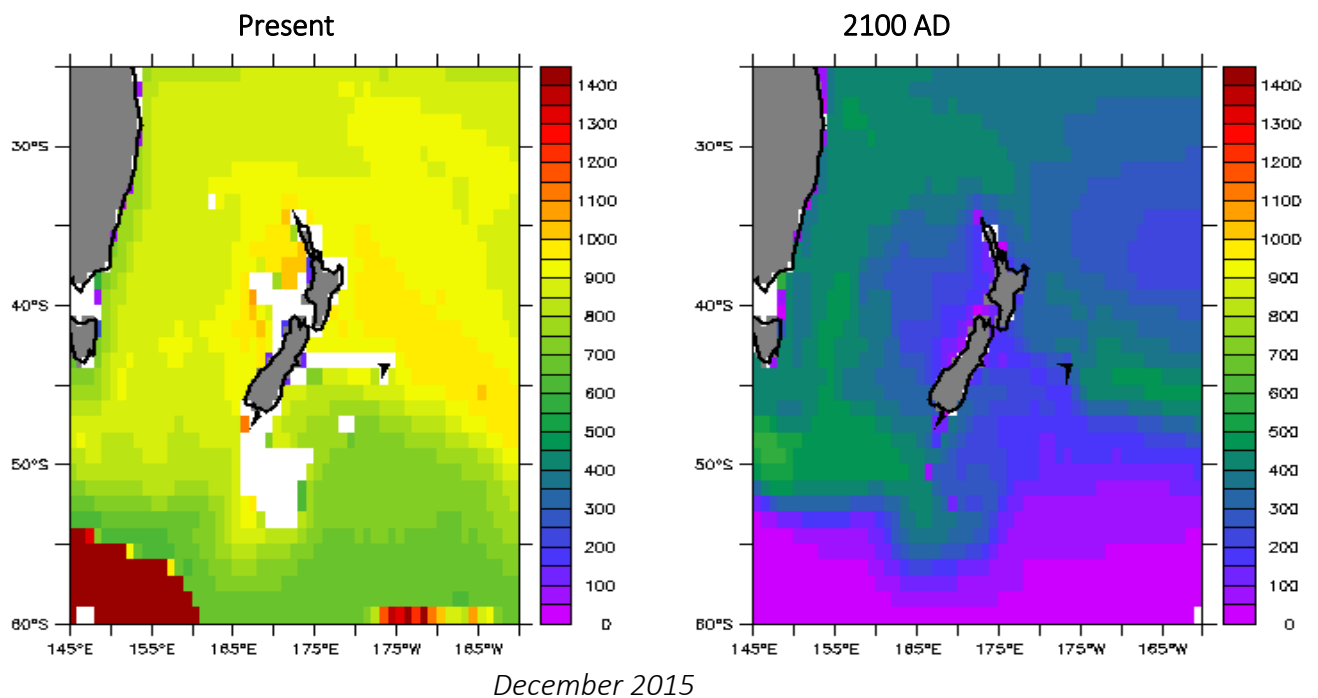# Development of models for predicting future distributions of protected coral species in the New Zealand Region

Prepared for Marine Species and Threats, Department of Conservation

Present	2100 AD

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Cover image:
GFDL-ESM2G projection of the aragonite saturation horizon (ASH) under the RCP.8 emissions pathway.

Contents

Reviewed by   Approved for release by

Di Tracey   Dr Julie Hall

Executive summary

Predicted changes in marine environmental conditions between the present and 2100 AD derived from global earth system models (ESMs) were used to predict the future distribution of protected deep-sea coral species in the New Zealand region. By incorporating future conditions from ESM models into habitat suitability models, specific areas with high potential for providing suitable conditions for future survival were identified for several protected coral groups.

Present-day and future distributions of protected coral species within the New Zealand region were estimated using Boosted Regression Tree (BRT) models. Key variables included environmental data layers for the 1986 to 2005 reference period and 2090 to 2110 future period as predicted by the best ESM, selected from a suite of candidate models according to the level of agreement between model simulations and observed carbonate parameters in the New Zealand region. The environmental and bathymetric variable layers for the two periods available for the BRT models comprised: bottom temperature, salinity, sea surface height; concentrations of aragonite, calcite, dissolved oxygen, dissolved inorganic carbon, nitrate, and chlorophyll; and two less mutable predictors, slope and seamount.

The modelled taxa comprised four species of reef-building scleractinian corals, four genera of gorgonian octocorals, and four genera of antipatharian black corals. The most important predictors of coral presence varied considerably among these taxa, but nitrate and oxygen levels, sea surface height, and slope had the most influence overall.

For scleractinian corals as a combined group, habitat suitability is predicted to decline markedly over much of the modelled region between the present day and 2100 AD. Notable declines in habitat suitability are also seen for three of the four individually modelled species, although to a more variable degree. The Chatham Rise, especially the extreme north-eastern area, stands out in contrast to the rest of the New Zealand region with generally similar or higher habitat suitability predicted for most of the scleractinian taxa in 2100 AD.

The predicted future distribution of the bamboo corals *Keratoisis* spp. and *Lepidisis* spp., the gorgonian coral *Primnoa* spp., and black corals are less affected by the predicted changes in the modelled environmental conditions. Although for the bamboo corals improved suitability is again indicated for the Chatham Rise, at the expense of other areas. In contrast, conditions for the gorgonian bubblegum corals (*Paragorgia* spp.) are predicted to improve substantially in almost all parts of the modelled region.

Future directions for research could include; aligning known or estimated species tolerances to environmental conditions with maps of seafloor habitat and predicted future environmental conditions; continuing to improve the accuracy of habitat suitability models by incorporating new, improved, and higher resolution predictor variable data as it becomes available; inclusion of additional presence and absence data from new sampling and new sources such as camera surveys; and further analyses of coral mineralogy and the application of in-aquaria stony coral dissolution experiments with varying temperature and pH regimes, both of which could help to inform the results of future predictions.

1   Background

1.1   Protected and threatened corals

The New Zealand region supports a very diverse deep-sea coral fauna (Cairns 1995; Cairns 2012; Gordon 2009) and several recent studies have described their importance in the ecosystem (e.g., Clark & Koslow 2007; Clark & Rowden 2009; Clark et al. 2014).

The calcifying, framework-forming reef corals (scleractinians, or branching stony corals) are a dominant group with records indicating them to be widely distributed throughout the region (Cairns 1995; Tracey et al. 2011a). These corals produce 3-dimensional matrix colonies that form 'reef', 'mound' or 'thicket' structures, and thus provide biogenic habitat on slope margins, ridges and seamounts (Mortensen & Buhl-Mortensen 2004; Auster et al. 2005; Reveillaud et al. 2008; Roberts et al. 2008; Henry & Roberts 2007; Rogers et al. 2007; Wheeler et al. 2007; Clark et al. 2014). These structures are often associated with high concentrations of fish and invertebrates (McCloskey 1970; Jensen & Frederikson 1992; Husebø et al. 2002; Costello et al. 2005; Stone 2006; Moore et al. 2008; Soffker et al. 2011).

The abundant and diverse black corals (Antipatharia) are found throughout the region from the shallow cold-water fjord regions to the deep sea and some forms are large, tree-like, and habitat forming. The gorgonian octocorals (Alcyonacea) are also an abundant group represented in the New Zealand region and include bubblegum corals (Paragorgidae), primnoid sea fan, sea whip corals (Primnoidae), and bamboo corals (Isididae). The gorgonian group include tree-like forms (Cairns 2012), and are also important habitat forming species (Buhl-Mortensen & Mortensen 2005). The stylasterid hydrocorals (Hydroida) such as *Errina s*pp. are also calcifiers. All of these coral groups are protected under the New Zealand Department of Conservation Wildlife Act 2010 (amendment of Schedule 7A of the Wildlife Act 1953).

Freeman et al. (2010) re-evaluated the threat status of New Zealand's marine invertebrates and assigned a threat category to several coral species. Several deep-sea stony corals, black corals, gorgonian corals, and hydrocorals are listed as nationally vulnerable, naturally uncommon, or data deficient. The threatened species list has been revised and added to and now includes several more deep-sea corals being placed into the various threat categories (Freeman et al. 2013).

The threats faced by deep-sea corals include mechanical damage from the impacts of deep-sea mining and fishing, as well as physiological damage from the alteration of the physical and chemical environment in which they live due to the effects of climate change, especially ocean warming and ocean acidification. The predicted shoaling of the aragonite saturation horizon (ASH) and calcite saturation horizon (CSH) into the present depth range of deep-sea corals is perceived as a very serious threat; reef-like scleractinians are particularly sensitive to low carbonate ion concentrations and rarely occur far below the modern aragonite saturation horizon (Bostock et al., 2015). Because of this, the world's deep-sea coral reefs are considered to be at high risk of extinction in the near future (Thresher et al. 2015).

In the current study, earth system model (ESM) simulations of present and future physical and chemical state of the oceans were used to provide a set of predictor variables that could be used alongside less mutable variables such as slope and bottom topography to estimate the distribution of protected coral species at the end of the 21st century. By doing this, potential refuges and high priority regions for protection may be identified.

1.2   Coral distribution

The spatial distribution of corals and other vulnerable deep-sea benthic invertebrate taxa within the New Zealand region has been the focus of a number of studies (Sanchez 2005; Consalvey et al. 2006; Tracey et al. 2011a & b; Baird et al. 2013; Opresko et al. 2014; Rowden et al. 2015).

A more recent study (Anderson et al. 2014) combined newly available data on seafloor saturation levels of aragonite and calcite with a suite of other environmental variables to estimate the current distribution of the most suitable conditions for 12 taxa of protected corals using boosted regression tree (BRT) modelling. The importance of carbonate ion saturation levels on the distribution of cold water corals has been noted (e.g., Tittensor et al. 2009, Davies & Guinotte 2011, Rengstorf et al. 2013) and it was thought likely to be an important environmental variable in these models as these ions are crucial for construction of coral calcareous skeletons (Bostock et al. 2015). Although important, aragonite and calcite saturation state had less influence than expected in these models, possibly because few presence records were available from locations undersaturated with carbonate ions, and saturation values above this level may not directly translate into a progressively more preferred environment. Dynamic topography (a proxy for nutrient supply) and bottom temperature (reflecting thermal tolerance of the coral species) were more influential overall.

Suitable conditions for the reef-forming scleractinian corals, as a group, were predicted to be widespread over the EEZ, with higher probabilities on the eastern Chatham Rise and along slopes, ridges, and features of the sub-Antarctic, North Island, and northern parts of the EEZ. High habitat suitability for the gorgonian bamboo coral genera *Keratoisis* and *Lepidisis* was predicted in relatively few areas, limited mainly to narrow depth bands on the Chatham Rise and isolated patches in the sub-Antarctic and on northern ridge features. High habitat suitability for the gorgonian *Primnoa* spp. and *Paragorgia* spp. was predicted in the Bounty Trough and Bounty Plateau, and in parts of the sub-Antarctic slope. For antipatharians (black corals) as a group, low habitat suitability was predicted over much of the EEZ, with higher probabilities restricted to the northwest Chatham Rise and some topographic features and major ridges in the north of the EEZ.

