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Assessing the environmental preferences of seabirds and spatial distribution of seabirds and marine mammals in the Southern Ocean Ross Sea region in late summer

New Zealand Aquatic Environment and Biodiversity Report No. 121.

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ISSN 1179-6480 (online)
ISBN 978-0-478-42333-4 (online)

January 2014

New Zealand Government

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Boosted regression tree models were used to model the relationships between available remote-sensed environmental data and four species of seabird, based on presence/absence data from the BioRoss *RV Tangaroa* voyage in February-March 2006 and presence data from CCAMLR observers in January-February 2006. Two species, Antarctic petrel (*Thalassoica antarctica*) and snow petrel (*Pagodroma nivea*), breed in the Antarctic and have an affinity to ice, whereas the wide-ranging cape petrel (*Daption capense*) and southern giant petrel (*Macronectes giganteus*) are more commonly found over open water. The environmental variables described large-scale physical and chemical oceanography as long-term averages and inter-annual variability, as well as distance from the shelf break.

Cross-validation within the models indicated that the models performed moderately well for Antarctic, cape, and snow petrels, with 83–88% probability that for any two random points the model correctly assigns them as present or absent (measured as the Area Under the Curve or AUC). The AUC value for southern giant petrel was lower at 70%. The distribution of each seabird species was influenced by different variables, with the most important factor being distance from shelf break for Antarctic petrels (explaining 50.2% of the deviance), circulation-modelled average surface temperature for snow petrels (57.6%), ice cover for cape petrels (42.4%), and chlorophyll summer maxima for southern giant petrels (26.2%). The area where the environmental conditions were predicted to be most suitable for Antarctic petrels was defined as the shelf break south to the eastern Ross Sea shelf edge. Favourable conditions for snow petrels included the wider shelf break-shelf area east of 180° and close to the coast on the western edge of the Ross Sea shelf, areas where ice cover is more persistent. In comparison, the most suitable conditions for cape petrels were predicted to be well north of the shelf break between 60° and 70° S. Lastly, the less well-performing model for southern giant petrels predicted a small area where the most favourable conditions for this species were present, mostly at the shelf break between 180° and 170° W, and failed to identify the wider distribution indicated by a larger dataset of presence data collected by longline fishery observers.

This report also includes a summary of seabird and marine mammal distribution data in the Southern Ocean Ross Sea region as a repository of information not reported elsewhere. These spatial data were collected during various biodiversity surveys and by CCAMLR observers on longline vessels in the toothfish fishery.

1. INTRODUCTION

A wide variety of seabirds and marine mammals is known to either visit or be resident in the Ross Sea and waters north to the Polar Front (at about 60° S) (Ainley et al. 1984, Woehler & Croxall 1997, see Shirihai 2002, Bengtson et al. 2011). Resident species are generally closely associated with ice (for example, Adélie penguins (*Pygoscelis adeliae*) and snow petrels (*Pagodroma nivea*)), whereas visiting birds (for example, sooty shearwaters (*Puffinus griseus*) are more likely to be observed foraging in open waters associated with oceanographic features.

The distribution of marine taxa in this environment may be influenced by a number of environmental factors, including the distribution of ice cover, bathymetry and associated water masses, sea surface temperature, and oceanic winds (Ainley & Jacobs 1981, Ainley et al. 1984, Hunt 1991, Stirling 1997, Bost et al. 2009, Ainley et al. 2010, Ballard et al. 2010). These factors may drive the availability and type of food resources (for example, Smith et al. 2007, Pinkerton et al. 2010a). Within the Ross Sea, salinity gradients, distance to the pack ice edge, and ice type are important factors in determining the distribution of species and species assemblages (for example, Ainley et al. 1984). Sea ice acts as a barrier to some seabird species, but the waters at the sea ice edge are rich in plankton and fish as an extension of the under-ice community (Hunt 1991). In the open waters, strong frontal systems result in increased productivity and thus influence foraging distributions (Pakhomov & McQuaid 1996, Ribic et al. 2011).

At the species or taxa level, the timing of the breeding season and associated events such as moult for penguin species, the life stage of the bird, the distribution of the preferred or available prey, and the uneven distribution of some species within their range will be important influences in the full at-sea extent of distribution. Human influences such as the presence and distribution of ships and fishing vessels also play their part; for example, by extending the southern range of birds known to be ship-followers or by opening up areas through their passage through ice.

Knowledge of the spatial distribution of species is fundamental for maintenance of biodiversity and identification of areas for conservation. Species distribution data collection in isolated areas such as Antarctica is challenging and costly, and increasingly, species distribution modelling methods are used to identify and describe the environmental niche or suitable habitat for a species (see Guisan & Thuiller 2005).

The ready access to large scale modelled environmental datasets derived primarily from remote sensing, has provided researchers with a large variety of explanatory continuous variables in the form of long-term averages and inter-annual variability for developing and testing species distribution modelling approaches (for example, see Elith et al. 2006, Leathwick et al. 2006, Phillips et al. 2006, 2009, Tremblay et al. 2009). One of the main drivers of the choice of species distribution model is whether the species data are presence-only data or are presence/absence data. In the Ross Sea area, several modelling approaches were used to model species distributions throughout the trophic web, on the seafloor, within the water column, and in surface waters or in the air (see Ainley et al. 2010, Ballard et al. 2010). The models used in these large bioregionalisation studies included MaxEnt which uses presence-only data (Phillips et al. 2006) and Boosted Regression Tree models (BRT) which can cater for presence/absence data (see Elith et al. 2008) and reported little difference in the outcomes. Others reported on the use of BRT to model a variety of species (Sharp et al. 2010), as well as a copepod within the water column in the Ross Sea area (Pinkerton et al. 2010b).

The BRT approach was considered a useful modelling tool in the above studies and was chosen as the analysis method for the objective addressed by this report, which was: *to explain the distribution of selected seabird species in and around the Ross Sea region – from remote-sensed modelled data.* However, several aspects of the BRT method should be noted here. The BRT models require presence and absence data, and we are assuming that there is no detection error or misidentification by the seabird observers and thus, when a species is not included in the count record, then it was not present. We are simply using the data points as binary representations of the counts originally recorded. These models require that the presence data for a species represent at least 10% of the total sampling points (presences and absences summed) (Barbet-Massin et al. 2012). Another important assumption is that the BRT method, and indeed, any predictive modelling method, assumes that there is a relationship between the environmental layers used and the species' spatial distribution. Therefore, we assume here that the long-term average sea surface temperature, for example, influences the distribution of the species modelled at the time of the observation records.

2. METHODS

2.1 The study area and base datasets

The study area (Figure 1) is defined by the distribution of the seabird sightings data made available for this work: a biodiversity survey to the Ross Sea in 2006 (referred to in this report as "TAN2006") and observer data from longline fishing activities ("CCAMLR2006") (described below). Thus, the study area includes the Ross Sea and waters north to 58° S, with east and west boundaries defined by the longitudinal extent of the 421 sampling stations from the TAN2006 voyage (MacDiarmid & Stewart in press). The sampling stations from the TAN2006 voyage were primarily from areas with depths over 1000 m, between latitudes 65° and 75° S, south of the main front activity in this area (Figure 1).

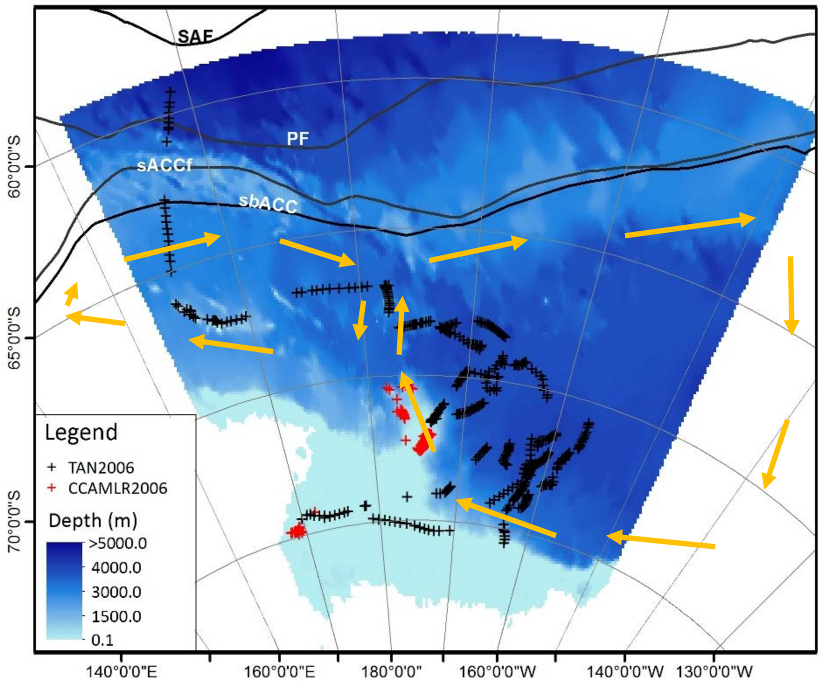

Figure 1: Locations of TAN2006 stations surveyed in February-March 2006 and CCAMLR observed longline sets in January-February 2006. SAF is the sub-Antarctic Front, PF is the Polar Front, sACCf is the southern Antarctic Circumpolar Current Front; and sbACC is the southern boundary of the Antarctic Circumpolar Current Front (from Orsi et al. 1995). The Ross Sea gyral system is indicated by orange arrows (see Hanchet et al. 2008).

2.1.1 Seabird sightings data

Standardised counts of seabirds used in this study were made during the TAN2006 biodiversity survey of the Ross Sea and Balleny Islands on *RV Tangaroa* during late January–early March 2006 (Mitchell & MacDiarmid 2006, MacDiarmid & Stewart in press, see Appendix 1). An instantaneous count and a 10-minute transect count of seabirds within about 300 m of the vessel were made at 421 stations on the hour every hour during daylight hours (when conditions allowed) using methods described by MacDiarmid & Stewart (in press). Seabirds within about 300 m of the vessel were counted during instantaneous counts. Each count was recorded with the associated station record (based on the location of the vessel) of position, time, and date and various environmental parameters logged by the vessel and researchers: wind speed and direction, ice cover, air temperature, and water temperature and salinity. Note that these environmental parameters were not used for modelling species distribution because global environmental parameters are required to predict the probability of presence of conditions favourable to a species, outside the sampled environment.

It was assumed that the recorded identifications were correct and that the seabird sightings data represented presences and absences for the seabird species. The species identified from this survey are given in Table 1.1 (Appendix 1). Note that the skuas were not identified to species level and thus ignored in this work. Of the 17 species reported from south of 60° S during the voyage (see Table 1.1 in Appendix 1), four had enough occurrence records for use in boosted regression tree modelling: Antarctic petrel (*Thalassoica antarctica*), cape petrel (*Daption capense*), snow petrel (*Pagodroma nivea*), and southern giant petrel (*Macronectes giganteus*). These four species formed the TAN2006 dataset. To assemble a dataset with enough presence data, we supplemented the TAN2006 data with the sightings (presence only) recorded by CCAMLR scientific observers on toothfish (*Dissostichus mawsoni*) longliners operating in the Ross Sea during January-February 2006. The CCAMLR data were not used for absences because it was unclear if the absence of a record of a specific bird species was due to the absence of the bird or the absence of a record. Figure 1 shows the distribution of these CCAMLR data where sightings of the chosen species were recorded. The TAN2006 and CCAMLR2006 data were combined to create the presence/absence modelling dataset.

A further dataset was created from opportunistic sightings recorded by researchers during a 2008 summer survey to the Ross Sea and from observations recorded by CCAMLR observers during 1997–2009 to document presence data from other sources (see Appendix 1).

2.1.2 Environmental data layers

For this study, a selection of available environmental data variables considered most relevant to Ross Sea seabirds was chosen from those collated for the Ross Sea Bioregionalisation spatial planning workshop of CCAMLR (Pinkerton et al. 2009, Sharp et al. 2010). A set of 12 variables was used, after the removal of some correlated variables from a possible set of 17. These are dominated by physical and chemical oceanographic variables (Table 1) and include both long-term averages of environmental properties and their interannual variability (Figures 2a and 2b).

Table 1: The twelve variables chosen for use in modelling the environmental preferences for the seabird species after Pinkerton et al. (2009). Figures 2a and 2b show the spatial distribution of these variables.

Variable	Description
depth	Average water depth, in metres, derived from GEBCO Digital Atlas (IOC, IHO and BODC, 2003).
depthanom	Difference (anomaly) between smoothed bathymetry (obtained using a median over a sliding 2° x 2° window) and the bathymetry (depth) layer (Burrough & McDonnell 1998).
slope	Derived from the bathymetry (depth) layer in ArcGIS based on the change in elevation from one pixel to the surrounding pixels.
ice15mean	Mean proportion of the time in a year for which ice concentration is under 15%, averaged between 1997 and 2006 (Cavalieri et al. 1990, updated 2007).
ice15sd	Standard deviation of the ice15mean (Cavalieri et al. 1990, updated 2007).
icefeb	Average ice concentration during February, based on 1979–80 to 2006–07 seasons (Cavalieri et al. 1990, updated 2007).
chlamax	Maximum SeaWiFS surface chlorophyll-a in summer (December–February), log-averaged between 1997 and 2007 (Hooker et al. 1992, NASA 2008).
sstsum	Mean summer (December–February) surface water temperature between 1991 and 2006 (Reynolds & Smith 1994).
sstsumsd	Standard deviation of summer sea surface temperatures (sst) between 1991 and 2006 (Reynolds & Smith 1994).
shelfbreak	Distance from the shelf break (defined by the 1000 m bathymetric contour, where offshore is positive and towards shore is negative).
speedsurf	Annual average current speed at the surface estimated by combining modelled meridional and zonal velocities (Schaffrey et al. 2009).
THIGEMsurf	Annual average temperature at the surface estimated by combining modelled meridional and zonal velocities (Schaffrey et al. 2009)

The data are largely derived from satellite observations and research vessel sampling and cover the extent of the area of the seabird sightings data, with values gridded at a nominal 4 km, in a polar stereographic projection. All the datasets chosen had full coverage of the study area. The environmental data may relate to the distribution of seabird species in different ways and may be proxies for other variables for which no data were available or for environmental complexity (Pinkerton et al. 2010b).

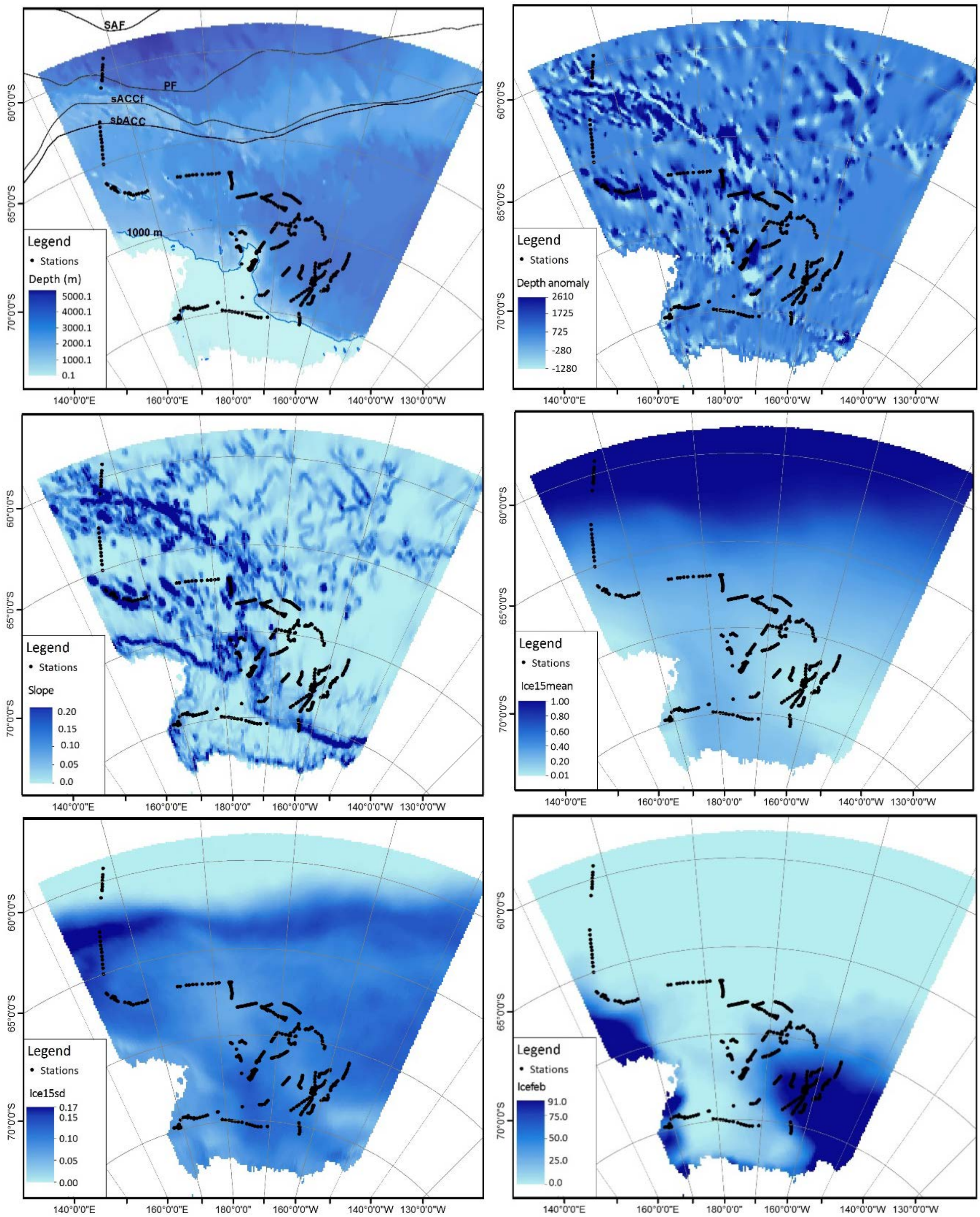

Figure 2a: Station data for the presence-absence dataset are plotted over environmental variable data for the study area, left to right from top to bottom, for variables given in Table 1: *depth*, depth anomaly *depthanom*, *slope*, < 15% ice coverage *ice15mean*, standard deviation of < 15 ice coverage *ice15sd*, and ice in February *icefeb*.

