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THE BIOGEOGRAPHIC ATLAS OF THE SOUTHERN OCEAN

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9.1. Climate change and predictions of pelagic biodiversity components

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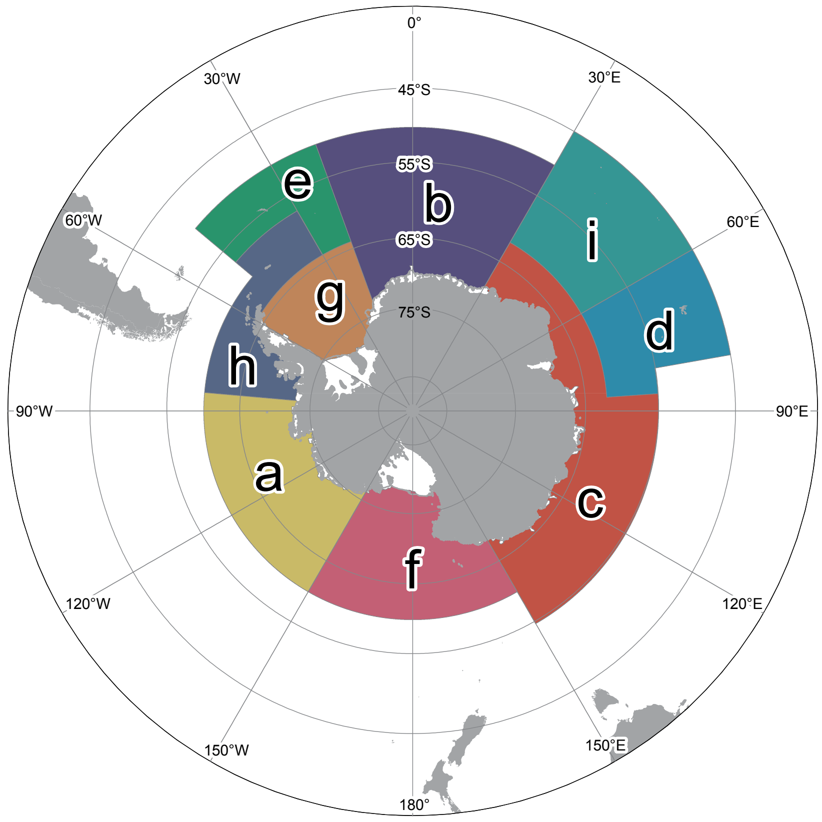
1. Introduction

Man-made climate change accepts no boundaries and affects virtually all components of the earth (Hilty *et al.* 2007, Turner *et al.* 2009, Bush *et al.* 2011, Brodie *et al.* 2012, Resendiz 2012). The ozone hole problematic showed us already that Antarctica as the 7th continent and very remote from industrial centers, is also directly affected by such impacts of industrialization and globalization (Turner *et al.* 2009, Reck 2011). A wider review of Antarctica and its current ecological set-up shows such impacts and patterns as a common scheme (Convey 2001, Thomas *et al.* 2008, Huettmann 2011, Resendiz 2012, Summerson 2012). For instance, marine mammals were overharvested for blubber and whale meat, and when the industrial revolution started in the Northern hemisphere allowing for such pursuits and creating a demand in the first place (Huettmann 2011 for context). Antarctic seabirds show signals of global economic development, too (Resendiz 2012). Nowadays, a continued overuse is found in Antarctica in some modern fisheries and krill harvests (Constable *et al.* 2000, Thomas *et al.* 2008; see also Trivelpiece *et al.* 2011, FAO Fishery Statistics 2012, Ainley *et al.* 2012 in Huettmann 2012). This is a direct analogy to modern Antarctica tourism where people from the Northern hemisphere travel to the far south or the South Pole (International Association Antarctica Tour Operations IAATO 2012), using up a precious carbon footprint and affecting a natural resource (e.g., through physical impact or through CO2 emissions from air plane travel for instance). This indeed has many implications for nature and global carrying capacity.

For billions of years Antarctica has been shaped by plate-tectonics, universal cycles and the underlying climate (Thomas *et al.* 2008, Turner *et al.* 2009, Martinson 2012). But now, man-made climate change includes the rise of carbon dioxide concentration, habitat transformation and subsequent global climate change. While some areas in the world experience cooling effects or no measurable climate effects, it is still valid to state that these are part of global climate change, too. They are therefore heavily driven by mankind (Millennium Ecosystem Assessment; http://www.unep.org/maweb/en/index.aspx). The Intergovernmental Panel on Climate Change (IPCC; www.ipcc.ch) has summaristed this knowledge into its public reports, based on assigned models (Intergovernmental Panel on Climate Change 2007). This work is available now to the global public for forecasting and strategic planning of natural resource management for instance (Brodie *et al.* 2013).

These models have already received major attention for the Antarctic (Thompson & Solomon 2002), some of its biodiversity (McClintock *et al.* 2008, Jenouvrier *et al.* 2009) and for modeling (Table 1). As a summary of these efforts, it becomes clear that wider, coherent and mutually accepted and efficient community efforts are lacking to preserve Antarctic biodiversity in earnest (Turner *et al.* in Turner *et al.* 2009, Brodie *et al.* 2013; but see De Broyer *et al.* this volume), that data qualities and methods are still developing and maturing, and that the warming impact for Antarctica is confirmed overall (some larger areas in Antarctica seem to show none or no strong environmental changes, thus far; Turner *et al.* 2009).

Here we use these latest IPCC models to assess for the first time the general trend for multiple species in the Antarctic ocean study area (Map 1) based on predictive niche models from publicly available ‘presence only’ data.



Predictions Map 1 Study area and management regions: (a) Amundsen-Bellingshausen, (b) Bouvet-Maud, (c) Eastern Antarctica, (d) Kerguelen Plateau, (e) North Scotia Arc, (f) Ross Sea Region, (g) Weddell Sea, (h) Western Antarctic Peninsula (South Scotia Arc), (i) del Cano-Crozett.

2. Methods

2.1. Biodiversity data

We followed the approach presented by Huettmann *et al.* (2011). We started with a compilation of 52 ‘presence only’ data from the GBIF.org and IOBIS.org websites (Table 2); additional data were included as they became available to us through colleagues. Eventually we selected 38 species (Table 2) for this study because they represent a pelagic community, and are among the major visual or otherwise known and recognised components of the study area. Secondly, we were able to obtain meaningful sample sizes (see Map 2 for examples of raw data for three selected species) and good models for these species (“best available science”). Third, we think that these species can be meaningful indicators for Antarctica and its pelagic wildlife community overall (Thomas *et al.* 2008, Turner *et al.* 2009), as well as for information regarding climate change.