1.3   Specific Objectives:

1. To look at changes in the environmental conditions (ocean acidification, temperature, oxygen) for 2100AD from global climate models to predict the future distribution of deep-sea corals in the New Zealand region.

This report describes the predicted distribution of conditions favourable for survival of deep-sea corals in the year 2100 AD, based on purpose-built mathematical models incorporating environmental data along with coral species presence/absence data. These models in turn utilise predicted oceanographic conditions in 2100 AD under the Representative Concentration Pathway 8.5 (RCP 8.5, IPCC 2014), a future scenario in which greenhouse gas emissions continue unabated. The NOAA-GFDL ESM2G ESM (Dunne et al., 2012) was selected from the CMIP5 suite of ESMs by evaluating the suite of available models against regional observations of oceanographic, biogeochemical and carbonate data (Rickard et al., 2015).

Details of the coral datasets used here are described in Baird et al (2013) and Anderson et al. (2014). The methods applied in this study were presented to the Marine Species and Threat Group, Department of Conservation, (DOC) and members of the Marine Species and Threat Technical Working Group in January 2014 (Tracey et al. 2014) and to members of the Ministry for Primary Industries (MPI) Biodiversity Research Advisory Group (BRAG) in June 2015.

This report has been prepared for Marine Species and Threat Group, Department of Conservation (Project DOC15304).

2 Methods

The groomed coral dataset described and used in Baird et al. (2013), Anderson et al. (2014), along with modelled present-day and future levels of a suite of oceanographic variables, were used as the basis for modelling the distribution of suitable habitat for protected coral taxa in the year 2100 AD. The analytical method applied was boosted regression trees (BRT) model (Elith et al. 2008).

2.1 Protected corals presence and absence data:

The coral occurrence (presence) dataset compiled and groomed for previous analyses of coral distribution in New Zealand waters (Baird et al. 2013, Anderson et al. 2014) was used here with no further records added from subsequent sampling or other acquisition. This dataset was assembled from NIWA research survey and invertebrate museum databases, published taxonomic memoirs, and MPI observer and research survey databases, and groomed to remove duplicates. The dataset comprises 7731 protected coral records.

The coral occurrence dataset is a subset of a full 'benthic stations' dataset which includes all research survey stations where all organisms were identified, including those with no corals (Tracey et al. 2011b). The benthic stations dataset therefore provides the absence data for predictive models, and consists of 62,144 records within the New Zealand 200 n. mile EEZ.

Further details of the coral occurrence and benthic stations datasets can be found in Anderson et al. (2014).

2.2 Selection of coral taxa for modelling

The species and genera modelled in this project were the same combinations as used in Anderson et al. (2014). The selected taxa were initially guided by the species listed in the DOC Threatened Species List (Freeman et al. 2010) and a recent DOC marine invertebrate expert panel list (Freeman et al. 2013). Further details of selection criteria and rationale for species groupings can be found in Anderson et al. (2014). The model coral taxa and number of presence records available for input into the habitat suitability models are shown in Table 2-1.

Table 2-1: Protected coral taxa considered for habitat suitability modelling, a brief description, and the number of recorded observations in the study area (NZ region) (from Anderson et al. 2014).

Order	Taxon	Description	Number of records
Scleractinia	Species combined: *Enallopsammia rostrata* *Solenosmilia variabilis* *Goniocorella dumosa* *Madrepora oculata*	Reef-like corals	779
	Enallopsammia rostrata	Reef-like coral	130
	Solenosmilia variabilis	Reef-like coral	311
	Goniocorella dumosa	Reef-like coral	212
	Madrepora oculata	Reef-like coral	126
Alcyonacea	*Paragorgia* spp.	Bubblegum corals (tree-like)	98
	Primnoa spp.	Primnoid sea-fans (tree-like)	73
	Genera combined: *Keratoisis* spp. *Lepidisis* spp.	Bamboo corals (tree-like)	241
Antipatharia	All species	Black corals (tree-like)	711
	Bathypathes spp.	Black coral (tree-like)	75
	Dendrobathypathes spp.[*]	Black coral (tree-like)	8
	Dendropathes spp.[*]	Black coral (tree-like)	16
	Leiopathes spp.	Black coral (tree-like)	67
	Lillipathes spp.[*]	Black coral (tree-like)	3
	Parantipathes spp.	Black coral (tree-like)	56
	Triadopathes spp.	Black coral (tree-like)	27

[*] *Dendrobathypathes*, *Dendropathes*, and *Lillipathes* were not modelled due to the small number of presence records (<25).

2.3 Environmental variables

The variables considered in the models were based on those used in Anderson et al. (2014), initially selected for their perceived relevance to the growth and survival of deep-sea corals, amended according to availability from global climate modelling. For many of the variables used in Anderson et al. (2014) (e.g., temperature, calcite and aragonite saturation states) it was not possible to obtain comparable estimates for 2100 AD due to the structure of the global climate models used. Therefore a new set of variables was produced, based on the RCP8.5 climate models, for which estimates of current conditions (1986-2005, the IPCC AR5 reference period) and future conditions (2090–2110) were not confounded by any differences in source data or modelling procedures.

The final set of variables produced comprised those relating to nutrient availability (sea surface height, concentrations of aragonite, calcite, dissolved inorganic carbon, nitrate, phosphate, and chlorophyll), physiological tolerances (bottom temperature, salinity, dissolved oxygen), and the physical environment (slope and seamount) (see Table 2-2).

Although new bathymetry data are now available for the New Zealand region (NIWA data) at a much higher resolution than used in previous models (ref. e.g., Anderson et al 2014) (250 m compared with 1 km), and other environmental variables could potentially be re-scaled to match this resolution, the precision of the coral presence and absence data cannot be improved. Due to the length of the trawl or research sled typically used to sample corals, and the difference between the trawl and the recorded vessel position, precision of these data match better to the coarser 1 km bathymetry data set. Therefore model resolution was retained at a cell size of 1 km^2.

2.4   Environmental variables 2100 AD

In place of some of the variables used by Anderson et al. (2014) to describe the current environmental state of the deep-sea around New Zealand, we used a combination of regional data and model simulations from one of the CMIP5 (Taylor et al., 2012) models to represent the current state of these variables over the IPCC AR5 reference period (1986-2005) and the potential state of these variables over the 2090-2100 period, if greenhouse gas emissions continue unabated. The CMIP5 simulations were used to inform the last Intergovernmental Panel on Climate Change (IPCC) report (IPCC, 2014). In an independently funded project NIWA evaluated this ensemble of models to determine which model simulations best represented the ocean biogeochemistry for the New Zealand Region (Rickard et al., 2015). Through this process, we selected the NOAA-GFDL ESM2G (Dunne et al., 2012) as the model that best represents modern observations for the New Zealand region.

CMIP5 model output is available for a range of scenarios with different assumptions about future changes in population, economic development, energy use and other human activities that cause greenhouse gas emissions. We focused our analysis on Representative Concentration Pathway 8.5 (RCP8.5), which is characterised by high population growth and modest changes in energy technology or intensity. RCP8.5 is often referred to as the "business-as-usual" scenario.

In order to ensure that the model output reflects climate change rather than shorter-term climate variability, we took the average of all climate variables between 2090 and 2100 for model output. Table 2-2 provides a summary of all model variables.

2.5 Variable selection for revised model runs

Table 2-2: Description of environmental data layers. Abbreviations used in relevant figures are given in italics.

Variable	Description and data source	Units	Reference
Depth (not used) *Bathy*	Depth at the seafloor interpolated from contours generated from various bathymetry sources, including multi-beam and single-beam echo sounders, satellite gravimetric inversion, and others. (native resolution 250 m).	m	CANZ (2008)
Seamount *seamount*	Seamount positions recorded in New Zealand region.	–	Rowden et al. (2008), Mackay (2007)
Slope *Slope*	Seafloor slope was derived from neighbourhood analysis of the bathymetry data.	°	CANZ (2008), Hadfield et al. (2002)
Dissolved Inorganic Carbon *DIC*	Seafloor DIC concentration. NOAA-GFDL ESM2G model simulations	mol/m3	Dunne et al. (2012)
Sea surface height *SSH*	Sea surface height above geoid. NOAA-GFDL ESM2G model simulations.	m	Dunne et al. (2012)
Bottom temperature *temperature*	In-situ bottom temperature. NOAA-GFDL ESM2G model simulations	Degrees C	Dunne et al. (2012)
Aragonite concentration *aragonite*	Seafloor aragonite concentration. NOAA-GFDL ESM2G model simulations	mol/m3	Dunne et al. (2012)
Calcite concentration *Calcite*	Seafloor calcite concentration. NOAA-GFDL ESM2G model simulations	mol/m3	Dunne et al. (2012)
Nitrate concentration *Nitrate*	Seafloor dissolved nitrate concentration. NOAA-GFDL ESM2G model simulations	mol/m3	Dunne et al. (2012)
Phosphate concentration *phosphate*	Seafloor dissolved phosphate concentration. NOAA-GFDL ESM2G model simulations	mol/m3	Dunne et al. (2012)
Oxygen concentration *Oxygen*	Seafloor dissolved oxygen concentration. NOAA-GFDL ESM2G model simulations	mol/m3	Dunne et al. (2012)
Chlorophyll concentration *chlorophyll*	Seafloor total chlorophyll mass concentration. NOAA-GFDL ESM2G model simulations	kg/m3	Dunne et al. (2012)
Salinity *Salinity*	Seafloor salinity. NOAA-GFDL ESM2G model simulations.	g/kg	Dunne et al. (2012)

Development of models for predicting future distributions of protected coral species

2.6   Habitat suitability modelling

The boosted regression tree (BRT) method was used to carry out the predictive distribution modelling. Inputs to the models were the coral presence/absence positional data and environmental predictors described above. Models were constructed and run using the R statistical package and related libraries (*gbm*) and functions described by Ridgeway (2006), Elith et al. (2008), Leathwick et al. (2008), Elith & Leathwick (2011).

A subtle difference between the models of Anderson et al. (2014) and the current models is in the consideration of the absence data and interpretation of model outputs. Whereas in Anderson et al. (2014) absence records were termed "pseudo-absences" here we recognise them as real absences, with the catchability of the sampling equipment (an unknown value between 0 and 1) reflected in the interpretation of model habitat suitability outputs as probability of capture rather than probability of presence, or simply a relative probability as used in Anderson et al. (2014).

To minimize the effect of spatial bias in the presence-absence data, and limit the influence of highly sampled areas in the models, all records were weighted by $\frac{1}{n+1}$ where n = the number of records in each cell (note that due to the use of real absence data this weighting differs from that used in Anderson et al. 2014).

All variables relevant to each individual taxon were offered to the models, without any identification or elimination of highly correlated variables. The BRT model technique (and other machine learning methods) is considered robust to correlated variables (Archer & Kimes 2008).