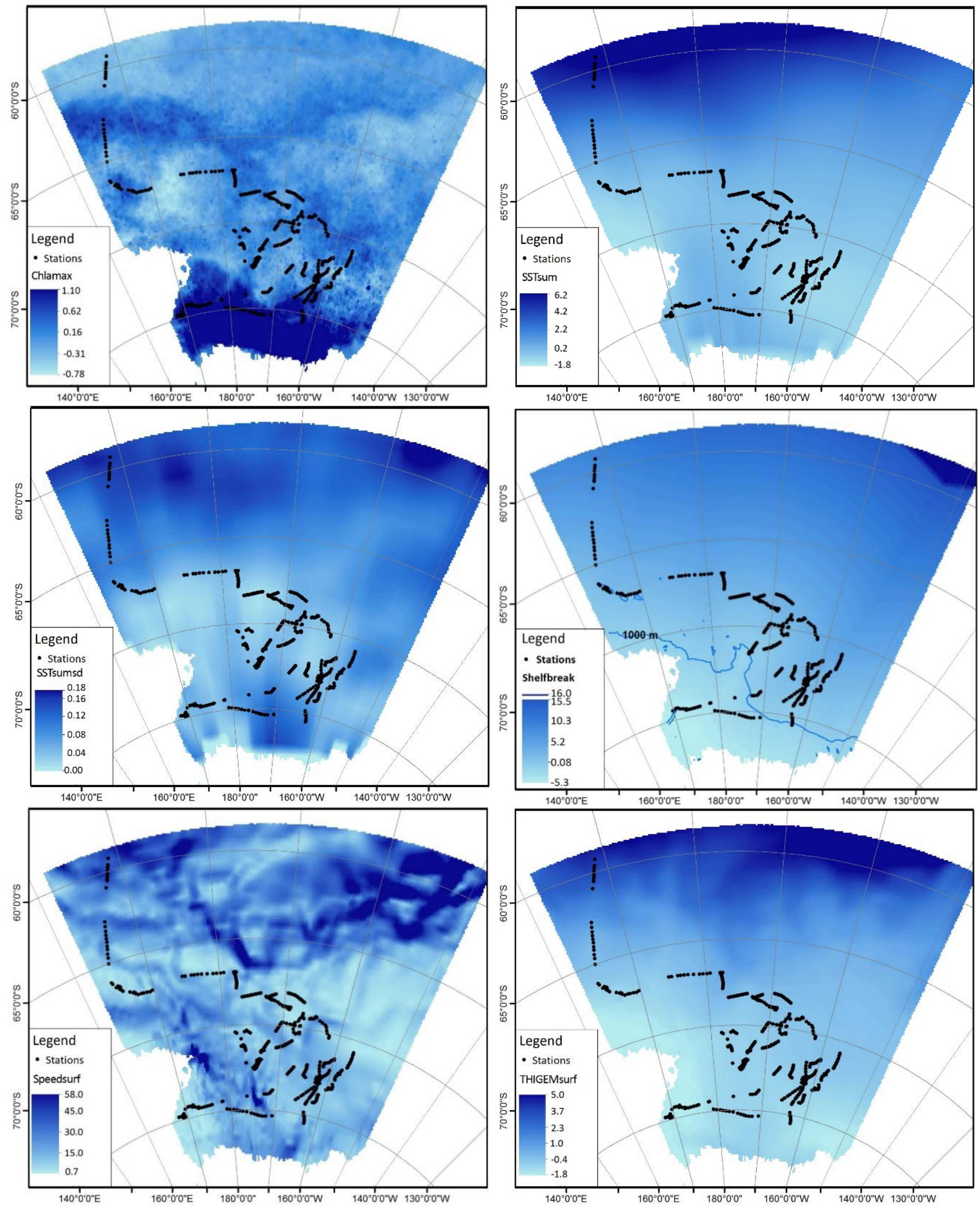

Figure 2b: Station data for the presence-absence dataset are plotted over environmental variable data for the study area, left to right from top to bottom, for remaining variables given in Table 1: maximum chlorophyll-a *chlamax*, summer sea surface temperature *sstsum*, standard deviation of summer sea surface temperature *sstsumsd*, distance from shelf break *shelfbreak*, surface current speed *speedsurf*, and surface temperature *THIGEMsurf*.

It is likely that most relate indirectly to the seabirds through their influence on the availability of prey, especially at the sea surface. The 12 data files were combined into one environmental dataset, restricted to the latitudinal and longitudinal extent of the seabird sightings sampling data (as shown by the bathymetry layer in Figure 1).

2.2 Data analysis

The presence/absence dataset (defined above) and the environmental variable dataset were projected to an Antarctic polar stereographic projection based on the WGS84 spheroid, with the central meridian at 175° W and standard parallel at 71° S. The 12 variable environmental dataset was then used to extract values for each variable for the location points of the presence/absence dataset using bi-cubic spline interpolation function ‘surface’ in GMT (Generic Mapping Tools) v. 4.5 over a 5.5 km x 5.5 km grid. These values were added to the seabird data to create a dataset for modelling the environmental preferences of each species.

Boosted regression tree (BRT) modelling was used to determine the main environmental influences, based on the 12 available variables, driving the spatial distribution of the four seabird species in the Ross Sea area in late summer. The analysis was conducted using the R statistical software package (R Development Core Team 2013) and used the *gbm* functions by Ridgeway (2006, 2013) and the BRT method and modified scripts (Elith et al. 2008, Leathwick et al. 2006, Elith & Leathwick 2013). It uses recursive binary splits within a tree structure to explain the relationship between the response and predictor variables, and the model performance is improved (“boosted”) through a combination of many simple models (Elith et al. 2008).

The BRT models used the binomial error distribution of the Bernoulli family to predict the probability of occurrence of each of the selected species. Three main features control the BRT model fit: the “learning rate”, the number of trees, and the number of interactions that determine a split (“tree complexity”). The first two are optimised within each model run, and the third was tested by varying the interaction complexity to determine the most parsimonious model. By allowing interactions, the model reflects that a number of variables may create an environment preferred by the seabird species under investigation.

The model output includes a plot of the response distribution for each included variable and the measure of the relative performance of the predictor variables, shown as the relative contribution (%). Cross-validation measures estimated within the model (using 75% as training data and 25% as test data) are the percentage deviance explained and the Area Under Curve (AUC) value for which 0.5 indicates that the model has no discriminatory power and 1 indicates that the model always identifies the occurrence. Generally, a model with an AUC of over 0.7 is considered ‘useful’ (Swets 1988). Initially all 12 variables were offered to each model, and those showing little influence were removed and the model re-run. The final models here all had learning rates between 0.005 and 0.0005, with the optimum numbers of trees being between 1000 and 2000, and a tree complexity of 2 (equivalent to one interaction allowed between variables).

The distribution of sampling points as shown in Figure 1 suggested that weighting may be necessary to reduce bias towards highly-sampled areas; however, the model runs for cape petrels were the only ones that provided an improved model when weighting was used (as the increased percentage cross-validated deviance). Thus, for the final model for cape petrels, the presence and absence data were weighted by one over the number of sampling points in each 0.5° cell, therefore down-weighting samples taken close to each other.

For each species, the optimised model was used to predict the probability of presence of the favoured environmental space for that species in the Ross Sea area, confined to the minima and maxima of the variable values in the presence-absence data. The prediction datasets, including the associated CVs were exported into GIS for display and interpretation.

3. RESULTS

The distribution of the main predictor variables for the full number of variables for the area in which the predictions were made and for the presence/absence data sets are shown in Appendix 2.

Instances of snow petrel and Antarctic petrel sightings were more common than for cape petrel and southern giant petrel (Table 2). About 50% of the sampling stations in the presence/absence dataset had records for Antarctic and snow petrels, whereas fewer than 25% had records of cape and southern giant petrels. The distributions of the sightings data for these species, using all the available data from CCAMLR observers and the two research trips on *Tangaroa* are shown in Appendix 1 in Figure 1.15 (Antarctic petrel), Figure 1.16 (cape petrel), Figure 1.14 (snow petrel), and Figure 1.9 (giant petrels). The modelling results and predictions are provided in Tables 2 and 3 and Figures 3–10.

The cross-validation measures suggest that the models for all species, other than the southern giant petrel, did moderately well, with between 43% and 51% of deviance explained and AUC values of 0.83–0.88 (see Table 2), meaning that for any two random points, there is 83–88% probability that the model correctly assigns them as present or absent.

3.1 Main predictor variables

At least 8 variables were included in the final models for the four species (see Table 2). Different variables were dominant influences for each seabird species (Table 3). For Antarctic petrels, the *shelfbreak* variable was the largest contributor (at 50.2%, Figure 3), whereas the variable for the mean proportion of the time when there was less than 15% ice cover (*ice15mean*) was dominant (42.4%, Figure 5) for Cape Petrels. The average annual temperature at the surface was the greatest influence on the snow petrel distribution (57.7%, Figure 7). The southern giant petrel influences were less well defined, with the greatest influence coming from the surface chlorophyll maximum (*chlamax*) at 26.2% (Figure 9), with added influences from the temperature-related variables of average annual surface temperature (*THIGEMsurf*) at 13.6% and mean summer sea surface temperatures (*sstsum*) at 11.7%, *ice15mean* (10.9%), and *shelfbreak* (10.9%).

Table 2: Summary of data input and model performance for each species. All models used family Bernoulli binomial error distribution and a tree complexity of 2. No weighting was used except for the cape petrel model. [AUC is the Area Under the Curve (see Section 2.2).]

Species	No. presences	No. absences	No. variables	% deviance explained	AUC
Antarctic petrel	264	258	9	43.0	0.83
Cape petrel	104	317	8	47.0	0.87
Snow petrel	294	237	8	51.0	0.88
Southern giant petrel	93	371	9	35.0	0.70

Table 3: The contribution (%) for each variable included in the final model, by species. Table 1 gives variable definitions. The highest contribution for each species is given in bold.

Variable	Antarctic petrel	Cape petrel	Snow petrel	Southern giant petrel
chlamax	5.0	17.6	3.1	**26.2**
depth	4.4	–	4.0	7.1
depthanom	–	4.06	–	–
ice15mean	4.0	**42.4**	15.4	10.9
ice15sd	6.9	–	–	8.3
shelfbreak	**50.2**	2.8	8.7	10.8
slope	3.5	–	3.1	5.6
speedsurf	6.3	7.3	3.2	–
sstsum	15.9	13.2	–	11.7
sstsumsd	3.8	6.8	4.8	5.9
THIGEMsurf	–	6.0	**57.6**	13.6

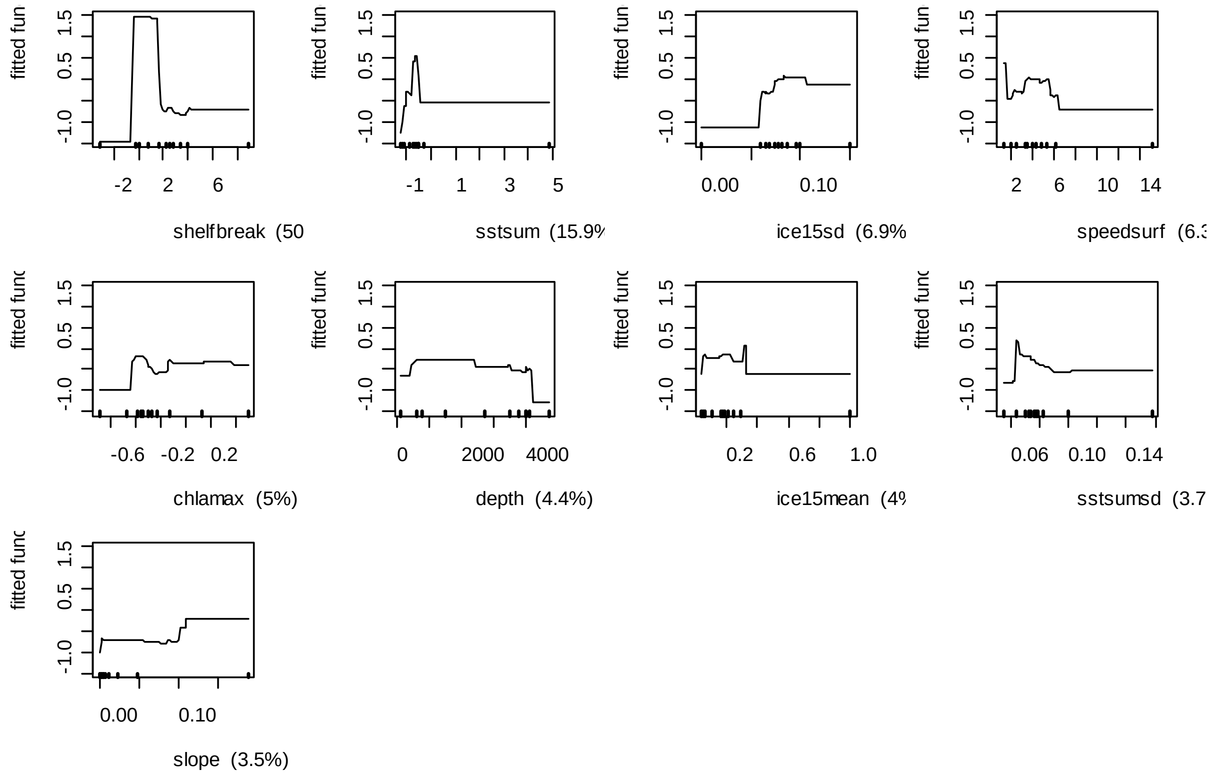

Figure 3: The fitted-functions produced from the Antarctic petrel boosted regression tree model which indicate the occurrence on the y-axis on a logit scale with a zero mean over the data distribution. The distribution of the full dataset across each chosen variable is shown as "rugs" on each x-axis, with each representing 10% of the data. The variable names are defined in Table 1.

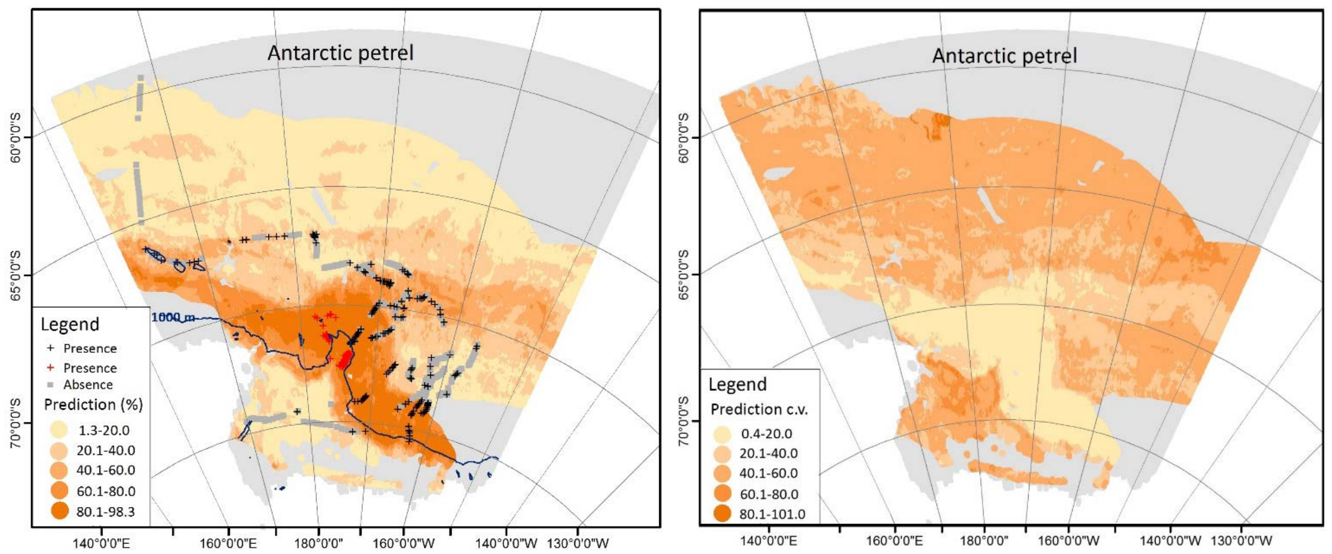

Figure 4: Distribution of Antarctic petrel presences by dataset (+ is TAN2006, + is CCAMLR) and absences overlaid on the predicted distribution (left), with the prediction CV (right). The continuous 1000 m contour indicates the area of the shelf break.

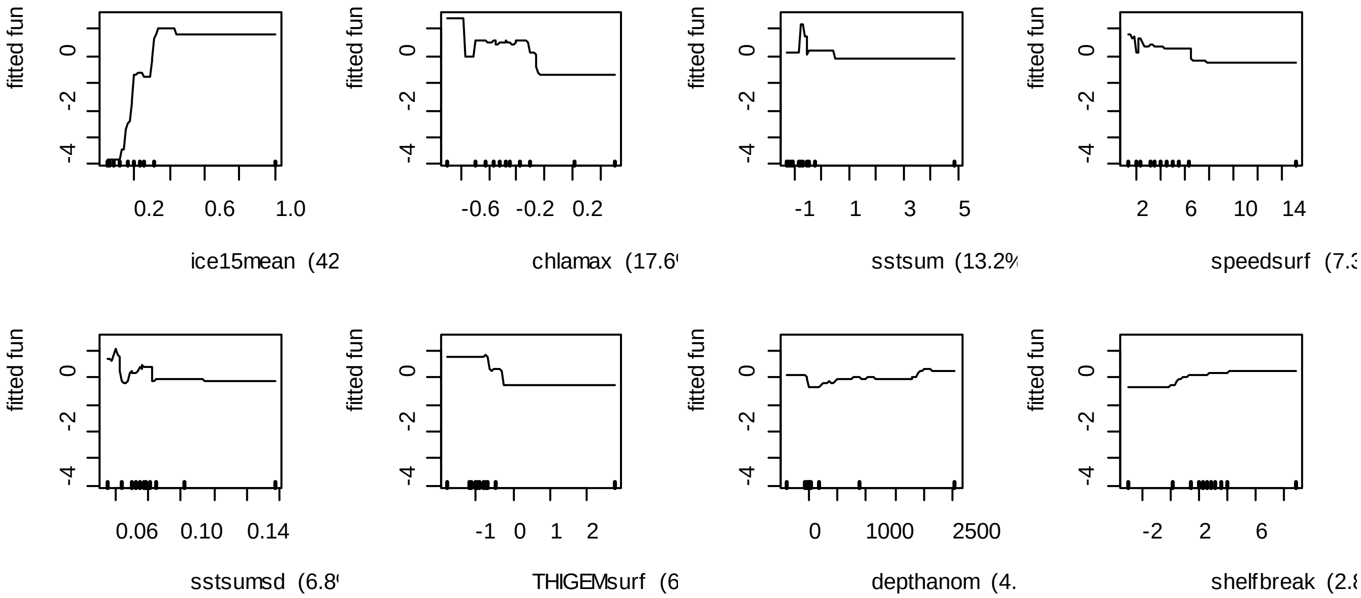

Figure 5: The fitted-functions produced from the cape petrel boosted regression tree model which indicate the occurrence on the y-axis on a logit scale with a zero mean over the data distribution. The distribution of the full dataset across each chosen variable is shown as "rugs" on each x-axis, with each representing 10% of the data. The variable names are defined in Table 1.

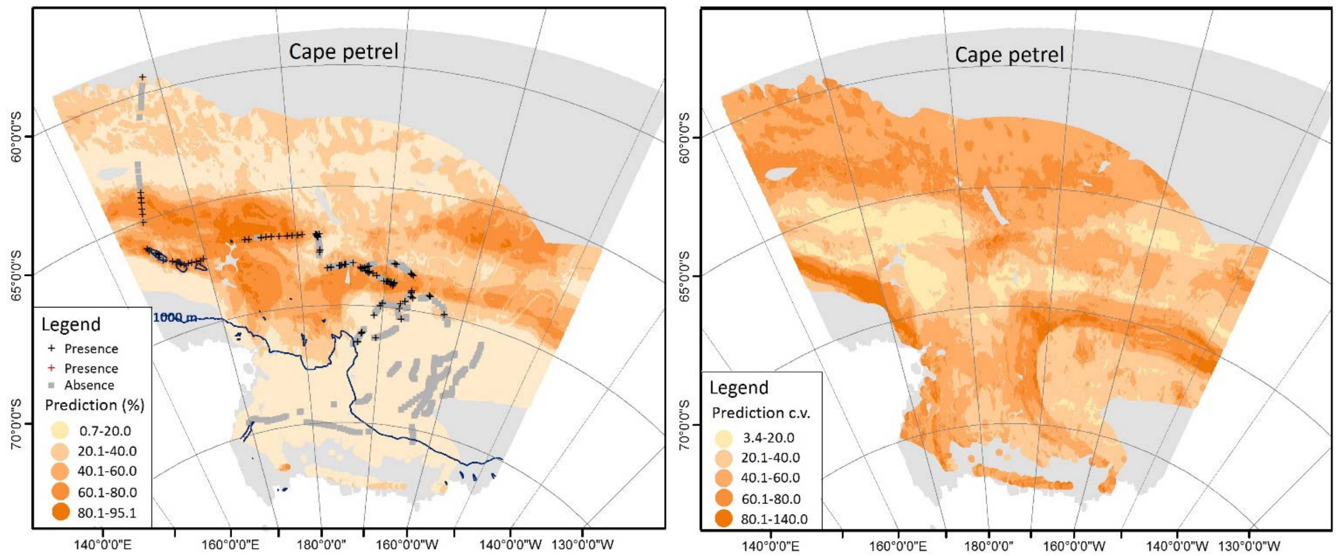

Figure 6: Distribution of cape petrel presences by dataset (+ is TAN2006) and absences overlaid on the predicted distribution (left), with the prediction CV (right). The continuous 1000 m contour indicates the area of the shelf break.