Table 1 Overview of selected studies for Antarctica using Climate Change Forecasts

Author	Focus species	IPCC Scenario used	Major finding
Ainley *et al.* (2010)	Adelie penguin	IPCC ARR4GFDL-CM2.1, GFDL-CM2.0, MIROC3.2(hi-res), and MRI-CGCM2.3.2a.. Analyzed the composited model ENSEMBLE to estimate the point of 2°C warming (2025–2052).	Changes in colony locations and more narrow ranges
Turner *et al.* (2009)	Ecosystem interpretation	IPCC, AR4 (local interpretation)	Sea ice changes and reductions. See also IPCC for details
Jouvenier *et al.* (2009)	Emperor penguin	16 climate models from IPCC AR3 assessment report (26) and averaged over the austral winter (July to September). Data from the World Climate Research Program’s (WCRP’s) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset.	Reduced population viability, and increased extinction risk

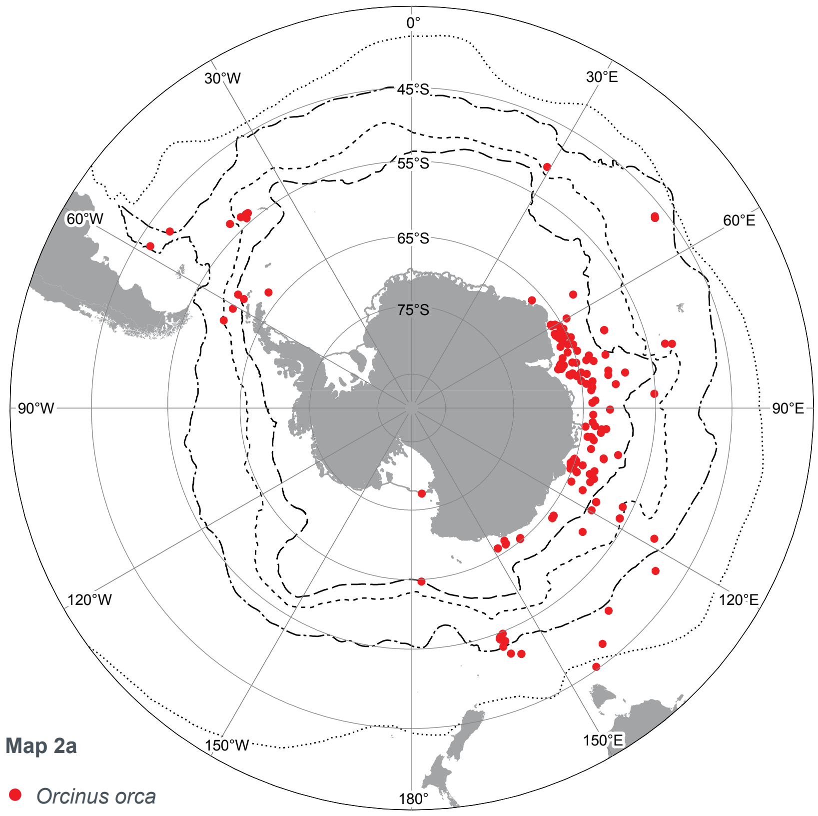
Table 2: Overview of species of which 38 were selected and modeled in this study with sufficient data

