

Ecography

ECOG-02590

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Supplementary material

Supplementary Material: Appendix 1

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Table A1. Seabird species included in the study, abbreviation used throughout the paper, IUCN status of conservation, total number of points for each species, years of sampling and the original publication of the tracking data. IUCN Status: LC=Least Concern, NT=Near Threatened, VU=Vulnerable, EN=Endangered, CR=Critically Endangered.

Common Name	Species	Abbreviation	IUCN Status	Points	Years
Black-browed Albatross	<i>Thalassarche melanophris</i>	BBA	NT	19,798	1996, 1997, 2002, 2003
Grey-headed Albatross	<i>Thalassarche chrysostoma</i>	GHA	EN	17,896	2003, 2006
Northern Giant Petrel	<i>Macronectes halli</i>	NGP	LC	14,854	1999, 2001
Southern Giant Petrel	<i>Macronectes giganteus</i>	SGP	LC	31,569	1999, 2001, 2011
Tristan Albatross	<i>Diomedea dabanena</i>	TA	CR	11,323	2005, 2007, 2008
Wandering Albatross	<i>Diomedea exulans</i>	WA	VU	54,706	2003
White-chinned Petrel	<i>Procellaria aequinoctialis</i>	WCP	VU	3,047	2003, 2004

Table A2. Environmental variables used for Species Distribution Modelling, abbreviation used throughout the paper, source (satellites names, or blended when using data from several satellite plus earth stations) and period of the dataset used.

Variable	Abbr	Units	Source	Dataset
Chlorophyll <i>a</i> concentration	CHL	mgm ⁻³	Orbview-2 SeaWiFS	Jan/2000-Dec/2010
Sea Surface Temperature	SST	°C	Blended	Jan/2003-Dec/2012
Wind Speed	WIND	ms ⁻¹	NCDC Blended	Jan/2000-Dec/2010
Sea Ice Cover	SIC	fraction	NCDC, AMSR+AVHRR	Jan/2003-Dec/2010
Bathymetry	BATH	Km	ETOPO1	-

Table A3. Ensemble Species Distribution Modelling parameterizations.

Model	Parameters
Generalized Linear Model	<pre> type = 'quadratic' interaction.level = 0 myFormula = NULL test = 'AIC' family = binomial(link = 'logit') mustart = 0.5 control = glm.control(epsilon = 1e-08, maxit = 50, trace = FALSE) </pre>
Generalized Boosted Model	<pre> distribution = 'bernoulli' n.trees = 2500 interaction.depth = 7 n.minobsinnode = 5 shrinkage = 0.001 bag.fraction = 0.5 train.fraction = 1 cv.folds = 3 keep.data = FALSE verbose = FALSE perf.method = 'cv' </pre>
Generalized Additive Model	<pre> algo = 'GAM_mgcv' type = 's_smoother' k = -1 interaction.level = 0 family = binomial(link = 'logit') method = 'GCV.Cp' optimizer = c('outer', 'newton') select = FALSE knots = NULL paraPen = NULL control = list(irls.reg = 0, epsilon = 1e-06, maxit = 100) trace = FALSE, mgcv.tol = 1e-07, mgcv.half = 15 rank.tol = 1.49011611938477e-08 nlm = list(ndigit=6, gradtol=1e-05, stepmax=2, steptol=1e-04, iterlim=200, check.analyticals=0) optim = list(factr=1e+07) newton = list(conv.tol=1e-06, maxNstep=5, maxSstep=2, maxHalf=30, use.svd=0) outerPSteps = 0, idLinksBases = TRUE, scalePenalty = TRUE, keepData = FALSE </pre>
Classification Tree Analysis	<pre> method = 'class' parms = 'default' cost = NULL control = list(xval = 5, minbucket = 5, minsplit = 5, cp = 0.001) maxdepth= 25 </pre>
Artificial Neural Network	<pre> NbCV = 5 size = NULL decay = NULL </pre>

	rang = 0.1
	maxit = 200
Surface Range Envelop	quant = 0.025
Flexible Discriminant Analysis	method = 'mars'
Multiple Adaptive Regression Splines	degree = 2
	nk = NULL
	penalty = 2
	thresh = 0.001
	prune = TRUE
Random Forest	do.classif = TRUE
	ntree = 500
	mtry = 'default'
	nodesize = 5
	maxnodes = NULL
Maximum Entropy	memory_allocated = 512
	maximumiterations = 200
	visible = FALSE
	linear = TRUE
	quadratic = TRUE
	product = TRUE
	threshold = TRUE
	hinge = TRUE
	lq2lqptthreshold = 80
	l2lqthreshold = 10
	hingethreshold = 15
	beta_threshold = -1
	beta_categorical = -1
	beta_lqp = -1
	beta_hinge = -1
	defaultprevalence = 0.5