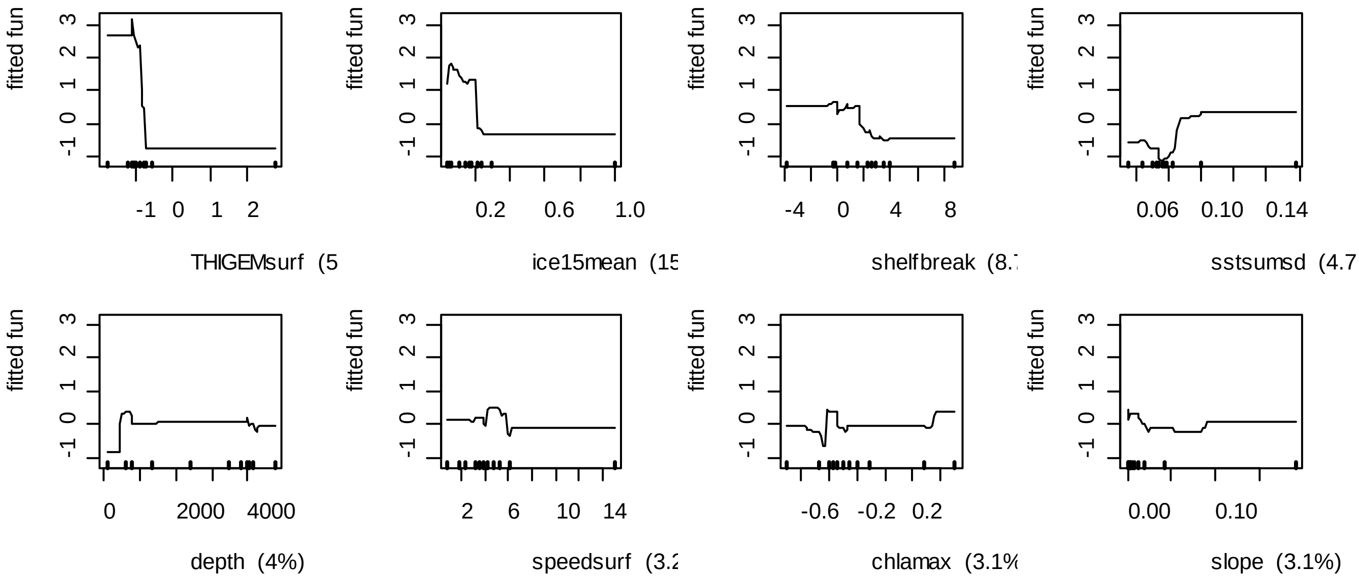

Figure 7: The fitted-functions produced from the snow petrel boosted regression tree model which indicate the occurrence on the y-axis on a logit scale with a zero mean over the data distribution. The distribution of the full dataset across each chosen variable is shown as "rugs" on each x-axis, with each representing 10% of the data. The variable names are defined in Table 1.

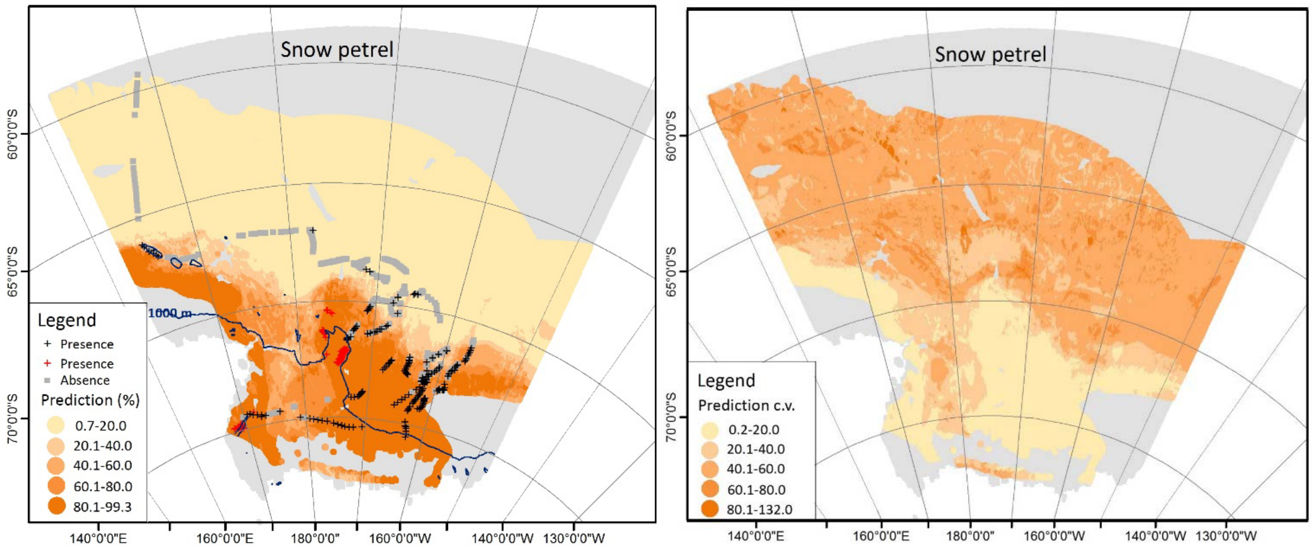

Figure 8: Distribution of snow petrel presences by dataset (+ is TAN2006, + is CCAMLR) and absences overlaid on the predicted distribution (left), with the prediction CV (right). The continuous 1000 m contour indicates the area of the shelf break.

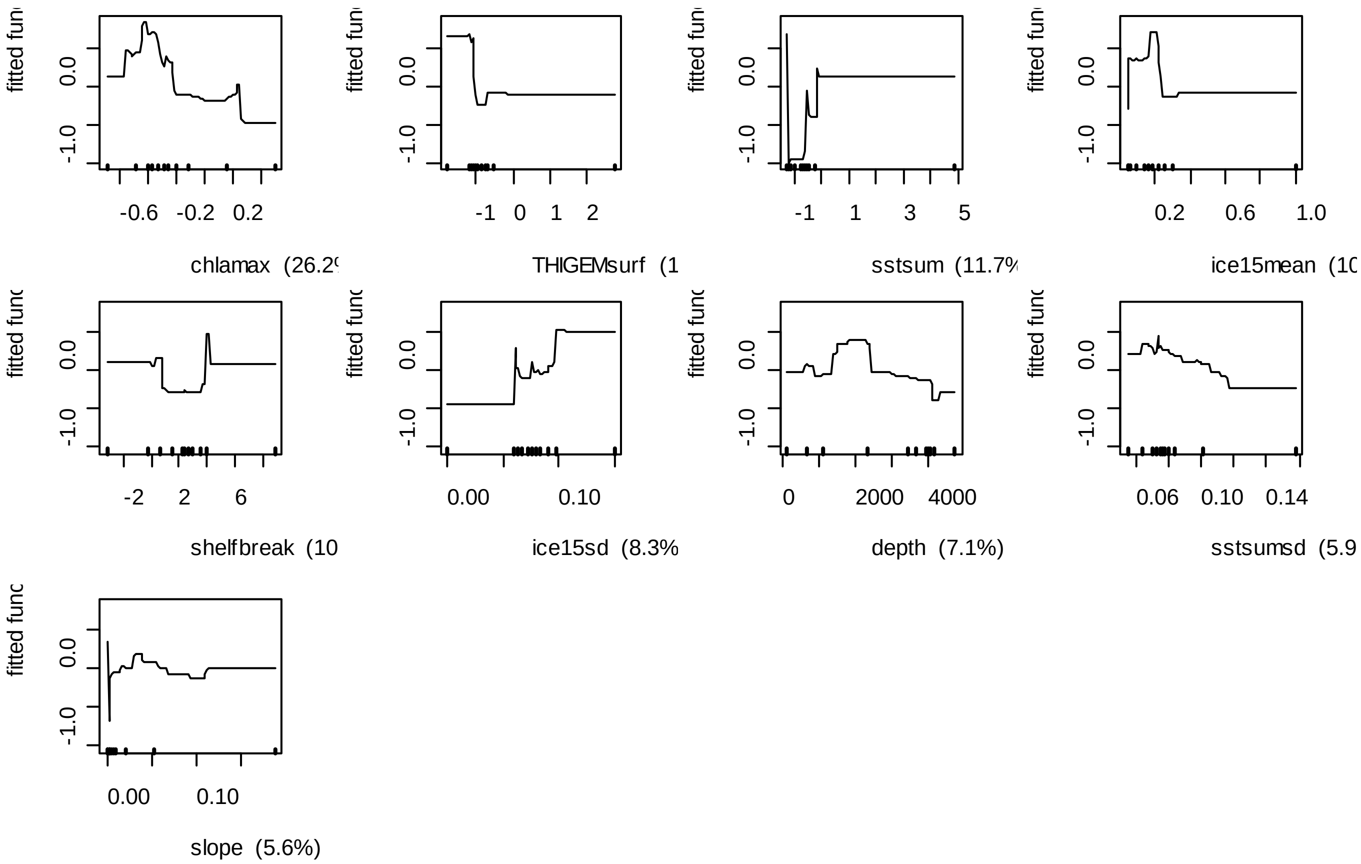

Figure 9: The fitted-functions produced from the southern giant petrel boosted regression tree model which indicate the occurrence on the y-axis on a logit scale with a zero mean over the data distribution. The distribution of the full dataset across each chosen variable is shown as "rugs" on each x-axis, with each representing 10% of the data. The variable names are defined in Table 1.

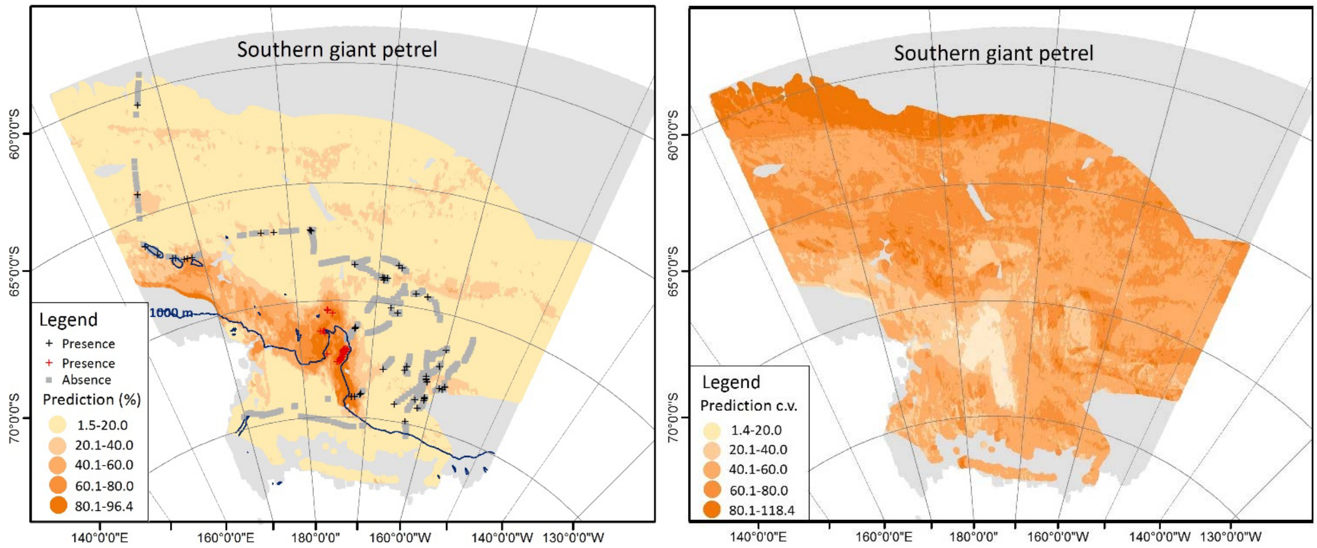

Figure 10: Distribution of southern giant petrel presences by dataset (+ is TAN2006, + is CCAMLR) and absences overlaid on the predicted distribution (left), with the prediction CV (right). The continuous 1000 m contour indicates the area of the shelf break.

The most significant variables in the interactions were *shelfbreak* with *ice15sd* for Antarctic petrels, *ice15mean* with *chlamax* for cape petrels, *THIGEMsurf* with *shelfbreak* for snow petrels, and *THIGEMsurf* with *chlamax* for southern giant petrels.

The importance of the dominant variables is evident in the final predictions that relate to each seabird species. The area predicted to have the environment conditions most preferred by Antarctic petrels is strongly associated with waters close to or immediately north of the shelf break, particularly south of about 70° S and east of 170° E (Figure 4). This area is also where the mean summer surface temperature is less than zero, and there is a (relatively) greater amount of inter-annual variation in ice cover and low-moderate levels of primary production. Most of the records of Antarctic petrel are located in this area, but a proportion of records are from areas where there is less likelihood of favourable conditions and less certainty in the prediction. This is especially evident in the areas of deeper waters east of 170° W between 70° and 74° S and further north in the vicinity of Scott Island (67.4° S, 179.92° W) and beyond where these birds have been recorded in the wider dataset (see Figure 1.15).

Conditions predicted to be most preferable for cape petrel were between 65° and 70° S (Figure 6) where the waters are likely to be relatively ice-free for a reasonable proportion of the year, chlorophyll-a levels are likely to be relatively low, with cooler surface water temperatures with little inter-annual variability, and relatively low surface speeds, away from the shelf break.

The prediction plot for snow petrels (Figure 8) shows sharply defined areas with the highest probability of encountering environmental conditions suitable for this species on the western and eastern Ross Sea across the shelf to the continental land mass, with very little chance of favoured conditions north of about 66° S. This strong signal indicates the influence of the relatively cold average annual temperatures from the variable *THIGEMsurf*, the relatively short time of the year when there is less than 15% ice cover, the larger variation in the summer surface temperature, and the shelf break.

Compared with predictions for the other species, the areas where the conditions match the influences on the distribution of southern giant petrels are more restricted, mainly to the waters reasonably close to the shelf break, particularly immediately east of 180° (Figure 10). The final BRT model for this species was the worst performer of the four models (see Table 2), and this species showed the widest spread of values for each variable included in the model. The prediction suggests that conditions favourable to these seabirds are unlikely to be present in most of the study area. The plots of the variables chosen as important influences by the model (see Figures 2a, 2b, and 9) show a low-moderate range of chlorophyll-a values (that is, generally away from the main shelf area), relatively low temperatures, a small proportion of the year in relatively ice-free conditions, and mainly over water depths of 1000–2500 m with fewer over deeper waters. As with all the predictions, the CVs are best in areas where there is over 80% probability of encountering the favoured conditions (see for example, Figure 10).

4. DISCUSSION

The environmental conditions and their importance to each seabird will differ, not only by species but also by morphology, life history, life stage, and individual behaviour depending on their prey preferences and the time of year. This work used seabird presence-absence data from one small period of the Ross Sea area summer and the data represented occurrence on a much smaller scale than that represented by the environmental variables. At the larger scale, the modelling indicated that the conditions that were the most defining in terms of the spatial location differed for each of the four seabird species.

Antarctic petrels and snow petrels breed on the Antarctic continent where the breeding season is constrained to a relatively short period of the Antarctic summer. About 1 million snow petrels and about 5.5 million Antarctic petrels are thought to inhabit the Ross Sea area, with both species having an affinity to ice, and snow petrels most commonly seen in pack-ice (see Ainley et al. 2010). In the summer season, they are likely to be at the end of chick provisioning and still undertaking relatively short foraging trips, depending on the extent of the sea ice, utilising local winds to access known rich feeding areas (for example, Watson et al. 1971, Croxall et al. 1984, Warham 1990, Creuwels et al. 2008, Ainley et al. 2010). Both these species are likely to readily obtain their natural prey of silverfish and krill in these areas (O'Driscoll et al. 2011). Snow petrel diets indicate a strong preference for silverfish (*Pleuragramma antarctica*) and krill (*Euphausia superba, E. crystallorophias*) and Antarctic petrel diets are similar though with relatively less reliance on silverfish (Ballard et al. 2010). Local ice cover in the form of icebergs, pack-ice, pancake ice, and broken glacial ice was reasonably extensive during much of the TAN2006 voyage (Mitchell & MacDiarmid 2006).

The complex frontal and current system within the Ross Sea gyral system contained by the ACC to the north and the Ross Sea continental shelf to the south redistributes water between the Ross Sea and the Southern Ocean (see Orsi et al. 1995, Hanchet et al. 2008, Rickard et al. 2010). The shelf break, which approximates the position of the Antarctic Slope Front and westward-flowing current as part of the Ross Sea gyral system, was strongly influential on the Antarctic petrel distribution. The complex bathymetry creates stronger current flow and upwelling conditions (see Rickard et al. 2010). In a similar way, ice cover was important for snow petrels as indicated by the stronger probability of conditions being suitable for this species at the western and eastern edges of the Ross Sea where the ice cover is more stable. Between these two areas lies the Ross Sea shelf, where a large area of open, productive ocean water or polynya opens up each summer and is utilised by the petrels (for example, Watson et al. 1971, see Ainley et al. 2010). The larger dataset of sightings in Appendix 1 shows that, during December–March, these two species may be encountered utilising the ice cover and open waters south of 60° S to the Antarctic continent (Figures 1.14 and 1.15). There was evidence of a more confined use of the Ross Sea waters by snow petrels compared with that of Antarctic petrels.

Although this work covers only a very short season in one year, the results concur with the MaxEnt and Zonation modelling by Ballard et al. (2010) using some similar environmental variables and a larger dataset (of presences only) collected over a number of years that included more samples from the ice shelf at higher latitudes (Ainley et al. 2010). Ballard et al. (2010) estimated a 26% overlap between Antarctic and snow petrels in horizontal space in summer, along the shelf break and areas on the shelf where upwelling of the Circumpolar Deep Water intruded onto the shelf near the large troughs and banks just west of 180° (see Ainley et al. 2010). *E. crystallorophias* is present over the inner Ross Sea shelf, whereas *E. superba* is more closely related to the shelf break, especially the western edge upwellings and *Pleuragramma antarctica* is distributed throughout the shelf waters out to the shelf break (Ainley et al. 2010, O'Driscoll et al. 2011).

Cape petrels and southern giant petrels range more widely with a more pelagic distribution utilising broad oceanic areas including visits from breeding colonies on sub-Antarctic islands (and the Antarctic continent for southern giant petrels) to the Ross Sea area. These birds are more likely to be ship followers than the other petrels, are known scavengers (for example, see Watson et al. 1971), and have a diversified diet (Ridoux & Offredo 1989, González-Solis et al. 2008).

The wider use of habitats, especially by the southern giant petrel, is reflected in the main influences determined by the respective models. Ainley et al. (2010) suggest that southern giant petrels use the shelf waters less than they did in the early 1980s. Certainly the distribution shown by the full set of observations in Figure 1.9 of Appendix 1 has few sightings over shelf waters. However, the closely-related southern and northern giant petrels are very similar morphologically, with the intersexual size differences greater than those between the species (see González-Solis et al. 2000, 2008). It may be that there was some confusion of the species by those recording sightings of southern giant petrels. Both species are shown to forage south of the Polar Front, but there is spatial segregation between the sexes of each species.

Model evaluation

By the standards set for this type of analysis, the AUC results suggest that the models did moderately well in explaining the influences of the chosen variables on the spatial distribution of three seabird species, and slightly less so for the fourth (southern giant petrel). There are similarities in the results of this work and those of the more in-depth and data-rich studies of Ballard et al. (2010) and Ribic et al. (2011), despite the limitations of the data in time and in scale. These variables represented a subset of variables that were readily available and singly or together may represent conditions or habitats where a seabird species is present or absent. Seabirds are highly mobile and may cross many habitats within an area or time period without necessarily being associated with them, and this characteristic creates difficulties in modelling their spatial distribution.

In summer, these species are central place foragers, driven to access prime feeding locations to ensure maximum energy gain from foraging on their return to the nest. The variables which were responsible for large influences on snow petrels, Antarctic petrels, and cape petrels (surface temperature, shelf break, and ice cover, respectively) are reasonably static compared with other variables retained by the model. Conditions that may impact largely on more local distribution, such as being within 300 m of a vessel, were not included here. Time of day and local weather conditions, including snowfall, prevailing wind and associated features such as direction and strength, type of ice cover, and light levels were also not considered. These locally-measured variables, and any associated aspects of bird behaviour (including the presence of a vessel) that place a bird within sight of an observer, will determine its presence or absence at a far finer scale than is possible with the remote-sensed data.

