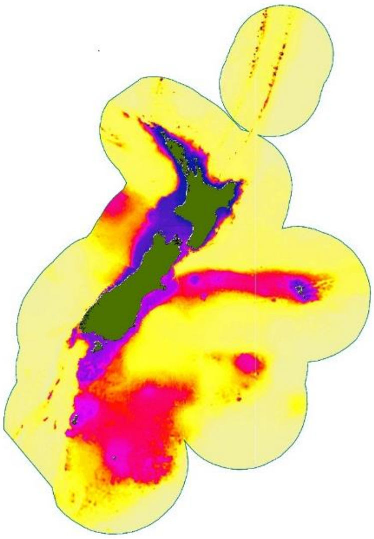
Refined habitat suitability modelling for protected coral species in the New Zealand EEZ

Prepared for Marine Species and Threats, Department of Conservation



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Executive summary

The estimated distributions of protected coral species within the New Zealand Exclusive Economic Zone (EEZ) were updated and refined using the habitat suitability modelling technique of Boosted Regression Trees (BRT). The revised predictive models incorporated recently constructed environmental grids for seafloor saturation levels of aragonite and calcite; forms of calcium carbonate integral to the formation of the calcareous endoskeletons of cold-water corals. The new models focussed more on distributions of individual species and genera than on combinations of structural forms considered in earlier models. The modelled taxa comprised four species of reef-building scleractinian corals, four genera of alcyonacean corals, and four genera of antipatharian corals.

After examination of correlations between all pairs of the available environmental predictors, ten were chosen for inclusion in the BRT model runs. These were similar to the set of variables used in earlier models, except for the inclusion of the new carbonate variables and the exclusion of the bottom depth variable, which was highly correlated with several other variables.

The resultant models generally showed relatively high discriminatory power, with those for taxa at finer taxonomic resolution (species) tending to perform better than those at a coarser level (genera and order). The variables with the most influence across all of the models were dynamic topography and bottom temperature. Dynamic topography (a measure of sea-surface height) is considered a proxy for nutrient supply and probabilities of coral habitat occurrence were strongly positively correlated with this variable, as they were in the earlier models. Temperature is a critical driver of cold-water coral distribution and its importance in these models probably reflects the thermal tolerances of the coral species examined. Surprisingly, aragonite and calcite saturation levels had only moderate influence in most of the models. As most of the presence records were at locations with supersaturated aragonite and calcite levels, it is possible that saturation values above this level may produce only a limited improvement in the corals' ability to incorporate these carbonate ions into their skeletons.

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. Individually, *Goniocorella dumosa* habitat was more restricted, with the most suitable conditions focussed around the shallower parts of the Chatham Rise, and a range of depths in eastern areas of the sub-Antarctic. *Madrepora oculata* habitat showed a similar distribution to *Goniocorella dumosa* in the sub-Antarctic but was predicted to be more common in deeper water on the Chatham Rise. Larger regions of high habitat suitability were predicted for *Solenosmilia variabilis* and *Enallopsammia rostrata*, mainly in isolated patches on the sub-Antarctic Plateaux, the northeast Chatham Rise, and northern parts of the EEZ.

For alcyonacean taxa, high habitat suitability for *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 *Primnoa* spp. and *Paragorgia* spp. was predicted in the Bounty Trough and Bounty Plateau, and in parts of the sub-Antarctic slope. Low suitability for alcyonaceans was predicted over much of the Chatham Rise and, for *Primnoa* especially, in northern areas.

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 features and major ridges in the north of the EEZ. Individually, high presence probabilities for *Leiopathes* spp. and *Triadopathes* spp. were restricted to northern areas, while *Parantipathes* spp. and *Bathypathes* spp. showed similar patterns to the combined antipatharians.

A substantial overlap between predicted coral habitat and the 20-year trawl footprint (>50%) occurs across the entire EEZ for *Goniocorella dumosa*, with lesser overlaps (<25%) for *Enallopsammia rostrata*, *Primnoa* spp., and *Bathypathes* spp. On the Chatham Rise, overlaps of >50% occur for *Goniocorella dumosa*, *Solenosmilia variabilis*, *Madrepora oculata*, and all genera of antipatharians except for *Bathypathes*. For all taxa, however, substantial areas of suitable habitat are predicted to exist across the EEZ outside of the historic trawl footprint.

1 Background

1.1 Protected and threatened corals

The New Zealand region supports a very diverse coral fauna (Cairns 1995; Cairns 2012), with the majority of records being the calcifying, framework-forming reef corals (scleractinians, or branching stony corals). Deepwater stony corals are widely distributed throughout the New Zealand region (Cairns 1995; Tracey et al. 2011a). The New Zealand fiords support deep-water emergent species including antipatharian black corals and stylasterid hydrocorals (e.g., *Errina* spp.), (Grange et al. 1981; 1985).

Some stony coral species 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). These structures can be large (e.g., 14 km long x 35 m high; Sula Ridge *Lophelia pertusa*; Huehnerbach et al. 2007), and 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).

Alcyonacean corals are also an abundant calcifying group represented in the New Zealand region and include: bubblegum corals (Paragorgidae), primnoid sea fan, sea whip corals (Primnoidae), and bamboo corals (Isididae), Alcyonaceans, like certain stony corals, include tree-like forms (Cairns 2012), and are also important habitat forming species (Buhl-Mortensen & Mortensen 2005).

The stylasterid hydrocorals (Hydroida) such as *Errina* spp. are also calcifiers. All of these groups, along with the black corals (Antipatharia), are protected under the New Zealand Department of Conservation Wildlife Act 2010 (amendment of Schedule 7A of the Wildlife Act 1953). The Order Gorgonacea has been revised and all gorgonians are now in the Order Alcyonacea as revised by Watling et al. (2011).

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 black corals, stony 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).

1.2 Coral distribution

The spatial variability of the protected deep-sea coral groups is reasonably well known for the New Zealand region (Sanchez 2005; Consalvey et al. 2006; Tracey et al. 2011a & b; Baird et al. 2013; Opresko & Tracey 2014; Rowden et al. in press). Tracey et al. (2011a) analysed the distribution of nine groups of protected corals based on bycatch records from observed trawl effort for 2007–10. Baird et al. (2013) further added to the knowledge of the distribution of protected corals by using data from research sampling and commercial fishing effort where observers had been present. Distributions of the protected corals within the EEZ were mapped by their structural differences and the potential biogenic habitat that they provide: "tree-like" (e.g., bubblegum corals); "reef-like" (e.g. the stony branching corals); "solitary small" (e.g., the scleractinian cup corals); and "whip-like" (e.g., bamboo coral *Lepidisis* spp. and black coral *Stichopathes* spp.).

1.3 Predictive modelling

Tracey et al. (2011b) modelled the distribution of five species of stony corals (Order Scleractinia) relative to 11 environmental variables using boosted regression trees (BRT). They identified depth and position relative to a seamount as consistently important factors, and a range of environmental factors that distinguished the deep-water species from the more shallow-occurring species. Baird et al. (2013) also used BRT analysis to predict the likely distribution of coral groups throughout the New Zealand Exclusive Economic Zone (EEZ), according to a set of 10 environmental variables. The areas where the environmental conditions were most suited to the coral groups were generally in deeper waters where the seafloor had steep slopes. Most of the known coral distributions were within the areas predicted by the models to have suitable environment, however, some deep-water and steep relief areas where corals were known to exist were not identified by the predicted distribution. By grouping the corals by their taxonomic orders and by "functional" groups, some details and differences in habitat preferences between species were effectively lost.

The MBIE-funded research project *Predicting the occurrence of vulnerable marine ecosystems for planning spatial management in the South Pacific region* (VME13301 - Vulnerable Marine Ecosystems), produced maps of predicted VME taxa habitat suitability for the New Zealand EEZ and the South Pacific Regional Fisheries Management Organisation (SPRFMO) region using both BRT and Maxent methods. Environmental data for this study were grouped into a 'regional' set of 11 environmental data layers for the New Zealand region, and a 'global' set of 9 environmental data layers for the wider SPRFMO region. The BRT and Maxent models predicted that suitable habitat for vulnerable marine ecosystem (VME) indicator taxa, including the major coral groups, was likely to be widespread across the region.

Baird et al. (2013) improved understanding of risks to protected coral taxa by characterising the nature and extent of the commercial fishing impacts in the New Zealand EEZ, and using records of coral catches to predict the extent of suitable habitat using BRT modelling. Baird et al. (2013) found that in many areas where commercial fishing was concentrated, for example on much of the Chatham Rise, the reported coral by-catch (and therefore also the predicted coral occurrence) was low. Many of the locations with coral bycatch match specific orange roughy fishery features described by Anderson & Dunn (2012).

1.4 Improving predictive models

Baird et al. (2013) recommended that when detailed map layers of the aragonite and calcite saturation horizon states became available for the New Zealand region, they could be used to improve predictive models of deep-sea coral habitat. 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.

Many marine organisms build skeletons of calcium carbonate ($CaCO_3$). The majority of these organisms are thought to use the CO_3^{2-} ion, but some have recently been found to use HCO^{3-}, or a combination of the two ions (Roleda et al. 2012). Predicted reductions in the availability of carbonate ions through acidification of the oceans will potentially limit the ability of stony and gorgonian corals to form their hard skeletons and, therefore, affect the amount of suitable biogenic habitat they provide for other marine organisms, including fish (Orr et al. 2005). In this study we used data for the saturation horizons of the two principal forms of carbonate found in corals; aragonite and calcite (Tracey et al. 2013), together with the environmental variables used in the BRT models carried out by Baird et al. (2013).

A broad scale sediment map being prepared as part of the MBIE-funded Vulnerable Marine Ecosystems Project was to be included as an environmental variable in this study if available in time. Unfortunately completion of this layer has been delayed by computational limitations due to the large amount of data involved, and thus it was not used here. This sediment layer, however, may have been of limited use due to its coarse spatial resolution and consequent lack of regional-scale detail for New Zealand. The usefulness of sediment data for predicting deep-sea coral distributions will be explored under the VME project.

1.5 Specific Objectives:

1. Produce models of protected coral distribution refined using the most recent data.
2. Use refined predictive models to inform an assessment of their risk to commercial fishing gear.

This report describes the distribution of deep sea corals in relation to areas where they are at risk from interactions with commercial fishing gear by producing refined models of protected coral distribution based on the most recent data. The results from these analyses were used to inform a risk assessment for deep-sea corals under Specific Objective 2.

The details of the environmental variables and datasets used here are described in Baird et al (2013). 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). Data to help inform a risk assessment using Productivity-Susceptibility-Analysis (PSA) are presented in Clark et al. 2014 (see Specific Objective 2).

This report has been prepared for Marine Species and Threat Group, DOC (Project DOC14302_POP2013-05).

2 Methods

To meet Specific Objective 1, the groomed coral dataset described and used in Baird et al. (2013), and additional sources of environmental information (aragonite and calcite saturation horizons, see Section 2.5) were used as the basis for modelling the distribution of suitable habitat for protected coral taxa. The analytical method applied was boosted regression trees (BRT) model (Elith et al. 2008).

2.1 Protected corals dataset:

The coral occurrence dataset compiled and groomed for the analysis of coral distribution in New Zealand waters by Baird et al. (2013) was used here to re-run the models of Baird et al (2013) with the new set of environmental data (Section 2.4). This coral dataset includes the verified (confirmed by coral taxonomists) fisheries-observer coral dataset as well as all available fisheries-observer coral data (non-verified) in combination with scientific research data collected from research biodiversity and trawl surveys. These coral occurrence data provide a large dataset to model with the environmental data to predict the distribution of corals throughout the region.

The protected coral dataset is a subset of a full ‘benthic stations’ dataset described in Tracey et al. (2011b), which includes all research survey stations where all organisms were identified, including those with no corals. The benthic stations dataset, which describes the sampling effort and provides pseudo-absence data for predictive models in the present study, includes 62 144 records, extending from about 30° S to 55° S and 162° E to 172° W within the New Zealand 200 n. mile EEZ.

The protected coral dataset comprises 7731 protected coral records and is bounded by similar limits to the full benthic dataset, though it effectively covers a smaller area as there are relatively few records from more southerly latitudes and from waters west of New Zealand.

The work by Baird et al (2013) produced predictive habitat models at the minimum taxonomic level of Order, with each model combining presence data for multiple genera and or species. Individual species or genera within these groupings are likely to show distinct distributions due to differing environmental requirements, and these are masked when groups of corals are analysed together at a higher taxonomic level. It was recommended by Baird et al. (2013) that models at the species or genus level should be built for taxa where the resolution of taxonomic identification is adequate and where there are sufficient data.