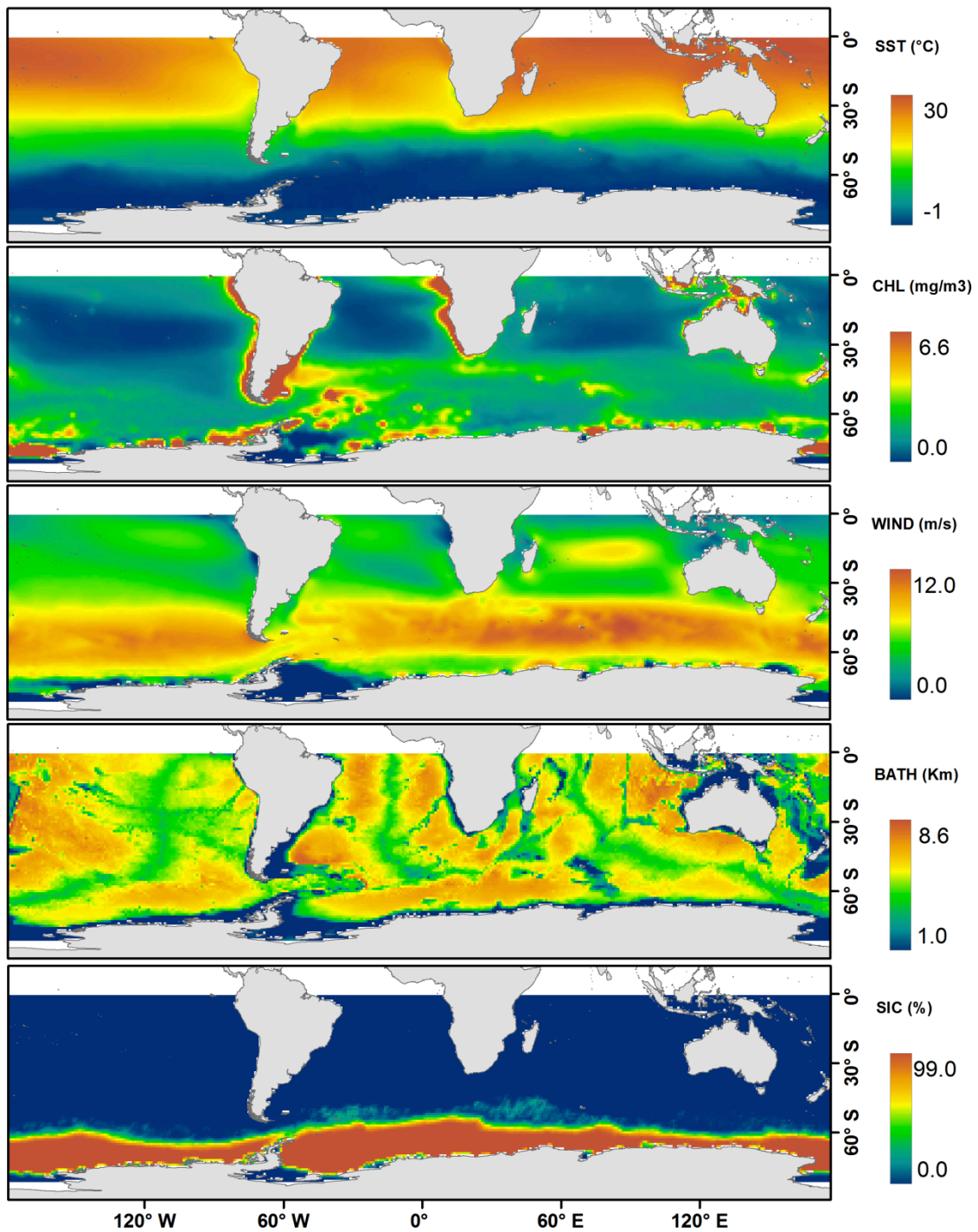


Figure A1. Spatial variability of environmental variables used in the modelling procedures. SST – Sea Surface Temperature, CHL – Chlorophyll-a concentration, WIND – wind speed, BATH – Bathymetry, SIC – Sea Ice Cover.

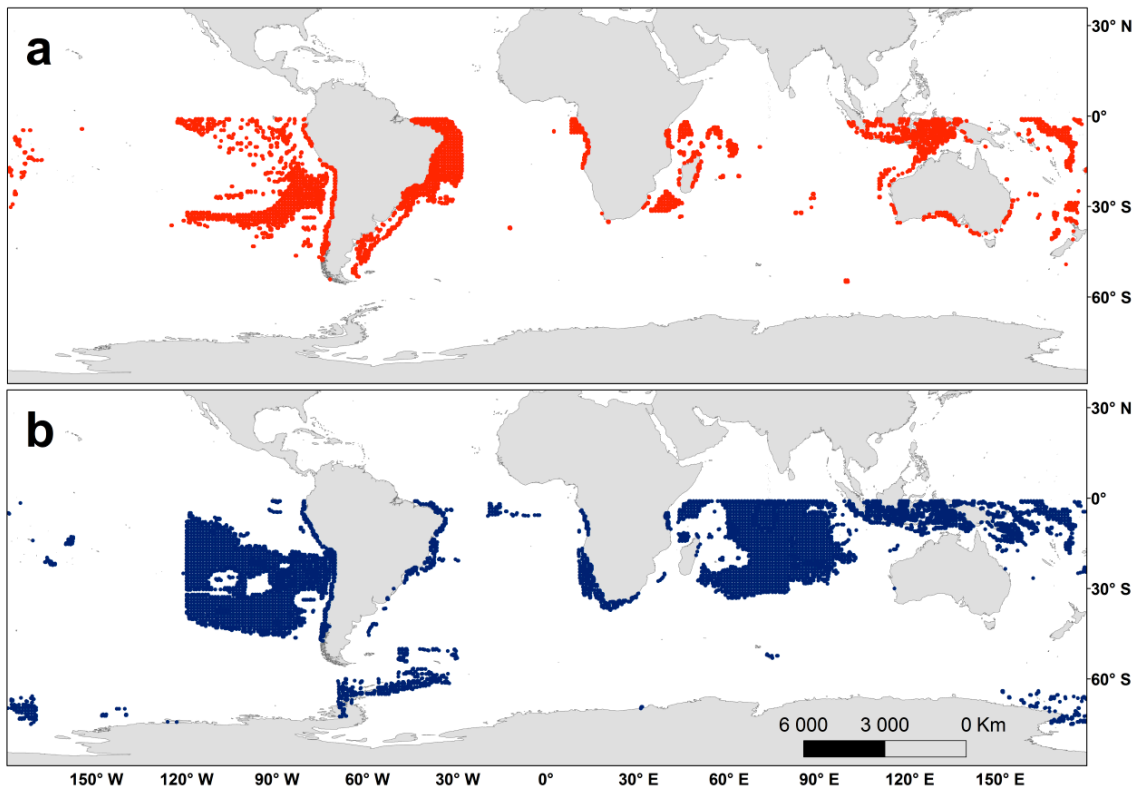


Figure A2. Fisheries distribution in the southern oceans, based on the values above the minimal standard deviation of landing values for high bycatch fisheries (a) and low bycatch fisheries (b), calculated from data of Halpern et al. (2015).