Model performance was measured statistically on internally retained test data using AUC (area under the Receiver Operating Characteristic curve), a model independent measure of performance which can be defined for presence-absence models such as BRT as the area under a plot of the fraction of true positives versus the fraction of true negatives. A model with an AUC of greater than about 0.9 is generally considered "good", a value of 0.8 "acceptable" and a value of 0.7 "fair" (Glover & Vaughn, 2010).

Habitat suitability grids for each coral taxon throughout the New Zealand region were created from the model functions, and displayed on maps produced in ArcGIS 10.3.1 (ESRI 2015) to enable interpretation.

3   Results

3.1   BRT model performance

Statistically, the models all performed above an acceptable level, with AUC values of between 0.84 and 0.94 (Table 3-1). However, this statistic may be overinflated to some extent as it is not based on fully independent data and because of the inherent spatial autocorrelation in the coral presence data (Vierod et al. 2014).

Table 3-1:   Model performance. Area under the receiver operating characteristic curve (AUC) values.

Taxon	ROC	Taxon	AUC
Scleractinia	0.884	*Keratoisis* & *Lepidisis* spp.	0.839
Enallopsammia rostrata	0.878	Antipatharia	0.877
Solenosmilia variabilis	0.915	*Bathypathes* spp.	0.854
Goniocorella dumosa	0.876	*Leipoathes* spp.	0.944
Madrepora oculata	0.905	*Parantipathes* spp.	0.870
Paragorgia spp.	0.880	*Triadopathes* spp.	0.925
Primnoa spp.	0.896		

Variable influence varied considerably among modelled taxa, but nitrate and oxygen levels, sea surface height, and slope had the most influence overall (**Figure 3-1**).
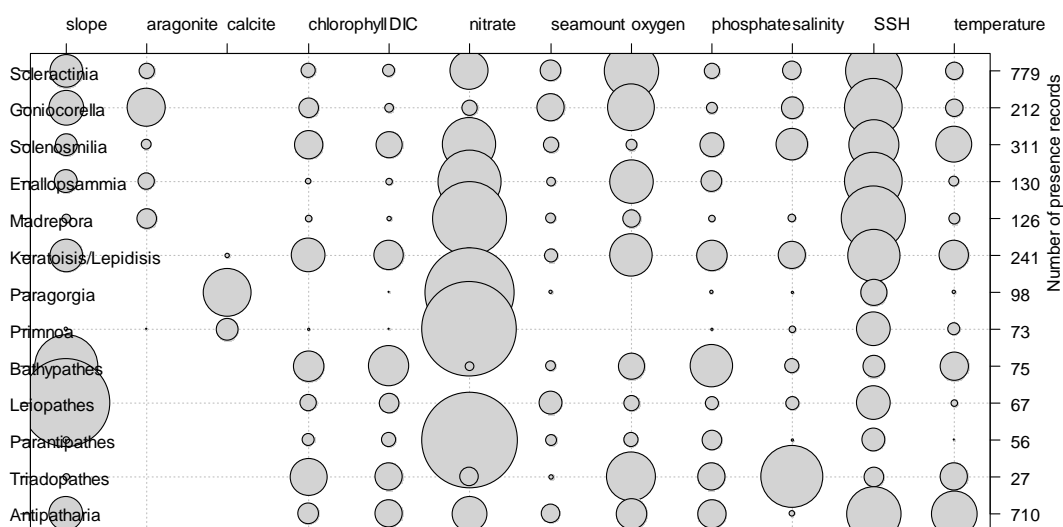

Figure 3-1:   Relative influence of each explanatory variable (Table 2-2) in the BRT predictive models for each coral taxon (see Section 2.3), and number of presence records in each model (right axis).

3.2   Predicted coral habitat distributions

3.2.1   Scleractinia

Current suitable habitat for Scleractinia as a combined group was predicted to be highly variable throughout the New Zealand region, and similar to that estimated by Anderson (2014). Habitat suitability is predicted to decline over much of the region by 2100, the exception being the Chatham Rise, where suitability remains either stable or increases (Figure 3-2).

Individually, present estimated distributions of the separate scleractinian species are also broadly similar to those estimated by Anderson et al (2014). The models for *Goniocorella dumosa* show lower probabilities than Scleractinia species combined, and smaller changes in probability and distribution over time. Somewhat higher habitat suitability is indicated for the Chatham Rise and parts of the sub-Antarctic plateaus in 2100, but there is little change in other areas (Figure 3-3). For *Solenosmilia variabilis* there is a general decline in habitat suitability between the present and 2100 in most areas, but increased suitability at the northeast limit of the Chatham Rise (Figure 3-4). The high habitat suitability shown for *Enallopsammia rostrata* in northern regions outside of the EEZ lessens only slightly by 2100, but suitability is reduced throughout much of the EEZ – with the exception of the

northeast corner of the Chatham Rise (Figure 3-5). Suitable habitat for *Madrepora oculata* either declines or remains little changed almost universally across the modelled region (Figure 3-6).
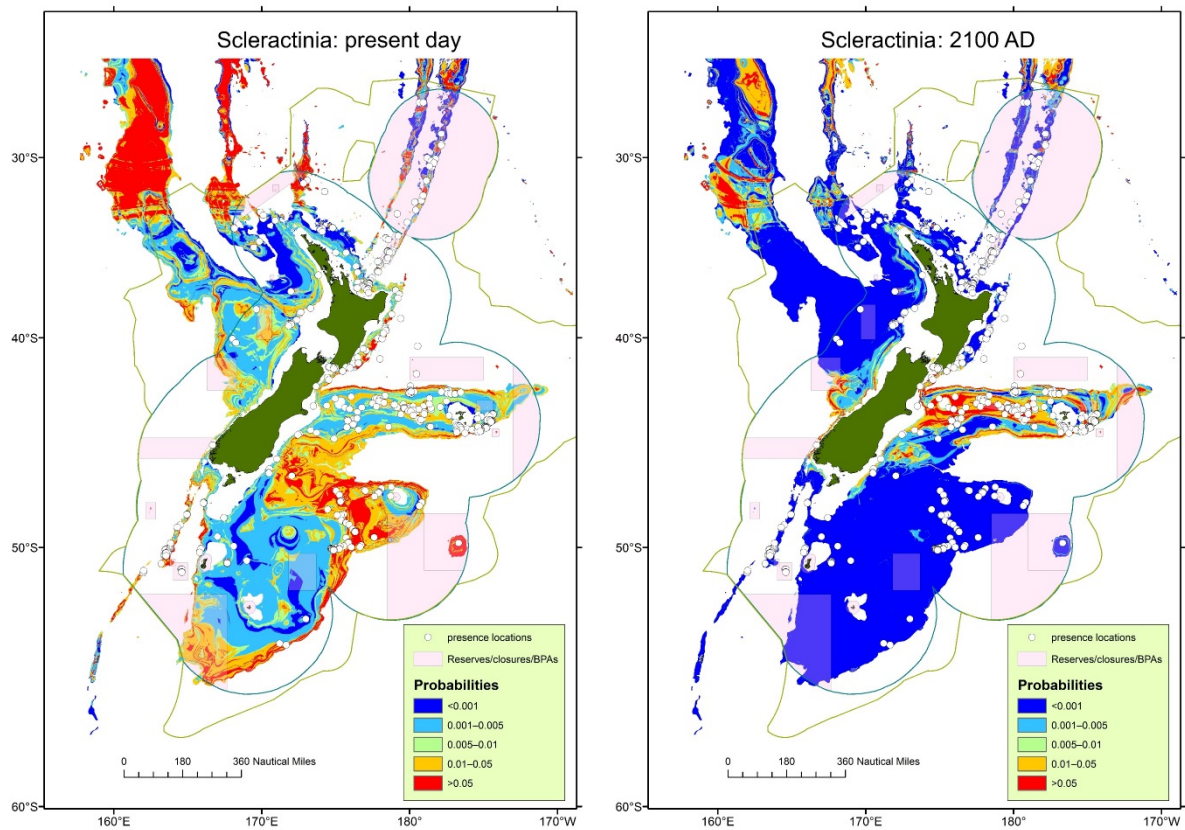

Figure 3-2: **Estimated probability of occurrence of suitable habitat for branching scleractinian coral species (*Solenosmilia variabilis*, *Goniocorella dumosa*, *Enallopsammia rostrata*, and *Madrepora oculata*) from BRT models based on 779 presence records. Left panel: present day; Right panel: 2100 AD.**

Figure 3-3: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Goniocorella dumosa* from BRT models (n = 212 presence records). Other details as for Figure 3-2.
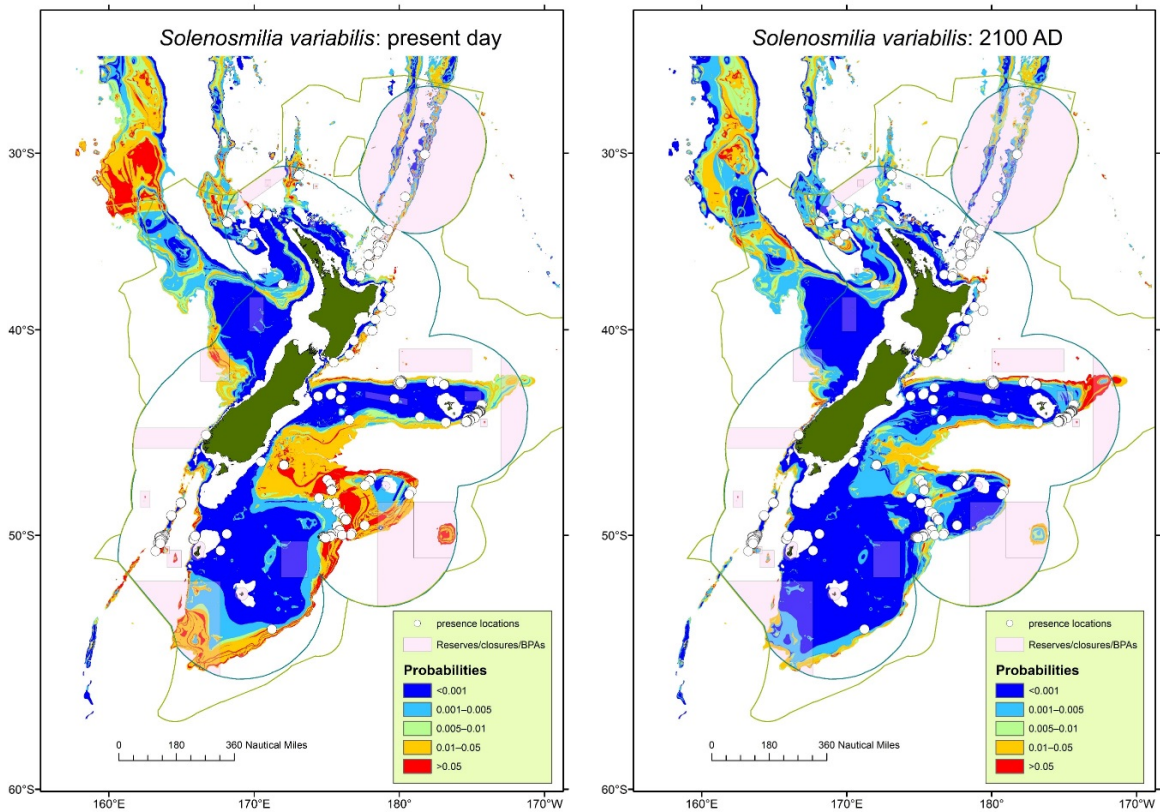
Figure 3-4: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Solenosmilia variabilis* from BRT models (n = 311 presence records). Other details as for Figure 3-2.