2.2 Coral selection criteria

Our selection of species or genera modelled in this project was guided by the species listed in the DOC Threatened Species List (Freeman et al. 2010) and by the most recent DOC marine invertebrate expert panel list (Freeman et al. 2013), where the listings of threatened New Zealand marine invertebrates have been reviewed and modified. The distribution data available for these species and or genera (see Sanchez 2005; Consalvey et al. 2006; Tracey et al. 2011a & b; Baird et al. 2013), were assessed for their suitability for modelling purposes to further refine the list of species or genera for which models will be made.

The recently completed field guide to commonly sampled New Zealand Antipatharian black corals (Opresko et al. 2014), was also a useful source to aid the selection of commonly occurring black coral genera. The revised and updated DOC Coral Guide (Tracey et al. 2014) was also a useful reference for taxonomic features for the key coral groups found in in the New Zealand region.

2.2.1 Threatened Species Listings

The final list of selected taxa includes those species listed under the categories of threatened and/or taxonomically indeterminate listings in the DOC Conservation Status of marine invertebrates, primarily from Freeman et al. (2013). This list informed our selection of coral taxa.

Several species within the scleractinian, octocoral, and black coral groups have been listed as Nationally Vulnerable under the Threatened Listings, or Declining under the At Risk criteria. Some species are listed as Naturally Uncommon (taxa whose distribution is confined to a specific geographical area or which occur within naturally small and widely scattered populations, where this distribution is not the result of human disturbance) e.g., certain *Errina* (red hydrocoral) and *Keratoisis* (bamboo coral) species. Some of the species in the category of ‘Taxonomically indeterminate, data deficient categories’, are also classified as being ‘At Risk’ because they are Naturally Uncommon. For fuller definitions of the categories for threatened and/ or taxonomically indeterminate listings see Townsend et al. (2008); Freeman et al. (2010; 2013).

2.3 List of selected corals for model runs

The final list of protected corals compiled for the model runs (Table 2-1), comprised species and or genera belonging to branching ‘reef-like’ and ‘tree-like’ forms as these are considered most vulnerable to trawling. They are also likely to have specific habitat requirements and therefore will

need to be treated separately in a risk assessment. The bamboo corals *Keratoisis* and *Lepidisis* were combined as the taxonomy for these genera is being reconciled (Juan Sanchez pers. comm. Universidad de los Andes, Santafé de Bogotá). Models were also produced at a coarser taxonomic level for Scleractinia (combining records for the reef-forming species in this group, as in Baird et al. 2013). This allowed a comparison of results from the two studies to be made.
Presence data in the protected coral dataset are based on specimen records from a combination of several sources, the main ones being the NIWA *Specify* (invertebrate museum) database and the MPI *Cod* (fisheries observer) and *Trawl* (research trawl survey) databases. The pseudo-absence data (from the benthic stations dataset) are derived from the NIWA *MarineDB* (research survey) database combined with a set of records from *Cod* during the period October 2007 to December 2010 when coral captures were closely monitored by observers (see Baird et al 2013 for further details).

Sample stations in the presence dataset but not in the absence dataset were identified and added to the absence dataset, and the absence dataset was checked for duplicate records. Records in both datasets with depths shallower than 200 m were removed. A set of predictor variables (see Table 2-2) were matched to the records for each dataset and any records with missing values for any of these predictors were removed. The number of presence records for each taxon of interest in this dataset 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 EEZ).

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.	Bubble-gum 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

2.4 Environmental variables

The variables considered in the models included those used in Baird et al. 2013, selected by those authors as being relevant to the distribution of protected coral orders. They represent modelled bio-chemico-physical properties of the EEZ waters, with values initially gridded at a resolution of 250 m, but resampled to a 1 km^2 grid, a scale more in keeping with the resolution of the sampling data (which varied from point locations through to the length of a commercial or research trawl).

These variables comprised depth, seamount, slope, dissolved organic matter, dynamic topography, bottom water temperature, tidal current speed, sea surface temperature gradient, surface water primary productivity, and particulate organic carbon flux (see Table 2-2).

2.5 New environmental variables

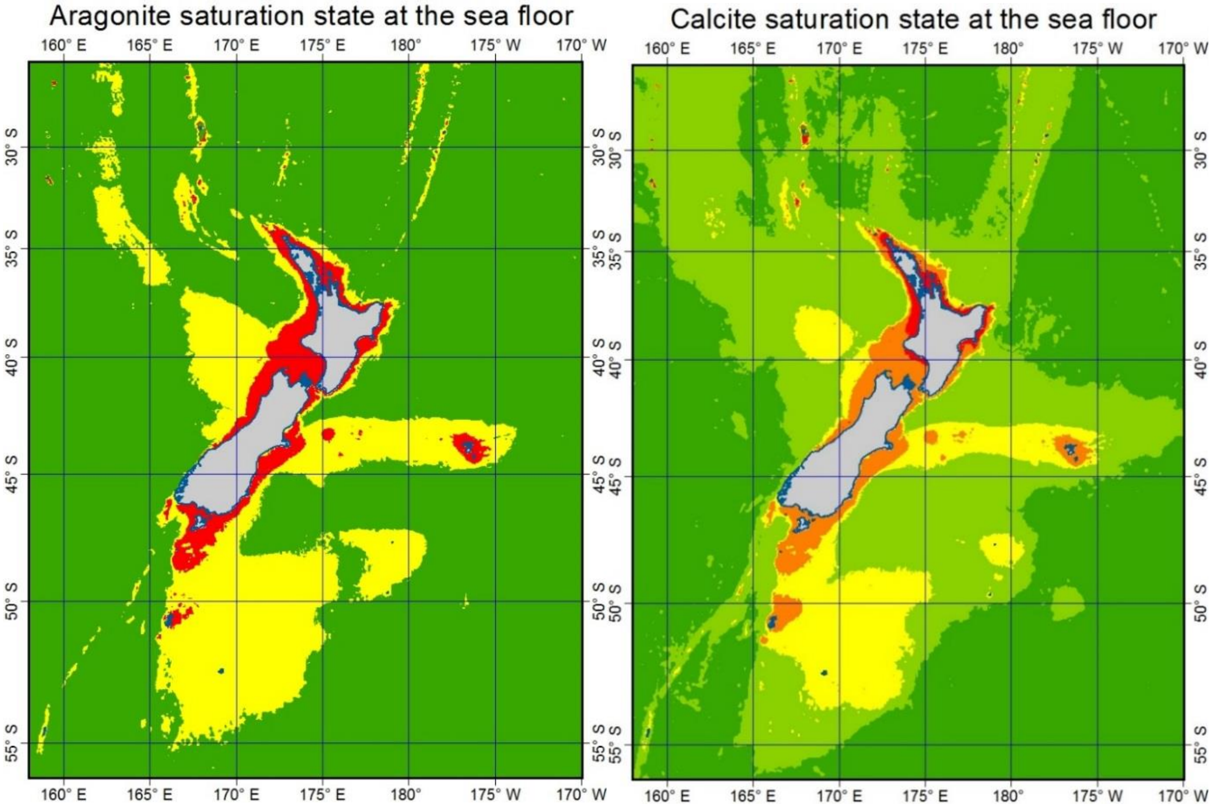
Two new environmental variables were available for the revised model runs, describing seafloor saturation states of the aragonite and calcite forms of calcium carbonate.

2.5.1 Carbonate layer data

The choice of environmental variables is fundamental to habitat suitability modelling. Several global studies have found that the distribution of habitat-forming deep sea corals are strongly controlled by the carbonate concentration (Guinotte et al., 2006; Davies and Guinotte, 2011; Yesson et al., 2012). The data available for the study by Baird et al. (2013), did not include ocean carbonate chemistry data because it was not available for the New Zealand region at the time. It was considered that these additional variables may have a strong influence on the distribution of corals in the New Zealand region and have the potential to improve the quality of the predicted distributions.

Models of the estimated carbonate saturation states (aragonite and calcite) at the sea floor were recently developed for southern hemisphere oceans using a series of multiple linear regression algorithms (Bostock et al. 2013), as part of the MPI Project ZBD201041 (Tracey et al. 2013) (Figure 2-1). These models were ground-truthed with opportunistic water samples collected between 2011 and 2014 and analysed for alkalinity and dissolved inorganic carbon at NIWA, Dunedin as part of the ZBD201041 project and the VME project.

Data for the two carbonate saturation states were considered along with the environmental variables used in Baird et al. (2013). Table 2.1 provides a summary of all model variables.



Aragonite saturation state at the sea floor

Calcite saturation state at the sea floor

Figure 2-1: Left: Map of the aragonite saturation state at the sea floor. Green colour represents under-saturated (Ω aragonite <1), yellow (Ω aragonite=1-2) and red (Ω aragonite=2-3) are saturated. Right: Map of calcite saturation state at the seafloor. Dark green colour represents under-saturated (Ω calcite <1), light green (Ω calcite 1-2), yellow (Ω calcite 2-3), orange (Ω calcite 3-4) and red (Ω calcite 4-5). Everything >1 is saturated with respect to calcite.

2.6 Variable selection for revised model runs

Table 2-2: Description of environmental data layers (based on Tracey et al. 2011b; Baird et al. 2013). Abbreviations used in relevant figures are given in italics.

Variable	Description and data source	Units	Reference
Depth *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. 250 m grid.	m	CANZ (2008)
Seamount *smt*	Seamount positions recorded in New Zealand region.	–	Rowden et al. (2008), Mackay (2007)
Slope *slope*	Sea-floor slope was derived from neighbourhood analysis of the bathymetry data.	°	CANZ (2008), Hadfield et al. (2002)
Dissolved organic matter *cdom*	Modified Case 2 inherent optical property algorithm applied to modified Case 2 atmospheric corrected SeaWiFS ocean colour remotely sensed data for the New Zealand region.	aDOM (443) m^{-1}	Pinkerton et al. (2006)
Dynamic topography *dynoc*	Mean of the 1993-1999 sea surface height above geoid, corrected for geophysical effects in the New Zealand region. This variable was produced by CLS Space Oceanography Division.	m	AVISO http://www.aviso.oceanobs.com
Bottom water temperature	Modelled seafloor temperature based on global climatologies.	°C	CARS (2009) (www.cmar.csiro.au/cars)
Tidal current speed *tidalcurr*	Maximum depth-averaged tidal current velocity estimated by interpolating outputs from the New Zealand region tide model.	ms^{-1}	Walters et al. (2001), Hadfield et al. (2002)
Sea surface temperature gradient *sstgrad*	Smoothed annual mean spatial gradient estimated from 96 months of remotely sensed SeaWIFS data.	°C km^{-1}	Uddstrom & Oien (1999), Hadfield et al. (2002)
Surface water primary productivity *vpgm*	Vertically generalised productivity model based on net primary productivity estimated as a function of remotely sensed chlorophyll, irradiance, and photosynthetic efficiency estimated from remotely sensed sea-surface temperature.	mg C m^{-2} d^{-1}	Behrenfield & Falkowski (1997)
Particulate organic carbon flux *poc*	Particulate organic carbon flux described as a function of the production of organic carbon in surface waters, scaled to depth below the sea surface.	mg C$_{org}$.m^{-2} d^{-1}	Lutz et al. (2007)
Aragonite saturation state *arag*	Saturation state of aragonite at the seafloor based on multiple linear regression algorithms developed from measured alkalinity and DIC compared with hydrographic data.	Ωaragonite	Bostock et al., 2013, Tracey et al., 2013
Calcite saturation state *calc*	Saturation state of calcite at the seafloor based on multiple linear regression algorithms developed from measured alkalinity and DIC compared with hydrographic data.	Ωcalcite	Bostock et al., 2013, Tracey et al., 2013

2.7 Habitat suitability modelling

The boosted regression tree (BRT) method, as used by Baird et al. (2013), was again used to carry out the predictive distribution modelling. Predictive species distribution modelling is a rapidly advancing field and a number of methods have been developed in recent years. BRT is one of several machine-learning (ML) methods which use an algorithm to learn the relationship between the response and its predictors rather than relying on the more subjective approach used in statistical methods. Other commonly used species distribution models include Random Forest models, GLMs, and Maxent. We have chosen the BRT method for this project as it has performed well in previous models of New Zealand deep-water invertebrates and fish (e.g., Rowden et al. in press, Leathwick et al. 2006, Compton et al. 2012) where it has been shown to make use of absence data (where available) to enhance predictive performance outside of the areas of known distribution.