Table A4. Results of the Species Distribution Models for Black Browed Albatross (BBA), Grey-Headed Albatross (GHA), Northern Giant Petrel (NGP), Southern Giant Petrel (SGP),Tristan Albatross (TA), Wandering Albatross (WA) and White-Chinned Petrel (WCP). Area Under the Receiver Operational Characteristic Curves (AUC) and True Skill Statistic (TSS), both measuring model accuracy by comparing the outputs of the 80% data used to train the model and 20% used for evaluation of it's performance. Sensitivity measures the percentage of cases of presence that are classified correctly as presences (true positive rate) by the models and Specificity measures the percentage of cases of pseudo-absences correctly classified as absences (true negative rate) by the models. The permutation importance of each environmental variable; bathymetry (BATH), chlorophyll-*a* concentration (CHL), sea ice cover (SIC), sea surface temperature (SST) and wind speed (WIND) was measured as the amount of reduction in the model AUC by excluding that variable from the model. Threshold is the probability of occurrence calculated by the models. Artificial Neural Networks ANN, Classification Tree Analysis CTA, Flexible Discriminant Analysis FDA, Generalized Additive Model GAM, Generalized Boosted Models GBM, Generalized Linear Model GLM, Multiple Adaptive Regression Splines MARS, Maximum Entropy MAXENT, Random Forest RF and Surface Range Envelop SRE.

Species	Model	AUC	TSS	Sensitivity	Specificity	BATH	CHL	SIC	SST	WIND	Threshold (%)
BBA	ANN	0.986	0.932	96.691	96.500	0.051	0.404	0.107	0.699	0.181	46.400
	CTA	0.991	0.965	98.025	98.450	0.010	0.177	0.025	0.685	0.263	49.000
	FDA	0.981	0.896	92.870	96.700	0.005	0.135	0.089	0.607	0.162	92.400
	GAM	0.992	0.922	96.358	95.800	0.020	0.271	0.016	0.467	0.185	42.400
	GBM	0.995	0.951	96.845	98.200	0.002	0.263	0.005	0.416	0.140	48.700
	GLM	0.975	0.878	92.460	95.350	0.046	0.423	0.072	0.395	0.148	54.500
	MARS	0.775	0.531	97.487	38.700	0.000	0.009	0.994	0.004	0.008	48.900
	MAXENT	0.972	0.936	94.178	99.400	0.086	0.139	0.018	0.504	0.282	33.200
	RF	0.999	0.983	98.692	99.650	0.043	0.224	0.046	0.453	0.230	67.700
	SRE	0.917	0.834	84.124	99.300	0.139	0.272	0.068	0.370	0.253	49.500
Mean		0.958	0.883	94.773	91.805	0.040	0.232	0.144	0.460	0.185	53.270
GHA	ANN	0.984	0.930	95.470	97.500	0.018	0.004	0.256	0.690	0.287	63.400
	CTA	0.992	0.945	95.948	98.550	0.010	0.028	0.127	0.362	0.413	67.800
	FDA	0.983	0.926	96.201	96.400	0.000	0.000	0.111	0.711	0.137	92.800
	GAM	0.994	0.935	96.455	97.050	0.008	0.002	0.030	0.725	0.106	54.500
	GBM	0.995	0.946	96.933	97.600	0.002	0.004	0.068	0.404	0.319	39.500
	GLM	0.992	0.931	96.230	96.900	0.002	0.000	0.077	0.612	0.161	55.400
	MARS	0.991	0.930	96.680	96.350	0.000	0.000	0.057	0.752	0.146	46.400
	MAXENT	0.966	0.911	91.756	99.300	0.049	0.018	0.063	0.668	0.165	21.400
	RF	0.998	0.971	98.199	98.850	0.027	0.039	0.085	0.420	0.228	64.600
	SRE	0.915	0.829	83.455	99.450	0.098	0.240	0.094	0.365	0.351	49.500
Mean		0.981	0.925	94.733	97.795	0.021	0.034	0.097	0.571	0.231	55.530
NGP	ANN	0.995	0.962	97.862	98.350	0.017	0.526	0.101	0.511	0.243	75.600
	CTA	0.993	0.971	98.642	98.450	0.024	0.440	0.030	0.231	0.286	46.000
	FDA	0.991	0.939	96.809	97.250	0.000	0.485	0.026	0.154	0.280	96.700
	GAM	0.997	0.961	97.183	98.900	0.004	0.461	0.016	0.214	0.244	71.700
	GBM	0.997	0.966	97.454	98.950	0.000	0.489	0.010	0.124	0.196	71.600