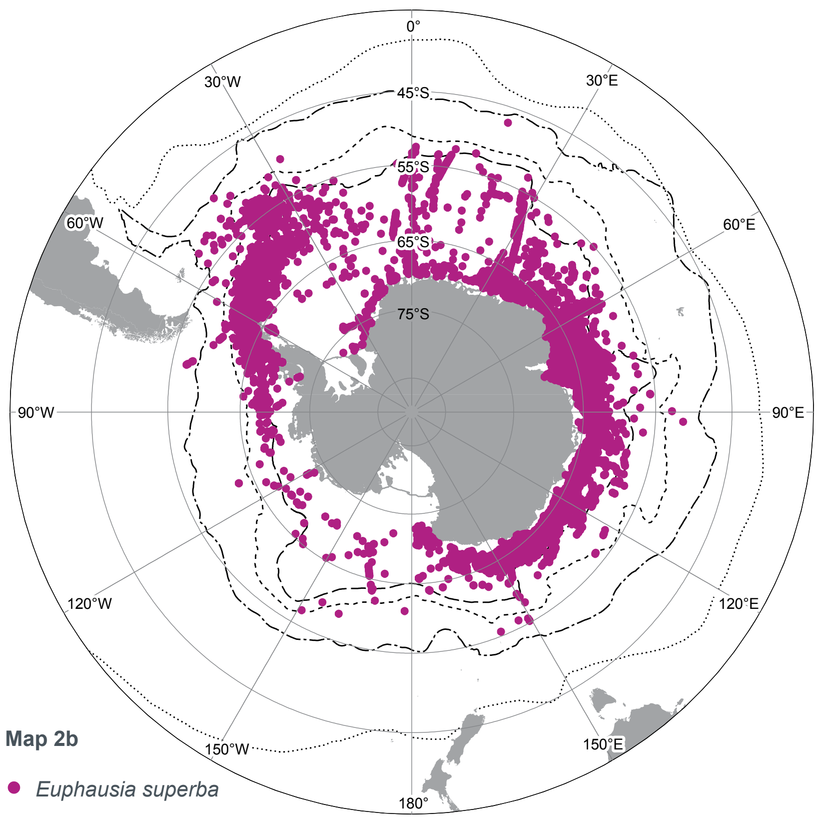
Common name	Scientific name	Modeled	Aphia number, WORMS	Taxonomic Status for Reclassification
Adélie penguin	*Pygoscelis adeliae*	Yes	225757	Stable
Atlantic petrel	*Pterodroma incerta*	Yes	212641	Medium
Antarctic fur seal	*Arctocephalus gazella*	Yes	231404	Stable
Antarctic krill	*Euphausia superba*	Yes	236217	Stable
Antarctic/southern minke whale	*Balaenoptera bonaerensis*	Yes	231405	Medium
Antarctic petrel	*Thalassoica antarctica*	Yes	205214	Medium
Antarctic prion	*Pachyptila desolata*	Yes	212649	Stable
Antarctic toothfish	*Dissostichus mawsonii*	Yes	234836	Weak
Black-bellied storm-petrel	*Fregetta tropica*	Yes	212696	Medium
Black-browed albatross	*Thalassarche melanophris*	Yes	225756	Weak
Blue petrel	*Halobaena caerulea*	Yes	212645	Medium
Blue whale	*Balaenoptera musculus*	No	137090	Stable
Broad-billed prion	*Pachyptila vittata*	Yes	212647	Medium
Cape petrel	*Daption capense*	Yes	212640	Medium
Chinstrap penguin	*Pygoscelis antarctica*	Yes	225747	Stable
Cory's shearwater	*Calonectris diomedea*	No	137194	Stable
Crabeater seal	*Lobodon carcinophaga*	No	344008	Stable
Crystal krill	*Euphausia crystallorophias*	No	236216	Medium
Emperor penguin	*Aptenodytes forsteri*	No	225773	Stable
Fin whale	*Balaenoptera physalus*	No	137091	Stable
Fairy prion	*Pachyptila turtur*	No	212648	Medium
Gentoo penguin	*Pygoscelis papua*	No	225777	Stable
Great-winged petrel	*Pterodroma macroptera*	No	212644	Medium
Greater shearwater	*Puffinus gravis*	No	137201	Stable
Grey-headed albatross	*Thalassarche chrysostoma*	Yes	212584	Weak
Humpback whale	*Megaptera novaeangliae*	No	137092	Stable
Imperial shag	*Phalacrocorax atriceps*	Yes	225759	Stable
Kelp gull	*Larus dominicanus*	No	212624	Stable
Killer whale (Type C)	*Orcinus orca*	Yes	137102	Weak
King penguin	*Aptenodytes patagonicus*	No	212656	Stable
Leopard seal	*Hydrurga leptonyx*	No	231417	Stable
Light-mantled sooty albatross	*Phoebetria palpebrata*	Yes	212631	Weak
Little shearwater	*Puffinus assimilis*	No	137200	Stable
Macaroni penguin	*Eudyptes chrysolophus*	No	212658	Stable
Minke whale	*Balaenoptera bonaerensis*	No	137087	Weak
New Zealand sea lion	*Phocarctos hookeri*	Yes	231422	Stable
Northern giant petrel	*Macronectes halli*	Yes	212637	Medium
Patagonian toothfish	*Dissostichus eleginoides*	Yes	234700	Weak
Pomarine jaeger	*Stercorarius pomarinus*	Yes	137173	Stable
Rockhopper penguin	*Eudyptes chrysocome*	No	212657	Stable
Ross seal	*Ommatophoca rossii*	Yes	231412	Stable
Royal penguin	*Eudyptes schlegeli*	No	225926	Stable
Sei whale	*Balaenoptera borealis*	Yes	137088	Stable
Short-beaked common dolphin	*Delphinus delphis*	No	137094	Stable
Short-tailed shearwater	*Puffinus tenuirostris*	No	225770	Stable
Snow petrel	*Pagodroma nivea*	Yes	225772	Stable
Soft-plumaged petrel	*Pterodroma mollis*	Yes	137199	Medium
Sooty albatross	*Phoebetria fusca*	Yes	212632	Weak
South polar skua	*Catharacta maccormicki*	Yes	159073	Medium
Southern elephant seal	*Mirounga leonina*	Yes	231413	Stable
Southern fulmar	*Fulmarus glacialoides*	No	212638	Stable
Southern giant petrel	*Macronectes giganteus*	Yes	212636	Medium
Southern right whale	*Eubalaena australis*	Yes	220222	Medium
Subantarctic skua	*Stercorarius lonnbergi*	Yes	137170	Medium
Wandering albatross	*Diomedea exulans*	Yes	212583	Weak
Weddell seal	*Leptonychotes weddellii*	Yes	195932	Stable
White-bellied storm petrel	*Fregetta grallaria*	Yes	212695	Medium
White-chinned petrel	*Procellaria aequinoctialis*	Yes	212651	Medium

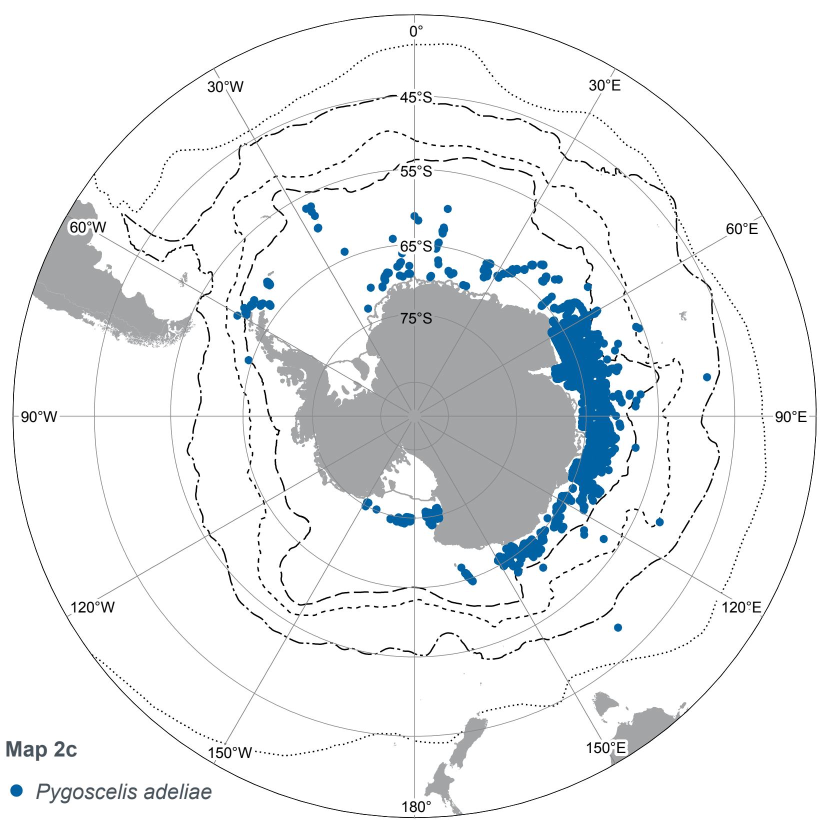
2.2. Environmental data layers

Many individual environmental data layers can be found for Antarctica, but a complete overview does not exist, yet (compare for instance with 170 freely online available data layers for the Arctic in Schmid 2012). Here we used the environmental Geographic Information System (GIS) data layers for the study area (Map 1) made available by the Macroscope working group (compiled by Raymond *et al.* unpublished; http://data.aad.gov.au/regionalisation/), topographic sources from colleagues, as well the layers compiled by Schmid (2012) for the comparison of representative concentration pathway (RCP) scenarios (Van Vuren *et al.* 2011). RCP scenarios for 2010 and 2100 were compared and based on 10 predictors (Table 3, more details in Schmid 2010 and and http://www.cccma.ec.gc.ca/ data/cgcm4/ CanESM2/ rcp85/ mon/ ocean/index.shtml).