Figure 3-5: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Enallopsammia rostrata* from BRT models (n = 130 presence records). Other details as for Figure 3-2.
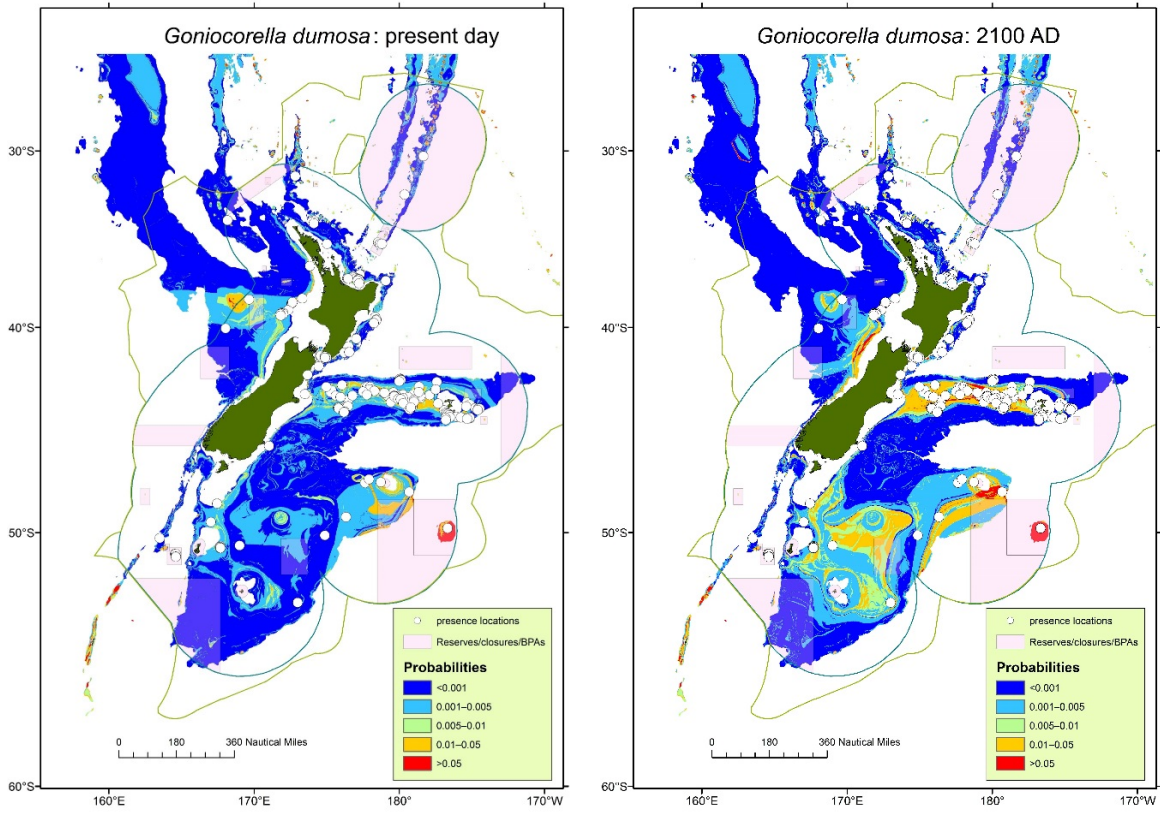

Figure 3-6: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Madrepora oculata* from BRT models (n = 126 presence records). Other details as for Figure 3-2.

3.2.2 Alcyonacea

Individually, present estimated distributions of the alcyonacean taxa modelled are broadly similar to those estimated by Anderson et al (2014), although less so for *Keratoisis*/*Lepidisis* spp. and *Paragorgia* spp. than for *Primnoa* spp. For *Keratoisis*/*Lepidisis* spp. habitat suitability declines slightly around much of the region between the present and 2100, but generally increases on the Chatham Rise – especially the northeast corner (Figure 3-7). In contrast to all other taxa, habitat suitability for *Paragorgia* spp. is predicted to generally improve between the present and 2100 in most areas (Figure 3-8). Habitat suitability for *Primnoa* spp. is predicted to change very little (Figure 3-9).

Figure 3-7: **Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Keratoisis* spp. & *Lepidisis* spp. from BRT models (n = 241 presence records). Other details as for Figure 3-2.**

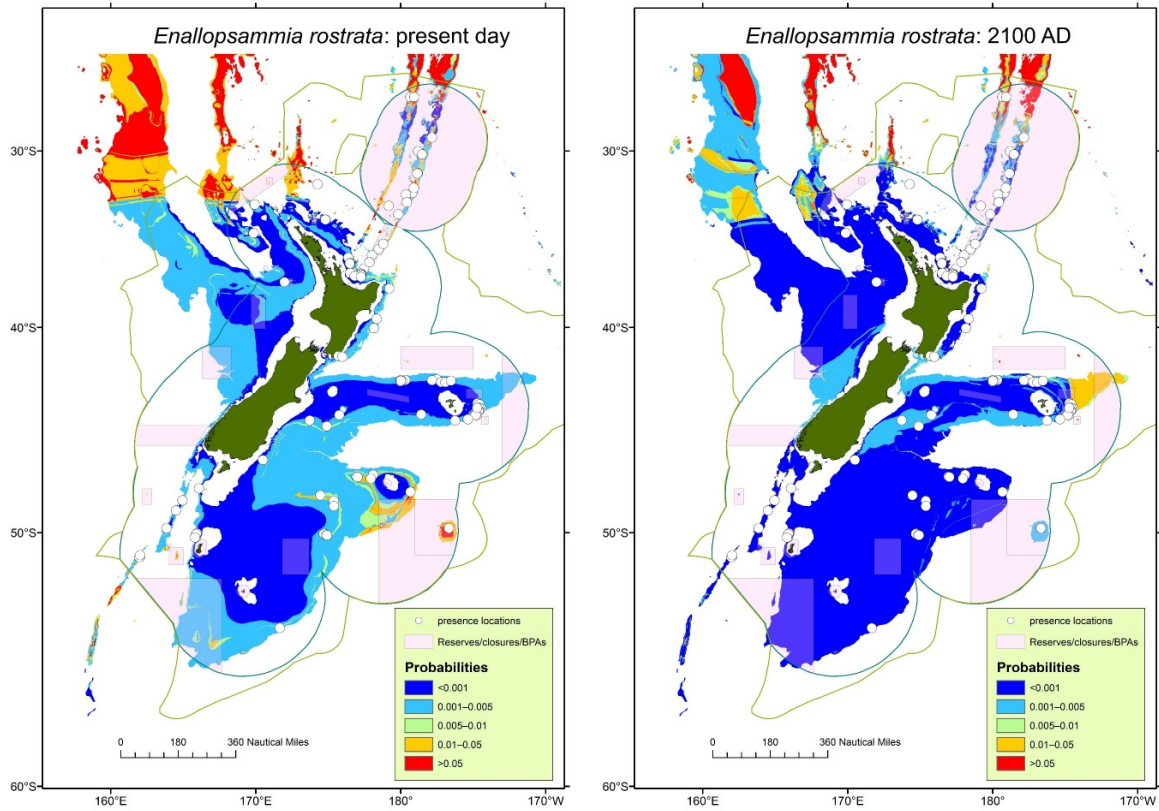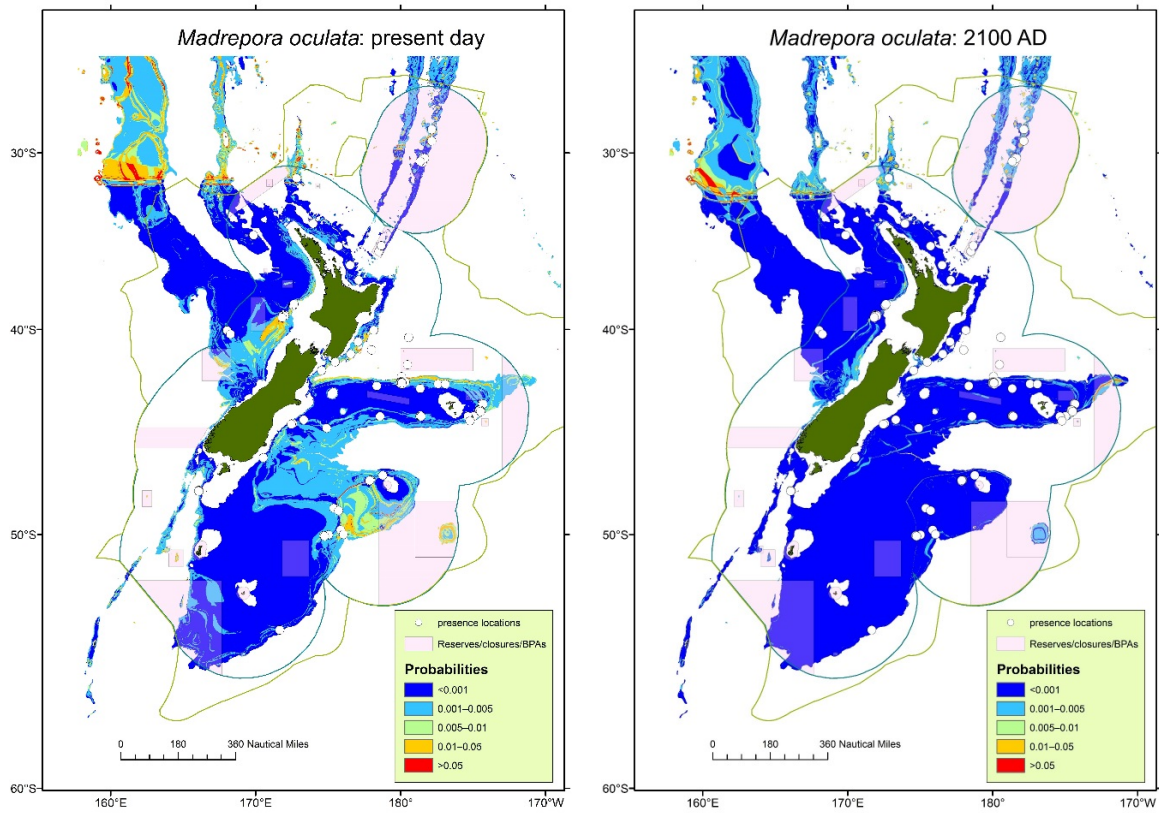**Figure 3-8:** Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Paragorgia* spp. from BRT models (n = 98 presence records). Other details as for Figure 3-2.