	GLM	0.985	0.930	96.029	96.950	0.004	0.193	0.063	0.392	0.289	66.700
	MARS	0.995	0.944	97.929	96.450	0.000	0.391	0.000	0.280	0.268	64.100
	MAXENT	0.974	0.942	94.773	99.400	0.045	0.344	0.024	0.234	0.238	40.700
	RF	1.000	0.989	99.423	99.450	0.014	0.362	0.028	0.185	0.208	45.500
	SRE	0.911	0.822	82.213	100.000	0.084	0.396	0.048	0.289	0.316	49.500
Mean		0.984	0.943	95.832	98.415	0.019	0.409	0.035	0.261	0.257	62.810
SGP	ANN	0.993	0.927	98.377	94.350	0.047	0.039	0.099	0.859	0.116	63.700
	CTA	0.994	0.978	98.750	99.000	0.033	0.062	0.012	0.905	0.079	43.500
	FDA	0.970	0.926	98.832	93.750	0.000	0.008	0.021	0.923	0.101	73.850
	GAM	0.996	0.961	98.166	97.900	0.014	0.031	0.276	0.781	0.087	57.600
	GBM	0.998	0.977	98.653	99.000	0.006	0.025	0.000	0.902	0.081	55.800
	GLM	0.985	0.907	95.975	94.700	0.007	0.026	0.246	0.871	0.076	68.600
	MARS	0.993	0.944	98.880	95.500	0.000	0.018	0.070	0.817	0.137	36.600
	MAXENT	0.989	0.946	95.067	99.500	0.028	0.049	0.041	0.678	0.134	30.600
	RF	0.999	0.990	99.010	99.950	0.028	0.084	0.047	0.631	0.088	80.800
	SRE	0.922	0.844	84.372	100.000	0.140	0.180	0.028	0.581	0.155	49.500
Mean		0.984	0.940	96.608	97.365	0.030	0.052	0.084	0.795	0.105	56.055
TA	ANN	0.977	0.907	95.362	95.300	0.109	0.139	0.192	0.674	0.145	51.400
	CTA	0.987	0.960	97.261	98.700	0.090	0.124	0.000	0.770	0.181	53.900
	FDA	0.975	0.878	95.495	92.300	0.005	0.000	0.000	0.965	0.064	86.400
	GAM	0.991	0.938	96.422	97.350	0.058	0.119	0.007	0.736	0.158	59.600
	GBM	0.996	0.958	97.703	98.100	0.053	0.100	0.000	0.772	0.136	44.550
	GLM	0.979	0.857	92.447	93.200	0.072	0.005	0.060	0.745	0.108	63.400
	MARS	0.985	0.891	94.832	94.300	0.046	0.000	0.000	0.879	0.081	57.500
	MAXENT	0.974	0.931	93.330	99.800	0.118	0.098	0.154	0.473	0.220	83.900
	RF	0.999	0.980	98.542	99.500	0.098	0.141	0.067	0.580	0.165	51.000
	SRE	0.930	0.860	86.042	100.000	0.179	0.160	0.176	0.515	0.196	49.500
Mean		0.979	0.916	94.744	96.855	0.083	0.089	0.066	0.711	0.145	60.115
WA	ANN	0.995	0.946	96.114	98.450	0.028	0.104	0.319	0.532	0.209	70.500
	CTA	0.990	0.957	96.524	99.150	0.000	0.019	0.110	0.662	0.241	53.400
	FDA	0.978	0.908	97.186	93.350	0.000	0.026	0.245	0.683	0.105	89.000
	GAM	0.996	0.951	95.798	99.300	0.010	0.039	0.094	0.547	0.154	62.600
	GBM	0.995	0.957	96.851	98.800	0.000	0.010	0.031	0.498	0.239	49.100
	GLM	0.994	0.932	96.049	97.150	0.007	0.016	0.180	0.491	0.207	50.500
	MARS	0.991	0.929	96.627	96.300	0.000	0.007	0.253	0.538	0.185	62.600
	MAXENT	0.981	0.912	91.362	99.800	0.009	0.003	0.000	0.694	0.327	28.600
	RF	0.999	0.978	98.761	99.050	0.027	0.079	0.092	0.403	0.198	66.700
	SRE	0.910	0.820	82.147	99.900	0.163	0.225	0.093	0.320	0.265	49.500
Mean		0.983	0.929	94.742	98.125	0.024	0.053	0.142	0.537	0.213	58.250
WCP	ANN	0.997	0.965	98.288	98.200	0.061	0.495	0.239	0.449	0.238	31.000
	CTA	0.994	0.973	98.459	98.800	0.006	0.689	0.000	0.558	0.168	51.800
	FDA	0.992	0.920	94.178	97.800	0.004	0.857	0.044	0.068	0.051	12.100
	GAM	0.998	0.976	98.801	98.800	0.006	0.662	0.125	0.353	0.256	49.000
	GBM	0.999	0.982	99.486	98.700	0.000	0.705	0.001	0.430	0.099	31.300
	GLM	0.993	0.943	95.548	98.800	0.007	0.726	0.308	0.031	0.142	58.600
	MARS	0.997	0.959	99.144	96.800	0.033	0.772	0.000	0.390	0.177	18.200

Figure A5. Northern Giant Petrel probability of occurrence from zero (blue) to one (red) for each of the Climate Change Scenarios (Representative Concentration Pathways RCP) and the predicted area of occurrence above the models' thresholds (solid black line).