2.7.1 Species–environment modelling with Boosted Regression Trees (BRT)

The BRT method uses recursive binary splits within a tree structure to explain the relationship between the response variable and the predictor variables, with “boosting” improving the model performance through a combination of many simple models (Elith et al. 2008). The BRT models used a binomial error distribution (family Bernoulli) to predict the probability of occurrence of each taxon, given a fixed set of predictor variables. The final model is a linear combination of many trees (hundreds to thousands) – and is equivalent to a regression model where each term in the model is a simple tree. BRT is an attractive method as it easily accommodates predictor variables of different types (e.g. binary, categorical, continuous), transformations are unnecessary, and outliers have little influence on model results. BRT can use pseudo-absence data drawn from the positions of benthic sampling stations, although these tend to be biased in their distribution in relation to the presence data and predictor variables. An alternative is to use randomly selected background data locations from across the region, in order to fully characterise the environmental variables across the area being predicted to. Although both options were trialled, initial models failed to converge with random background data and so final species predictions were based solely on models using sampling station pseudo-absence data.

The analysis used 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).

Two of the primary factors that control the BRT model fit, the ‘learning rate’ and the number of trees, were optimised within the model. The third factor ‘tree complexity’ was set to a moderate level of 3, where 1 is no interactions (following the procedure used by Baird et al. (2013)). All other settings required used the defaults given in *gbm* (Ridgeway 2006). The importance of each environmental predictor variable is presented as their relative influence (%), based on the number of times the variable is selected for splitting, and partial dependence plots are presented for each predictor.

The BRT technique requires a set of known presence data and a set of known absence data. The protected coral dataset described above formed the basis of the input data, with a binomial presence field created (1 for present, 0 for absent) for each species. The data set was treated in much the same way as in Baird (2013), except that for each taxon model separately, the absence data was checked for stations also present in the presence data, and removed for that model run. Both presence and absence stations are highly unevenly distributed across the EEZ, and tend to reflect the areas of most interest to fishing or deep-sea research. The absence data were not treated here as true absences because it is very possible for the sampling equipment (e.g., bottom trawl, seamount sled) to encounter a live coral but not catch it. Ideally absence data will be collected by ROV/AUV or a drop camera system where absences can be more reliably verified. Because absences were likely to have been overestimated, and to limit the influence of highly sampled areas in the models, the following weighting was applied to the data: presence records were weighted by 1/n, where n=the number of records in each 1 km^2 cell; absence records were given equal weight, at a value such that the sum of the presence weights was equal to the sum of the absence weights.

Datasets of the probability of suitable habitat occurrence for each coral taxon throughout the EEZ were created from the model functions, and displayed on maps produced in ArcGIS 10 (ESRI 2011) to enable interpretation.

2.8 Fisheries trawl footprint data

For each of the selected coral taxa, we compared the resulting plots of habitat suitability with the 20-year (1989–90 to 2008–09) trawl footprint layer as used in Baird et al. (2013). This was very similar to the 16-year footprint also examined by Baird et al. (2013) but with more recent data (including some newly fished areas on the Chatham Rise) providing a more current assessment. The overlaps between the habitat suitability plots and the trawl footprint were assessed using separate cut-off thresholds for each taxon based on the mean of the predicted probabilities across the entire modelled area (after Liu et al. 2005; Cramer 2003).

Because of inherent inaccuracies in predictive models resulting from the incomplete coverage and spatial bias of pseudo-absence data and explanatory variables, percentage overlaps (with indeterminate precision) are not presented. Instead overlaps are characterised as low (<25%), medium (25–50%), or high (>50%) thus providing a simple but more reliable measure with categories in a similar form to those applied to the Chatham Rise orange roughy fishery for the PSA risk assessment (Clark et al. 2014).

3 Results

3.1 Final variable selection for BRT models

The 12 variable layers considered were each believed to be relevant to the distribution of the protected coral taxa being examined, but to avoid including highly correlated variables in the models, correlations between all potential predictor variables were examined across the entire spatial extent of the layers within the EEZ and 200–2000 m model depth boundaries (Figure 3-1), and separately for the presence record locations of each taxon separately (not shown).

Depth was in all cases highly correlated with calcite, aragonite, and bottom temperature and was excluded from all models. The strong relationship between depth and bottom temperature was dealt with in Baird et al. (2013) and in other studies (e.g., Tracey et al. 2011b, Leathwick et al. 2006) by substituting the bottom temperature variable with residuals from a regression model describing the relationship between depth and temperature, but in this case the removal of depth as a predictor obviated the need for this and bottom temperature was used unmodified in the models. Dissolved organic matter was highly correlated with particulate organic carbon flux at the presence locations for all taxa (but less so over the entire layer extent); particulate organic carbon flux was excluded from all models in favour of dissolved organic matter as the data layer coverage was more complete. Aragonite and calcite saturation states were highly correlated with each other; based on the known chemical composition of the modelled taxa (Tracey et al. 2013), calcite saturation state only was used in the models for Antipatharians and Gorgonaceans, and aragonite saturation state only was used in models for Scleractinians. An exception to this was made for the alcyonacean *Primnoa* spp. which are bimineralic species with a skeleton made up of a number of different layers of both aragonite and Mg calcite (Tracey et al. 2013); both aragonite and calcite variables were used in the model for this group. The complete layer data for the remaining 10 variables were combined into a data frame in R (R Core Team, 2012) and, for the purposes of predicting presence probabilities within depths that deep-water corals occur and are vulnerable to impact from commercial fishing, were restricted to regions within the EEZ for which the modelled depth was 200–2000 m.

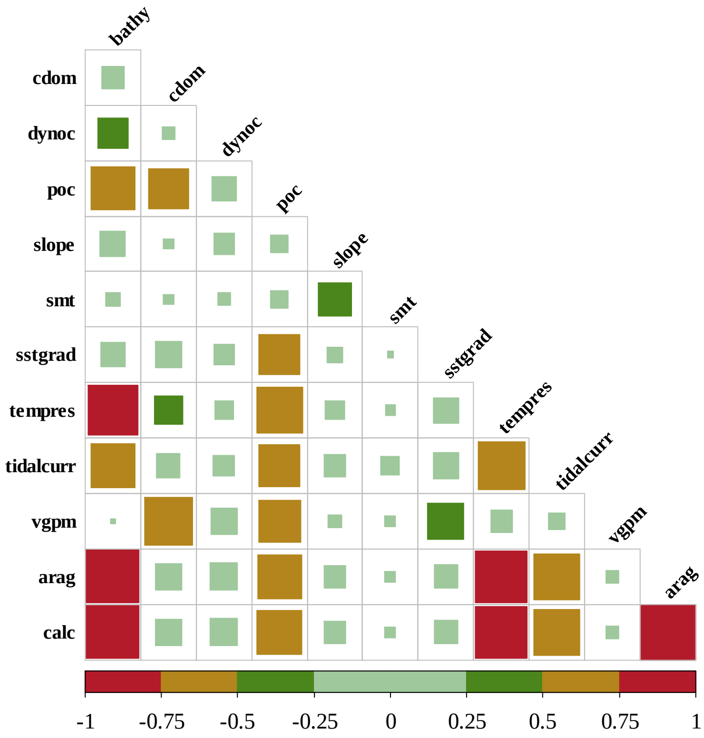


Figure 3-1: Graphical depiction of the correlation matrix for the environmental variables considered for the BRT models. Filled square size is proportional to correlation level. The correlation level and coding colour is shown on the x-axis, variable abbreviations are as in Table 2-2.

3.2 BRT model performance

Model performance was measured statistically using ROC scores (area under the receiver operating characteristic curve), where a value of 0.5 indicates a model with no discriminatory power and a value of 1 indicates a model that correctly identifies all presence records. A model with a ROC score 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). Most of the models performed well, with ROC scores of over 0.9 in all but the models for Scleractinia combined (0.68), *Paragorgia* spp. (0.88), and *Primnoa* spp. (0.89).

The variables with the most influence overall were dynamic topography and bottom temperature (Figure 3-2). Dynamic topography was the most important variable in the models for Scleractinia as a group as well as *Goniocorella dumosa* and *Madrepora oculata* separately. It was also the most important variable overall for black corals; explaining most of the variability for Antipatharia (combined), *Leiopathes* spp., *Triadopathes*, and *Parantipathes* spp., and was the second most important variable for *Bathypathes* spp..

Bottom temperature had a more variable influence in the models; it was the most important in each of the Alcyonacean (selected gorgonian octocorals) models, in particular, explaining over 50% of the variability in the *Paragorgia* spp. model. It also explained over 50% of the variability in the *Solenosmilia variabilis* model but a more modest 12–18% of the variability in the other scleractinian models. In contrast, it was only a minor variable in the Antipatharia models, explaining 3–11% of the variability.

Sea-surface primary productivity (vgpm) had an influence in most of the Scleractinian and Alcyonacean models (7–21%), where there was frequently a peak in influence at about 700 mg C m^{-2} d^{-1}, or a drop-off at higher values, but influence was relatively low for bamboo corals (*Keratoisis*/*Lepidisis*) and Antipatharians (1–8%).

Sea-surface dissolved organic matter had very little influence in the Alcyonacean models (1–2% for *Primnoa* and *Paragorgia*), but had moderate importance (11%) in both the combined Scleractinians (positive correlation) and combined Antipatharians (negative correlation), and in the individual taxa within these groups.

Depth-averaged tidal current speed was important in the scleractinian *Enallopsammia* and *Madrepora* models (12–15%), and the Antipatharian *Parantipathes* model (19%), but across all models did not show a consistently positive correlation as might be expected with this indicator of food supply. However, the strongest currents were mainly in depths shallower than the coral records and may have been decreasing in strength through the range of increasing preferential depth for some species.

Sea surface temperature gradient was moderately important in most models, up to 19% in *Leiopathes*, but not in *Primnoa* or *Paragorgia* (< 4%). This variable is a proxy for the location of ocean fronts and may indicate productivity in the water column. In most cases, however, SST gradient was negatively correlated with probability of species presence, suggesting a more complex relationship.

The influence of proximity to seamount locations was mostly low, < 3.5% in all models except those for Scleractinia (8%) and *Goniocorella* (12%), but in all models the probability of presence was greater on seamounts than off them.

Aragonite was only moderately useful in the Scleractinia models where it was used, up to 14% influence in the *Goniocorella* model, and generally showed a strongly positive correlation with coral occurrence. Calcite was slightly more influential in the alcyonacean and antipatharian models where it was used (12–23%), but not for *Paragorgia* (1%) and *Leiopathes* (4%). Neither carbonate variable had a significant influence in the *Primnoa* model (<4%).

Sea-floor slope had a small to moderate influence in most models (maximum of 19% in *Parantipathes*) but not in *Primnoa* (0.5%) or *Triadopathes* (2%). Greater slope is associated with harder substrates and greater current flow/food supply and, as may be expected, probabilities are positively correlated with slope in the models.

Further details of the influence of each of the variables in Figure 3-2 are shown in the partial dependence plots for each model in Appendix A.

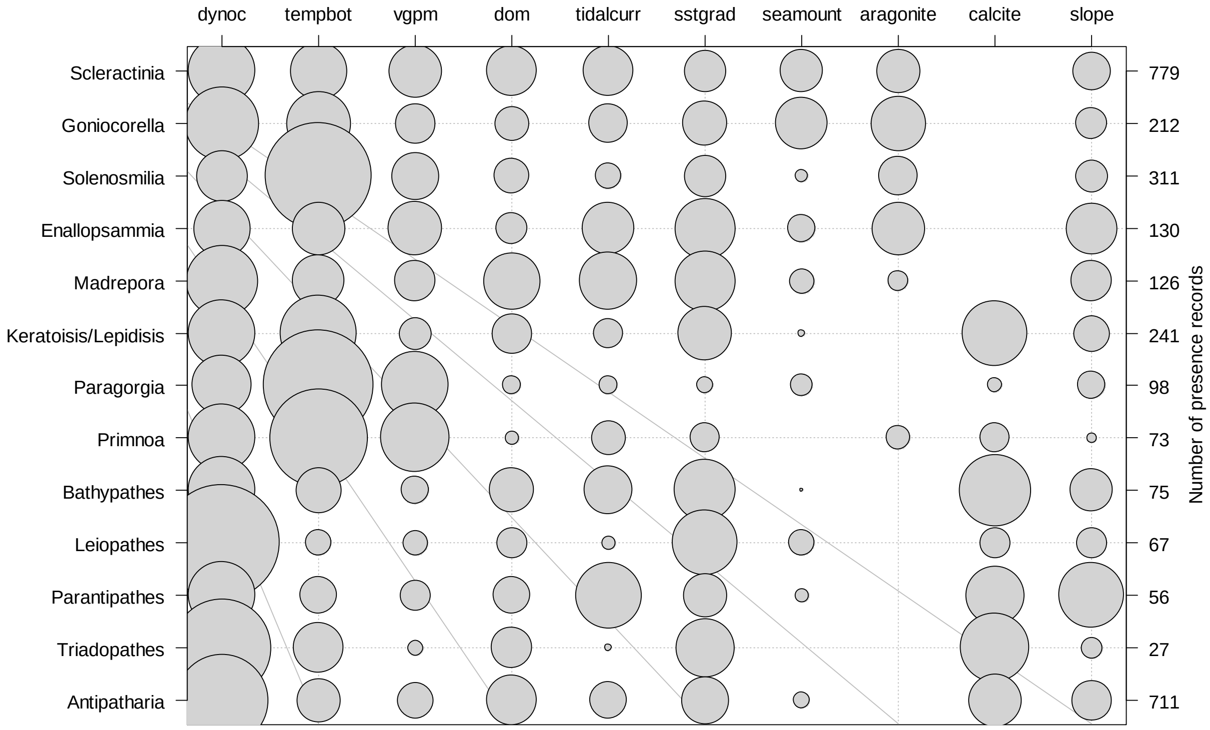


Figure 3-2: **Bubble plot showing the relative influence of each explanatory variable (Table 2-2) in the BRT predictive models for each protected coral taxon (see Section 2.3), and the number of presence records in each model (right axis).**

3.3 Predicted coral habitat distributions

3.3.1 Scleractinia

As a combined group, suitable habitat for the four species of reef-forming scleractinian corals is predicted to be widely spread over the EEZ (Figure 3-3). The highest probabilities of occurrence (>75%) are around the eastern Chatham Rise, especially on the top of the Rise and in deeper water to the north and east, along the sub-Antarctic slope to the southeast of the Campbell and Bounty Plateaux, the Macquarie Ridge, and around the northern North Island and Colville/Kermadec Ridges. Low probabilities (<25%) are predicted for the western Chatham Rise, west coast South Island, and shallower parts of the southern Plateaux. This is not substantially different from the predicted distribution for this group from Baird et al. (2013), although in that study probabilities were relatively lower on the eastern Chatham Rise.