Figure 3-9: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Primnoa* spp. from BRT models (n = 73 presence records). Other details as for Figure 3-2.

3.2.3   Antipatharia

Individually and overall, present estimated distributions of the antipatharian taxa modelled are broadly similar to those estimated by Anderson et al (2014). For the order overall, habitat suitability is predicted to remain relatively stable over time – but with slight improvements in some regions, e.g., the Chatham Rise and Challenger Plateau (Figure 3-10). Only slight changes in habitat suitability, not substantially improving or worsening, are predicted for *Bathypathes* (Figure 3-11), *Leiopathes* (Figure 3-12), *Parantipathes* (Figure 3-13), and *Triadopathes* (Figure 3-14).

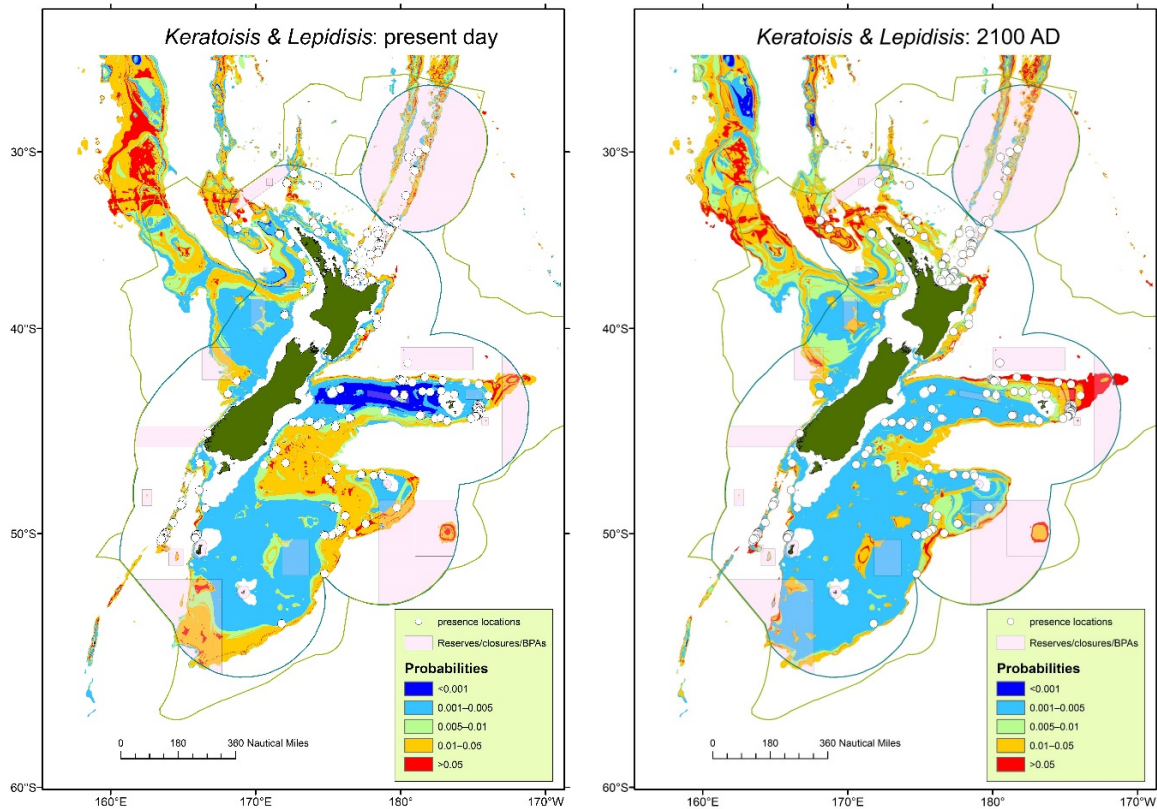**Figure 3-10:   Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for Antipatharia from BRT models (n = 711 presence records). Other details as for Figure 3-2.**
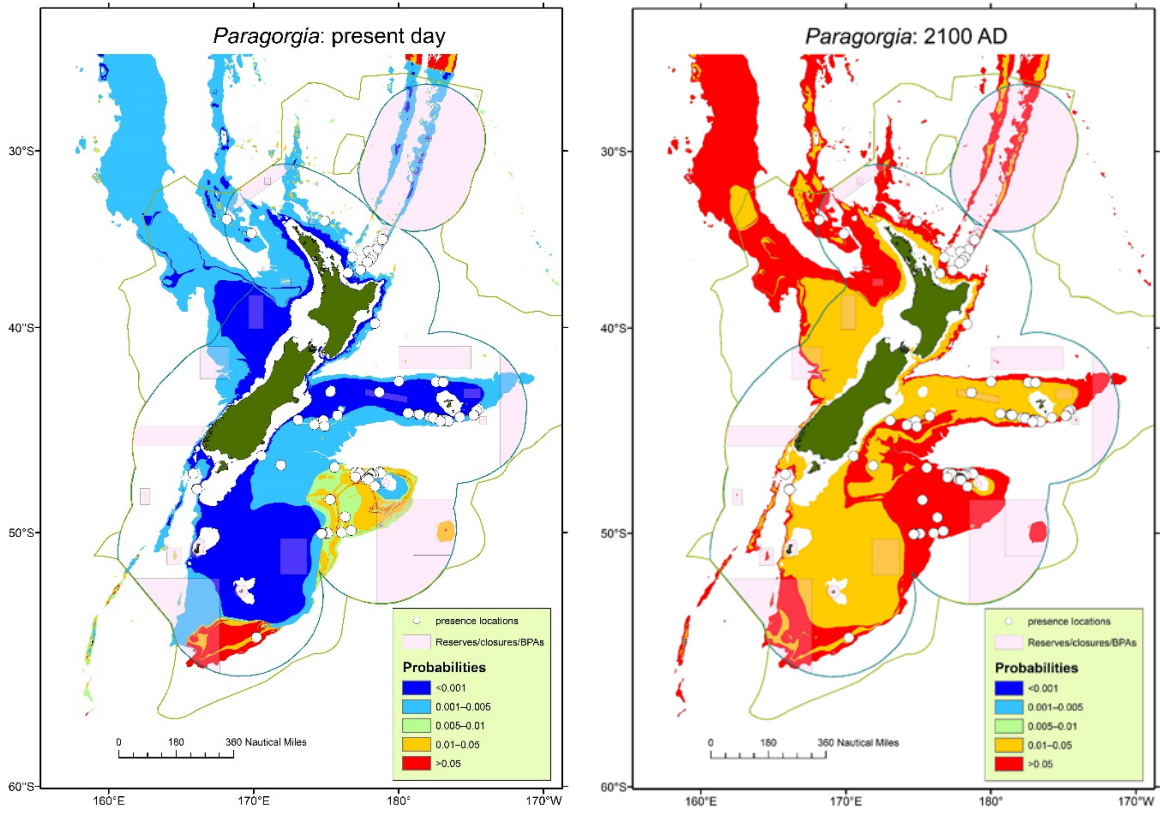
Figure 3-11: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Bathypathes* spp. from BRT models (n = 75 presence records). Other details as for Figure 3-2.
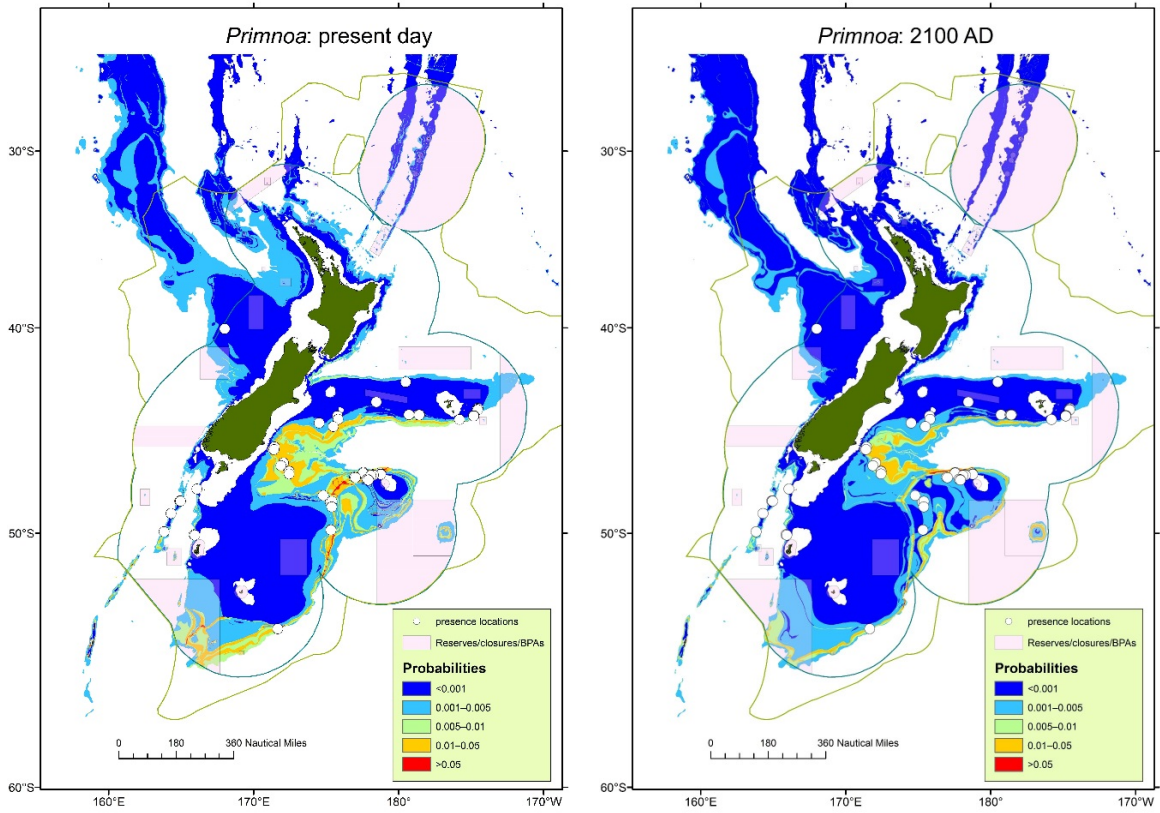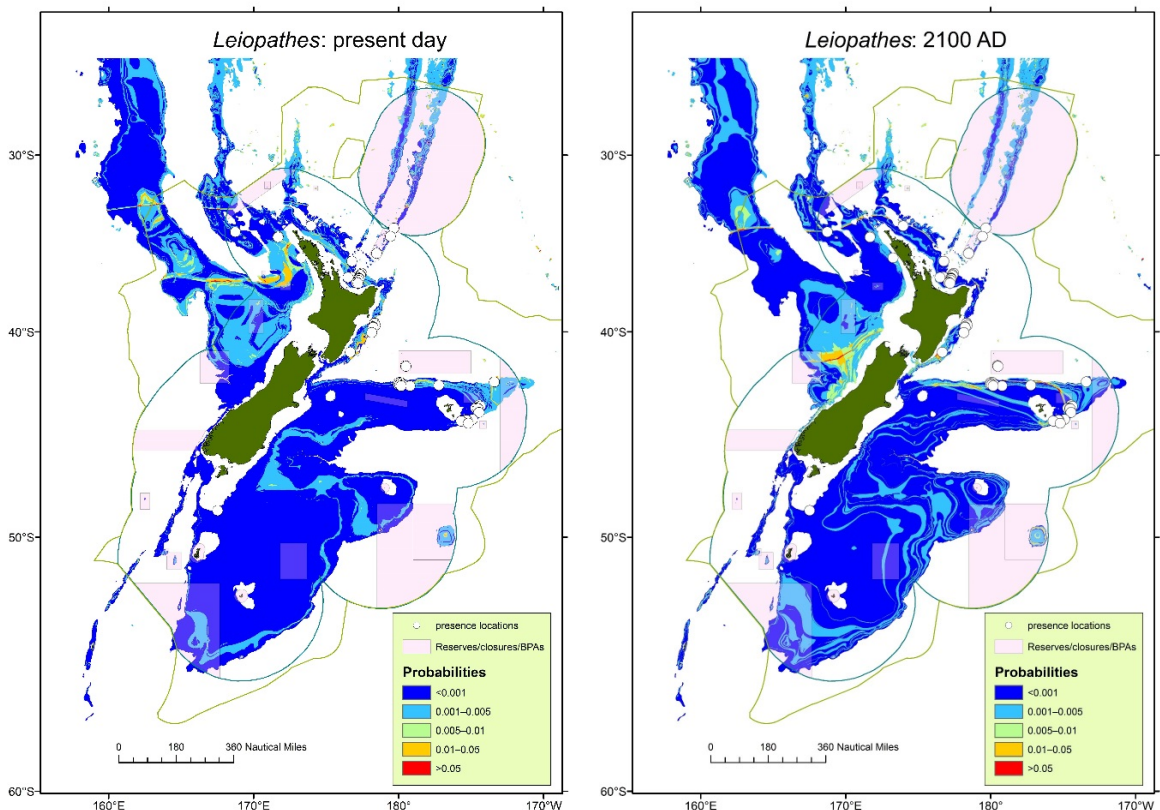