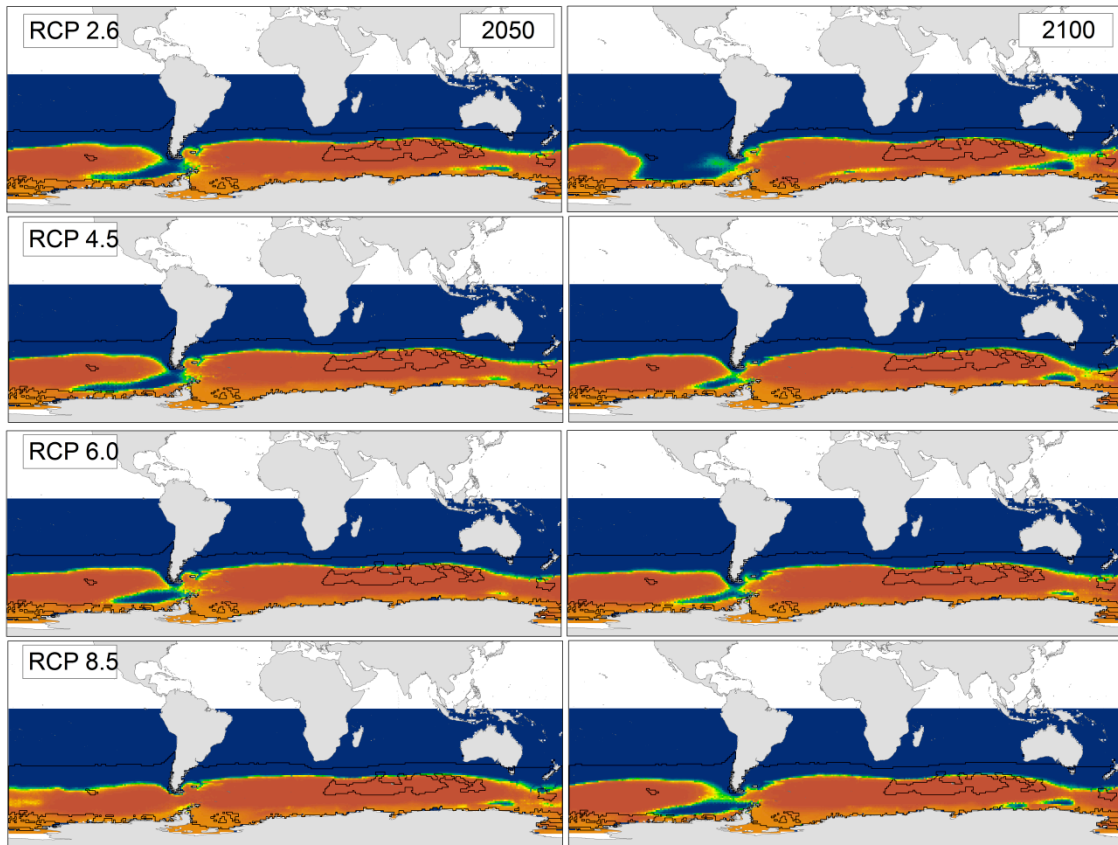


Figure A6. Southern Giant Petrel probability of occurrence from zero (blue) to one (red) for each of the Climate Change Scenarios (Representative Concentration Pathways RCP) and the predicted area of occurrence above the models' thresholds (solid black line).

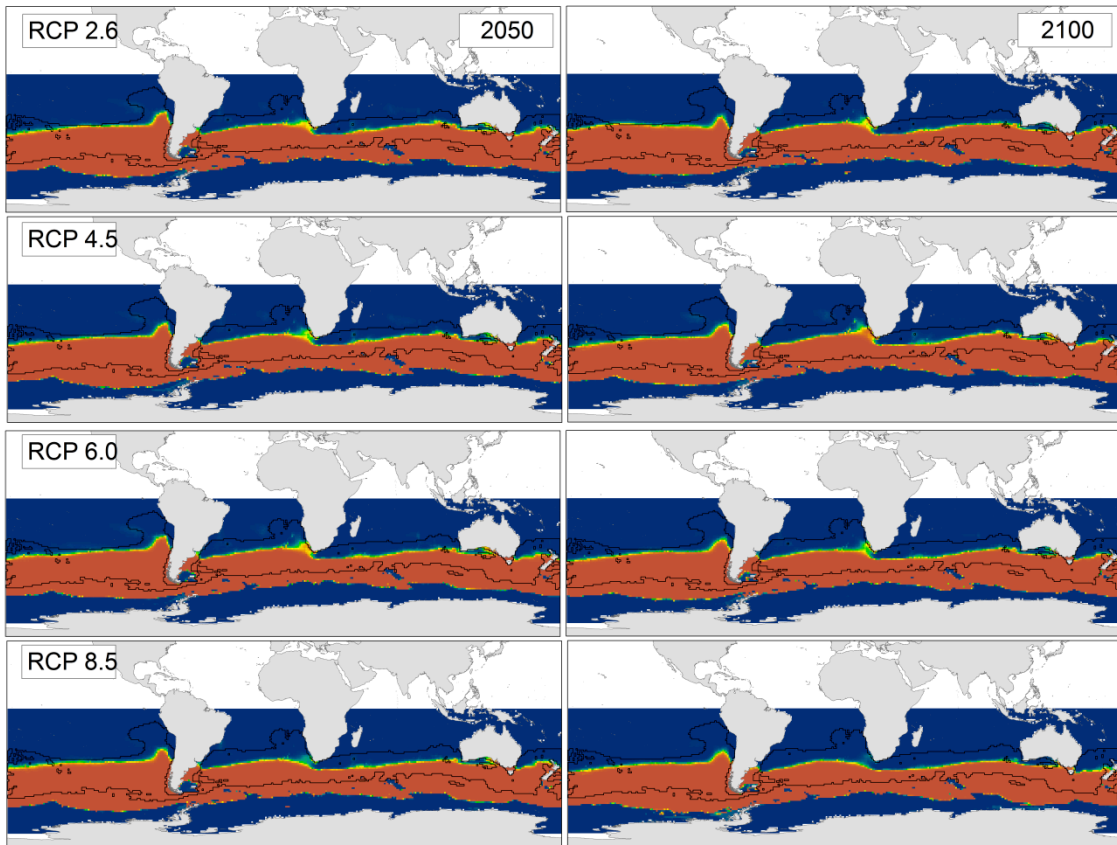


Figure A7. Tristan Albatross probability of occurrence from zero (blue) to one (red) for each of the Climate Change Scenarios (Representative Concentration Pathways RCP) and the predicted area of occurrence above the models' thresholds (solid black line).