For future predictions we used the RCP scenarios with a high radiative forcing of 8.5 w/mm^2 (app. 4.5 degrees Celsius atmospheric warming) as predicted by the Canadian Earth System Model 2 (CanESM2); they carry a







Predictions Map 2 Distribution map of 'presence only' points for selected species: (a) Killer whale, (b) Antarctic krill, (c) Adélie Penguin.

resolution of 2.8 degrees (Chylek *et al.* 2011). The RCP scenario models were chosen for the latest ICCP updates (see for details at http://www.pik-potsdam.de/~mmalte/rcps/). They performed fairly well on a global scale (Van Vuren *et al.* 2011); therefore, they are expected to have a good quality for the large area of Antarctica also. The CanESM2 was available in a readily accessible digital format and appeared to predict well. However, it was already noted by Ainley *et al.* (2010) that no very good climate change scenario exist for all of Antarctica because (static) models have difficulties to reproduce well the (dynamic) polar fronts (Moore *et al.* 1999) and related features (including some seafloor temperature locations for instance).

We decided to use RCP85 data to create a baseline of climate change effects on the modeled species. The RCP85 scenario was initially thought as the upper bound 'baseline', and when the global warming will be ca 2.5 degrees Celsius or less (Ainley *et al.* 2010). But by now with expected global warming scenarios of over 4 degrees, RCP85 shows a realistic summary of the outlook the world faces with climate change and when considering that all relevant policies and targets on the climate change agenda have virtually been missed (Kyoto and Biodiversity Convention; Mace *et al.* 2010, Huettmann 2012 for polar-wide impacts). It is unlikely that man-made climate change will be under control during the next 50 years, and while the global human population and their consumption appears to keep growing (Friedman 2010 for expert assessment, Summerhayes *et al.* in Turner *et al.* 2009). Therefore, the RCP85 scenario sets a realistic baseline for this study.

2.3. Niche model building

We followed an ecological niche modeling approach for seabirds, as outlined and described in Huettmann & Diamond (2001), Elith *et al.* (2006), Franklin (2010), Hegel *et al.* (2010) and Humphries et al. (2012). For each species we linked the 'presence only' data with 10,000 random points (pseudo-absence) in the rectangular bounding box of the study area; this allowed for a representative background sampling. We followed a similar approach sampling the 20 clusters within the bioregionalization model (that work is presented elsewhere and in review). We built automated randomForests models in R (http://cran.r-project.org/web/packages/randomForest/index.html), also employing the Geospatial Modeling Environment (GME; www.spatialecology.com/gme/) for overlays, and importing and exporting relevant layers as CSV files into ArcGIS10. The stereographic south polar projection was used in ArcGIS (version 10); latitude and longitude data were reprojected accordingly. The R-code is essentially a workflow batch of commands and libraries and packages mentioned. It allowed us to create diagnostics and statistical analyses based on bagging (a specific internal bootstrap testing in randomForest) and the confusion matrix (ROC curve etc) from the presence/pseudoabsence data; some of the relevant metrics are presented here. We then employed the obtained randomForests model file (a so called groove file) to a 'lattice' of 8967 equally spaced points all over the circular Antarctic pelagic study area. The 'lattice' was overlaid in GME over the same set of environmental predictors as the species layers. This allowed us to obtain the randomForests predictions for each of the lattice points and for the year 2010.

2.4. Forecasting

The randomForests model for species (and bioregional cluster membership) vs. environmental data layers from the IPCC (CanESM2) was developed for the year 2010. This model was then applied to a new lattice containing the environmental data layers of the CanESM2 for the year 2100 (Map 3 shows an example for the TOS metric for 2010 and 2100). The future prediction was also automated using the R-code environment and which summarised diagnostic metrics of the 2100 models (when compared to 2010).

2.5. Model comparisons over time

For each species, we compared the predicted ecological niche change happening from 2010 to 2100 based on the randomForests algorithm for the 'presence only' vs. random absence data (The same comparison was done for the bioregional cluster membership; details presented elsewhere). This comparison was done by applying the relative occurrence index (ROI) for each species and by presenting its frequency distribution (expressed by descriptive metrics of minimum, mean, median, maximum and range) and differences between species and between years. For consistency, all these comparisons were done using the CanESM2 scenario framework (we also have assembled predictive models for 2010 that are based on over 20 predictor layers, other than the smaller set of 10 RPC IPCC predictors here; their results are presented elsewhere. For details contact the authors). Finally, a regression was run to visualise and to explain the maximum changes by latitude and longitude in the study area; this was done with a machine learning algorithm also (TreeNet, from www.salford-systems.com/).

3. Results

3.1. Predicted Relative Occurrence Indices (ROIs) for 2010

The R-code models for the 38 species ran in less than two hours (PC 32bit Windows OS; the code follows the R sources provided in the methods. Further details available from the author). The bioregional model was achieved within less than five minutes. Such model performance assures that data and assumptions can be easily fine-tuned and re-run as necessary in the future. Models with a good accuracy were achieved quickly, and a variable ranking of importance across the 10 predictors was seen for all 38 species. The individual break down of the predictors is presented in Table 3, showing top

Table 3: Overview matrix and summary of the Top3 predictors in the randomForest model from RCP85 predictors for the year 2010 for each of the 38 species in Antarctica (Table headers: Tos= Sea surface temperature, Sos=Sea surface salnity, No3= Nitrate, Chl = Chlorophyl, Mrr = Monthly Mixing Depth, 07=July, 12 = December. Numbers in the table cells indicate the importance rank of the predictor in the randomForest; only the first 3 predictors are shown for each model).