It was assumed that the presence and absence data were complete and that there were no problems with the detection of an individual of any of the four species within the defined observation ‘sampling space’. It was also assumed that the likelihood of seeing any of these species was equal throughout the observation periods, although the observation platforms were themselves limited by ice presence and survey priorities or by the longline fishery areas that defined the ship tracks. Each sample was considered to be independent from the others despite there being a high degree of spatial autocorrelation (MacDiarmid & Stewart in press), and the effect of this may differ, depending on the distance between sampling points. For example, some birds are ship-followers and some will roost on a large ice-berg. Potentially both may be in the observation space for more than one sample, or not. A recorded presence may represent a different bird or group of birds from that recorded in previous samples or it may be a re-sighting. A bird that may represent an outlier in the natural distribution of a species cannot be distinguished, neither can a curious bird, a bird that has been ‘blown’ into the sample observation area, or one that is foraging, commuting, or ship-following. Thus, there is a large amount of uncertainty in the underlying distribution data.

Other modelling methods have been used for this kind of study (for example, Ballard et al. 2010, Ribic et al. 2011), and where comparisons have been made between methods (for example, Oppel et al. (2012) who used five methods to predict spatial distribution and abundance of Balearic shearwaters, there were differences in the predicted distributions but the performance of the methods varied little. These authors suggested that more useful results could be achieved by combining the predictions into an "ensemble prediction".

This current study has identified potential influences in distribution for four species. These predictions of their favoured environmental conditions are based on the best available data. We recognise that there are large underlying assumptions, that critical variables that describe the local environment at the time of observation are not included, and that we cannot say anything about the abundance of these species in this area at this time (late summer), or the distribution of these species at other times of the year. Although all four species used the shelf break waters to some extent, the method resulted in discrimination of areas used between seabird species with an affinity to ice and therefore a distribution in higher latitudes (Antarctic and snow petrels) and seabird species that visit the area and prefer more open waters generally (cape petrels and southern giant petrels).

5. ACKNOWLEDGMENTS

Grateful thanks to Brent Wood (NIWA) for advice and GMT output, to Matt Pinkerton (NIWA) who provided the gridded environmental data layers and valuable advice, and to Peter (Chazz) Marriott for an earlier review. Thanks to Stu Hanchet for his advice and review of this manuscript. This work was funded by Ministry for Primary Industries. The review by Mary Livingston (MPI) is gratefully acknowledged.

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APPENDIX 1:

Spatial distribution of seabird and marine mammal species in the Ross Sea area based on sightings from a research vessel and from observed commercial longline effort.

This appendix provides distribution maps for seabirds and marine mammals in the Ross Sea area, south of about 60° S, based on three sources of information, each at a different level of data collection. The largest source of observations is from the annual observation counts made from the toothfish (*Dissostichus antarcticus*, *D. mawsoni*) longline vessels by the on-board Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) observers over 12 seasons between 1997 and 2009. The other two sources are from late summer voyages by *RV Tangaroa* in 2006 (BioRoss survey), when systematic counts were made from the vessel, and in 2008 (IPY-CAML voyage) when opportunistic sightings were recorded (by digital images).

METHODS

RV Tangaroa data

The *RV Tangaroa* IPY-CAML voyage in 2008 was the survey under which this objective sits, but there was no capacity on the voyage for the collection of standardised sightings data following a pre-determined set of protocols. However, digital images of seabird and marine mammals were taken opportunistically during the voyage by science staff and crew.

Initially, the plan was to use the underlying EXIF files from these digital images to determine a position for each seabird or mammal image based on the time the image was taken and the position of the vessel at that time. The underlying timestamp data of the images were not consistent or reliable for most of the cameras used. Thus, it was not possible to assign a position to an image. The date stamp data for each image were more reliable. These data were used to assign each image to the segment of the ship’s track for the relevant day. Thus for the 2008 images, the presence of a seabird or marine mammal (captured in an image) is understood to have been recorded somewhere along the ship’s trackline on a given day. Figure 1.1 in Appendix 1 shows the voyage trackline for the area represented in this report. The species recorded were verified by the primary photographer (Peter Marriott, NIWA).

Seabird and marine mammal count data from the 2006 voyage were systematically collected following set protocols by three science staff (Mitchell & MacDiarmid 2006, MacDiarmid & Stewart in press). The observations were located by vessel position coordinates at the time the counts were made, and the extent of these sightings was between about 60° and 76° S and 161° E and 158° W (see Figure 1.1 in Appendix 1).

CCAMLR data

CCAMLR Scientific Observers are required to collect observations of seabirds and marine mammals during longline activities to quantify incidental catch rates, assess vulnerability, and assess the abundance of seabirds and marine mammals around the vessel during setting and hauling of longlines targeting the toothfish species (Baird 2004).

Seabird and marine mammal observation data were extracted from the CCAMLR database used by NIWA for the CCAMLR annual stock assessments of toothfish in the Ross Sea fishery. Species data for all seasons except the 2007 season were included. Groomed set location data used in these stock assessments (for example, Dunn & Hanchet 2010) were matched to the seabird and marine mammals sighting data by trip and set numbers to assign a location and date to the sighting record. Other than obvious typographic errors, the species identification data as recorded were accepted as correct.

Background literature

Several recent, thorough documents summarised the available information relevant to the seabird and marine mammal distributions presented here. For example, Pinkerton et al. (2010a) describe the oceanography of the Ross Sea area and the abundance and distribution of seabirds and marine mammals as part of the development of the trophic modelling research. The information in these reviews is not repeated here; however, they offer valuable background material supporting the general distribution, foraging, and abundance of the bird and mammal taxa presented here.

SPATIAL DISTRIBUTION

Appendix 1a provides maps of the voyage tracks and CCAMLR longline set start locations for all data combined from 1997 to 2009; distribution maps for the seabirds (as species or higher taxonomic groups) from the three data sources; and distribution maps for the marine mammal sightings from the 2006 *RV Tangaroa* voyage and the CCAMLR observations. In the CCAMLR data, 4214 sets contained records for at least one seabird or marine mammal taxon. The 2006 research voyage data contained 375 records of seabird sightings, and the 2008 data had image records for 15 days in February and 8 in March.

Spatial extent of observations

The sea ice extent limited the research vessel and fishing vessel access. Both the *RV Tangaroa* voyages departed in late January and returned in late March. The 2006 voyage followed a more easterly track than the 2008 voyage and reached the edge of the shelf just south of 75° S at about 158° W (see Figure 1.1 of Appendix 1). The 2008 voyage was mainly between 170° E and 180° and reached the Ross Sea ice shelf at about 77° S.

CCAMLR sightings were based on the locations of fishing effort shown in Figure 1.2 of Appendix 1. At the beginning of the time series fishing effort was markedly restricted by the larger-than-normal ice extent. In most years fishing was limited to north of the shelf edge, in waters of over 1000 m. The sightings data presented in this report were from trips over 12 seasons, from 1997–2006, 2008–09, where a season may be from December through to June the following year, depending on the extent of the ice and the amount of fishing effort. During the early years of the fishery from 1998 to 2000, vessels fished usually through to March, but in the following three seasons vessels fished longer, from January to May in 2001 and 2002, and from December to June in 2003 (the longest season), when some vessels made two trips. In subsequent years, fishing was more contracted occurring during December–March in 2004 and 2005, December–February in 2006–08 seasons, and December–January in 2009 because the catch limit was taken more quickly.

Species records

The seabird and marine mammal presence data from both *RV Tangaroa* voyages and the CCAMLR observers are plotted by species or higher taxonomic group (listed in Tables 1.1 and 1.2) and presented in Appendix 1a. The species identifications are those supplied by the scientific staff on the 2006 voyage, a seabird photographer on the 2008 voyage, and the CCAMLR observers. The presence of these species is shown for the waters south of the Polar Front (about 60° S), but the presence of taxa in the sub-Antarctic waters south to 60° S is also described.

Presence of seabird taxa

At least 38 seabird taxa were sighted in and north of the Ross Sea, based on the observations from the three data sources (Table 1.1). A wider range of taxa was reported from the CCAMLR data, which is not surprising given the larger number of years covered and the generally longer period of time spent in the area in each year (season). For one or two taxa reported here, the expected distribution may be in more northern waters; however for a taxon not normally known from the Southern Ocean, there is no evidence to discount it from these data.

Order Sphenisciformes, Family Spheniscidae – penguins

Two penguin species were reported from the *Tangaroa* trips and three from the CCAMLR trips. Adélie penguins (*Pygoscelis adeliae*) have a circumpolar distribution and in the Ross Sea region, breed along the coast and offshore islands of the western Ross Sea (Shirihai 2002, Ainley et al. 2010, Ballard et al. 2010, see Pinkerton et al. 2010a). Adélie penguins were reported from waters south of 65° S, but most sightings were generally south of 72° S, either in deeper waters off the shelf or close inshore, with all sightings east of 165 E (Figure 1.3 in Appendix 1a). Clusters of sightings reported in the CCAMLR data were near colony areas, for example, off Ross Island (~77° 33'S, 166° 05' E) and from waters over the shelf break east of Cape Adare (71°17' S, 170° 14' E). The most eastern observations were from the research voyage in 2006 when most sightings were from waters between 2000 and 4000 m deep. The digital images from the 2008 research voyage showed several small groups (fewer than 15 birds) on ice floes.

Chinstrap penguins (*Pygoscelis antarctica*) were reported from one CCAMLR trip in January 2004, in waters off Cape Adare over the continental shelf and a single animal in about 1500 m deep water north of 65° S. This species has a circumpolar distribution, generally south of 60° S near the Ross Sea, with the nearest breeding colony at Balleny Islands.

Emperor penguins (*Aptenodytes forsteri*) breed at six colonies in the western Ross Sea area (Shirihai 2002, Ainley et al. 2010). They were rarely recorded in the data summarised here (Figure 1.4 in Appendix 1a), during February of 2006 and 2008. Usually during late January–February, emperor penguins undertake their moult and concentrate for 3–4 weeks on the large floes in the pack-ice mainly in the eastern Ross Sea area, but also near Balleny Islands (Croxall et al. 2002, Kooyman et al. 2004).

Table 1.1: Presence of each of the seabird taxa recorded from *RV Tangaroa* 2006 and 2008 voyages and the CCAMLR data (1997–2009). An asterisk denotes that a taxon was reported from waters north of 60° S and beyond the distribution map extent. A question mark indicates that skuas were recorded but not to the species level.

Taxon		CCAMLR	2006	2008
Order Sphenisciformes, Family Spheniscidae - penguins				
Adelie penguin	*Pygoscelis adeliae*	✓	✓	✓
Chinstrap penguin	*Pygoscelis antarctica*	✓	–	–
Emperor penguin	*Aptenodytes forsteri*	–	✓	✓
Order Procellariiformes, Family Diomedeidae - albatrosses				
Amsterdam albatross	*Diomedea amsterdamensis*	✓	–	–
Snowy albatross	*Diomedea chionoptera*	✓	–	–
Wandering albatross	*Diomedea exulans*	✓	✓	✓
Southern royal albatross	*Diomedea epomophora*	✓	✓*	✓*
Buller's albatross	*Thalassarche bulleri*	✓	–	–
Black-browed albatross	*Thalassarche* spp.	✓	✓	✓*
Grey-headed albatross	*Thalassarche chrysostoma*	✓	–	–
Salvin's albatross	*Thalassarche salvini*	–	–	✓*
Yellow-nosed albatross	*Thalassarche chlororhynchos*	✓	–	–
Light mantled sooty albatross	*Phoebetria palpebrata*	✓	✓	✓
Sooty albatross	*Phoebetria fusca*	✓	✓	–
Order Procellariiformes, Family Procellariidae – fulmars, prions, petrels, shearwaters				
Northern giant petrel	*Macronectes halli*	✓	–	–
Southern giant petrel	*Macronectes giganteus*	✓	✓	✓
Grey petrel	*Procellaria cinerea*	✓	–	–
White-chinned petrel	*Procellaria aequinoctialis*	✓	–	✓
Flesh-footed Shearwater	*Puffinus carneipes*	✓	–	–
Pink-footed Shearwater	*Puffinus creatopus*	✓	–	–
Great Shearwater	*Puffinus gravis*	✓	–	–
Short-tailed shearwater	*Puffinus tenuirostris*	✓	–	–
Sooty shearwater	*Puffinus griseus*	✓	✓	✓
Great-winged petrel	*Pterodroma macroptera*	✓	–	–
Mottled petrel	*Pterodroma inexpectata*	–	✓	✓
White-headed petrel	*Pterodroma lessonii*	✓	–	✓
Antarctic prion	*Pachyptila desolata*	✓	✓	✓
Blue petrel	*Halobaena caerulea*	✓	✓	–
Antarctic petrel	*Thalassoica antarctica*	✓	✓	✓
Cape petrel	*Daption capense*	✓	✓	✓
Snow petrel	*Pagodroma nivea*	✓	✓	✓
Southern (Antarctic) fulmar	*Fulmarus glacialoides*	✓	✓	✓
Order Procellariiformes, Family Hydrobatidae – storm petrels				
Black/white-bellied storm petrels	*Fregetta* spp.	✓	–	–
Black-bellied storm-petrel	*Fregetta tropica*	✓	–	–
Wilson's storm petrel	*Oceanities oceanicus*	✓	✓	✓
Order Charadriiformes, Family Laridae – gulls, terns, noddies				
Antarctic tern	*Sterna vitatta*	✓	✓	–
Order Charadriiformes, Family Stercorariidae – skuas				
Antarctic skua	*Catharacta lonnbergi*	✓	**?**	–
Great/Brown Skua	*Catharacta skua*	✓	**?**	–
South polar skua	*Catharacta maccormicki*	✓	**?**	✓

Order Procellariiformes, Family Diomedeidae - albatrosses

At least 11 albatross taxa were present in the combined records, representing three genera (see Table 1.1). Of the great albatrosses, four species are included in these records: Amsterdam albatross *Diomedea amsterdamensis*, southern royal albatross *D. epomophora*, snowy albatross *D. chionoptera*, and wandering albatross *D. exulans* (Figure 1.5). Birds of this genus are readily confused, particularly with immature birds because of their similar plumage (Shirihai 2002). The two December sightings of Amsterdam albatross may be an example of this, because this species is reportedly almost indistinguishable from the Antipodean wandering albatross, and it has a very small population. However, Shirihai (2002) notes that the distribution may extend from the South Indian Ocean east and south to Tasmania.

Few sightings were made of these species. The *RV Tangaroa* sightings of wandering albatross were confined to north of about 65° S, west of 180°, in February–March, on both outgoing and return sectors of the 2008 voyage. In contrast, the CCAMLR sightings were south of 63° S to the shelf edge waters west of 180°. Southern royals were also seen north of 60° S during the *RV Tangaroa* trips, although more southern observations were reported by CCAMLR observers during January and February, to the shelf edge at about 72° S. A single sighting of snowy albatrosses was reported from east of 180°, at about 67° S during March. These albatrosses are known to forage the Southern Ocean waters and may follow ships to southern waters.

One or two records exist in these data for two of the smaller *Thalassarche* species. The New Zealand endemic Buller's albatross (*Thalassarche bulleri*) was reported from just south of 65° S in February and yellow-nosed albatross (*T. chlororhynchos*), which breed on sub-Antarctic islands in the South Atlantic and South Indian oceans (Shirihai 2002), from north of 65° S in April (Figure 1.6). More commonly reported were the grey-headed albatross *T. chrysostoma* between 63° and 71° S during December-March and the "black-browed" albatrosses *T. impavida* (Campbell albatross) and *T. melanophris* (black-browed albatross) south of 60° S to the continental shelf edge at about 72° S (Figures 1.6 and 1.7). "Black-browed" albatross were seen between December and May, but mainly in February–March.

Reports of light-mantled sooty albatross (*Phoebetria palpebrata*) showed a wider distribution than the other smaller albatrosses (Figure 1.8). Sightings were reported during December–May from CCAMLR observers. This species has a circumpolar distribution and is known to range to the northern edge of the pack ice (Ainley et al. 1984, Shirihai 2002), as is confirmed by the locations of these sightings data. It is easily confused with sooty albatross (*Phoebetria fusca*), a species which breed on the islands in the South Indian and Atlantic oceans and is distributed from south of 30° S, preferring deeper waters north of the Polar Front (Shirihai 2002). The records from the *RV Tangaroa* voyages and CCAMLR suggest a more ranging and southern distribution than the literature.

Order Procellariiformes, Family Procellariidae – fulmars, prions, petrels, shearwaters

Family Procellariidae is represented by 10 different genera in these data (Table 1.1). Some of these species rarely leave the Southern Ocean and Ross sea area, for example, Antarctic petrel and snow petrel (Ainley et al. 2010); whereas others, such as the shearwaters, grey and white-chinned petrels breed on islands well north of the Ross Sea, but forage south to use the rich food resources.

One genus that utilises a wide latitudinal range is *Macronectes*, the giant petrel (Shirihai 2002). The Southern Ocean is a natural foraging area for the southern giant petrel (*M. giganteus*), though this species is known to forage north to about 20° S. Its breeding islands are situated between the Antarctic coast at about 70° S and 40° S in the South Atlantic Ocean compared with the narrow range of the northern giant petrel (*M. halli*), north of about 58° S to the Chatham Islands at about 43° S. The distributions shown by the CCAMLR and *RV Tangaroa* data show a southerly distribution (Figure 1.9), and it appears that the CCAMLR records of northern giant petrels are in similar areas to the southern giant petrels. Once again, this is a genus where the species are easily confused, and observers did on occasion report both species present together. Both species were reported from most months of the observed CCAMLR effort. Ainley et al. (2010) consider that the southern giant petrel no longer frequent waters over the Ross Sea shelf, but CCAMLR observers reported this species over these waters in most years of the dataset, with the most southern record from about 77° 36' S.

Other visitors to the area, as indicated by these data, include birds belonging to the *Procellaria* and *Puffinus* genera. Grey petrels (*P. cinerea*) and white-chinned petrels (*P. aequinoctialis*) were reported by CCAMLR observers from as far south as the continental shelf break, to about 72° for grey petrels and 76° S for white-chinned petrel during January–March (Figure 1.10). These species breed on sub-Antarctic islands between 35° S and 55° S and are circumpolar in their distribution, but generally forage over waters north of 60° S (Shirihai 2002).

The *Puffinus* shearwaters reported in these data were mainly sooty shearwaters (*P. griseus*) (Figure 1.11). The *RV Tangaroa* 2006 sightings were centred on the Balleny Islands (between latitudes 66° 15’ and 67° 20’ S and longitudes 162° 15’ and 164° 45’ E), and the 2008 observations were mainly from around Scott Island (67° 24’ S,179° 55’ W). The most southern sighting was from about 73° 30’ S, 162° W. Most birds were sighted in February. This species breeds in the sub-Antarctic and has a wide circumpolar distribution that includes waters south of 65° S north of the Ross Sea (Shirihai 2002).

The CCAMLR data included a small number of records from February-March for short-tailed shearwaters (*P. tenuirostris*), flesh-footed shearwater (*P. tenuirostris*), pink-footed shearwater (*P. carneipes*), and great shearwater (*P. gravis*). All these species have more northern distributions during the months covered by the observations. Great shearwaters are generally distributed in the South Atlantic Ocean, based on their breeding colony locations, into the South Indian Ocean, to about 58° S. Flesh-footed shearwaters range from the South Indian Ocean to east of New Zealand, in latitudes north of about 50° S. Short-tailed shearwaters are known to forage in Antarctic waters during January–March, including in waters near the Ross Sea (Klomp & Schultz 2000). They are mainly limited in their southern extent to about 55° S within a 110° E–170° W longitudinal range (in waters centred around southern Australia, east to New Zealand), individuals have been tracked to Antarctic waters. Lastly, pink-footed shearwaters are unlikely to be seen in these waters.

Three gadfly petrels (*Pterodroma* spp.) were recorded: white-headed petrels (*P. lessonii*), mottled petrels (*P. inexpectata*), and great-winged petrels (*P. macroptera*) (Figure 1.12). All were reported rarely, usually one sighting of a species in a dataset. White-headed petrels have a circumpolar distribution known to extend to south of 75° S in the eastern Ross Sea area, and the New Zealand endemic mottled petrels have a similar southern extent, whereas great-winged petrels are generally distributed north of 55° S (Shirihai 2002).