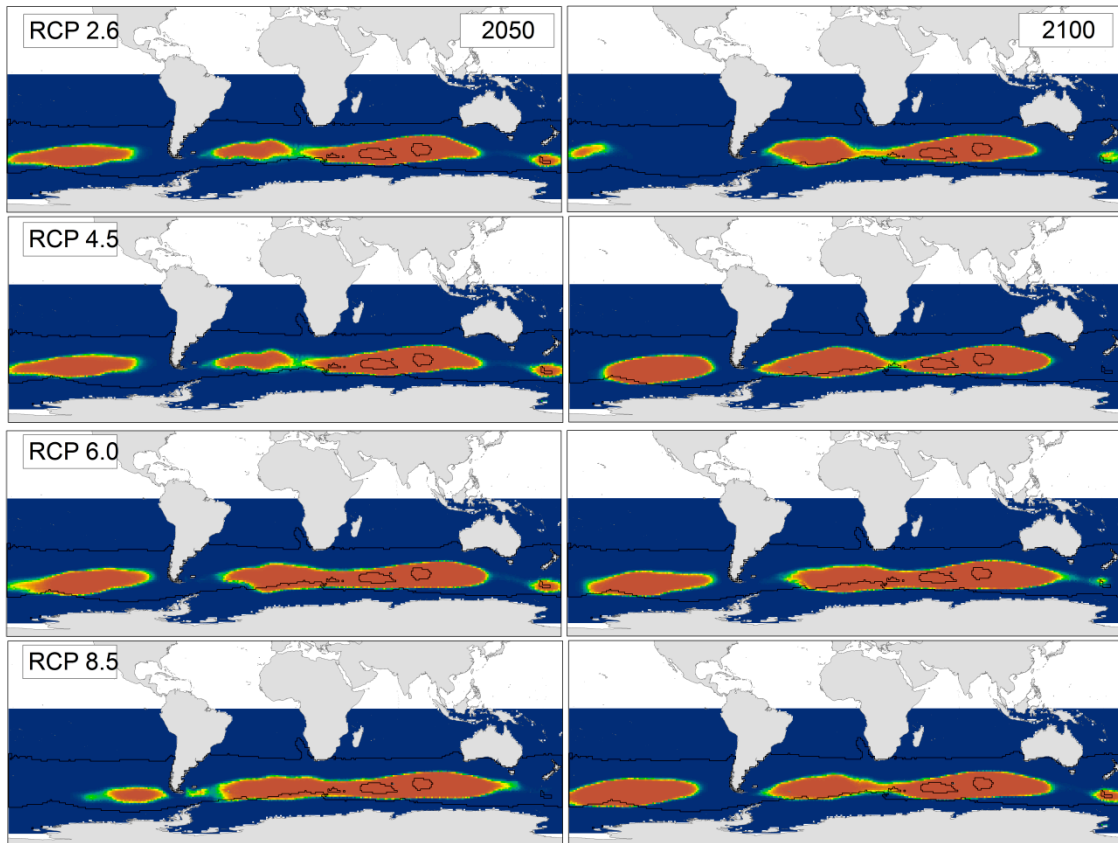


Figure A8. Wandering Albatross probability of occurrence from zero (blue) to one (red) for each of the Climate Change Scenarios (Representative Concentration Pathways RCP) and the predicted area of occurrence above the models' thresholds (solid black line).

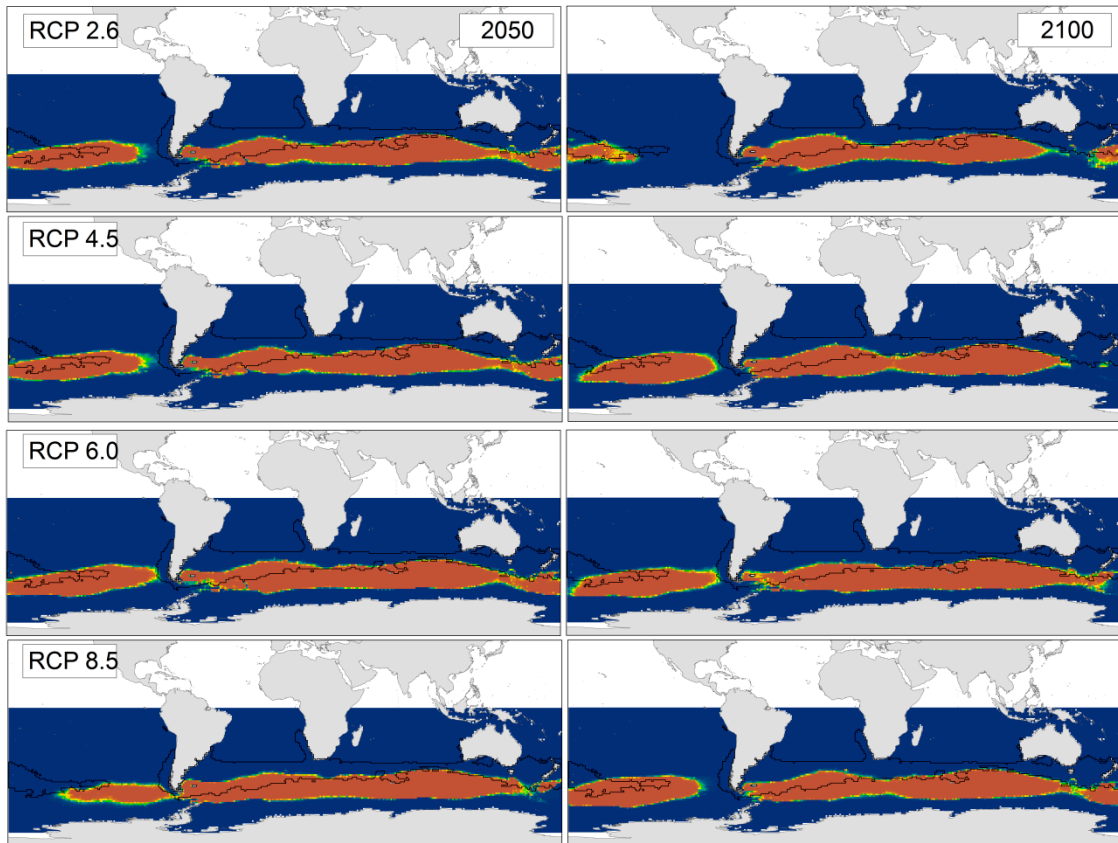


Figure A9. White Chinned Petrel probability of occurrence from zero (blue) to one (red) for each of the Climate Change Scenarios (Representative Concentration Pathways RCP) and the predicted area of occurrence above the models' thresholds (solid black line).