Individually, *Goniocorella dumosa* shows a more restricted distribution with lower probabilities overall (generally <50%), and the most suitable habitats focussed around the shallower parts of the Chatham Rise (less than about 1000 m), and a wider depth range (up to 2000 m) on the sub-Antarctic slope and the Bollons Seamount (Figure 3-4). *Madrepora oculata* shows a similar distribution to *Goniocorella dumosa* in the sub-Antarctic but is predicted to be more common in deeper water (1000–2000 m) on the Chatham Rise (Figure 3-7). For *Solenosmilia variabilis* (Figure 3-5) and *Enallopsammia rostrata* (Figure 3-6), there are more regions with probabilities >50% than for the other two species of scleractinians, and these mainly occur in isolated patches on the sub-Antarctic Plateaux, the northeast Chatham Rise, and northeast of New Zealand including the main ridge features.

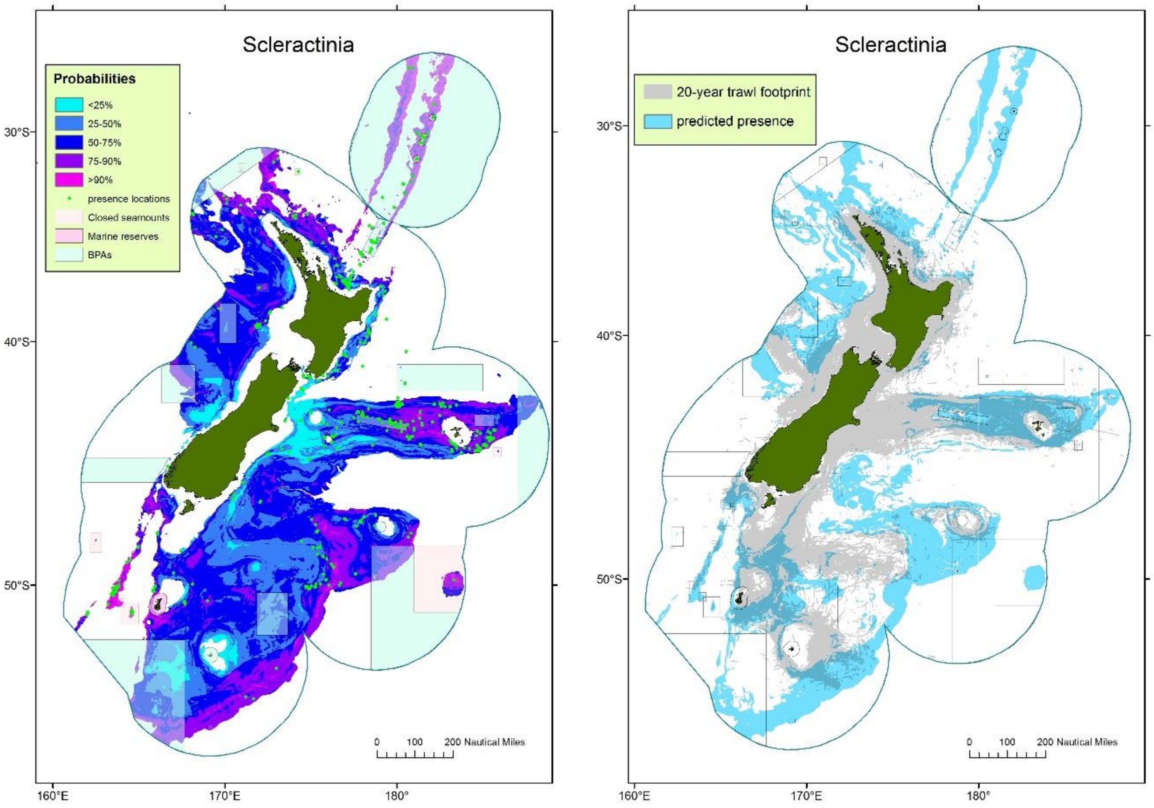


Figure 3-3: Probability of occurrence of suitable habitat for branching scleractinian coral species (*Solenosmilia variabilis*, *Goniocorella dumosa*, *Enallopsammia rostrata*, and *Madrepora oculata*) from BRT models. Left panel: probabilities of occurrence (based on n= 779 presence records); closed seamounts (introduced in 2001); Benthic Protected Areas (introduced in 2007), and large Marine Reserves. Right panel: predicted occurrence of scleractinian habitat based on probabilities greater than the model mean, relative to the 20-year trawl footprint (1989–90 to 2008–09).

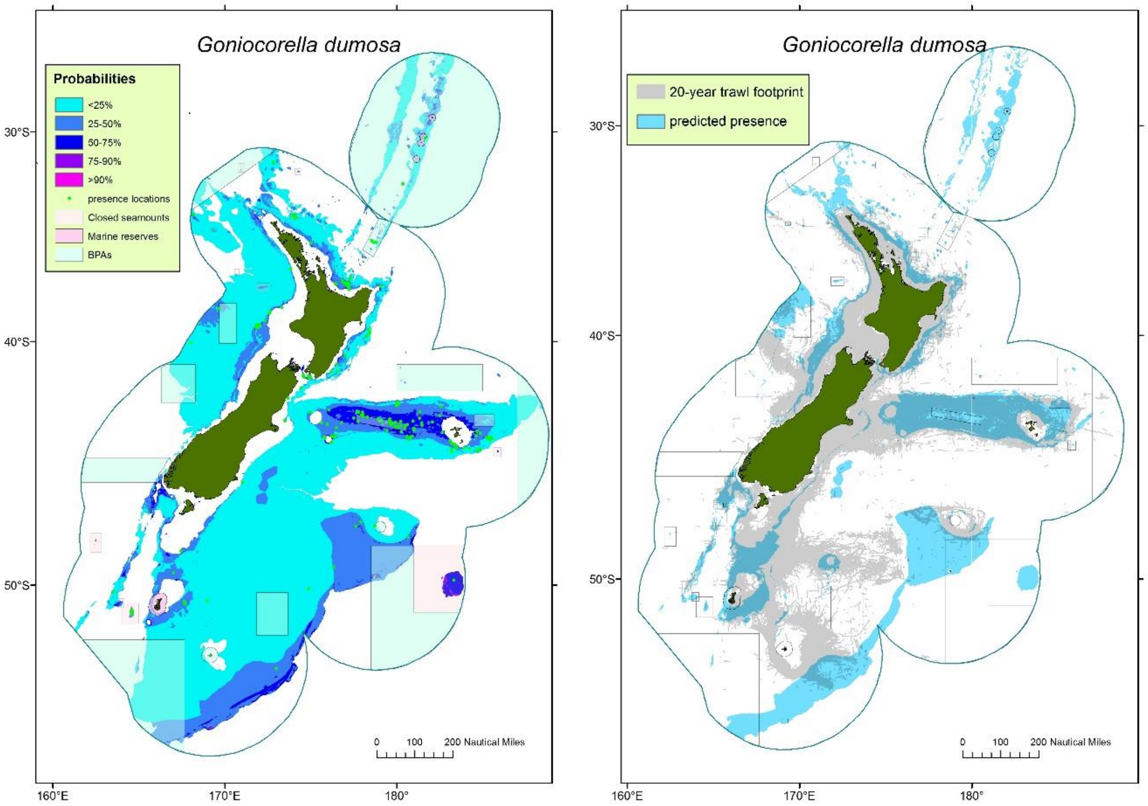


Figure 3-4: Probability of occurrence of suitable habitat for *Goniocorella dumosa* from BRT models (n = 212 presence records). All other details as for Figure 3-3.

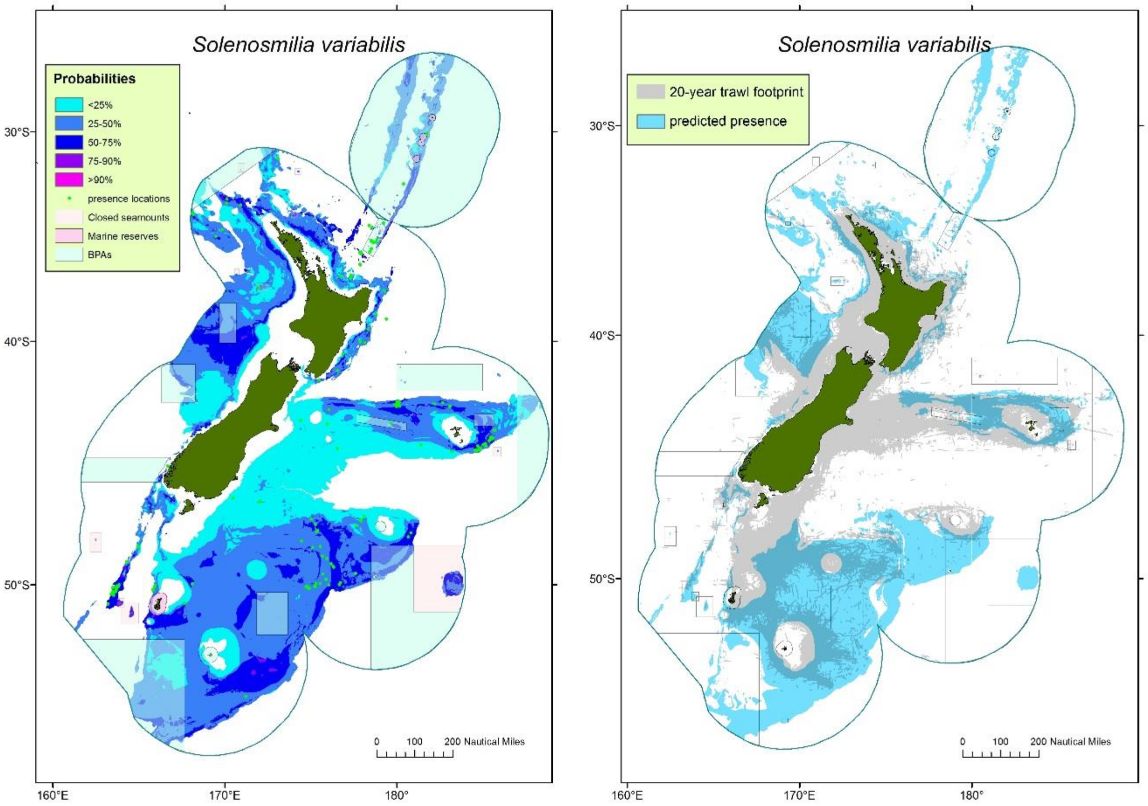


Figure 3-5: Probability of occurrence of suitable habitat for *Solenosmilia variabilis* (n = 311 presence records). All other details as for Figure 3-3.