Figure 3-12: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Leiopathes* spp. from BRT models (n = 67 presence records). Other details as for Figure 3-2.

Figure 3-13: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Parantipathes* spp. from BRT models (n = 56 presence records). Other details as for Figure 3-2.
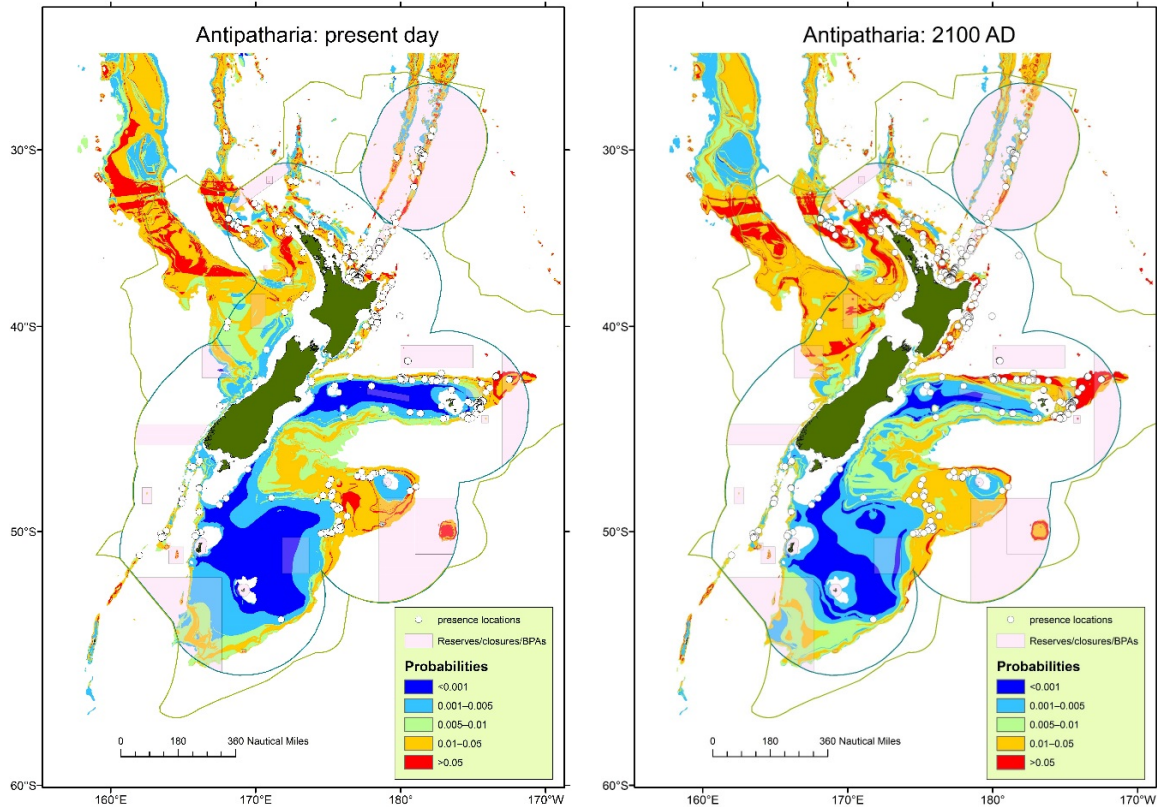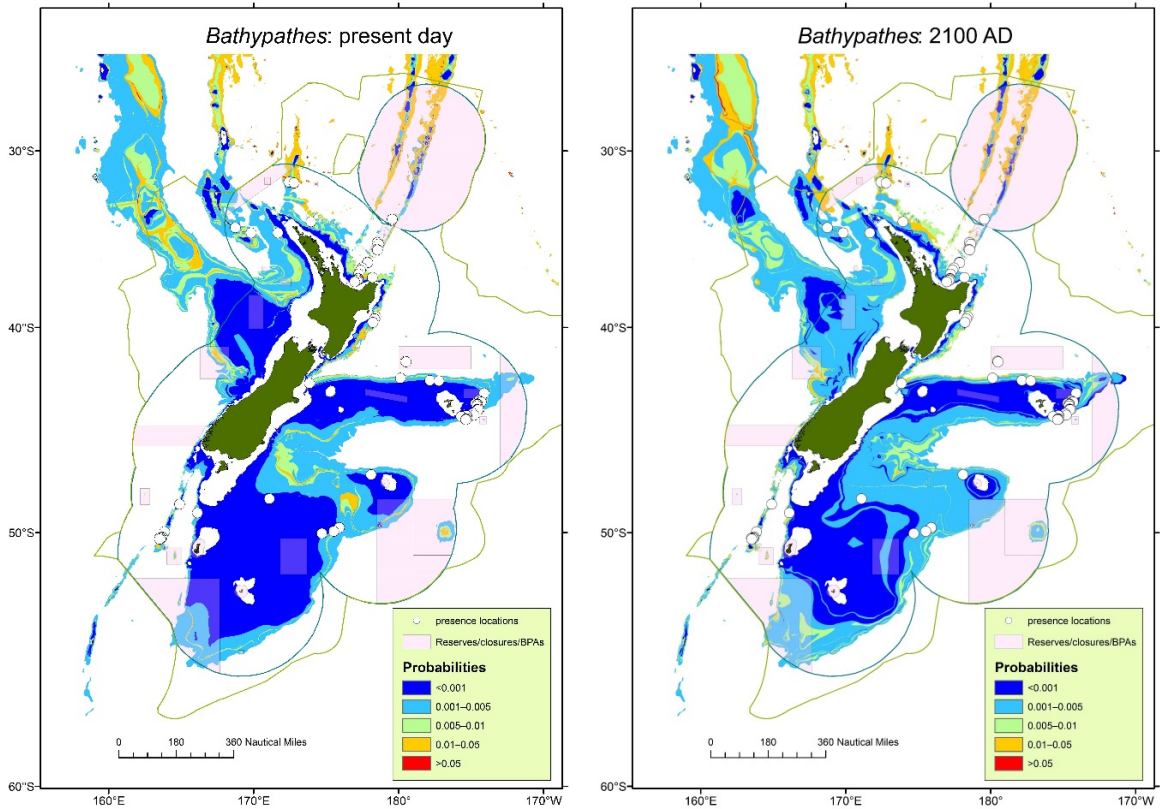