Species name	Name of Predictor from RCP2010									
	Tos07	Tos12	Sos07	Sos12	No307	No312	Chl07	Chl12	Mrr07	Mrr12
Adelie penguin					2	3				1
Atlantic petrel	2	3		1						
Antarctic krill		1		2		3				
Antarctic petrel					2	3	1			
Antarctic prion				1		3		2		
Antarctic toothfish		2			1				3	
Antarctic fur seal	1		3				2			
Black-bellied storm petrel		1	3	2						
Black-browed albatross			3	1			2			
Blue petrel			3				1	2		
Broad-billed prion				1			2	3		
Cape petrel		3		1			2			
Crabeater seal			1				2			3
Fairy prion				3			2	1		
Grey-headed albatross			3	1			2			
Imperial shag		3	1	2						
Killer whale					2	3				1
Light-manteled sooty albatross				3	2		1			
New Zealand sea lion						3	2	1		
Northern giant petrel		2	3						1	
Patagonian toothfish		2			1		3			
Pomarine jaeger	1							3	2	
Ross seal				3	2					1
Sei whale					3	2			1	
Snow petrel	2				3		1			
Soft-plumed petrel			2	3			1			
Sooty albatross					1	2	3			
Southern elephant seal	3				2		1			
Southern giant petrel	3			2	1					
Southern right whale		1	2	3						
South polar skua					2	3				1
Subantarctic skua							3		1	2
Wandering albatross		1					3	2		
Weddell seal				3	2		1			
White-bellied petrel				1			3	2		
White-bellied storm-petrel				3	2		1			
SUM	12	19	24	36	28	25	39	16	8	9
How often selected as top3	**6**	**10**	**10**	**18**	**15**	**9**	**21**	**8**	**5**	**6**

three predictors for each species, and how often the predictors were selected by the randomForest algorithm overall. Modeled rcp2010 chlorophyll (July), salinity (December) and nitrogen (July) were occurring most often as top3 predictors.

3.2. Predicted ROIs for 2100

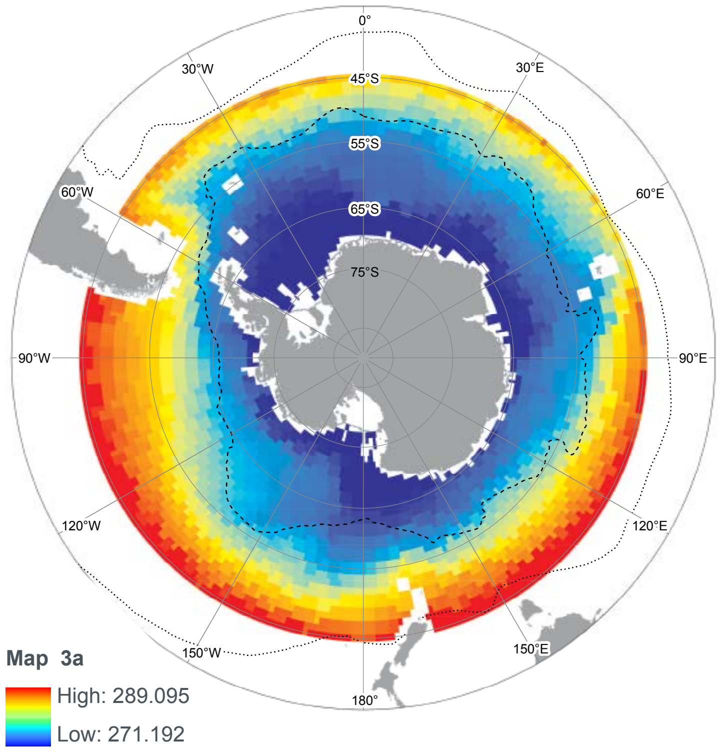
The R-code for applying the 38 species models to lattice points based on RCP 2100 data ran within less than 20 minutes; the bioregionalisation model ran within less than five minutes. A summary is presented in Table 4. To summarize model predictions across the 38 species for the 8967 lattice points, we computed the averaged median and present a ROI frequency distribution of all changes (Figure 1). The mapped out result is shown in Map 4: Model differences 2010 vs 2100 showed a general decline of ROIs. We think this presents an indication of declining habitat quality and of decreasing range sizes (similar as stated by others; Jenouvrier *et al.* 2009, Ainley *et al.* 2010). As a matter of fact, it indicates a decay of the current Antarctic character (see Summerson 2012). A detailed look at the largest predicted ROI changes (Map 4b) for each management zone (Map 1) presents that eastern Antarctic waters, Ross Sea region, Western Antarctic Peninsula and south of Australia receive the biggest predicted changes over time. However, changes should be seen in the wider context, and the overall (global) change needs to be considered. This suggests that impacts on Antarctica are already widespread. Figure 2 shows such a generalised breakdown of ROI values (y-axis as a gradient from low to high) by latitude (upper panel) and longitude (lower panel). It highlights the frontal system positions (e.g. latitudes -65 to – 55 degrees) as well as wider Eastern Antarctic regions (e.g. longitudes 40 to 180 degrees) as areas of major change in Antarctica.