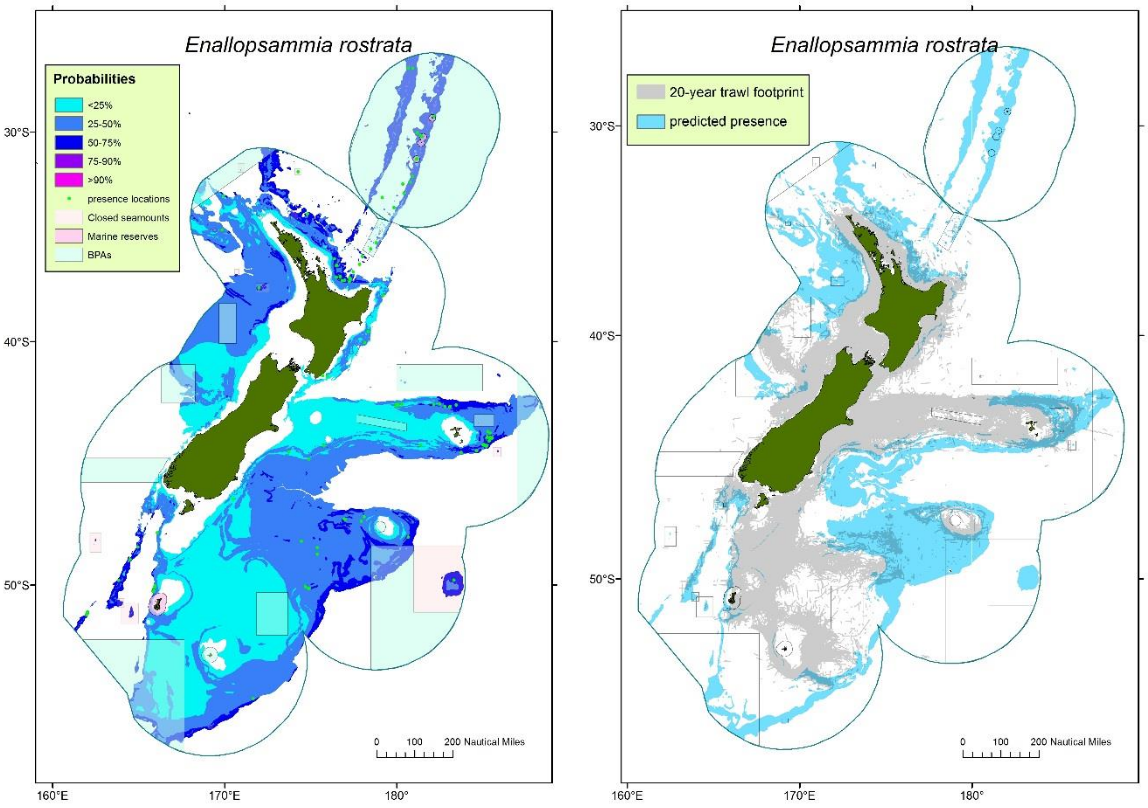


Figure 3-6: Probability of occurrence of suitable habitat for *Enallopsammia rostrata* (n = 130 presence records). All other details as for Figure 3-3.

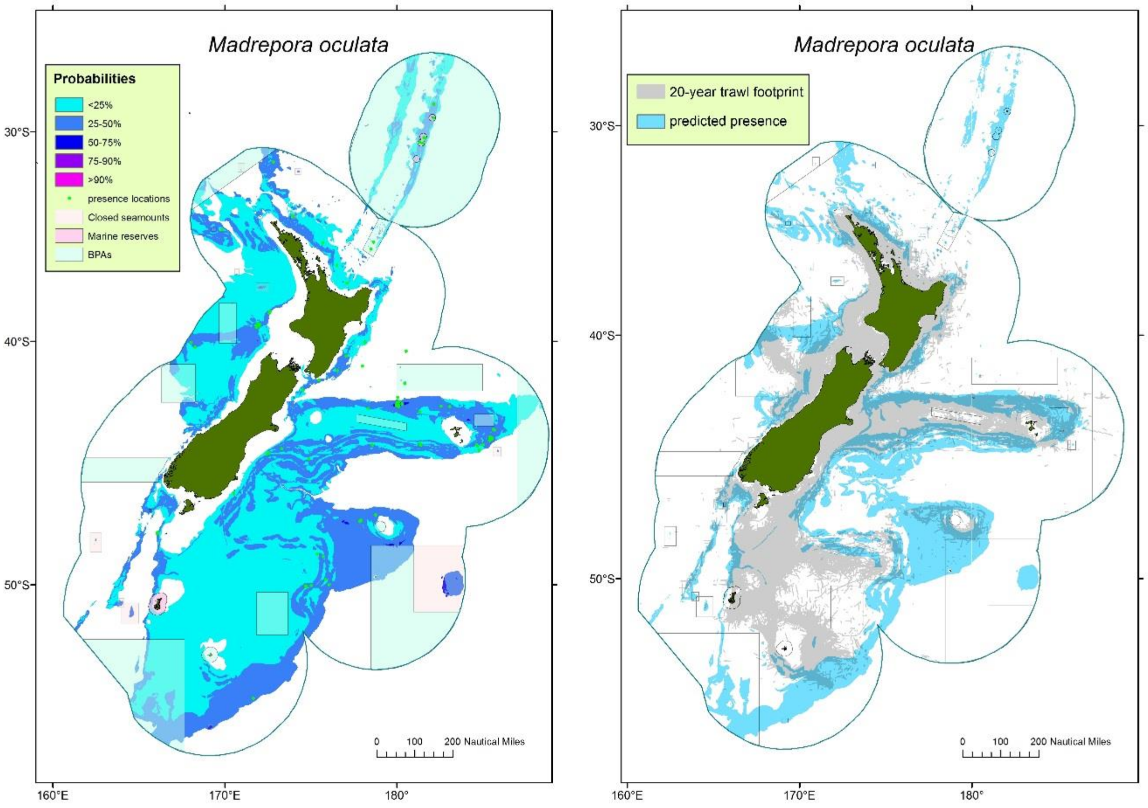


Figure 3-7: Probability of occurrence of suitable habitat for *Madrepora oculata* (n = 126 presence records). All other details as for Figure 3-3.

3.3.2 Alcyonacea

There were few areas where the model for *Keratoisis*/*Lepidisis* predicted a high probability of suitable habitat (>75%). These were mainly in a narrow depth band (centred at about 500 m) on the north and south of the eastern Chatham Rise, and in isolated pockets in the south and east sub-Antarctic and major northern ridge features. The areas with the lowest probabilities were mainly on the western Chatham Rise, the east coast North Island, and parts of the west coast South Island and sub-Antarctic (Figure 3-8). Plots for *Primnoa* spp. and *Paragorgia* spp. both show high probabilities in the region of the Bounty Trough and Bounty Plateau south of the Chatham Rise, and in parts of the sub-Antarctic slope (Figure 3-9, Figure 3-10). The probabilities for both genera are predicted to be less over much of the Chatham Rise (except for below about 1000 m on the southern Rise) and, for *Primnoa* especially, at all depths in northern areas.

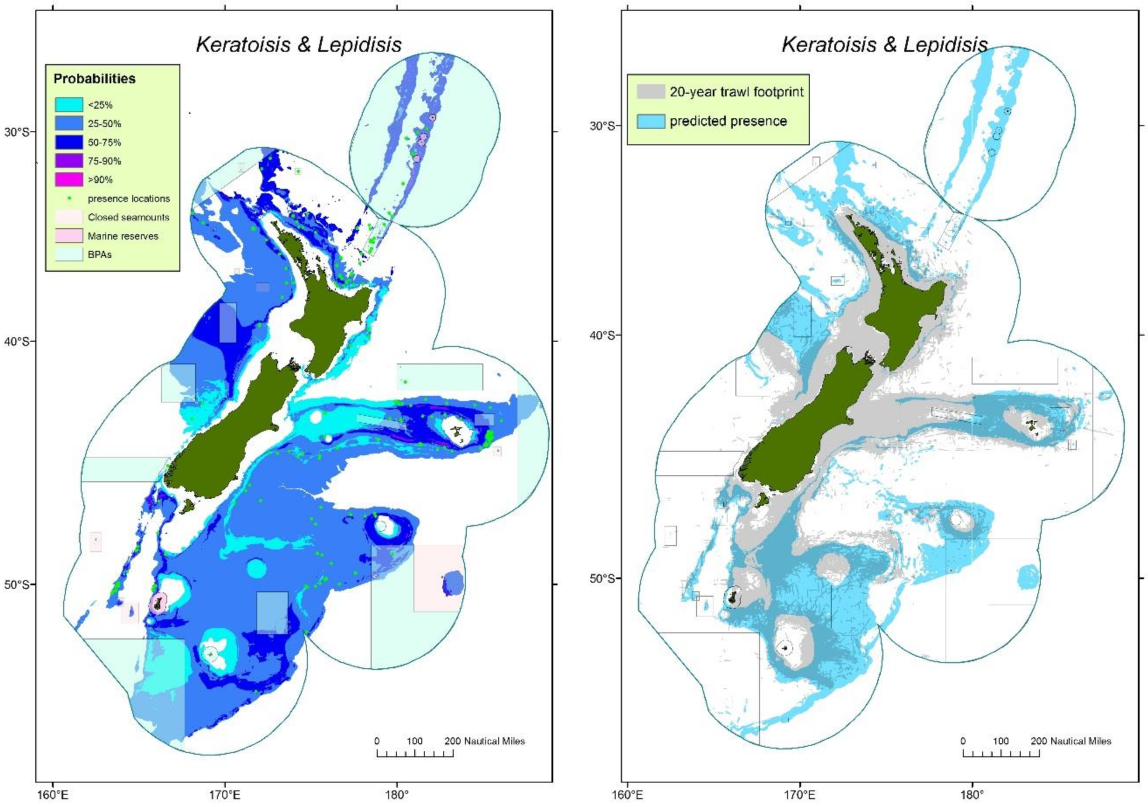


Figure 3-8: Probability of occurrence of suitable habitat for *Keratoisis* spp. & *Lepidisis* spp. (n = 241 presence records. All other details as for Figure 3-3.

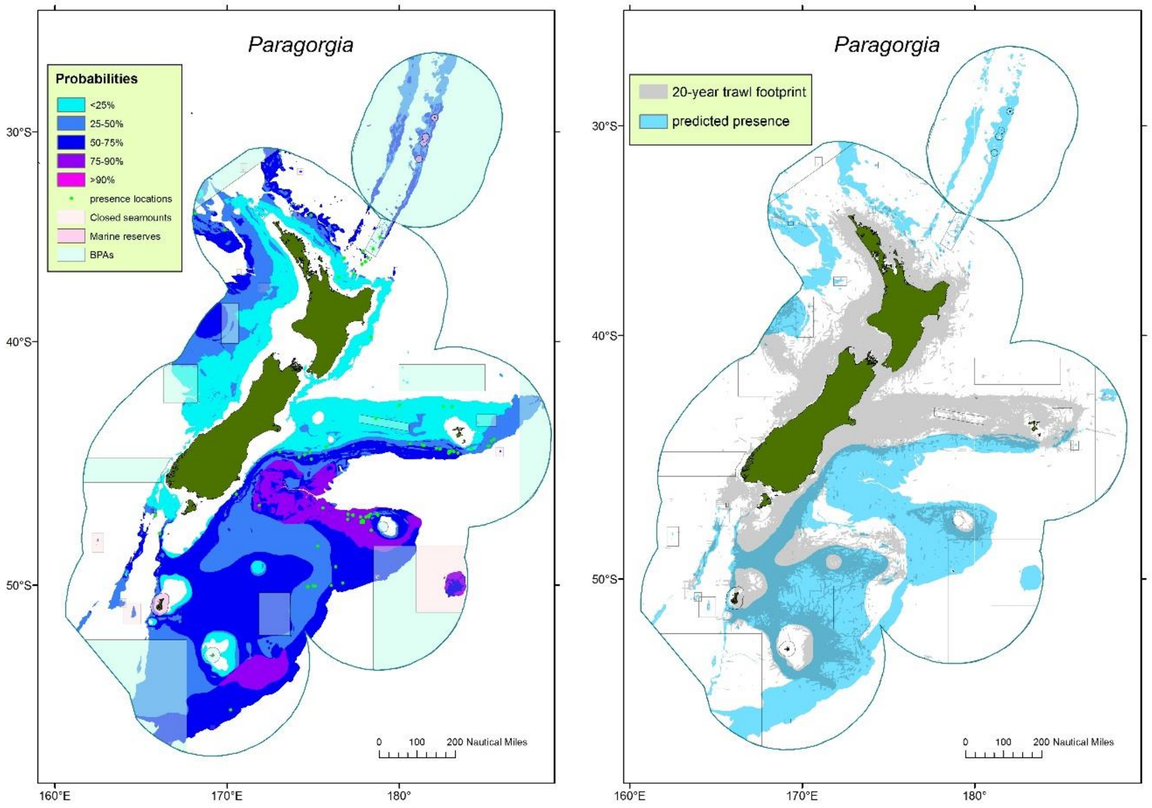


Figure 3-9: Probability of occurrence of suitable habitat for *Paragorgia* spp. (n = 98 presence records). All other details as for Figure 3-3.