Blue petrels (*Halobaena caerula*) have a circumpolar distribution and breed on sub-Antarctic islands, with the closest colony to the Ross Sea region at Macquarie Island (Shirihai 2002). Antarctic prions (*Pachyptila desolata*) are widely distributed in Antarctic waters, though their known distribution near the Ross Sea appears to be limited over the eastern Ross Sea, despite breeding at Scott Island and Macquarie and Auckland islands (Shirihai 2002). Both these species are easily confused with one another and with other prions in the region. The records of these birds are mainly between 63° and 70° S, especially to the northeast of Scott Island (Figure 1.13).

The Antarctic-breeding Procellariidae represented in these datasets are the southern (Antarctic) fulmar (*Fulmarus glacialoides*), Antarctic petrel (*Thalassoica antarctica*), cape petrel (*Daption capense*), and the snow petrels (*Pagodroma nivea*). The latter are considered to have two taxa: a lesser and a greater, with the lesser (*P. n. nivea*) having a circumpolar distribution and breeding sites in the vicinity of the Ross Sea, on Scott and Balleny islands, as well as elsewhere on the Antarctic continent; and the greater known to breed only on the Balleny Islands (Shirihai 2002). Snow petrels were regularly observed over the continental shelf and over deeper waters south of 65° S in all the months of observations (Figure 1.14). The most northern observation was within the known general limit of around 58° S. Snow petrels are abundant in summer in iceberg and pack ice, and this was evident in the digital images from the 2008 voyage.

Antarctic petrels and cape petrels have very similar breeding and at-sea distributions to snow petrels, although cape petrels are likely to be over deeper waters away from the continental shelf (see Shirihai 2002). The Antarctic petrel records shown here reflect this (Figure 1.15) with records from all months of observation effort. Cape petrels were also observed throughout the longline season, although in the 2008 and 2009 seasons records were from December-January only (Figure 1.16).

Southern fulmars breed at the Balleny Islands and on the nearby Antarctic coast, with a circumpolar distribution; however, these birds were reported less frequently than were the Antarctic and snow petrels and were rarely seen east of 170° W (Figure 1.17). Concentrations of all these summer-breeding species seemed to occur off the shelf break and around the Balleny and Scott islands.

Order Procellariiformes, Family Hydrobatidae – storm petrels

Wilson's storm petrels (*Oceanites oceanites*) breed on or near the western Ross Sea coast, Balleny Islands, and at Scott Island as well as numerous other Antarctic and sub-Antarctic sites beyond the Ross Sea area (Shirihai 2002). Sightings were made from the *RV Tangaroa* voyages near Scott Island in both years, and more widely in 2006, although relatively fewer records were from waters east of 170° W (Figure 1.18). The CCAMLR records were distributed off the shelf edge east of Cape Adare and south to the Ross Sea ice shelf and Ross Island. Storm petrels are small birds that fly close to the water surface and may be harder to detect than other, larger birds.

Black-bellied storm petrels (*Fregetta tropica*) were rarely recorded by CCAMLR observers, and some records were undetermined for *Fregetta*. A white-bellied *F. gallaria* is easily confused with *F. tropica* species. Both species breed on sub-Antarctic islands and have a circumpolar distribution, but *F. gallaria* has a more northern distribution at the longitudinal range of the Ross Sea, at north of about 35° S (Shirihai 2002).

Order Charadriiformes, Family Laridae – gulls, terns, noddies

Antarctic terns (*Sterna vitatta*) were rarely sighted, and the distribution of the sightings was south of 65° S to the continental shelf break (Figure 1.19). North of the Ross Sea, this species breeds on New Zealand offshore islands and sub-Antarctic islands, as well as at many sub-Antarctic islands between 70° E and 90° W (Shirihai 2002). Unidentified gulls were recorded as present around longline vessels by CCAMLR observers. The gull with the most southern distribution in the Ross sea area is the kelp gull (*Larus dominicanus*) and the locations of sightings shown in Figure 1.19 fit the general distribution given by Shirihai (2002).

Order Charadriiformes, Family Stercorariidae – skuas

Three species of skua were reported by CCAMLR observers: Antarctic skua (*Catharacta lonnbergi*), great/brown skua *C. skua*, and south polar skua *C. maccormicki*. The taxonomy given here is that provided to CCAMLR observers. However, there has been debate over the classification of skuas (see Shirihai 2002), and currently it does not appear that this has been resolved. Although they all appear to have a circumpolar distribution, the south polar skua is the true Antarctic-breeding skua, breeding all around the Antarctic continent. Other skuas, such as *C. lonnibergi* breed on sub-Antarctic islands. The observations in Figure 1.20 show a southern distribution, centered along the continental shelf break, east of Cape Adare. This is not surprising because in many years of the CCAMLR data this was the most southern limit of the fishery because of ice cover.

PRESENCE OF MARINE MAMMAL TAXA

Sightings of marine mammals were relatively few compared with those for seabirds. Sightings from the 2006 BioRoss voyage are shown in Figure 1.21 and CCAMLR longline sets with mammal observations are shown in Figures 1.22–1.25. Few marine mammal images were recorded for the 2008 voyage, and these are mentioned in the text below.

Two otarid species and three phocid species of pinniped were observed (Table 1.2). CCAMLR observers reported one Antarctic fur seal (*Arctocephalus gazella*) close to the continental shelf break at about 170° W and South American sea lions (*Otaria byronia*) near Scott Island and close to the shelf break east of Cape Adare (Figure 1.22). The nearest breeding colony for Antarctic fur seals to the Ross Sea area is at Macquarie Island, but South American sea lions are generally distributed around the South American continent, south of 30° S; *O. byronia* is the most southern breeding sea lion (Shirihai 2002).

Leopard seals (*Hydrurga leptonyx*), Weddell seals (*Leptonychotes weddellii*), and Crabeater seals (*Lobodon carcinophagus*) have summer distributions close to the Antarctic continent, particularly amongst pack ice (Shirihai 2002, Ainley et al. 2010, Ballard et al. 2010, Bengtson et al. 2011). Records of these seals from the CCAMLR trips were from shelf break waters east of Cape Adare (Figure 1.23). Images from the 2008 voyage show crabeater and leopard seals on pack ice, either singly or in small groups.

Four families of cetaceans were identified in the records. Minke whales (*Balaenoptera acutorostrata*) were reported from all datasets. The species name given here is that from the CCAMLR data, but as there are several minke whales present in the area, the composition of these records cannot be determined. Minke whales were reported from the southwestern extent of the 2006 voyage track and from shelf waters close to the western coast of the continent (Figure 1.24) and as far south as the Ross ice shelf in the CCAMLR records. Two blue whales (*B. musculus*) and a humpback whale (*Megaptera novaeangliae*) were seen close to Scott Island during the 2008 voyage. Records of other cetacean sightings include humpback whales, a fin whale (*B. physalus*), long-finned pilot whale (*Globicephala melas*), sperm whales (*Physeter catodon*), and killer whales (*Orca orcinus*) (Figures

1.21, 1.24, and 1.25). The records for killer, humpback, blue, and minke whales concur with the distributions shown by Ainley et al. (2010) and Ballard et al. (2010). The only taxon listed above that is outside its general distribution, as summarised by Shirihai (2002), is the long-finned pilot whale.

Table 1.2: Presence of each marine mammal taxon recorded from *RV Tangaroa* 2006 and 2008 voyages and the CCAMLR data (1997–2009). A question mark indicates that seals were present, but they were not identified to a lower taxonomic level. The taxonomy is that used by CCAMLR.

Taxon		CCAMLR	2006	2008
Order Pinnipedia, Family Otariidae – eared seals				
Antarctic fur seal	*Arctocephalus gazella*	✓	**?**	–
South American sea lion	*Otaria byronia(flavescens)*	✓	–	–
Order Pinnipedia, Family Phocidae – true seals				
Leopard seal	*Hydrurga leptonyx*	✓	**?**	✓
Weddell seal	*Leptonychotes weddellii*	✓	**?**	–
Crabeater seal	*Lobodon carcinophagus*	✓	**?**	✓
Order Cetacea, Family Delphinidae - dolphins				
Long-finned pilot whale	*Globicephala melas*	✓	–	–
Killer whale	*Orcinus orca*	✓	–	–
Order Cetacea, Family Physeteridae – sperm whales				
Sperm whale	*Physeter catodon*	✓	–	–
Order Cetacea, Family Ziphiidae – beaked whales				
Beaked whale	unknown	–	✓	–
Order Cetacea, Family Balaenopteridae - rorquals				
Minke whale	*Balaenoptera acutorostrata*	✓	✓	✓
Blue whale	*Balaenoptera musculus*	–	–	✓
Fin whale	*Balaenoptera physalus*	✓	✓	–
Humpback whale	*Megaptera novaeangliae*	✓	✓	✓

FINAL COMMENTS

Several aspects of the data collection methods used to produce the datasets for the species distributions shown here will influence the inclusion of a species and the extent of the distribution.

1. The spatial and temporal extent covered by the vessel from which the observations are made defines the overall distribution limits.
2. Environmental conditions at the data collection time will influence the presence of a taxon; this may be especially true in these higher latitudes, because of the effect of oceanic winds and the type and extent of ice cover.
3. The natural ecology and behaviour of the seabird or marine mammal taxon.
4. The design of the sampling protocols may influence the likelihood of seeing all taxa, for example, some taxa approach vessels, others keep their distance. Time of day may be an important factor also.
5. The detection rate of those collecting the data may vary: for example, one "observer" may detect the presence of small seabirds like storm petrels whereas another may not; and the prevailing weather or presence of ice may limit the ability of the "observer" to detect species or numbers.
6. The experience and knowledge of the data collectors in observing and correctly identifying taxa.

Most of the seabird and marine mammal taxa listed in the tables above are known from Antarctic waters (Marchant & Higgins 1990). However, at-sea identification of these marine animals, especially seabirds, is difficult and relies on expert knowledge of the life history and life-stage characteristics. Many of these seabirds have similar body characteristics and plumage and are easily confused (Marchant & Higgins 1990, Shirihai 2002), even between adults and immatures of different species. For those species that are readily recognised, there will be no concerns with respect to the level of confidence in the species identification, and certainly the digital imagery used in the small 2008 dataset allows for verification of identification. However, even in some of those images, the weather and distance of the image subject from the photographer limited the number of images able to be used.

The presence of the Antarctic Convergence or Polar Front (broadly at around 60–65° S north of the Ross Sea) is a defining feature for many seabird species (Ainley et al. 1984), as is the Antarctic Slope Front (Ainley et al. 2010), and Scott Island (where several seabirds breed, Wilson & Harper 1996) was an important area in the distributions shown here. The shelf break areas also appeared important for many of the distributions shown here, but this is heavily influenced by the location of the CCAMLR fishing effort, which in turn was limited by the ice extent. For most species, there were no extraordinary sightings in terms of location. The albatrosses are known to forage south of their breeding grounds over open ocean waters and some are recognised as ship-followers. Satellite tracking of bird species has shown that individuals may utilise quite different feeding areas from others from the same population (for example, Birdlife International 2004), and oceanic winds may play an important part in the dispersal of some species. Thus, the observations of single birds (for example, some of the shearwaters that are unlikely to be in Antarctic waters) may be real, but more probably have been mis-identified. This may be true also for some species that are known from Antarctic waters; for example, southern giant petrels may be mis-identified as northern giant petrels or even sooty albatrosses (see Marchant & Higgins 1990), and many of the procellariiform species may be readily mistaken for others in the same family (Shirihai 2002).

Appendix 1a: Distribution maps

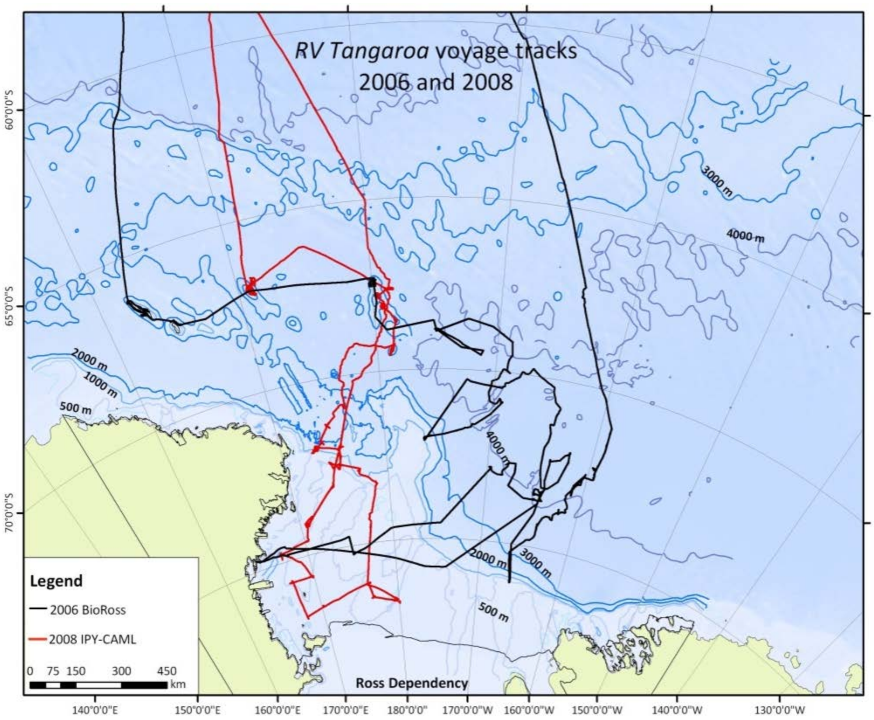

Figure 1.1: ***RV Tangaroa*** **tracks for the 2006 BioRoss voyage (TAN2006) and 2008 IPY–CAML voyage.**

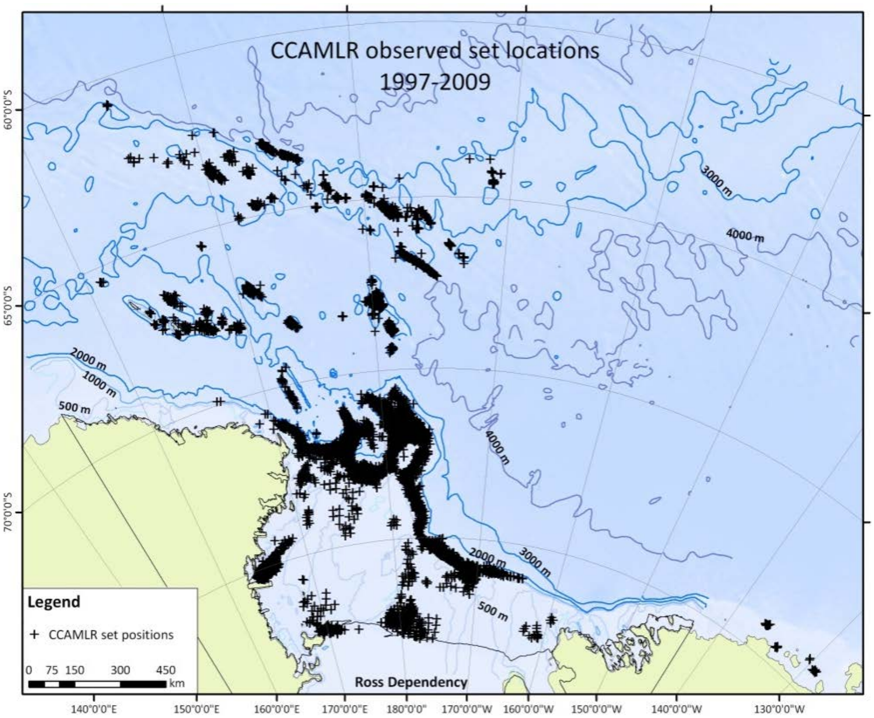

Figure 1.2: Set start positions of longlines reported by CCAMLR observers, 1997–2009 seasons.

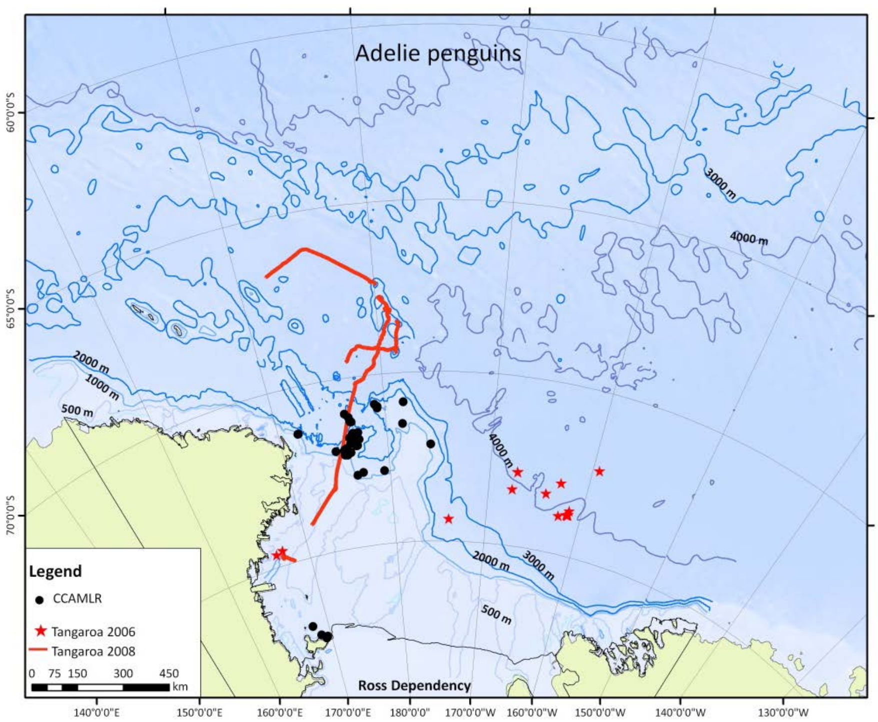

Figure 1.3: Locations of sightings of Adélie penguins (*Pygoscelis adeliae*) based on CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

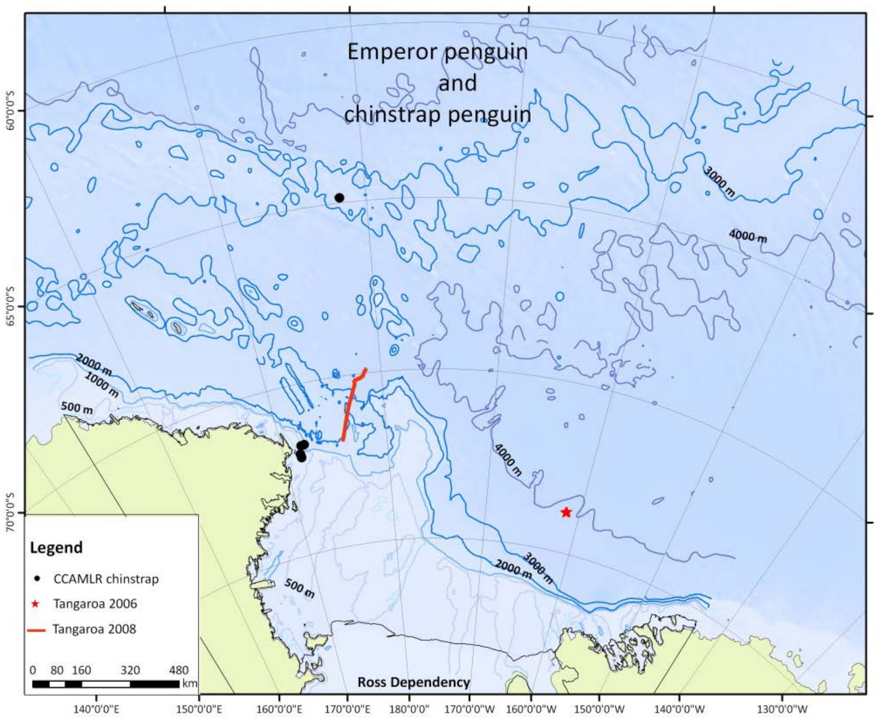

Figure 1.4: Locations of sightings of chinstrap penguins (*Pygoscelis antarctica*) from CCAMLR observer reports 1997–2009, and emperor penguins (*Aptenodytes forsteri)* based on standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