Figure 3-14: Estimated present (left panel) and future (right panel) probability of occurrence of suitable habitat for *Triadopathes* spp. from BRT models (n = 27 presence records). Other details as for Figure 3-2.
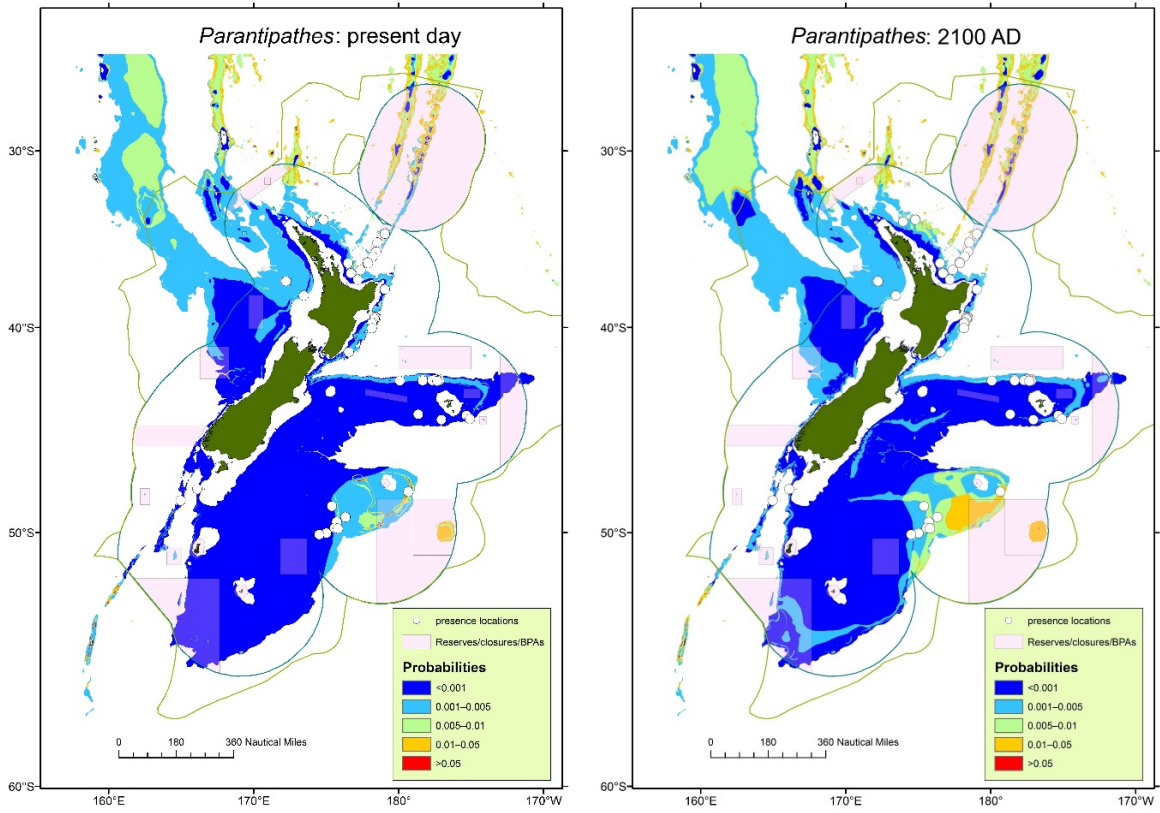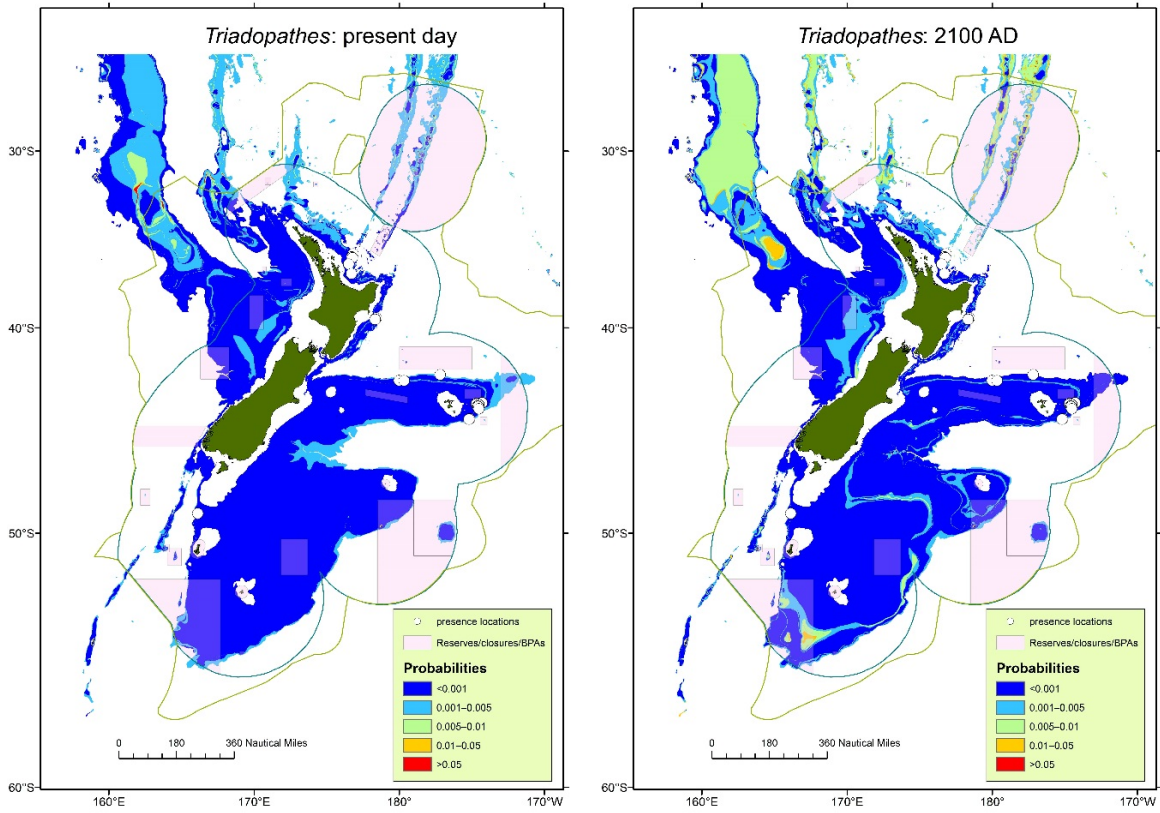
4   Discussion

This research presents the first application of habitat suitability models to predicted future seafloor conditions for the estimation of likely future coral species distributions. Although the procedure limited the predictor variables mainly to those available from ESM models, an initial assessment of potential future coral habitats in the New Zealand region was possible.

While overall the model predictions were broadly similar to previous studies for the present day, despite a somewhat different set of variables, the projected model runs showed substantial changes in distribution are likely for several taxa, and potential areas of refugia for these corals and their associates were identified. Parts of the Chatham Rise show unchanged or increased habitat suitability for all scleractinian reef-forming species, and some regions of the sub-Antarctic plateaus and/or the northern ridge systems provide further suitable habitat in 2100 AD for each species individually. For the alcyonaceans examined, the Chatham Rise also shows a potential refuge for bamboo corals, and habitat suitability is predicted to improve in all areas for bubblegum corals, but little change in suitability is predicted for *Primnoa* spp.. For black corals, relatively little change in habitat suitability was predicted over time.

It is difficult to fully interpret the complex interactions of environmental variables leading to the changes in habitat suitability across the EEZ, but one driver may be changes in concentration of oceanic nitrate, one of the key predictors for most taxa. Nitrate levels are predicted to generally increase across the study area, but this is less evident on parts of the Chatham Rise where habitat suitabilities were seen to remain relatively high.

Substantial uncertainties exist, however. The ESM simulations used to predict the future state of the ocean have coarse spatial resolution (~1°x1°) within our domain, as do all other state of the art global ESMs. Thus, the future model simulations can only be expected to capture relatively large scale features of climate change. This was partially ameliorated by interpolating the models to the resolution of our dynamic topography and sampling them not at the modelled sea floor but at the true topography. Further, there are substantial uncertainties in ESM predictions of properties associated with biological stressors in the oceans (e.g. Bopp et al., 2013), and only one ESM was used in this study due to the scope of the project.

Further refinements in habitat suitability modelling will be possible in the future as improvements in the quality of the currently available input variable layers (both current conditions and predicted future conditions) are made, and as other potentially important variables such as sediment type are developed to a point where they can be usefully incorporated into these models. With these refinements higher resolution of input variables can be expected, and these can potentially be used with a subset of presence/absence data (or additional data) for which the precision is sufficiently fine (e.g. short trawls, camera surveys).

The scope of this project did not allow for a full exploration of the resulting habitat suitability maps and how they relate to the tolerances of each taxon to the environmental variables examined, and how critical conditions are predicted to change over time and space. A closer examination of the observed tolerances of each coral taxon with respect to predicted changes in the most relevant environmental variables would be a useful extension to this work and the deep-sea coral distribution research of Bostock et al. (2015).

Any additional research on the spatial range, mineralogy, growth, and dissolution rates of the study species would help provide a better understanding of species response to predicted environmental changes. For example, the bi-mineralic *Primnoa* spp. has a skeleton made up of a number of different layers of aragonite and magnesium calcite, an unusual composition compared to other members of the gorgonian groups (Tracey et al. 2011). There is a need to examine differences in mineralogy

among different populations of this genus to see if they are caused by a regional effect, colony age, or are a genetic effect. Further knowledge for all taxa on the dissolution levels from in-aquaria experiments would help inform tolerance from changing temperatures and acidity.

Aligning known or estimated tolerances with maps of predicted future seafloor environmental conditions has revealed an alarmingly small area of refugia for deep-sea scleractinian corals in Southern Australia (Thresher et al. 2015) and it may be critical for the ultimate survival of deep-sea corals in the New Zealand region to identify and protect such areas.

5 Acknowledgements

6 References

Anderson, O.; Tracey, D.; Bostock, H.; Williams, M.; Clark, M. (2014). Refined habitat suitability modelling for protected coral species in the New Zealand EEZ. NIWA Client Report prepared for Department of Conservation. WLG2014-69.

Archer, K.J.; Kimes, R.V.; (2008). Empirical characterization of random forest variable importance measures. *Computational Statistics and Data Analysis 52*: 2249–2260.

Auster, P.J.; Moore, J.; Heinonen, K.B.; Watling, L. (2005). A habitat classification scheme for seamount landscapes: assessing the functional role of deep-water corals as fish habitat. *In:* Freiwald, A., Roberts, J.M. (Eds.), Cold-Water Corals and Ecosystems. Springer-Verlag, Berlin, Heidelberg.

Baird, S.J., Tracey D., Mormede, S., Clark, M. (2013). The distribution of protected corals in New Zealand waters. Research report for the Department of Conservation. Available for download from http://www.doc.govt.nz/publications/conservation/marine-and-coastal/conservationservices-programme/csp-reports/distribution-of-protected-corals/

Bopp, L.; Resplandy, L.; Orr, J. C.; Doney, S. C.; Dunne, J. P.; Gehlen, M.; Halloran, P.; Heinze, C.' Ilyina, T.; Séférian, R.; Tjiputra, J.; and Vichi, M. (2013). Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models, *Biogeosciences, 10*, 6225-6245, doi:10.5194/bg-10-6225-2013.

Bostock, H.C.; Tracey, D.M.; Currie, K.I.; Dunbar, G.B.; Handler, M.R.; Mikaloff-Fletcher, S.E.; Smith, A.M.; Williams, M.J.M. (2015). The carbonate mineralogy and distribution of habitat-forming deep-sea corals in the southwest pacific region. *Deep-Sea Research I 100*: 88–104.

Buhl-Mortensen, L.; Mortensen, P.B. (2005). Distribution and diversity of species associated with deepsea gorgonian corals off Atlantic Canada. Cold-Water Corals and Ecosystems. Springer Publishing House, Heidelberg, Germany, pp. 849–879.

Cairns, S.D. (1995). The Marine Fauna of New Zealand: Scleractinia (Cnidaria: Anthozoa). *New Zealand Oceanographic Institute Memoir 103*:210 p.

Cairns S.D. (2012). The Marine Fauna of New Zealand: New Zealand Primnoidae (Anthozoa: Alcyonacea). Part 1. Genera *Narella*, *Narelloides*, *Metanarella*, *Calyptrophora*, and *Helicoprimnoa*. *NIWA Biodiversity Memoir 126*: 71 p.

CANZ (2008). New Zealand Region Bathymetry. NIWA Chart, Miscellaneous Series No. 85, National Institute of Water and Atmospheric Research, Wellington, New Zealand.

Clark, M.R.; Koslow, J.A. (2007). Impacts of fishing on seamounts. In: Pitcher, T.J.; Hart, P.J.B.; Morato, T.; Santos, R.; Clark, M. (eds). Seamounts: ecology, fisheries and conservation. Blackwell Fisheries and Aquatic Resources Series 12, Blackwell Scientific, Oxford, p 413–441.

Clark, M.R.; Rowden, A.A. (2009). Effects of deepwater trawling on the macro-invertebrate assemblages of seamounts on the Chatham Rise, New Zealand. *Deep-Sea Res I 56*:1540–1544.