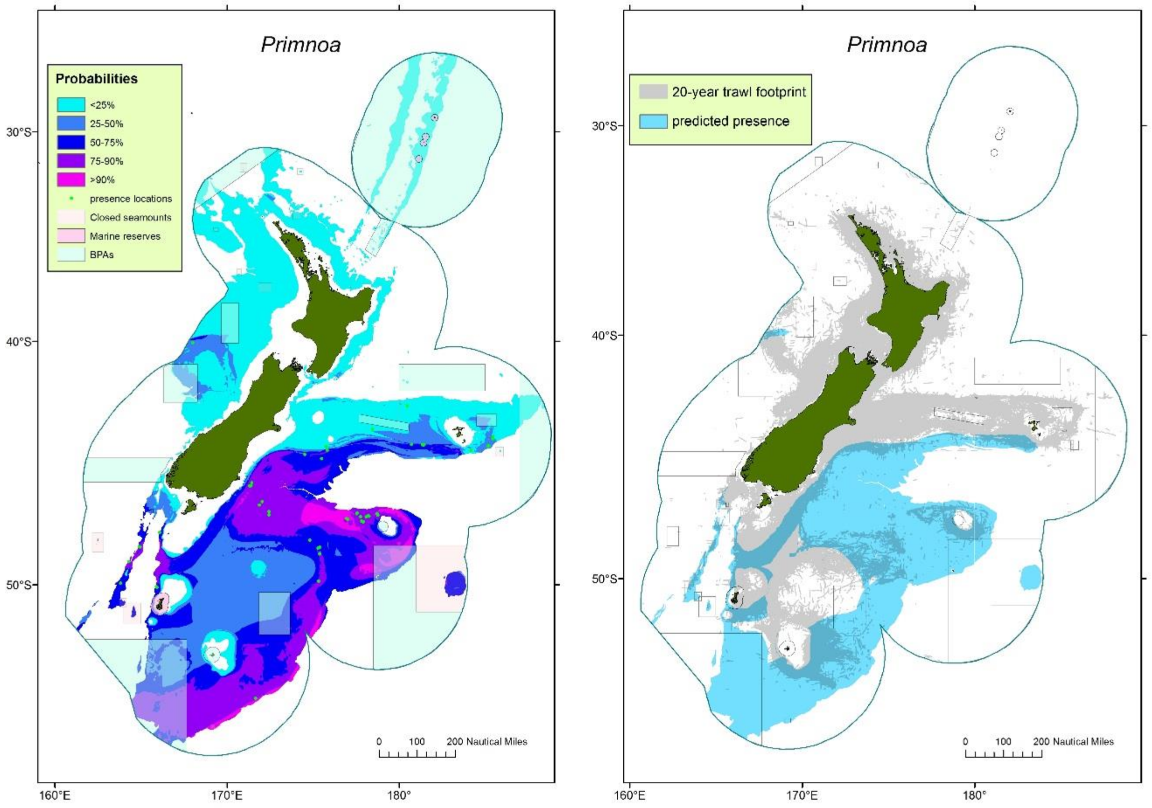


Figure 3-10: Probability of occurrence of suitable habitat for *Primnoa* spp. (n = 73 presence records). All other details as for Figure 3-3.

3.3.3 Antipatharia

As a combined group, the black corals showed low probabilities of suitable habitat occurrence (<25%) over much of the area; higher probabilities (50–75%) were restricted to parts of the northwest Chatham Rise, northern New Zealand from the West Norfolk Ridge to East Cape, and parts of the major northern ridge features (Figure 3-11). For the individual genera, *Leiopathes* spp. (Figure 3-13) and *Triadopathes* spp. (Figure 3-15) show predicted habitat distributions which are more restricted to northern areas, whereas predictions for *Parantipathes* spp. (Figure 3-14) and *Bathypathes* spp. (Figure 3-12) are similar to that of Antipatharia as a group.

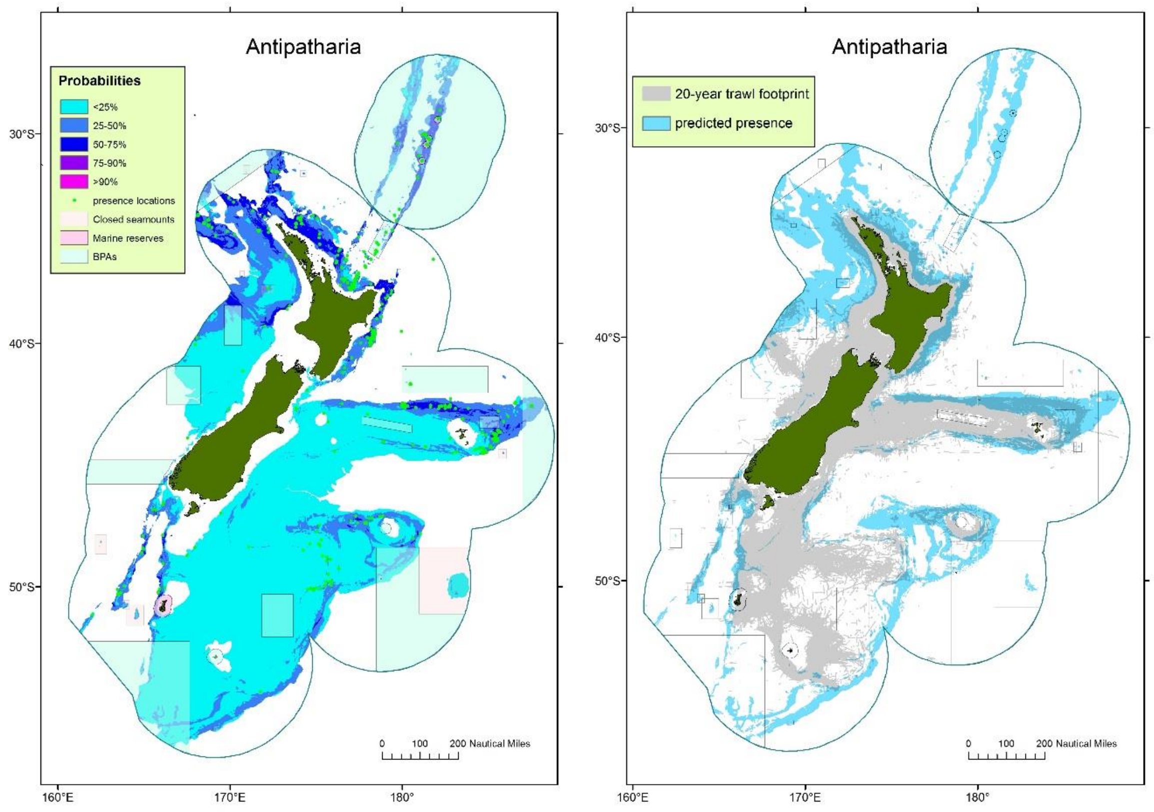


Figure 3-11: Probability of occurrence of suitable habitat for Antipatharia (n = 711 presence records). All other details as for Figure 3-3.

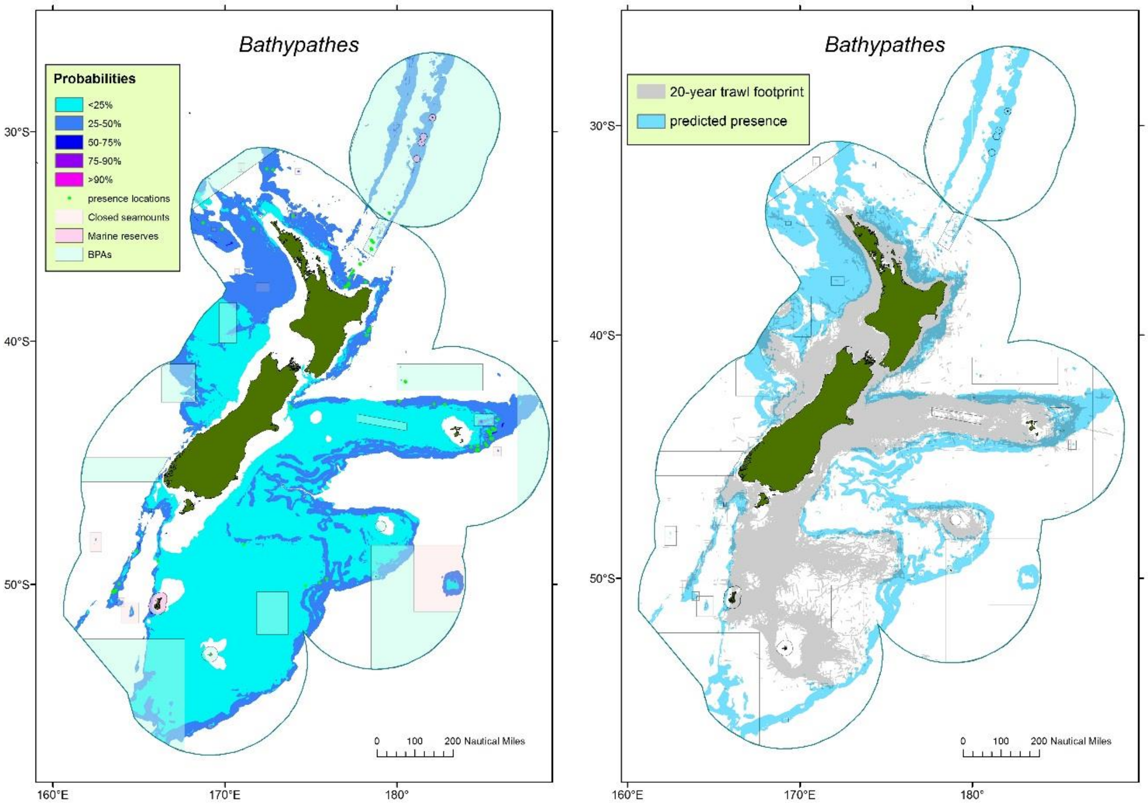


Figure 3-12: Probability of occurrence of suitable habitat for *Bathypathes* spp. (n = 75 presence records). All other details as for Figure 3-3.

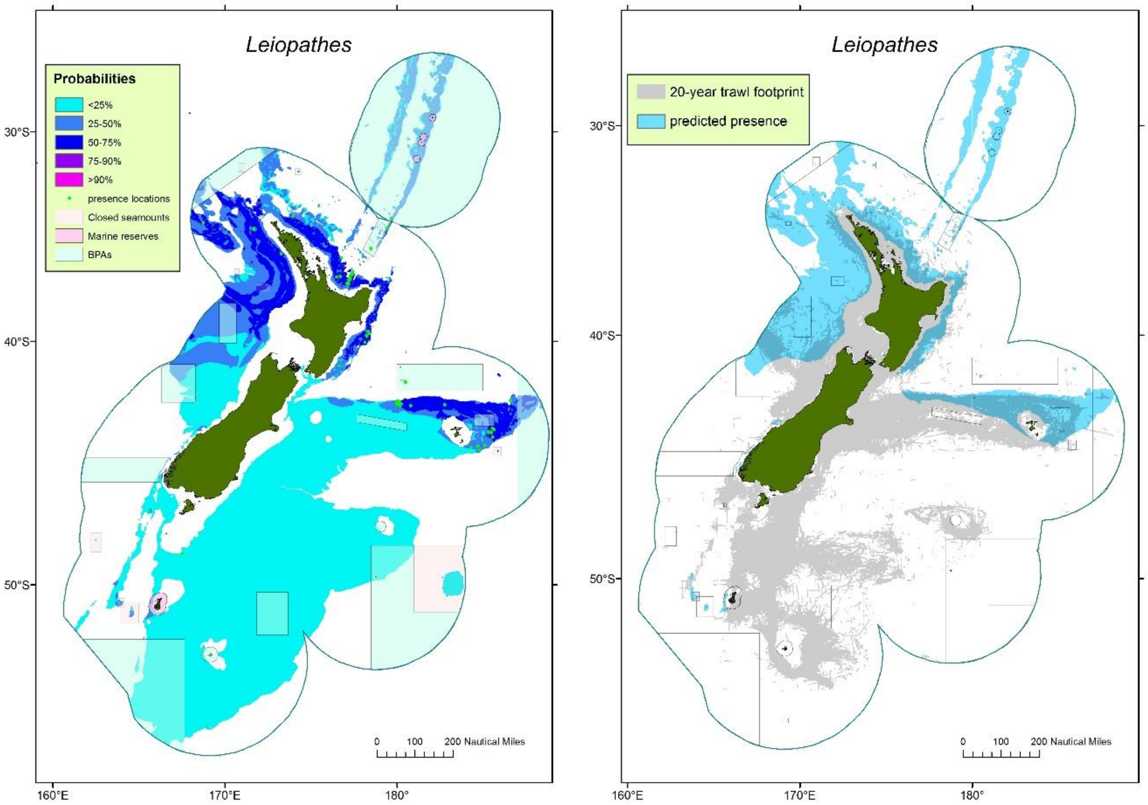


Figure 3-13: Probability of occurrence of suitable habitat for *Leiopathes* spp. (n = 67 presence records). All other details as for Figure 3-3.