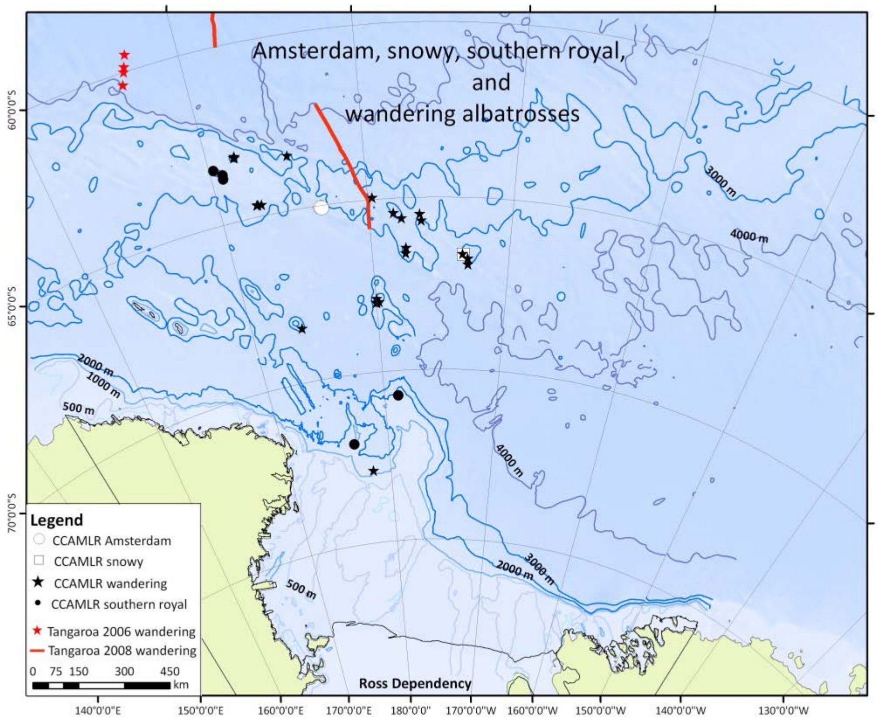

Figure 1.5: Locations of sightings of Amsterdam albatross (*Diomedea amsterdamensis*), snowy albatross (*D. chionoptera*), and southern royal albatross (*D. epomophora*) from CCAMLR observer reports 1997–2009, and wandering albatrosses (*D. exulans*) from CCAMLR reports and standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

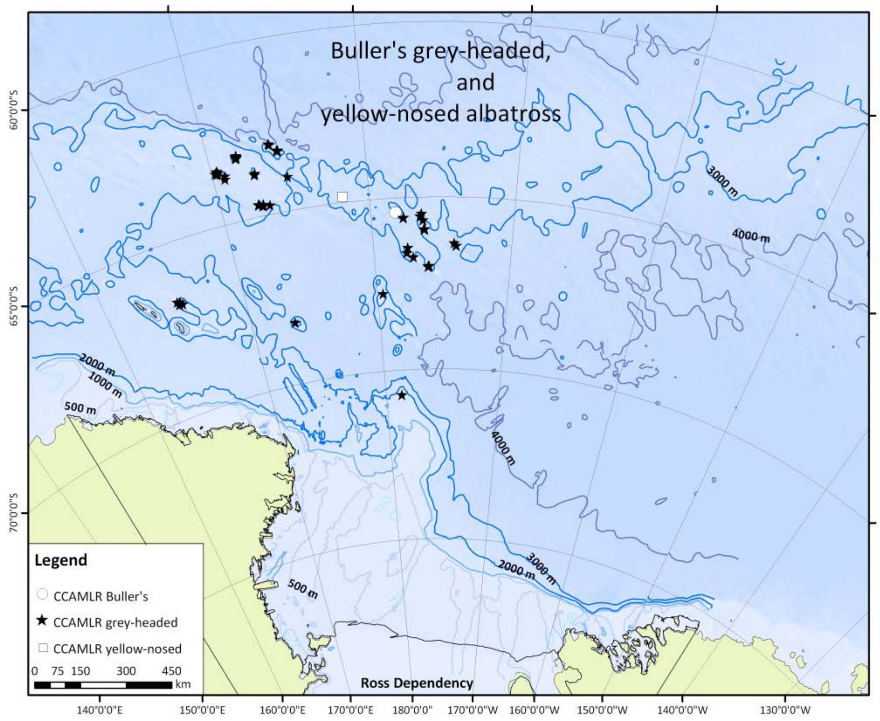

Figure 1.6: Locations of sightings of Buller's albatross (*Thalassarche bulleri*), grey-headed albatross (*T. chrsostoma*), and yellow-nosed albatross (*T. chlororhynchos*) from CCAMLR observer reports 1997–2009.

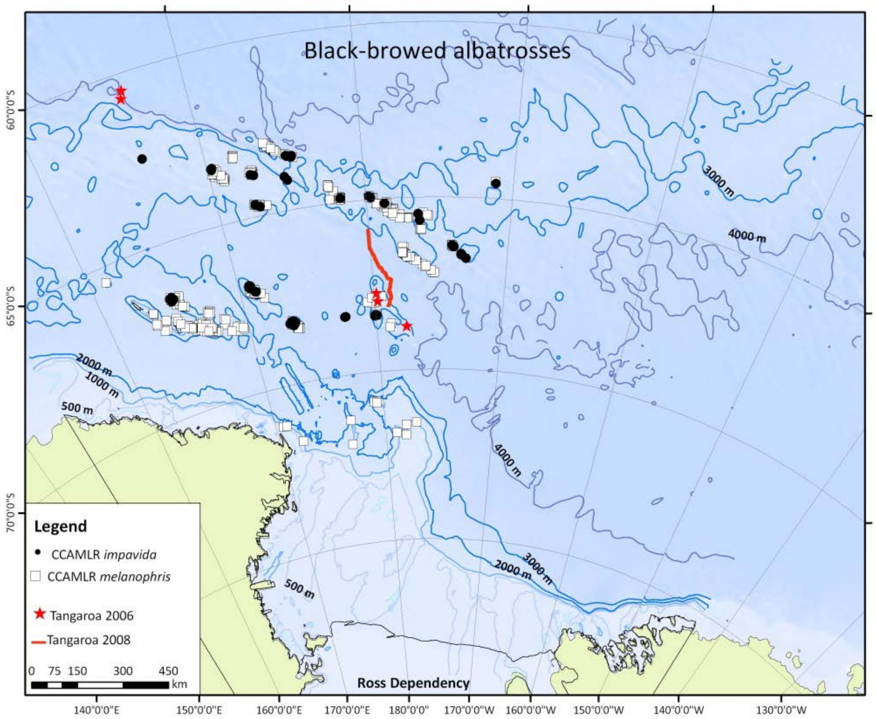

Figure 1.7: Locations of sightings of black-browed albatross (*Thalassarche* spp) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings of *T. melanophris*) from the 2008 *RV Tangaroa* IPY–CAML voyage.

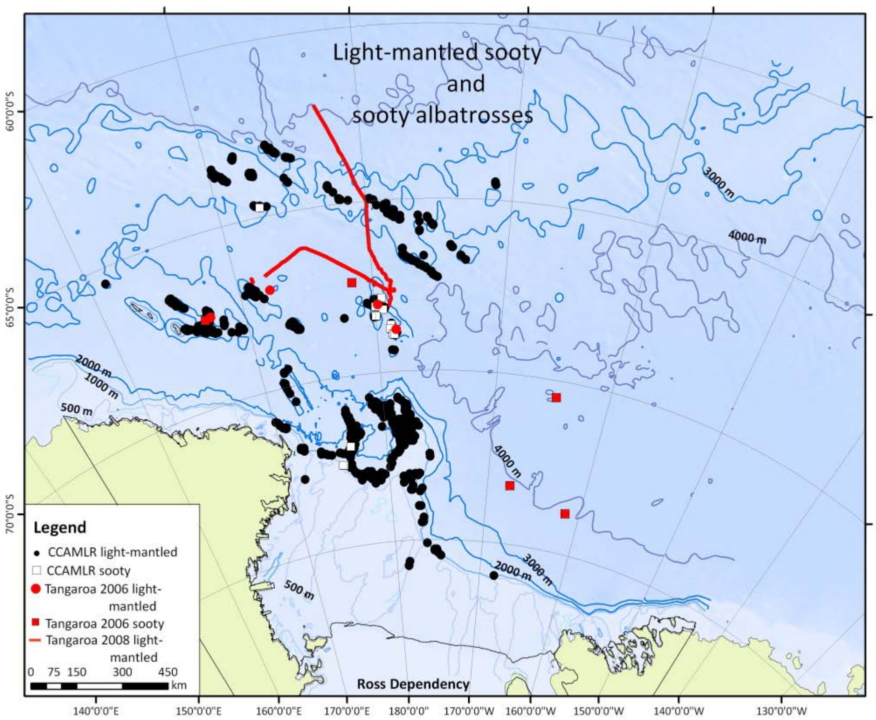

Figure 1.8: Locations of sightings of light-mantled sooty albatross (*Phoebetria palpebrata*) and sooty albatross (*Phoebetria fusca*) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

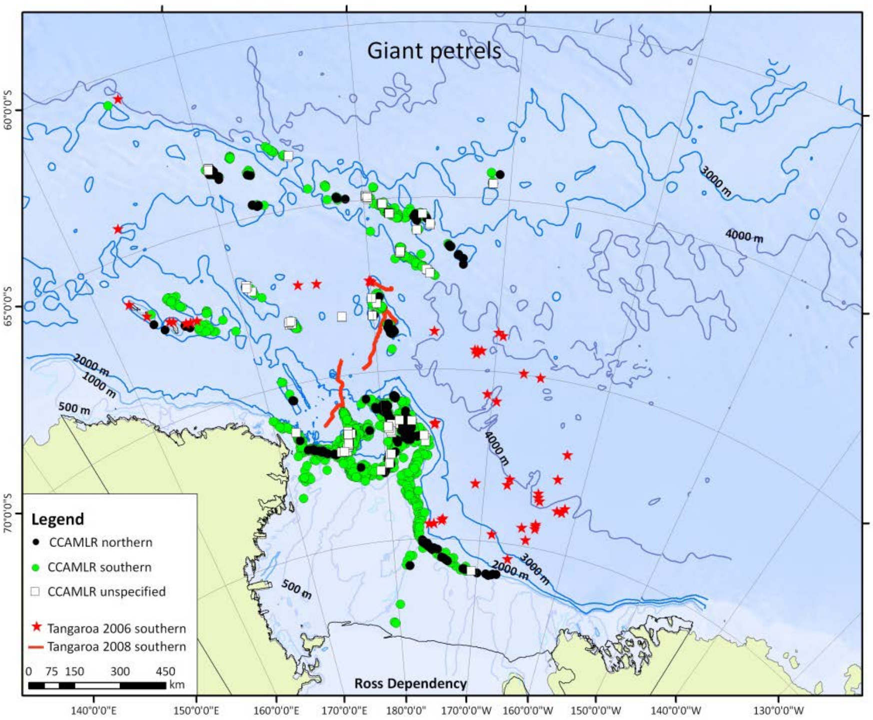

Figure 1.9: Locations of sightings of giant petrels, northern (*Macronectes halli*) and southern (*M. giganteus*) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

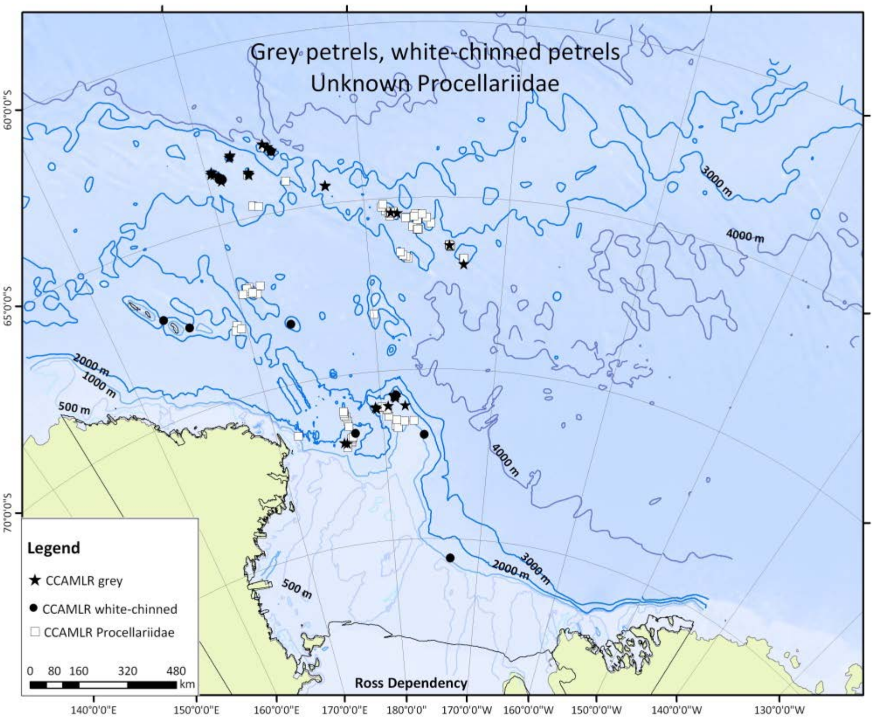

Figure 1.10: Locations of sightings of grey petrels (*Procellaria cinerea*), white-chinned petrels (*P. aequinoctialis*), and unspecified procellariidae from CCAMLR observer reports 1997–2009.

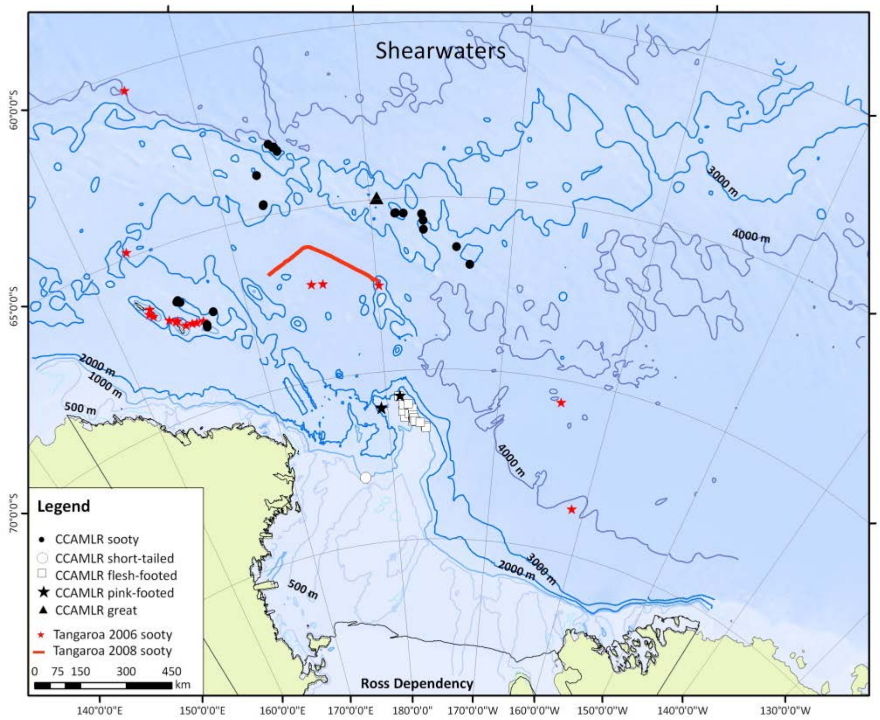

Figure 1.11: Locations of sightings of sooty shearwaters (*Puffinus griseus*) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage, and other shearwaters from CCAMLR reports.

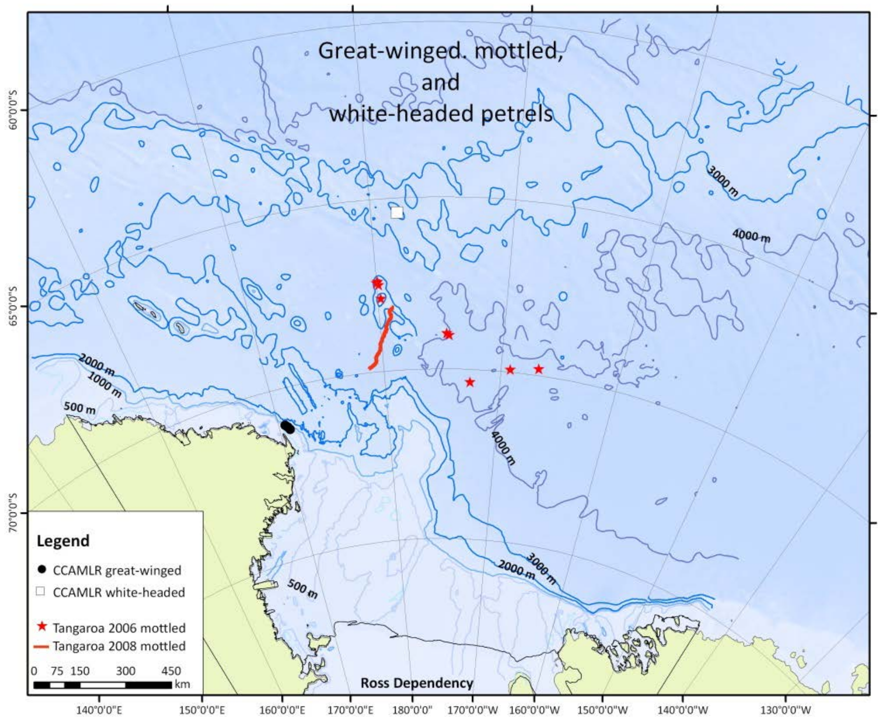

Figure 1.12: Locations of sightings of great-winged petrels (*Pterodroma macroptera*) and white-headed petrels (*P. lessonii*) from CCAMLR observer reports 1997–2009, and mottled petrels (*P. inexpectata*) from standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

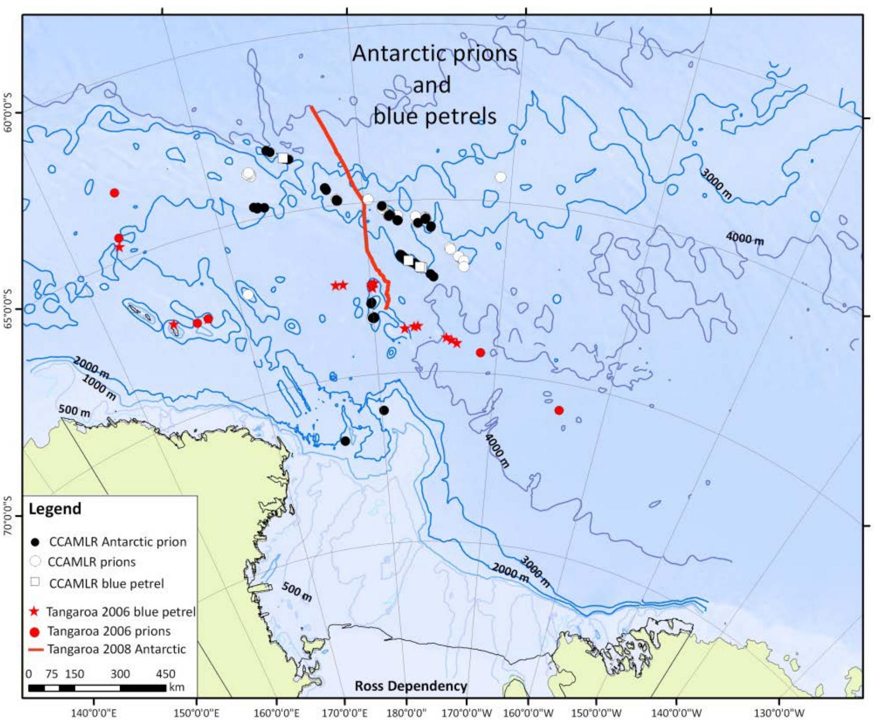

Figure 1.13: Locations of sightings of Antarctic prions (*Pachyptila desolata*) and blue petrels (*Halobaena caerulea*) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