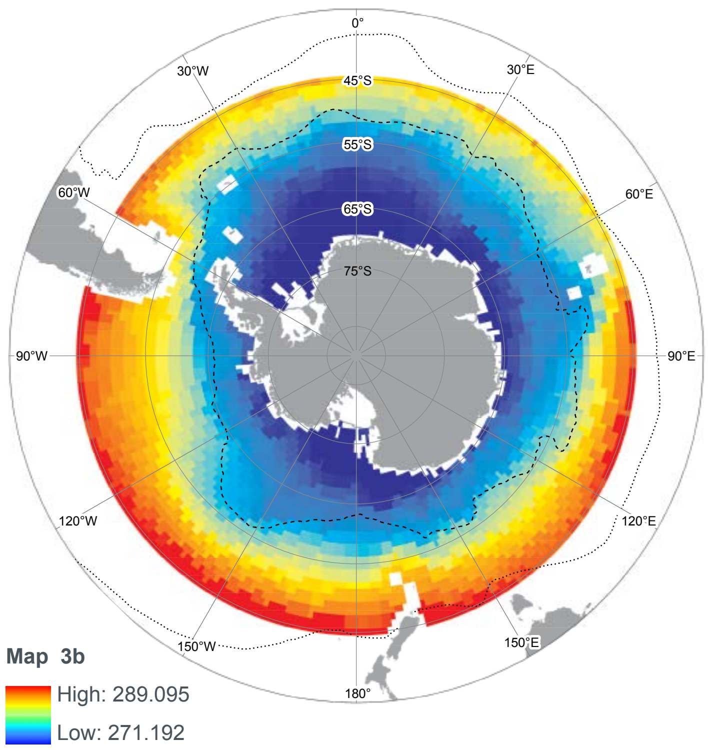
4. Discussion

Our models rely on (empirical) data. Strong models can be obtained when powerful data mining algorithms are able to extract robust trends, even from limited or poor data (Booms *et al.* 2011, Hardy *et al.* 2011, Wei *et al.* 2011 for similar models as used here). For this study we were interested in assessing first general trends and to develop a first model and baseline. This presents 'best available science', and allows for coming years to easily run updates in case better and further downscaled environmental data become available. While good metadata were still missing for these data (Huettmann 2011b), the actual data content used for all models appeared to be very good, e.g. taxonomic identification and geo-referencing. Compiled species data over time were comparable, and comparisons with other known products and knowledge matched our expectations for the year 2010 (no data discrepancies were found; model accuracies satisfied, data are readily available for a public review and improvement over time as needed). We sampled the entire Antarctic ocean for background sampling (pseudo-absences) and for a baseline when compared with presence only records. The use of machine learning should be robust to extract the signals from such data and allows to generalised such results. As common with most future predictions, the quality of the model for 2100 was somewhat inferior to the quality of the model for 2010 (Lawler *et al.* 2012). Predictions This is due to the fact that data for the future are missing and are impossible to assess (Huettmann & Gottschalk 2011). Only over time and then looking back we can learn about the real accuracy of those earlier models. Such studies should be considered in the future and to inform management decisions. Here such a research agenda is set up.

In terms of sensitivities, spatial data were found to be accurate and when they were imported into GIS; the grid layers we obtained were created in appropriate projections. The use of 'south polar stereographic' was mostly just done for visualisation purposes because it can create spatial skews during an analysis; the actual GIS overlays were done with latitude longitude data (lattices) and within the WGS84 geographic datum for all data layers.

Here we focused on pelagic data sets and models. Several of the species we chose to model dominate in coastal regimes too. However, such areas are poorly mapped and many of our environmental data would need substantial improvement in these regions and for such habitats. This shortcoming in Antarctic data is widely recognised. We therefore had to exclude some of such coastal pixels which showed these uncertainties, and we focus in our





Predictions Map 3 IPCC rcp85 map for (a) sea surface temperature in December (Antarctic summer) 2010, (b) sea surface temperature in December (Antarctic summer) 2100 (Legend: Red indicates warmer temperatures, green cooler ones).

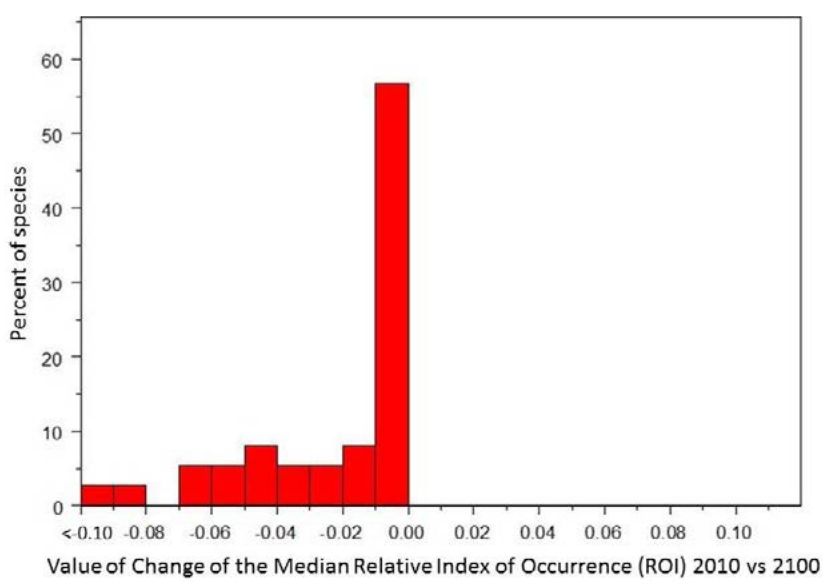


Figure 1 Frequency distribution trend of median changes from 2010 to 2100 for the 38 selected species based on rcp85 IPCC models (Table 4).

assessment on pelagic regions instead. As part of future efforts, such regions should receive more attention, and data gaps can either be model-predicted or should be mapped more thoroughly. This is crucial for four reasons: a) the majority of biodiversity is located in shallower waters where mixing favors biological productivity , b) human development and climate change will affect coastal areas strongly, e.g. through construction, travel and sea level rise, c) the ice edge has always been a hotspot of Antarctic life, and d) the diverse ice edge zone has always been heterogeneous and its components were poorly quantified.