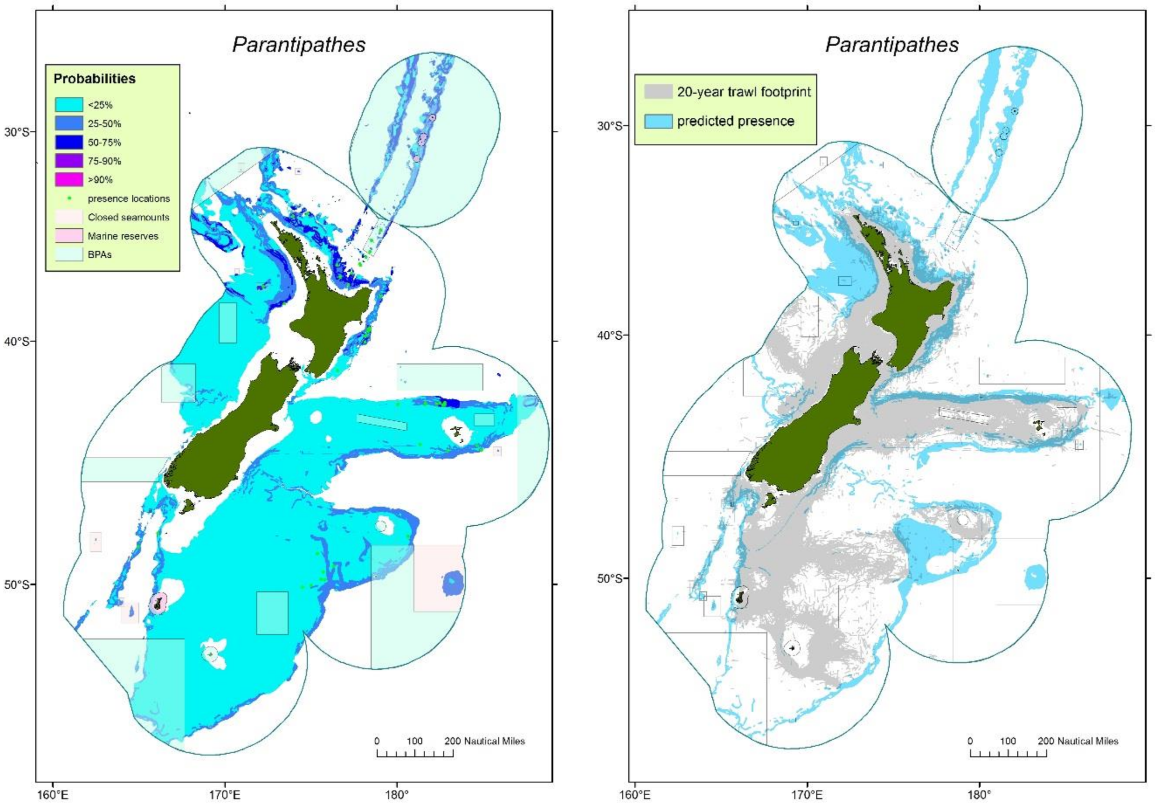


Figure 3-14: Probability of occurrence of suitable habitat for *Parantipathes* spp. (n = 56 presence records). All other details as for Figure 3-3.

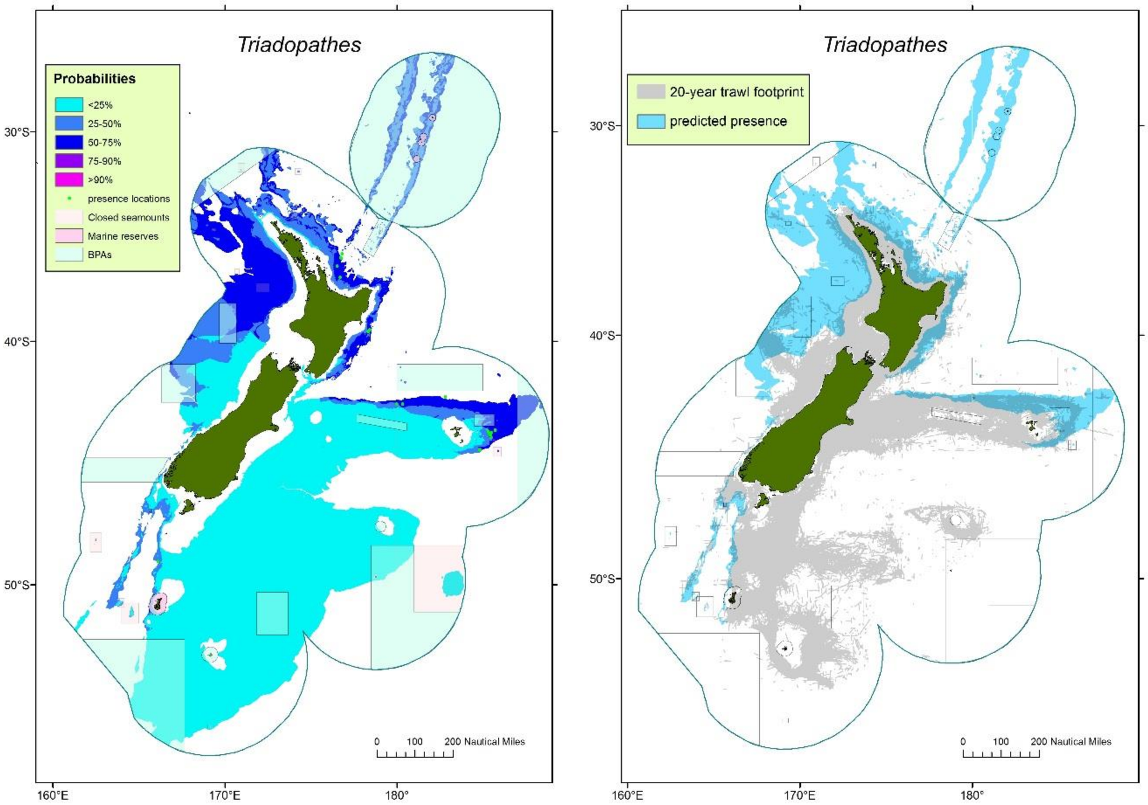


Figure 3-15: Probability of occurrence of suitable habitat for *Triadopathes* spp. (n = 27 presence records). All other details as for Figure 3-3.

3.4 Overlap of likely presence with fishing trawl footprint

There is no consensus as to which is the best of many possible threshold criteria to use for producing binary habitat maps such as shown here to assess the overlap with trawl fishery footprints, although the commonly-used threshold based on a simple model output probability of 0.5 is considered one of the worst due to the general inadequacy of the background or pseudo-absence data used in modelling (Cramer 2003, Jimenez-Valverde & Lobo (2007). The taxon-specific mean-probability method used here was chosen for its simplicity of calculation and interpretation, and because it performed adequately in tests by Liu et al. (2005).

Substantial overlaps with the 20-year trawl footprint occur on the Chatham Rise for the four species of scleractinian combined and for *Goniocorella dumosa* and *Solenosmilia variabilis* separately (Figure 3-3, Figure 3-4, Figure 3-5). The other two scleractinian species are also overlapped here but their distributions are predicted to extend into deeper water on parts of the Rise away from historical trawl fishing effort (Figure 3-6, Figure 3-7). Overlaps with the trawl footprint in other areas are strongest for *Solenosmilia variabilis*, especially in the southwest of the region and off the west coast of the North Island, but suitable habitat for all four species is predicted over large parts of the eastern sub-Antarctic, major ridges and other features in the north of the EEZ, and on parts of the Challenger Plateau.

Predicted areas of suitable habitat for each of the three alcyonacean taxa show similar overlap with the trawl footprint across the main features south of the Chatham Rise (Figure 3-8, Figure 3-9, Figure 3-10), with these species occurring over much of the footprint in depths greater than about 500 m. Around the Chatham Rise itself, however, *Paragorgia* spp. and *Primnoa* spp. show little overlap, whereas most of the predicted habitat for *Keratoisis* spp. and *Lepidisis* spp. lies within the footprint. Across the study area as a whole, large areas of each species' predicted habitat distribution lies outside of the footprint, especially around the sub-Antarctic Plateaux.

The main areas of overlap with the trawl footprint for Antipatharia (combined) and *Bathypathes* spp. habitats are around the flanks of the Chatham Rise and off the northern and eastern coasts of the North Island (Figure 3-11, Figure 3-12). Substantial areas of the modelled distributions of these groups occur outside of the footprint in the northwest of the EEZ and around the flanks of the sub-Antarctic Plateaux. Species of *Leiopathes* (Figure 3-13) and *Triadopathes* (Figure 3-15) are both well overlapped with the footprint within their limited distributions on the Chatham Rise but, along with *Parantipathes* spp. (Figure 3-14), show large areas of predicted habitat outside of the footprint in northern parts of the EEZ.

Based on the criteria explained in Section 2.8 the predicted habitat distributions of these protected coral taxa mostly showed a 'high' overlap with the trawl footprint on the Chatham Rise (Table 3-1). This is largely because the Chatham Rise is an important fishing ground for a wide range of commercial species, and the footprint shows a more or less blanket coverage of the fishable depths on the feature. Suitable habitats for taxa with a 'medium' overlap (*Enallopsammia rostrata*, *Primnoa* spp., *Bathypathes* spp.) or a 'low' overlap (*Paragorgia* spp.) were predicted to also exist in refuges in deeper water on the eastern, northern, or southern fringes of the Rise.

For the EEZ as a whole, only *Goniocorella dumosa* showed a 'high' overlap with the trawl footprint (Table 3-1), and this was mainly due to a large proportion of its distribution lying on the Chatham Rise, as well as on highly-fished regions of the sub-Antarctic and off the coasts of the North and South Islands. Overlap with the trawl footprint was 'low' for *Enallopsammia rostrata*, *Bathypathes* spp., and Antipatharia combined, for which large fractions of the predicted distributions were in deep water; and for *Primnoa* spp. for which suitable habitat was predicted over much of the sub-Antarctic Plateaux, but very little of the Chatham Rise.

Table 3-1: Overlap of the 20-year (1989–90 to 2008–09) trawl footprint area with predicted suitable habitat (based on mean probability thresholds) for cold-water corals in the New Zealand EEZ as a whole (All areas), and for the Chatham Rise separately. L, <25%; M, 25–50%; H, >50%

Taxon	Mean probability (%)	Overlap	
		All areas	Chatham Rise
Scleractinia	59	M	H
Goniocorella dumosa	20	H	H
Solenosmilia variabilis	34	M	H
Enallopsammia rostrata	33	L	M
Madrepora oculata	23	M	H
Keratoisis spp. & *Lepidisis* spp.	38	M	H
Paragorgia spp.	45	M	L
Primnoa spp.	43	L	M
Antipatharia	20	L	H
Bathypathes spp.	22	L	M
Leiopathes spp.	17	M	H
Parantipathes spp.	19	M	H
Triadopathes spp.	24	M	H

4 Discussion

While much development of habitat suitability models has taken place in terrestrial ecosystems (e.g., see Leathwick et al., 2010), deep-sea corals have been the central taxa in the development of these models in marine systems, both in New Zealand and worldwide (e.g., Davies & Guinotte 2011, Rengstorf et al. (2013, 2014), Tracey et al. 2011b). As a result, the habitat requirements for this group are becoming better understood. The differences in the availability of reliable environmental data layers for models at different spatial scales influences the dominant explanatory factors in the models. Where fine-scale bathymetry data are available to localised models, allowing the construction of highly localised benthic terrain variables such as slope, Benthic Position Index (BPI), and rugosity, these variables (which act as proxies for currents and food supply) are dominant; in more regional or global models for which such variables are not available, predictors such as temperature, alkalinity, and oxygen saturation become more important (Rengstorf et al. 2012). The models we have constructed, with variable resolution at 1 km^2, lack highly resolved terrain variables and their most important explanatory variables are more similar to those of the latter set, temperature in particular.

The models presented here provide an indication of the areas in the New Zealand EEZ where the combinations of variables being modelled are at their optimal values for each coral taxon or group of taxa. Within these areas, however, there will be localities where the state of other unmodelled parameters such as sediment and bottom roughness are such that the species cannot get a foothold, and the models will, therefore, tend to over-predict. Over-prediction of habitat ranges is also likely to occur when there is a mis-match between the scale of the sampling method (e.g., a narrow trawl or benthic sled) and the scale of the predictor variables (Rengstorf et al 2012, Guisan and Thuiller 2005). An example of a region in these models which may be suffering from this effect is the Challenger Plateau, an area known to be largely covered in soft sediment and free of hard substrate, and yet models for the reef-forming scleractinians, especially *Solenosmilia variabilis*, showed a relatively high probability of suitable habitat occurring in this area due to favourable values for the primary predictor variables (bottom temperature, dynamic topography, and surface water primary productivity), none of which provide any information on the physical characteristics of the seabed.