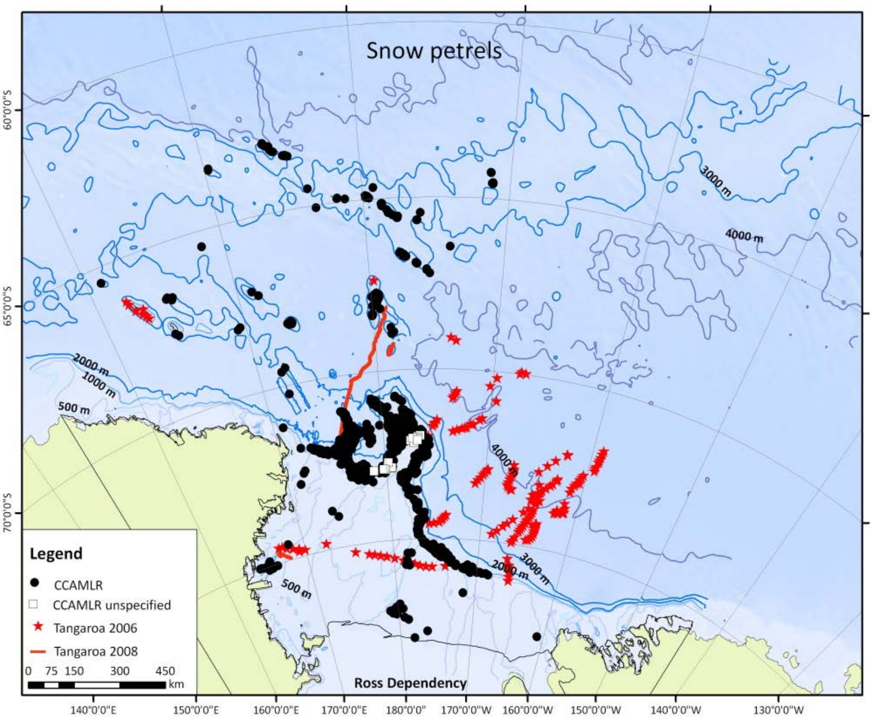

Figure 1.14: Locations of sightings of snow petrels (*Pagodroma nivea*) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

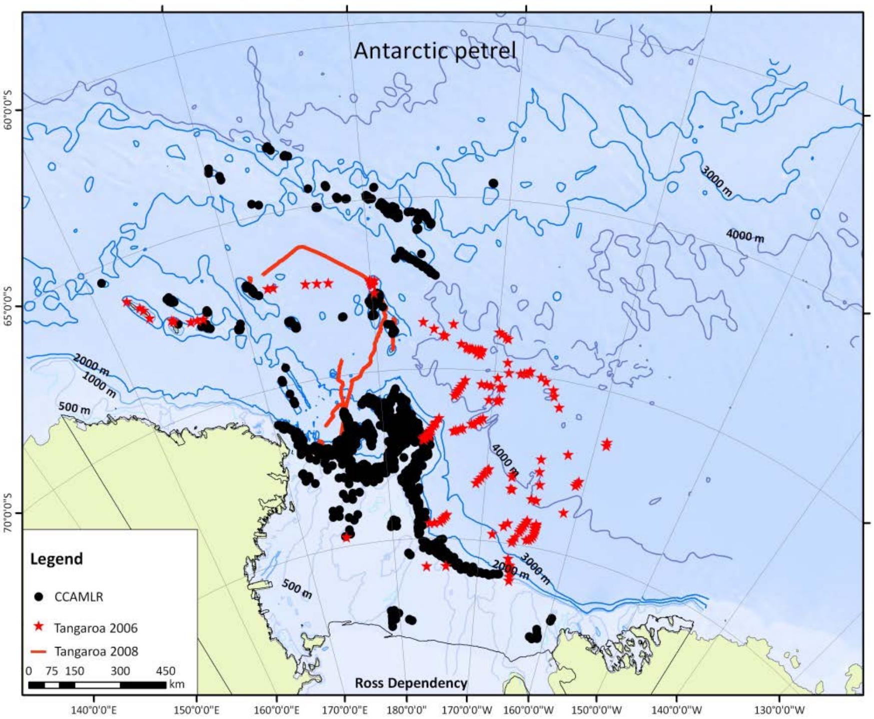

Figure 1.15: Locations of sightings of Antarctic petrels (*Thalassoica antarctica*) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

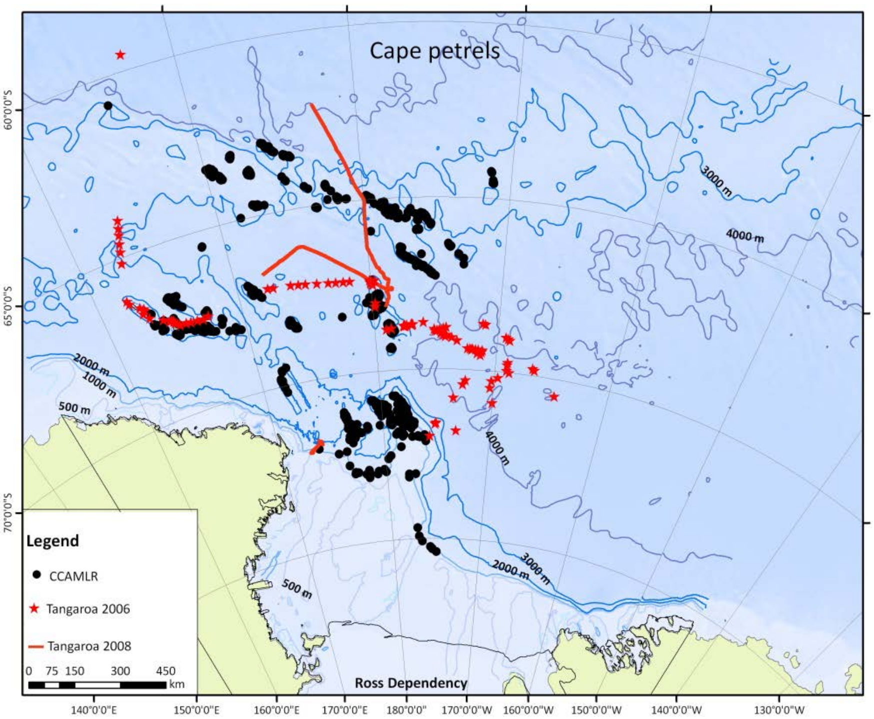

Figure 1.16: Locations of sightings of cape petrels (*Daption capense*) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

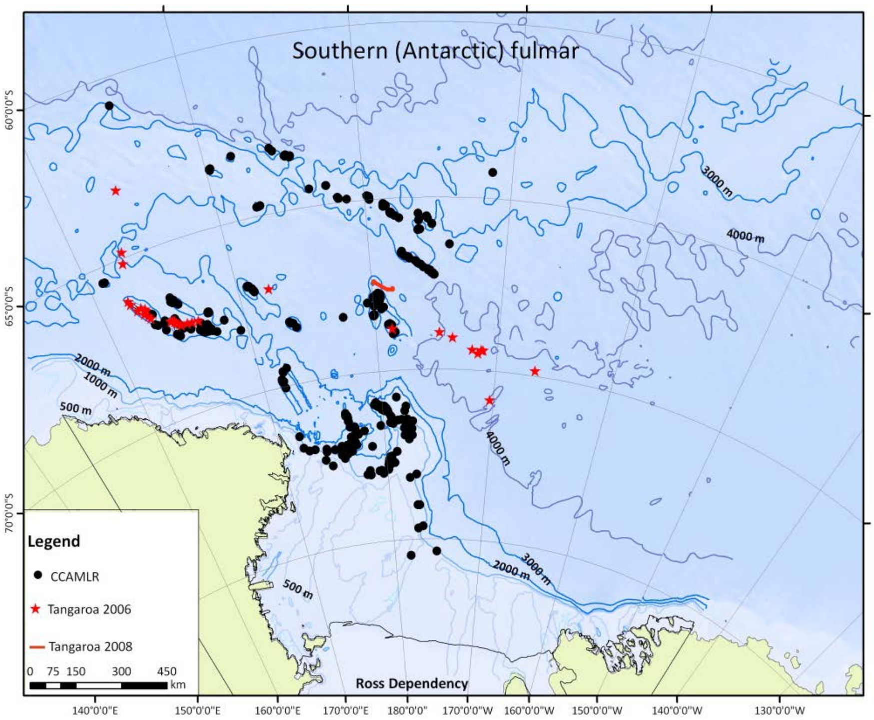

Figure 1.17: Locations of sightings of southern (Antarctic) fulmars (*Fulmarus glacialoides*) from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

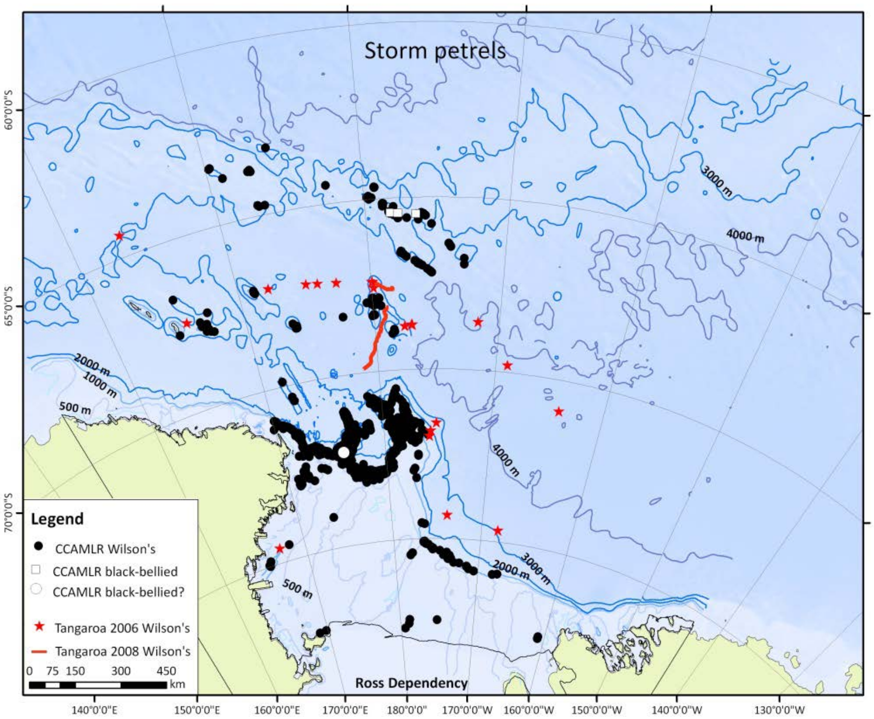

Figure 1.18: Locations of sightings of Wilson's storm petrels (*Oceanites oceanicus*), black-bellied storm petrels (*Fregetta tropica*), and unknown *Fregetta* birds from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings from the 2008 *RV Tangaroa* IPY–CAML voyage.

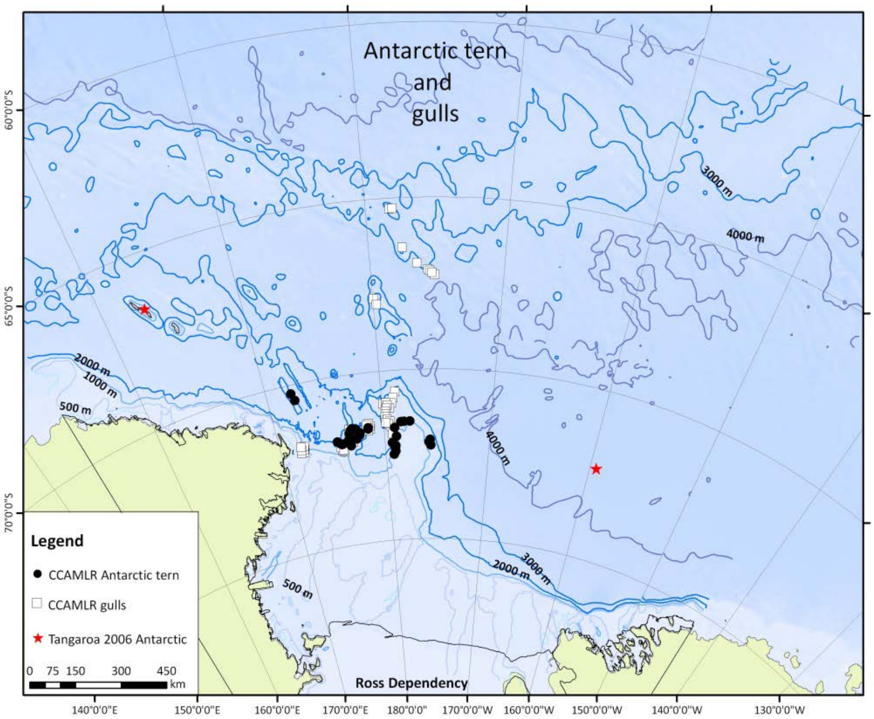

Figure 1.19: Locations of sightings of Antarctic terns (*Sterna vitatta*) and gulls from CCAMLR observer reports 1997–2009, and standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage.

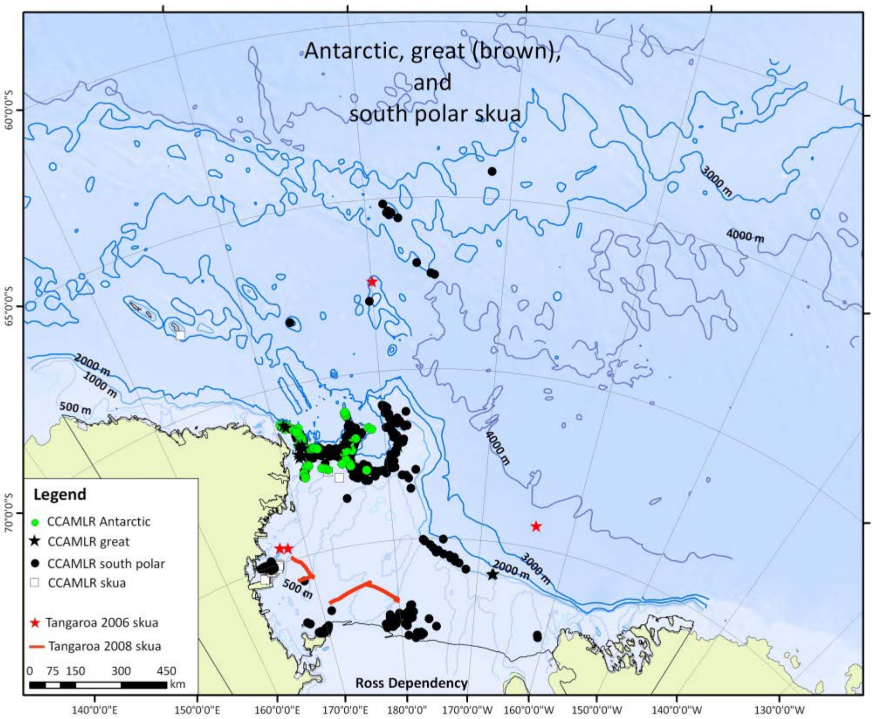

Figure 1.20: Locations of sightings of Antarctic skuas (*Catharacta lonnbergi*), great skuas (*C. skua*), south polar skuas (*C. maccormicki*), and unknown skuas from CCAMLR observer reports 1997–2009, standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage, and opportunistic sightings of south polar skuas from the 2008 *RV Tangaroa* IPY–CAML voyage.

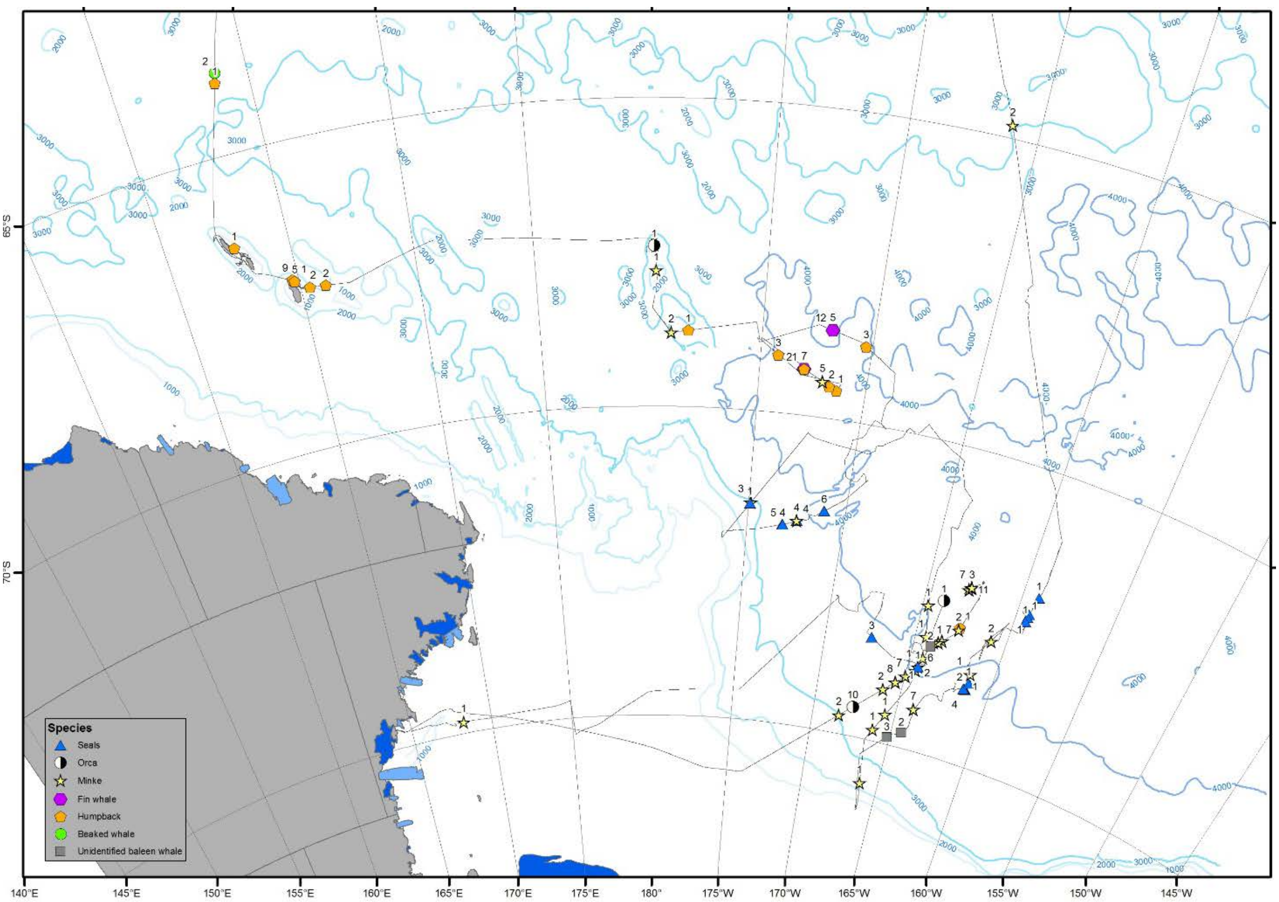

Figure 1.21: Locations of sightings of marine mammals from standardised data counts from the 2006 *RV Tangaroa* BioRoss voyage (reproduced from MacDiarmid & Stewart in press). Numbers indicate numbers of animals.