Clark, M.R.; Rowden, A.A; Schlacher, T.A.; Guinotte, J.; Dunstan, P.K.; Williams, A.; O'Hara, T.D.; Watling, L.; Niklitschek, E.; Tsuchida, S. (2014). Identifying Ecologically or Biologically Significant Areas (EBSA): A systematic method and its application to seamounts in the South Pacific Ocean. *Ocean & Coastal Management 91*: 65–79.

Consalvey, M.; MacKay, K.; Tracey, D. (2006). Information review for protected deep-sea coral species in the New Zealand region. NIWA Client Report prepared for Department of Conservation. WLG2006-85. 60 p.

Costello, M.J.; McCrea, M.; Freiwald, A.; Lundalv, T.; Jonsson, L.; Bett, B.J.; van Weering, T.C.E.; de Haas, H.; Roberts, J.M.; Allen, D. (2005). Role of cold-water *Lophelia pertusa* coral reefs as habitat in the NE Atlantic. *In:* Freiwald, A; Roberts, J.M. (Eds.), *Cold-Water Corals and Ecosystems*. Berlin: Springer-Verlag, 771–805.

Davies, A.J.; Guinotte, J.M. (2011). Global habitat suitability for framework-forming cold-water corals. *PLoSONE, 6*: e18483.

Dunne, J.P.; John, J.G.; Adcroft, A.J.; Griffies, S.M.; Hallberg, R.W.; Shevliakova, E.; Stouffer, R.J.; Cooke, W.; Dunne, K.A.; Harrison, M.J.; Krasting, J.P.; Malyshev, S.L.; Milly, P.C.K.; Phillipps, P.J.; Sentman, L.T.; Samuels, B.L.; Spelman, M.J.; Winton, M.; Wittenberg, A.T.; Zadeh, N. (2012). GFDL's ESM2 Global Coupled Climate–Carbon Earth System Models. Part I: Physical Formulation and Baseline Simulation Characteristics. *J. Climate*, 25, 6646–6665.

Elith, J.; Leathwick, J.R.; Hastie, T. (2008). A working guide to boosted regression trees. *Journal of Animal Ecology 77*: 802–813.

Elith, J.; Leathwick, J.R. (2011). Boosted Regression Trees for ecological modelling. http://cran.r-project.org/web/packages/dismo/vignettes/brt.pdf. 22 p.

ESRI (2015). ArcGIS Desktop: Release 10.3.1. Redlands, CA: Environmental Systems Research Institute.

Freeman, D.J.; Marshall, B.A.; Ahyong, S.T.; Wing, S.R.; Hitchmough R.A. (2010). Conservation status of New Zealand marine invertebrates, 2009. New Zealand Journal of Marine and Freshwater Research Vol. 44, No. 3, September 2010, 129-148

Freeman, D.J.; Schnabel, K. Marshall, B.A.; Gordon, D.; Wing, S.R.; Tracey, D.; Hitchmough, R.A.(2013): Conservation status of New Zealand marine invertebrates, 2013. Department of Conservation Report. 25 p.

Glover, T.A.; Vaughn, S. (eds.) (2010). The Promise of Response to Intervention: Evaluating Current Science and Practice. Guilford Press, New York. 322 p.

Gordon, D. P. (editor) (2009). New Zealand Inventory of Biodiversity Volume One: Kingdom Animalia Radiata, Lopotrochozoa, Deuteromstomia. Canterbury University Press. 648 p.

Hadfield, M.; Uddstrom, M.; Goring, D.; Gorman, R. (and others) (2002). Physical variables for the New Zealand Marine Environment Classification System: development and description of data layers. NIWA Client Report CHC2002-043. NIWA, Wellington.

Henry, L.A.; Roberts, J.M. (2007). Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. *Deep Sea Research 1 54:* 654–672.

Husebø, A.; Nøttestad, L.; Fosså, J.H., Furevik, D.M., Jørgensen, S.B. (2002) Distribution and abundance of fish in deep-sea coral habitats. *Hydrobiologia 471*: 91–99.

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jensen, A.; Frederikson, R. (1992). The fauna associated with the bankforming deepwater coral *Lophelia pertusa* (Scleractinaria) on the Faroe shelf. *Sarsia 77*: 53–69.

Leathwick, J.R.; Elith, J.; Francis, M.P.; Hastie, T.; Taylor, P. (2008). Variation in demersal fish species richness in the oceans surrounding New Zealand: an analysis using boosted regression trees. *Marine Ecology Progress Series 321*: 267–281.

Mackay, K. A. (2007). Database documentation: SEAMOUNT. NIWA Internal Report. 42 p.

Mackay, K.A.; Rowden, A.A.; Bostock, H.C.; Tracey D.M. (2014). Revisiting Squires' Coral Coppice, Campbell Plateau, New Zealand. *New Zealand Journal of Marine and Freshwater Research Vol. 48(4)*. 19 p.

McCloskey, L.R., (1970). The dynamics of the community associated with a marine scleractinian coral. *Internationale Revue der gesamten Hydrobiologie und Hydrographie 55*: 13–81.

Moore, J.; Auster, P.; Calini, D.; Heinonen, K.; Barber, K.; Hecker, B. (2008). The false boarfish *Neocyttus helgae* in the western North Atlantic. *Bulletin of the Peabody Museum of Natural History 49*: 31–41.

Mortensen, P.B.; Buhl-Mortensen, L., (2004). Distribution of deep-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). *Marine Biology 144:*1223–1238.

Opresko, D.; Tracey, D.; Mackay, E. (2014). Antipatharia (black corals) for the New Zealand region. A field guide of commonly sampled New Zealand black corals including

illustrations highlighting technical terms and black coral morphology. New Zealand Aquatic Environment and Biodiversity Report 136: 20 p.

Rengstorf, A.M.; Yesson, C.; Brown, C.; Grehan, A.J.; (2013). High-resolution habitat suitability modelling can improve conservation of vulnerable marine ecosystems in the deep sea. *J. Biogeogr 40*: 1702–1714.

Reveillaud, J.; Freiwald, A.; Van Rooij, D.; Le Guilloux, E.; Altuna, A.; Foubert, A.; Vanreusal, A.; Roy K.O.-L.; Henriet, J.P. (2008). The distribution of scleractinian corals in the Bay of Biscay, NE Atlantic. *Facies 54,* 317–331.

Rickard, G.; Behrens, E.; Chiswell, S. (2015). CMIP5 Earth System Models with Biogeochemistry: An Assessment for the New Zealand Exclusive Economic Zone, in prep for submission to JGR-Oceans.

Ridgeway, G. (2006) Generalized boosted regression models. Documentation on the R package "gbm", version 1.5-7. http://www.i-pensieri.com/gregr/gbm.shtml.

Roberts, J.M.; Henry, L.A.; Long, D.; Hartley, J.P. (2008). Cold-water coral reef frameworks, megafaunal communities and evidence for coral carbonate mounds on the Hatton Bank, north east Atlantic. *Facies 54:* 297–316

Rogers, A.D.; Baco, A.; Griffiths, H.; Hall-Spencer, J.M. (2007). Corals on seamounts. In: Pitcher, T.J.; Morato, T.; Hart, P.J.B.; Clark, M.R.; Haggan, N.; Santos, R.S.; Oxford, M. (Eds.), *Seamounts: Ecology, Fisheries and Conservation.* Blackwell Publishing Fisheries and Aquatic Resources Series, Blackwell Scientific pp. 141–169.

Rowden, A.A.; Oliver, M.; Clark, M.R.; Mackay, K. (2008). New Zealand's "SEAMOUNT" database: recent updates and its potential use for ecological risk assessment. *New Zealand Aquatic Environment and Biodiversity Report 27*. 49 p.

Rowden, A. A.; Clark, M. R.; Lundquist, C. J.; Guinotte, J. M.; Anderson, O. F.; Julian, K. A.; Mackay, K. A.; Tracey, D. M.; Gerring, P. K. (2015). Developing spatial management options for the protection of vulnerable marine ecosystems in the South Pacific Ocean region. *New Zealand Aquatic Environment and Biodiversity Report 155*. 76 p.

Sánchez, J.A. (2005). Systematics of the bubblegum corals (Cnidaria: Octocorallia: Paragorgiidae) with description of new species from New Zealand and the Eastern Pacific. *Zootaxa 1014*: 1–72.

Soffker, M.; Sloman, K.A; Hall-Spencer, J.M. (2011). *In situ* observations of fish associated with coral reefs off Ireland. *Deep Sea Research I 58:* 818–825.

Stone, R.P. (2006). Coral habitat in the Aleutian Islands of Alaska: depth distribution, fine-scale species associations, and fisheries interactions. *Coral Reefs 25*: 229–238.

Taylor, K.E.; Stouffer, R.J.; Meehl G.M. (2012). An overview of CMIP5 and the experiment design. Bull. Amer. Meteor. Soc, 90, 1467-1485.

Thresher, R.E; Guinotte, J.M.; Matear, R.J.; Hobday, A.J. (2015). Options for managing impacts of climate change on a deep-sea community. *Nature Climate Change 5.* 635–9. DOI: 10.1038/NCLIMATE2611

Tittensor, D.P.; Baco-Taylor, A.R.; Brewin, P.; Clark, M.R. (and others) (2009). Predicting global habitat suitability for stony corals on seamounts. *J Biogeogr 36*:1111–1128

Tracey, D.; Baird, S.J.; Sanders, B.M.; Smith, M.H. (2011a). Distribution of protected corals in relation to fishing effort and assessment of accuracy of observer identification. NIWA Client Report No: WLG2011-33 prepared for Department of Conservation, Wellington. 74 p.

Tracey, D.M.; Rowden, A.A.; Mackay, K.A.; Compton, T. (2011b). Habitat-forming cold-water corals show affinity for seamounts in the New Zealand region. *Marine Ecology Progress Series 430*: 1–22.

Tracey, D.; Anderson, O.; Bostock, H.; Clark, M. (2014). Report on the methods used to describe the distribution of deep sea corals in relation to areas where they are at risk of interactions with commercial fishing gear. Project: 4527 RFP Development of Coral Distribution Modelling Prepared for comment from: CSP Technical Working Group. 13 p.

Vierod, A.D.T.; Guinotte, J.M.; Davies, A.J. (2014). Predicting the distribution of vulnerable marine ecosystems in the deep sea using presence-background models. *Deep-Sea Research II 99*: 6–18.

Watling, L.; France, S.C.; Pante, E.; Simpson, A. (2011). Biology of deep-water octocorals. *Advances in Marine Biology 60*: 41–122.

Wheeler, A.J.; Beyer, A.; Freiwald, A.; de Haas, H.; Huvenne, V.A.I.; Kozachenki, M.; Olu-Le Roy, K.; Opderbecke, J. (2007). Morphology and environment of cold-water coral carbonate mounds Ministry for Primary Industries Ocean Acidification in Fisheries Habitat on the NW European margin*. International Journal of Earth Sciences (Geologisch Rundschau) 96:*37–56.