Table A5. Results of Fisheries Distribution Model. Area Under the Receiver Operational Characteristic Curves (AUC) and True Skill Statistic (TSS) both measure models accuracy by comparing the outputs of the 80% data used for calibrating with the 20% used for evaluation. Sensitivity measures the percentage of cases of presence that are classified correctly as presences (true positive rate) by the models and Specificity measures the percentage of cases of pseudo-absences correctly classified as absences (true negative rate) by the models. The permutation importance of each variable was measured as the amount of reduction in model AUC by excluding the variable from the model. Artificial Neural Networks ANN, Classification Tree Analysis CTA, Flexible Discriminant Analysis FDA, Generalized Additive Model GAM, Generalized Boosted Models GBM, Generalized Linear Model GLM, Multiple Adaptive Regression Splines MARS, Maximum Entropy MAXENT, Random Forest RF and Surface Range Envelop SRE. Bathymetry BATH, Chlorophyll-*a* concentration CHL, Sea Ice Cover SIC, Sea Surface Temperature SST and Wind Speed WIND.

Fishery Type	Model	AUC	TSS	Sensitivity	Specificity	Threshold	BATH	CHL	SIC	SST	WIND
High Bycatch	ANN	0.982	0.908	95.089	95.72	44.4	0.152	0.131	0.242	0.274	0.515
	CTA	0.989	0.959	98.1	97.78	51.5	0.179	0.178	0	0.544	0.423
	FDA	0.979	0.87	93.904	93.1	19.1	0.12	0.137	0	0.661	0.221
	GAM	0.987	0.898	93.115	96.7	64.6	0.123	0.064	0.446	0.06	0.611
	GBM	0.994	0.945	97.137	97.38	36.9	0.137	0.123	0	0.543	0.39
	GLM	0.971	0.861	96.644	89.4	42.4	0.096	0.016	0.278	0.171	0.486
	MARS	0.98	0.867	89.882	96.79	61.6	0.103	0.087	0	0.792	0.237
	MAXENT	0.969	0.873	91.831	95.45	10.1	0.192	0.178	0.035	0.254	0.573
	RF	1	0.998	100	99.79	40.4	0.168	0.14	0.033	0.343	0.396
	SRE	0.909	0.817	82.108	99.63	49.5	0.226	0.179	0.22	0.391	0.535
	Mean ± SD	0.98 ± 0.03	0.90 ± 0.05	93.78 ± 5.10	96.17 ± 3.09	42.05 ± 17.06	0.15 ± 0.04	0.12 ± 0.05	0.16 ± 0.13	0.40 ± 0.23	0.44 ± 0.13
Low Bycatch	ANN	0.958	0.843	92.123	92.117	34.1	0.155	0.004	0.239	0.41	0.176
	CTA	0.986	0.926	95.431	97.121	53.5	0.154	0.086	0.002	0.362	0.833
	FDA	0.965	0.852	90.087	95.038	81.7	0.076	0	0.01	0.698	0.235
	GAM	0.973	0.861	91.143	94.975	57.4	0.113	0.003	0.009	0.367	0.517
	GBM	0.987	0.897	95.711	93.97	31.2	0.114	0.01	0	0.393	0.376
	GLM	0.956	0.807	87.694	92.965	53.8	0.089	0.002	0.022	0.573	0.283
	MARS	0.964	0.857	91.881	93.834	39.4	0.101	0	0	0.58	0.35
	MAXENT	0.946	0.828	87.885	94.881	3	0.203	0.106	0.044	0.346	0.463
	RF	1	0.998	99.911	99.906	48.5	0.153	0.079	0.026	0.244	0.566
	SRE	0.891	0.783	80.695	97.603	49.5	0.194	0.107	0.093	0.111	0.787
	Mean ± SD	0.96 ± 0.03	0.87 ± 0.06	91.26 ± 5.27	95.24 ± 2.35	45.21 ± 20.51	0.14 ± 0.04	0.05 ± 0.04	0.07 ± 0.05	0.41 ± 0.17	0.46 ± 0.22