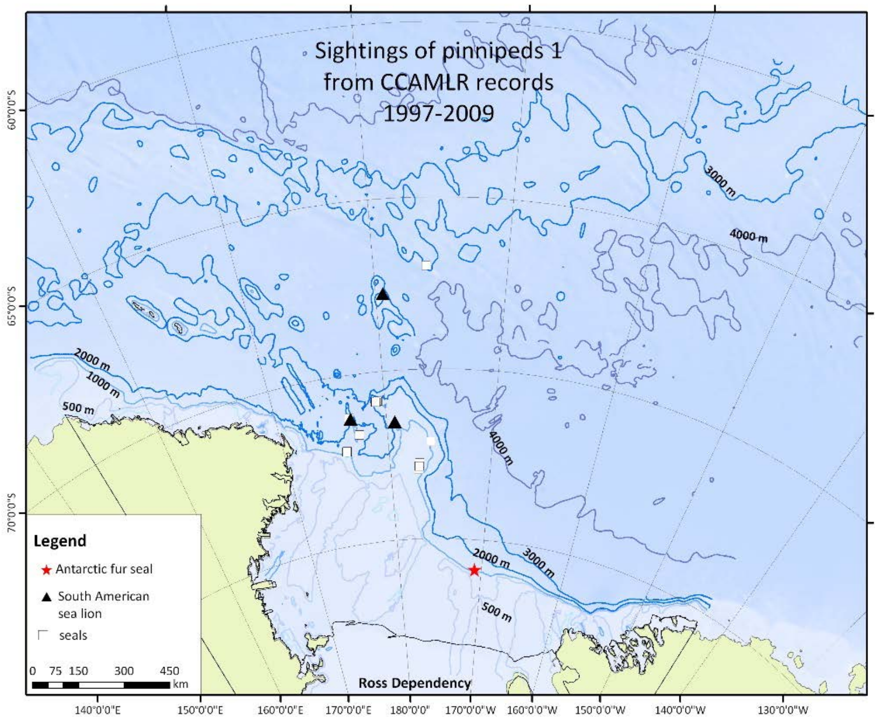

Figure 1.22: Locations of sightings of an Antarctic fur seal (*Arctocephalus gazella*) and South American sea lions (*Otaria byronia*), and unidentified seals from CCAMLR observer reports 1997–2009

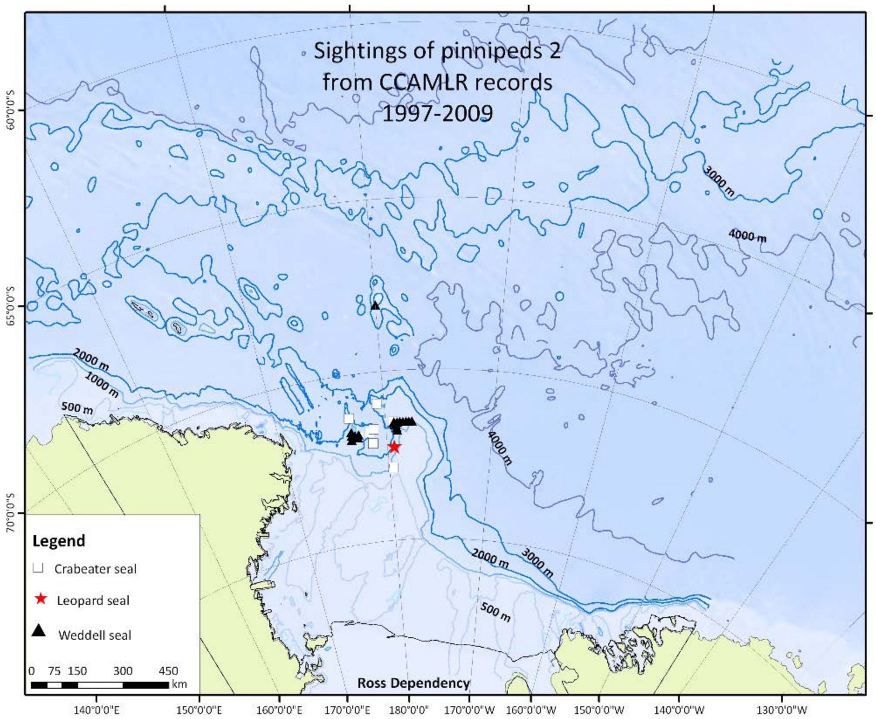

Figure 1.23: Locations of sightings of leopard seals (*Hydrurga leptonyx*), Weddell seals (*Leptonychotes weddellii*), and crabeater seals (*Lobodon carcinophagus*) from CCAMLR observer reports 1997–2009.

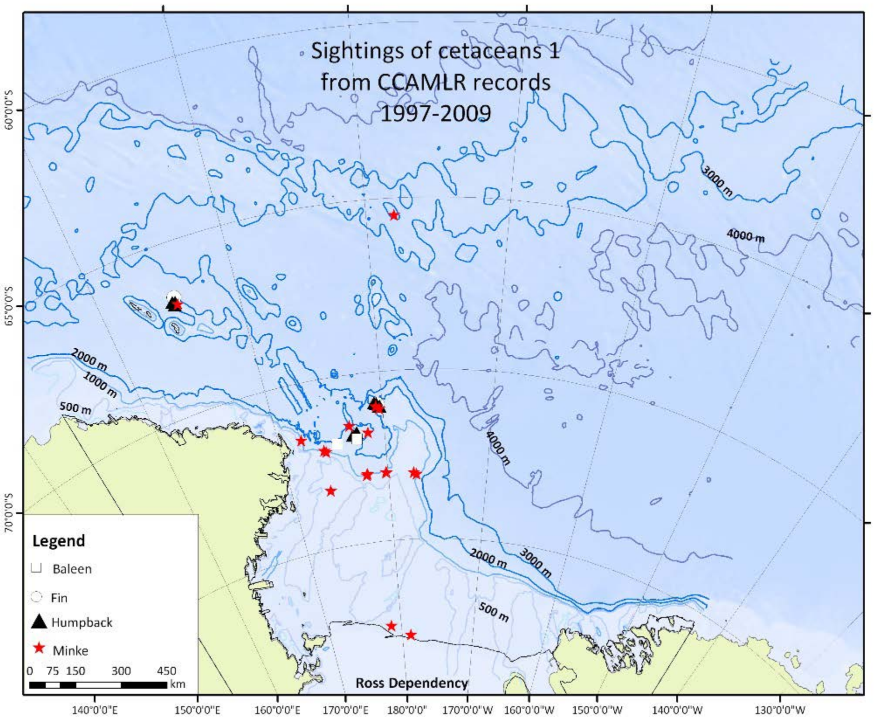

Figure 1.24: Locations of sightings of unidentified baleen whales, fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*), and minke whales (*B. acutorostrata*) from CCAMLR observer reports 1997–2009.

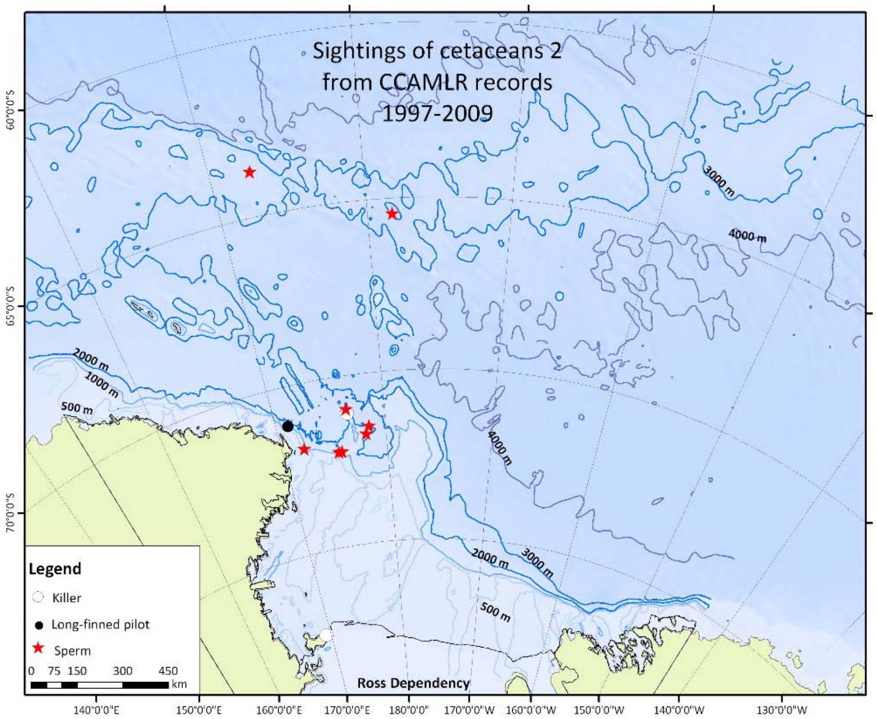

Figure 1.25: Locations of sightings of killer whales (*Orca orcinus*), long-finned pilot whales (*Globicpehala melas*), and sperm whales (*Physeter catodon*) from CCAMLR observer reports 1997–2009.

APPENDIX 2: Distribution of environmental data variables

A.

B.

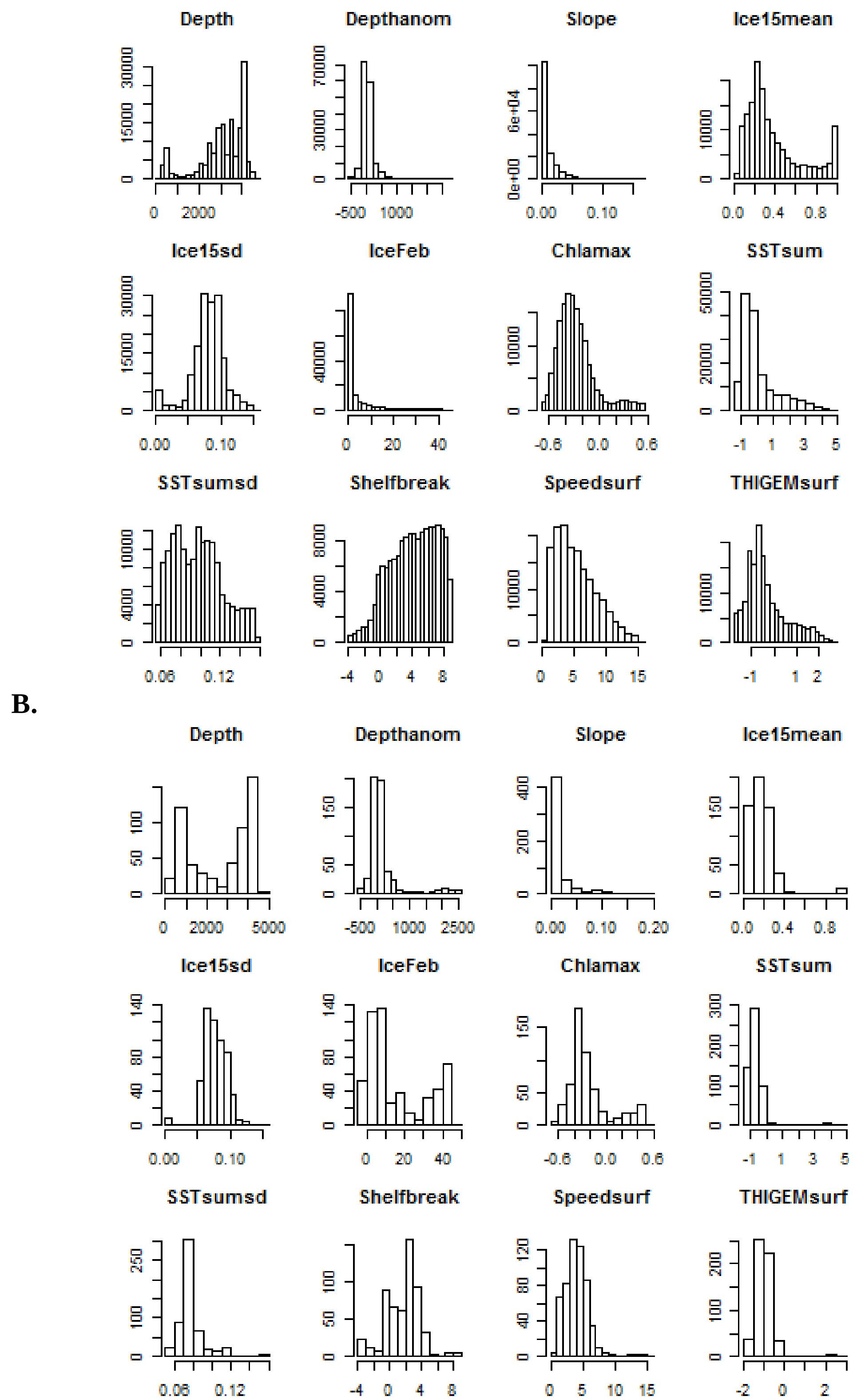

Figure 2.1: Frequency distribution of the 12 environmental variables used in the BRT modelling for: A. the final prediction area (see prediction extent in Figure 4) and B. the sampling stations in the presence/absence dataset. See Table 1 and Figures 2a and 2b for variable descriptions.

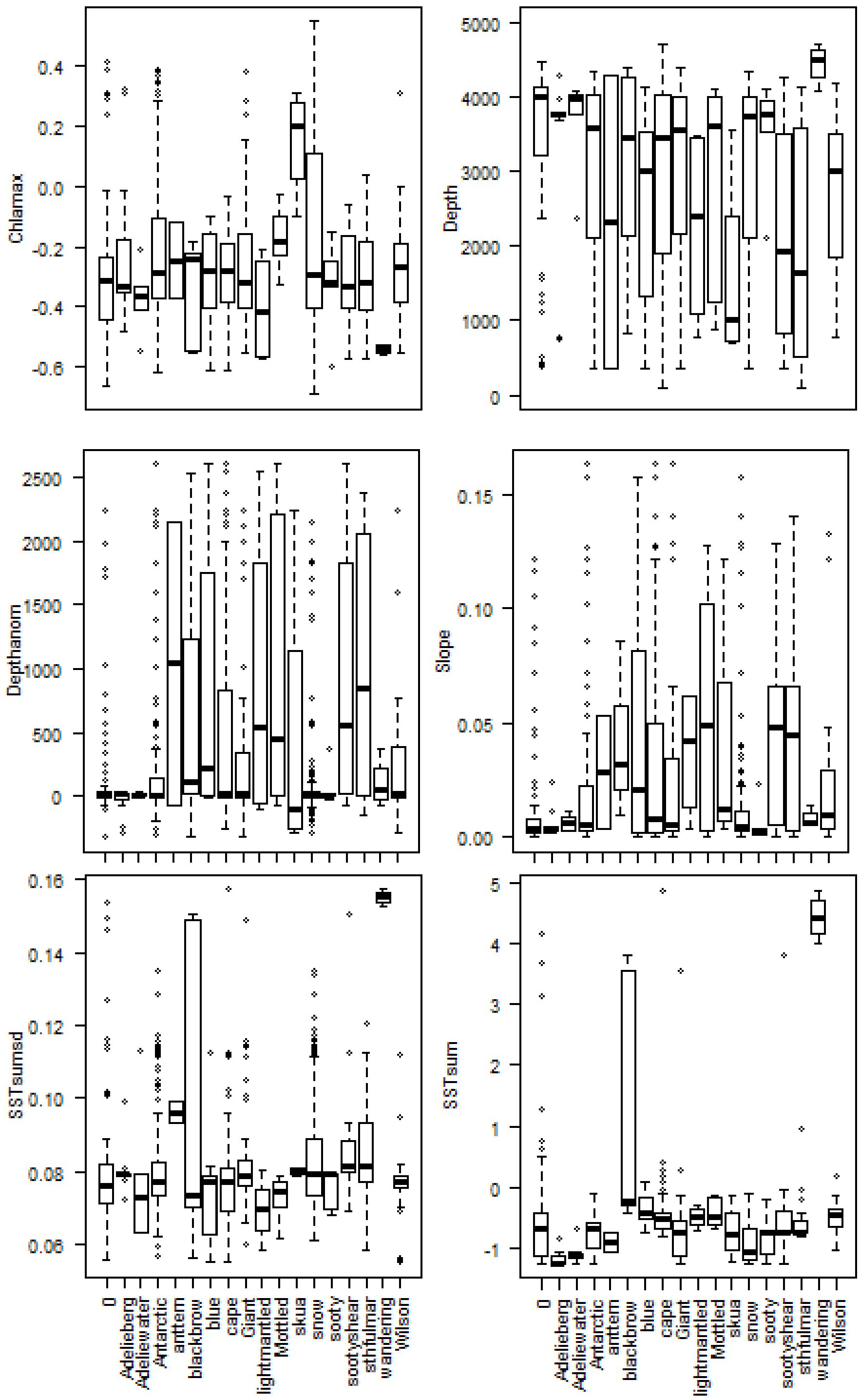

Figure 2.2: Frequency distribution of the 12 environmental variables for the full dataset of seabird species in the TAN2006 data the final prediction area (see prediction extent in Figure 4). See Table 1 and Figures 2a and 2b for variable descriptions. The x-axis labels refer to (from left to right) stations with zero birds, Adélie penguins on icebergs, Adélie in the water, Antarctic petrel, Antarctic tern, black-browed albatross, blue petrel, cape petrel, southern giant petrel, lightmantled sooty albatross, mottled petrel, skuas, snow petrel, sooty albatross, sooty shearwater, southern fulmar, wandering albatross, and Wilson's storm petrel.

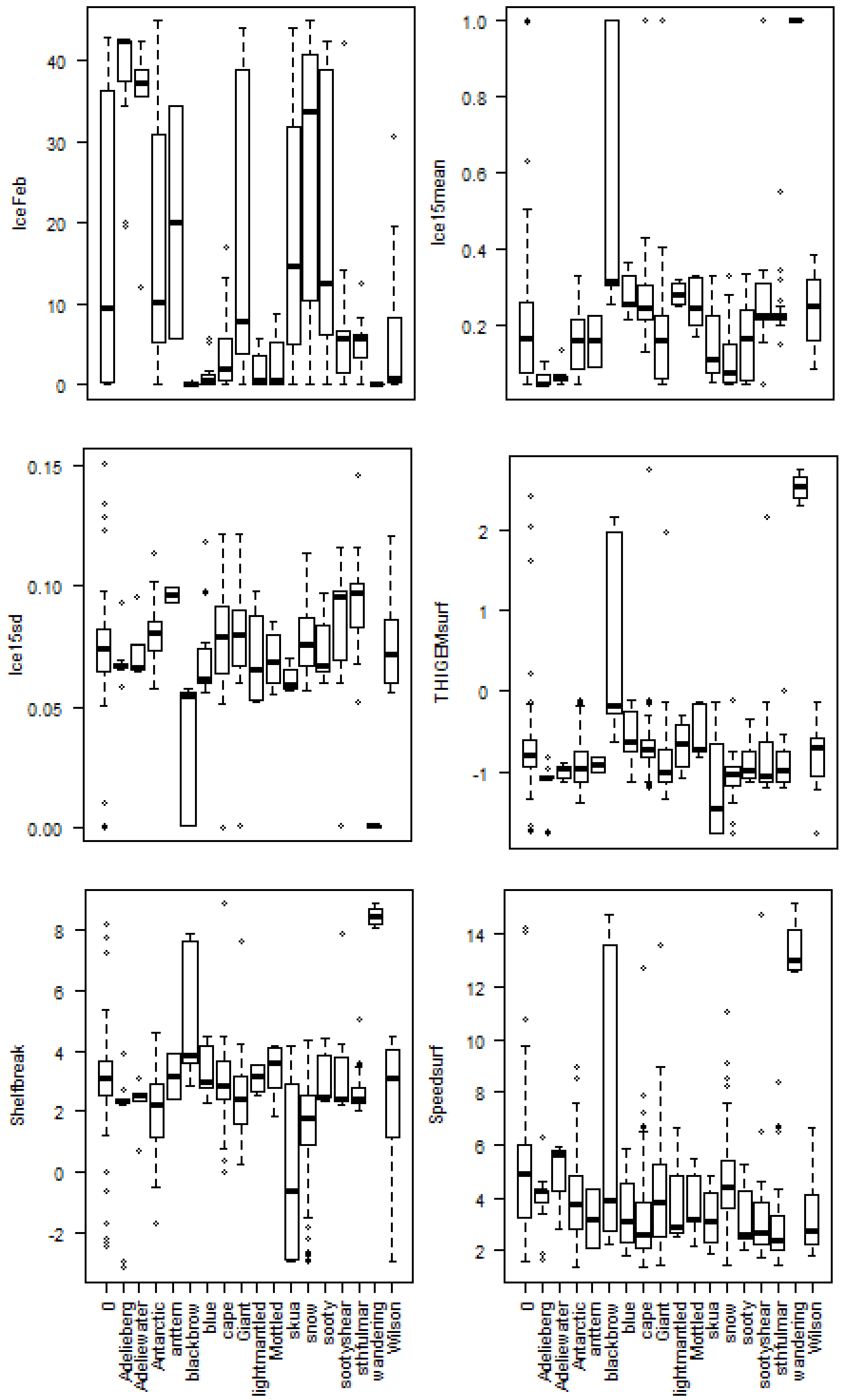

Figure 2.2: ***continued.***