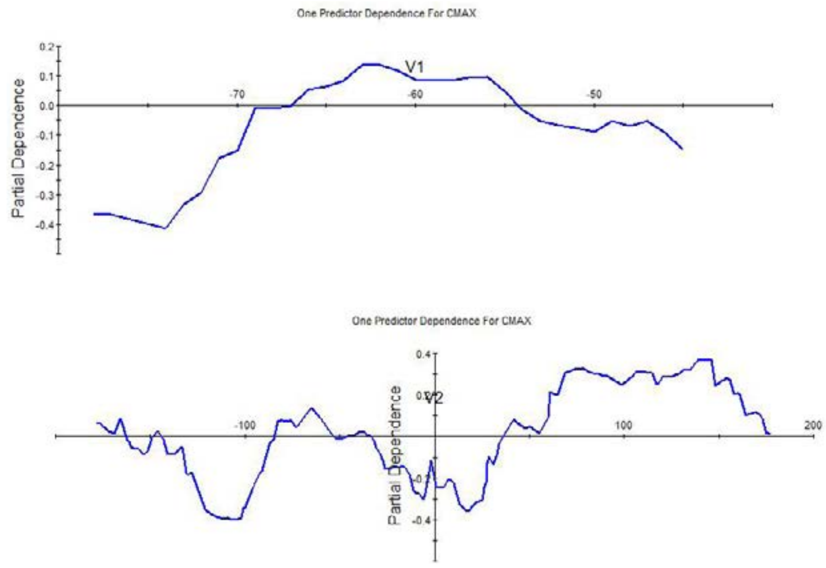
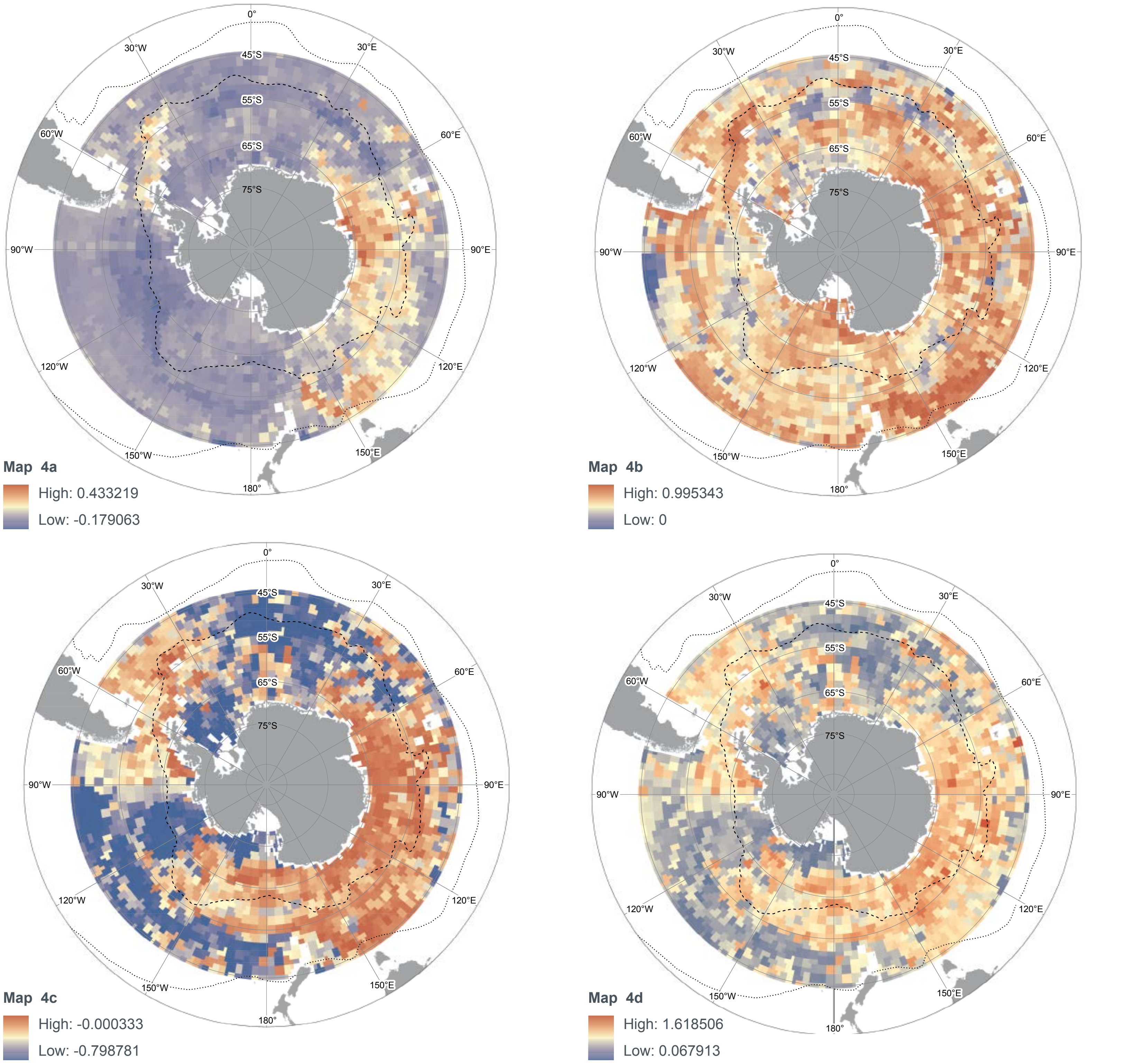


Figure 2 Generalized regression trends (based on machine learning TreeNet algorithm) modeled for latitude (6a: upper panel, -90 til -40 decimal degrees) and longitude (6b: lower panel. -180 to 0 to 180 decimal degrees) to explain the biggest (max) average change of the relative occurrence index (ROI) for 38 species in Antarctica.

Table 4 Table of summary statistics for 38 species predicted 2010 vs 2100 (based on a grid of 8,967 lattice points in the pelagic Antarctic study area). The minimum, mean, median, maximum and range describes the frequency distribution of these differential pixels 2010 vs 2100. A negative median indicates for instance a predicted decline of the ROI (~suitable pixels) for a species in 2100 (when compared to the 2010 baseline).

Species	Min	Mean	Median	Max	Range
Adélie penguin	-0.384	0.022	0	0.970	1.354
Atlantic petrel	-0.133	-0.003	0	0.619	0.752
Antarctic fur seal	-0.552	-0.015	-0.014	0.992	1.544
Antarctic krill	0	0	0	0	0
Antarctic petrel	-0.397	0.050	-0.019	0.960	1.357
Antarctic prion	-0.502	0.011	-.0.049	0.979	1.481
Antarctic toothfish	-0.043	0	0	0.412	0.456
Black-bellied storm-petrel	-0.578	0.007	-0.037	0.990	1.569
Black-browed albatross	-0.798	-0.062	-0.096	0.946	1.745
Blue petrel	-0.570	0.039	-0.049	0.991	1.561
Broad-billed prion	-0.516	0.032	-0.020	0.956	1.472
Cape petrel	-0.530	0.042	-0.048	0.973	1.504
Chinstrap penguin	-0.209	-0.209	-0.010	-0.001	0.983
Crabeater seal	-0.452	0.035	0	0.982	1.435
Fairy prion	-0.609	0.002	-0.017	0.099	1.604
Grey-headed albatross	-0.782	-0.005	-0.086	0.917	1.699
Imperial shag	-0.168	-0.004	0	0.974	1.142
Killer whale	-0.293	0	-0.007	0.852	1.145
Light-mantled sooty albatross	-0.634	0.031	-0.064	0.978	1.613
New Zealand sea lion	-0.496	-0.002	0	0.918	1.415
Northern giant petrel	-0.466	-0.009	-0.029	0.982	1.449
Patagonian toothfish	-0.213	-0.013	-0.004	0.978	1.192
Pomarine jaeger	-0.205	0	0	0.096	0.304
Ross seal	-0.295	0.004	0	0.857	1.152
Sei whale	-0.396	-0.005	0	0.972	1.368
Southern elephant seal	-0.699	0.11	0	0.983	1.682
Southern giant petrel	-0.460	0.009	-0.053	0.977	1.437
Southern right whale	-0.161	0	0	0.478	0.639
Snow petrel	-0.527	0.052	0	0.973	1.500
Soft-plumaged petrel	-0.555	-0.009	-0.03	0.974	1.529
Sooty albatross	-0.277	0	-0.008	0.943	1.220
South polar skua	-0.176	-0.005	-0.009	0.960	1.136
Subantarctic skua	-0.057	0	0	0.558	0.616
Wandering albatross	-0.486	0.002	-0.670	0.923	1.414
Weddell seal	-0.117	0	0	0.609	0.727
White-bellied storm-petrel	-0.453	-0.007	-0.009	0.983	1.436
White-chinned petrel	-0.639	0.047	-0.051	0.967	1.607