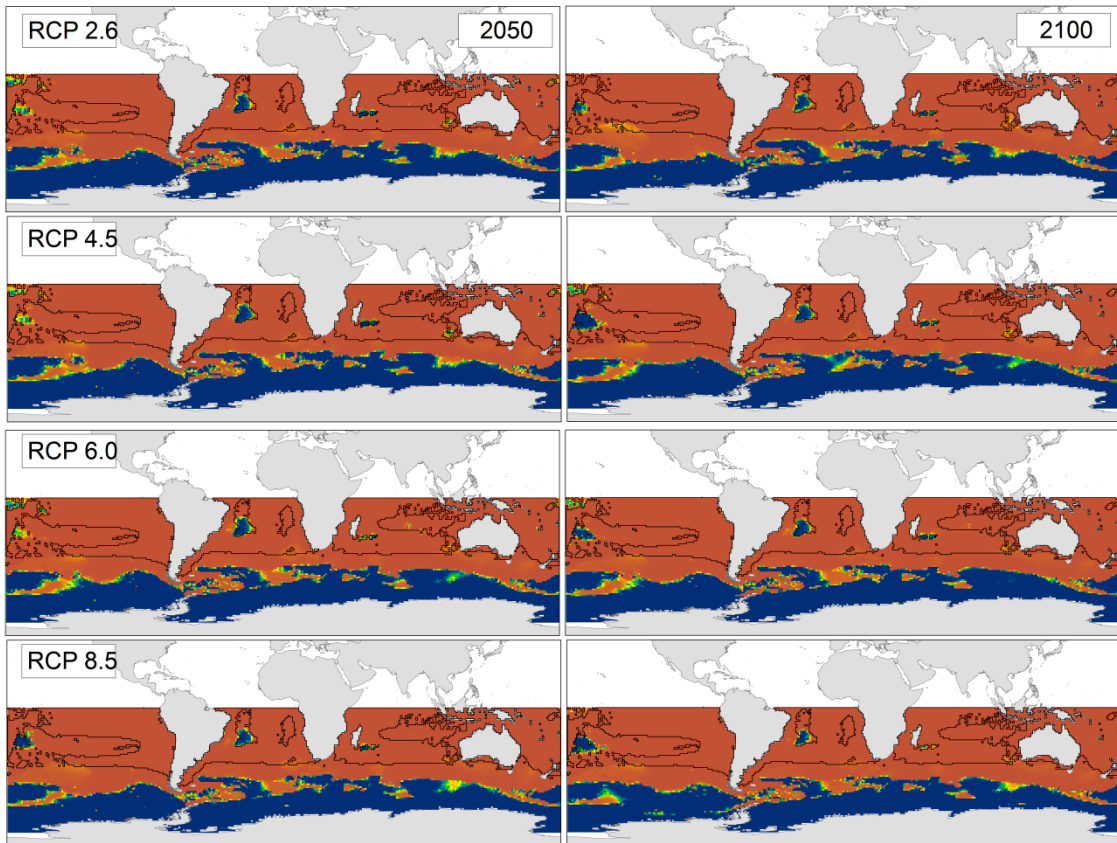


Figure A10. High bycatch fisheries probability of occurrence from zero (blue) to one (red) for each of the Climate Change Scenarios (Representative Concentration Pathways RCP) and the predicted area of occurrence above the models' thresholds (solid black line).

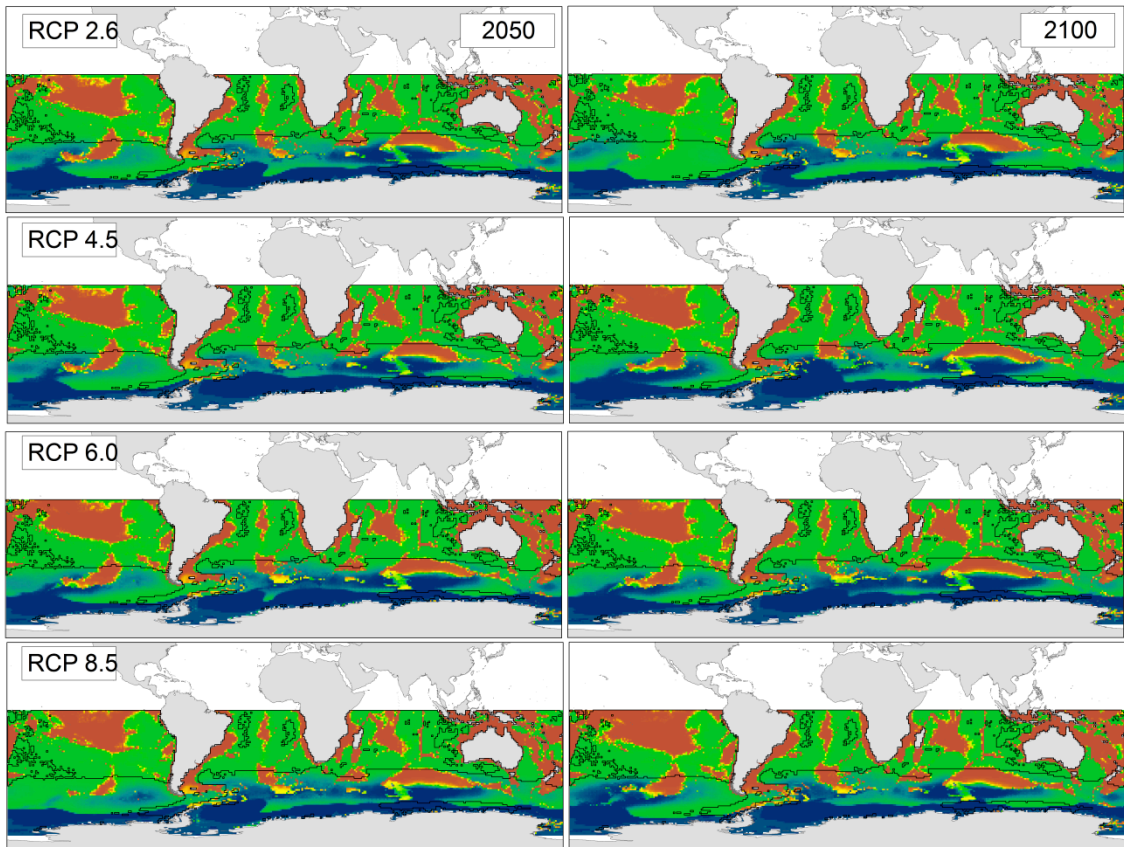


Figure A11. Low bycatch fisheries probability of occurrence from zero (blue) to one (red) for each of the Climate Change Scenarios (Representative Concentration Pathways RCP) and the predicted area of occurrence above the models' thresholds (solid black line).