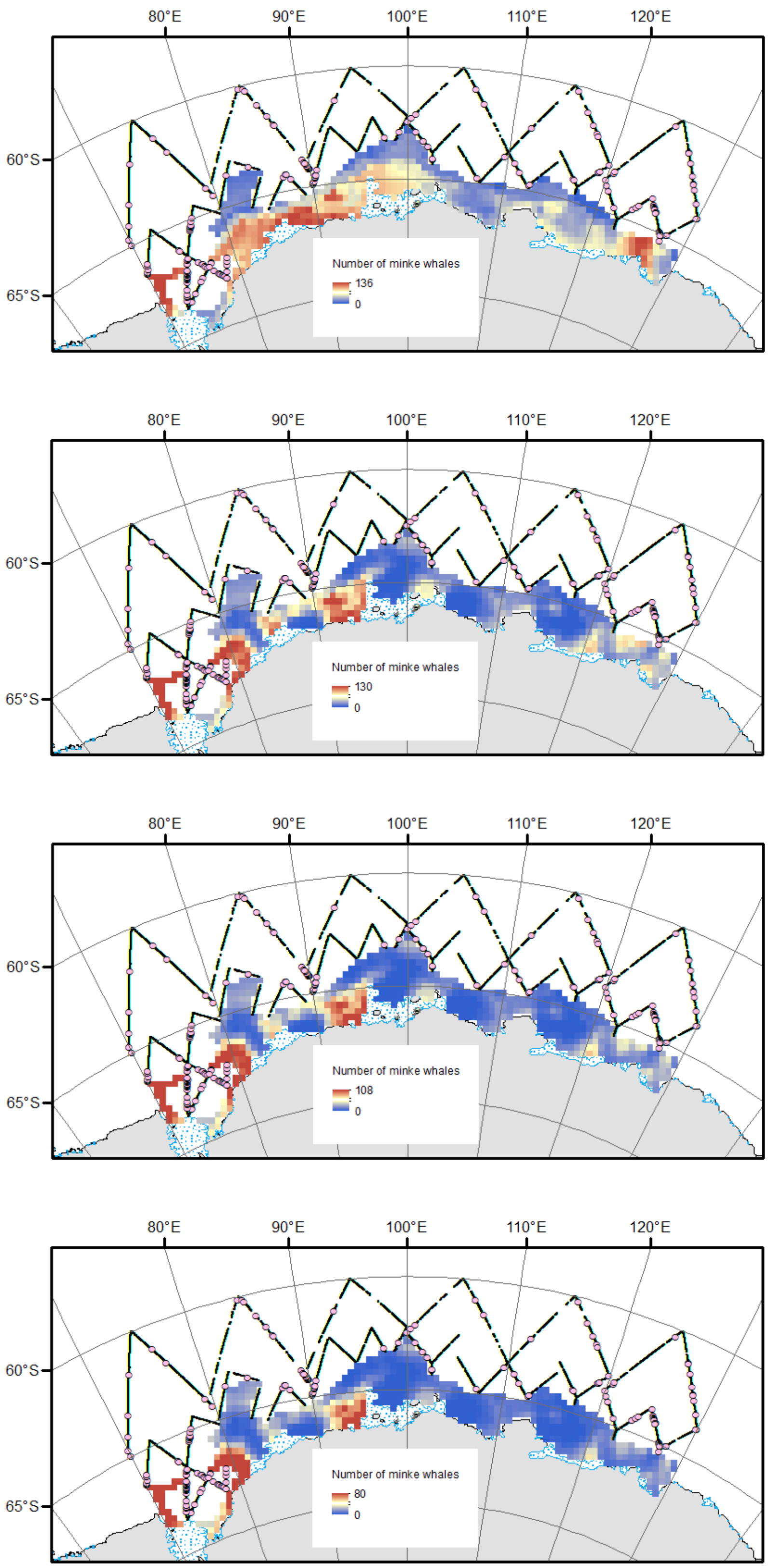



Fig. 9. Assumed functions to decrease abundance of Antarctic minke whales within sea ice filed in relation to sea ice concentrations (IC).




(a)

(b)

(c)

(d)

Fig. 10. Estimated spatial distribution of Antarctic minke whales within the sea ice field. Abundance unaffected by sea ice concentrations (IC) (a), and abundance decreased as functions of 1-(IC/100)^0.5 (b), 1-IC/100 (c) and 1-(IC/100)^2 (d). Note difference of scales of color bars in the figure.