The general trends of our study indicate a decline in ROI predictions for 2100. We think this represents an indication for a declining habitat quality and decreasing distribution range for traditional Antarctica species. Similar findings were discussed by Turner *et al.* (2009) and many others (Jenouvrier *et al.* 2009, Ainley *et al.* 2010). Our models do not inform so well on the Antarctic frontal systems, yet. But changes in such features and related ecological processes will presumably still be rather relevant and should receive special scrutiny in future efforts. For space reasons, here we do not present all predicted species for 2010 and 2100 as maps. But our summary assessment of these findings suggests that species will show the greatest change in eastern Antarctic waters, Ross Sea region, Western Antarctic Peninsula, south of Australia, and around 60 degrees latitude. This makes for a diverse



Predictions Map 4 Summary maps of predicted changes for relative occurrence indeces (ROI) for 38 species based on 2010 vs 2100 predictions using rcp85 IPCC models showing (a) mean, (b) maximum, (c) minimum and (d) range change (Legend: Green indicates low change, red indicates high change. Note: This index is relative for each species prediction and essentially without units. It allows though to detect general trends in the data and for each pixel between 2010 vs 2100).

set of regions. While the distribution range of many species will get pushed towards the coastline of Antarctica, clear longitudinal species gradients can be found as well, peaking at frontal systems and Eastern Antarctica (Figure 2). Such a development where species are redistributed and come in from outside would lead to stressed populations of ice-related and endemic species in Antarctica. Also, less of the original habitat is related in 2100 to cold waters and ice, and which are traditional hotspots in 2010. However, our model does currently not indicate how many non-native or invasive species would possibly move into Antarctic waters, and where this occurs exactly (pixel-based). While this scenario of warming and incoming species would favour 'enrichment', in reality, it means even more destruction of the Antarctic ecosystem. That is because new species tend to be more aggressive than the ones they replace, and because such invasive processes also tend to bring in diseases and parasites (Kerry & Riddle 2009), apart from a changed ecosystem overall and increasing anthropogenic pressures. Such situations are known to go hand in hand with climate change and its drivers (Hilty *et al.* 2007, Bush *et al.* 2011, Brodie *et al.* 2012, Resendiz 2012).

Here we provide a first summary of future species predictions based on climate change questions. State-of-the-art climate change data, species distribution and bioregionalisation data in combination with data mining methods using machine learning can provide this valuable outlook into the future. While basic data and good technology exist to provide reliable answers, the biggest constraint for a more complete and reliable assessment is the availability and documentation of better climate change scenarios, species data (Huettmann 2011b) and funding to achieve the next goals. However, better models are re-run and developed constantly, and therefore we can contribute here a first methodological platform and assessment framework on this important topic and for an informative assessment and outlook before more harm occurs.

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THE BIOGEOGRAPHIC ATLAS OF THE SOUTHERN OCEAN

Scope

Biogeographic information is of fundamental importance for discovering marine biodiversity hotspots, detecting and understanding impacts of environmental changes, predicting future distributions, monitoring biodiversity, or supporting conservation and sustainable management strategies.

The recent extensive exploration and assessment of biodiversity by the Census of Antarctic Marine Life (CAML), and the intense compilation and validation efforts of Southern Ocean biogeographic data by the SCAR Marine Biodiversity Information Network (SCAR-MarBIN / OBIS) provided a unique opportunity to assess and synthesise the current knowledge on Southern Ocean biogeography.

The scope of the Biogeographic Atlas of the Southern Ocean is to present a concise synopsis of the present state of knowledge of the distributional patterns of the major benthic and pelagic taxa and of the key communities, in the light of biotic and abiotic factors operating within an evolutionary framework. Each chapter has been written by the most pertinent experts in their field, relying on vastly improved occurrence datasets from recent decades, as well as on new insights provided by molecular and phylogeographic approaches, and new methods of analysis, visualisation, modelling and prediction of biogeographic distributions.

A dynamic online version of the Biogeographic Atlas will be hosted on www.biodiversity.aq.

The Census of Antarctic Marine Life (CAML)

CAML (www.caml.aq) was a 5-year project that aimed at assessing the nature, distribution and abundance of all living organisms of the Southern Ocean. In this time of environmental change, CAML provided a comprehensive baseline information on the Antarctic marine biodiversity as a sound benchmark against which future change can reliably be assessed. CAML was initiated in 2005 as the regional Antarctic project of the worldwide programme Census of Marine Life (2000-2010) and was the most important biology project of the International Polar Year 2007-2009.

The SCAR Marine Biodiversity Information Network (SCAR-MarBIN)

In close connection with CAML, SCAR-MarBIN (www.scarmarbin.be, integrated into www.biodiversity.aq) compiled and managed the historic, current and new information (i.a. generated by CAML) on Antarctic marine biodiversity by establishing and supporting a distributed system of interoperable databases, forming the Antarctic regional node of the Ocean Biogeographic Information System (OBIS, www.iobis.org), under the aegis of SCAR (Scientific Committee on Antarctic Research, www.scar.org). SCAR-MarBIN established a comprehensive register of Antarctic marine species and, with biodiversity.aq provided free access to more than 2.9 million Antarctic georeferenced biodiversity data, which allowed more than 60 million downloads.

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