The environmental predictors with the most influence in the models were dynamic topography and bottom temperature. Dynamic topography was also the main predictor for most of the models in Baird et al. (2013) and is likely to be a proxy in some way for nutrient supply. Probabilities of suitable habitat occurrence were generally were strongly positively correlated with dynamic topography over the range of values experienced by the corals, in some cases showing a step-change at around 0.45–0.5 m (e.g. Figure A-1). Temperature has been shown in other studies to be a critical driver of cold water coral distribution (e.g., Friewald et al. 2004, Davies & Guinotte 2011, Rengstorf et al. 2013). In this study, probabilities were generally strongly negatively correlated with bottom temperature, with 'preferred' temperatures of generally below 7° C, a notable exception being *Goniocorella dumosa* which showed a preference for relatively warmer water (8–10° C) (Figure A-2). Aragonite and calcite seafloor saturation did not have as significant an influence on the models as might have been expected given the importance of these compounds in the construction of the endoskeletons of cold-water corals (Bostock et al., in review). Most of the coral presence records were associated with locations where aragonite and calcite are supersaturated at the seafloor and it may be that saturation above this level produces only a limited improvement in the corals' ability to incorporate calcium carbonate into their skeletons. Although suitable coral habitat was positively correlated with seamounts in all models, the association was not strong. The seamount variable may be partly a proxy for substrate, as the greater current flow around these features limits the deposition of particulate matter and therefore provides suitable hard substrate for attachment of newly settled coral polyps, but the increased current flow around seamounts is likely to also provide an increased food supply to the filter-feeding community.

Earlier BRT modelling on the same four reef-forming scleractinian species examined here (Tracey et al. 2011b) identified depth and position relative to a seamount as consistently important factors determining their distribution. Overall there is general agreement between these earlier models and the distributional maps produced here for these species but some differences can be seen for individual species. The areas of highest probability for *Madrepora oculata* are around the fringes of most of the Chatham Rise, the sub-Antarctic plateaux, and northern ridge features in both studies but the earlier study predicts a wider area of relatively suitable habitat on the Challenger Plateau. For *Solenosmilia variabilis*, both studies predict highly suitable habitat in areas of the southern and eastern sub-Antarctic Plateaux, the Macquarie Ridge and around the northern North Island and associated ridges, but the current study incorporates new presence records around the northeast Chatham Rise and thus predicts suitable habitat around the northeast Chatham Rise whereas the earlier study does not. The two studies give very similar results for *Goniocorella dumosa*, the distribution of this species being well defined by the numerous presence records on the Chatham Rise and a scattered distribution of records around much of the rest of the study area. Both studies predict the most suitable habitat to be on the top of the Chatham Rise, the Bollons Seamount, and Puysegur Bank. The habitat suitability maps for *Enallopsammia rostrata* both show high probabilities around the Bounty Plateau, Macquarie Ridge, sub-Antarctic slope, and northern Ridge and Rise features but the current study, with new records for the species from the northeast Chatham Rise, shows relatively higher probabilities in this area. Patterns of habitat suitability also differ around the Challenger Plateau and Bounty Trough, where the earlier study predicted some narrow bands of higher suitability.

The BRT analysis of Baird et al. (2013) predicted likely distribution of corals for the same area as modelled in this study, using a similar set of environmental variables but with the notable exclusion of aragonite and calcite saturation, and the use of depth and bottom temperature residuals in place of unadjusted temperature in this model. The areas where the environmental conditions were most suited to the coral groups in that study were generally in deeper waters where the seafloor had steep slopes. Most of the known coral distributions were within the areas predicted by the models to have suitable environment; however, some deep-water and steep relief areas where corals were known to exist were not identified by the predicted distribution.

Comparison of the models produced here with those of Baird et al (2013) for the same set of protected corals are generally not possible because of the grouping of taxa in that study into "functional" groups: "tree-like" e.g., bubblegum corals; "reef-like", e.g. the stony branching corals; "solitary small" e.g., the scleractinian cup corals; and "whip-like", e.g., bamboo coral *Lepidisis* spp. and black coral *Stichopathes* spp.). One of the primary recommendations of Baird et al. (2013), and a core purpose of this continuation of their research, was to create models at a finer taxonomic level because of the conflicting effects of the differing environmental tolerances of individual species within these functional groups. However, a model for the four reef-forming scleractinian species combined is common to both studies, and habitat suitability maps for these models were similar except for relatively lower predictions on the eastern Chatham Rise in the earlier study. The notably lower ROC score for the Scleractinia model in this study (0.68) compared with those for individual genera or species (0.88–0.99) supports the decision to develop models at the finest taxonomic level possible. It is notable, too, that the ROC scores for the functional groups in Baird et al. (2013) were all low (0.70–0.86) compared with those at finer taxonomic level in this study.

5 Acknowledgements

We thank Suze Baird (NIWA) for assistance with provision of environmental and fisheries layer data and BRT modelling, and David Bowden (NIWA) for his thorough review and useful suggestions to improve the manuscript. We acknowledge the support of Kris Ramm and William Arlidge, Marine Species and Threats, Department of Conservation — Te Papa Atawhai.

6 References

Anderson, O.F.; Dunn, M.R. (2012). Descriptive analysis of catch and effort data from New Zealand orange roughy fisheries in ORH 1, 2A, 2B, 3A, 3B, 7A, and 7B to the end of the 2008–09 fishing year. New Zealand Fisheries Assessment Report 2012/20. 82 p.

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/

Behrenfeld, M.J.; Falkowski, P.G. (1997). Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnol. Oceanogr. 42*: 1–20.

Bostock, H.C., Mikaloff-Fletcher, S.E., Williams, M.J.M., 2013. Estimating carbonate parameters from hydrographic data for theintermediate and deep waters of the Southern Hemisphere oceans. Biogeosciences, doi:10.5194/bg-10-6199-2013.

Bostock, H.; Tracey, D.M.; Currie, K.L.; Dunbar, G.B.; Handler, M.R; Mikaloff-Fletcher, S.E.; Smith, A.M.; Williams, M.J. (in review). The carbonate mineralogy and distribution of habitat forming deep-sea corals in the New Zealand region. (Submitted to *Deep-Sea Research Part I*)

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.; Williams, A.; Rowden, A.A.; Hobday, A.J.; Consalvey, M. (2011). Development of seamount risk assessment: application of the ERAEF approach to Chatham Rise seamount features. New Zealand Aquatic Environment and Biodiversity Report No. 74. 18 p.

Clark, M.R.; Stokes, K.; Baird, S-J. (submitted). Development of a methodology for Ecological Risk Assessments for New Zealand deepwater fisheries. Draft Aquatic Environment & Biodiversity Report.

Clark, M.; Tracey, D.; Anderson, O.; Parker, S. (2014). Pilot ecological risk assessment for protected corals. *Prepared for Marine Species and Threats, Department of Conservation.* NIWA Client Report No: WLG2014-70. NIWA Project: DOC14302. 32 p.

Compton, T.J.; Bowden, D.A.; Pitcher, R.C.; Hewitt, J.E.; Ellis, N. (2012). Biophysical patterns in benthic assemblage composition across contrasting continental margins off New Zealand. *Journal of Biogeography 40(1)*: 75-89.

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.

Cramer, J. S. 2003. Logit models: from economics and other fields. Cambridge Univ. Press, 184 p.

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

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 (2011). ArcGIS Desktop: Release 10. 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.

Freiwald, A.; Fosså, J.H.; Grehan, A.; Koslow, T.; Roberts, J.M. (2004). Cold-water coral reefs. UNEP-WCMC, Cambridge, UK.

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

Grange, K.R. (1985). Distribution, standing crop, population structure, and growth rates of black coral in the southern fiords of New Zealand. *New Zealand Journal of Marine and Freshwater Research 19*:467–475.

Grange, K.R.; Singleton, R.J.; Richardson, J.R.; Hill, P.J.; Main, W. de L. (1981). Shallow rock wall biological associations of some southern fiords of New Zealand. *New Zealand Journal of Zoology 8*:209–227.

Guinotte, J.M.; Orr, J.; Cairns, S.; Freiwald, A.; Morgan, L.; George, R. (2006). Will human-induced changes in seawater chemistry alter the distribution of scleractinian bioherms? Frontiers in Ecology and the Environment 4: 141–146

Guisan, A.; Thuiller, W. (2005). Predicting species distribution: offering more than simple habitat models. *Ecology Letters 8(9)*: 993–1009.

Guisan, A.; Edwards, T.C. Jr.; Hastie, T. (2002). Generalized linear and generalized additive models in studies of species distributions: setting the scene**.** *Ecological Modelling 157*: 89–100.

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.

Hadfield, M.G.; Rickard, G.J.; Uddstrom, M.J. (2007). A hydrodynamic model for Chatham Rise, New Zealand. *New Zealand Journal of Marine and Freshwater Research 41*:239–264.

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.

Hobday, A.J.; Smith, A.; Webb, H.; Daley, R.; Wayte, S.; Bulman, C.; Dowdney, J.; Williams, A.; Sporcic, M.; Dambacher, J.; Fuller, M.; Walker, T. (2007). Ecological Risk Assessment for the Effects of Fishing: Methodology. Report R04/1072 for the Australian Fisheries Management Authority, Canberra. Available at http://www.afma.gov.au/environment/eco_based/eras/docs methodology.pdf

Hobday, A.J.; Smith, A.D.M.; Stobutzki, I.C.; Bulman, C.; Daley, R.; Dambacher, J.M.; Deng, R.A.; Dowdney, J.; Fuller, M.; Furlani, D.; Griffiths, S.P.; Johnson, D.; Kenyon, R.; Knuckey, I.A.; Ling, S.D.; Pitcher, R.; Sainsbury, K.J.; Sporcic, M.; Smith, T.; Turnbull, C.; Walker, T.I.; Wayte, S.E.; Webb, H.; Williams, A.; Wise, B.S.; Zhou, S. (2011). Ecological risk assessment for the effects of fishing. Fish and Fisheries 108: 372-384.

Huehnerbach, V.; Blondel, P.; Huvenne, V.; Freiwald, A. (2007). Habitat mapping on a deep-water coral reef off Norway, with a comparison of visual and computer-assisted sonar imagery interpretation. *In:* Todd, B.; Greene, G. (Eds.), Mapping the Seafloor for Habitat Characterization*. Geological Association of Canada Special Paper 47:* 297–308

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.

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

Jimenez-Valverde, A.; Lobo, J.M. (2007). Threshold criteria for conversion of probability of species presence to either–or presence–absence. *Acta Oecologica* 31: 361–369.

Leathwick, J.R.; Elith, J.; Francis, M.P.; Hastie, T.; Taylor, P. (2006). 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.

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.

Leathwick, J.R.; Moilanen, A.; Ferrier, S.; Julian, K. (2010). Complementarity-based conservation prioritization using a community classification, and its application to riverine ecosystems. Biological Conservation 143: 984–991.

Liu, C.; Berry, P.M.; Dawson, T.P.; Pearson, R.G. (2005). Selecting thresholds of occurrence in the prediction of species distributions. *Ecography 28*, 385–393.

Lutz, M.J.; Caldeira, K.; Dunbar, R.B.; Behrenfeld, M.J. (2007). Seasonal rhythms of net primary production and particulate organic carbon flux to depth describe the efficiency of biological pump in the global ocean. *J. Geophys Res Oceans 112*:C10011 doi: 10.1029/2006JC003706.

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.

Orr, J.; Fabry, V.J.; Aumont, O.; Bopp, L.; Doney, S.C.; Feely, R.A.; Gnanadesikan, A.; Gruber, N.; Ishida, A.; Fortunat, J.; Key, R.M.; Lindsay, K.; Maier-Reimer, E.; Matear, R.; Monfray, P.; Mouchet, A.; Najjar, R.G.; Plattner, G.-K.; Rodgers, K.B.; Sabine, C.L.; Sarmiento, J.L.; Schlitzer, R.; Slater, R.D.; Totterdell, I.J.; Weirig, M.-F.; Yamanaka, Y.; Yool, A. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature 437*: 681–686. doi:10.1038/nature04095.

Pinkerton, M.H.; Moore G.F.; Lavender, S.J.; Gall, M.P.; Oubelkheir, K.; Richardson, K.M.; Boyd, P.W.; Aiken, J. (2006). A method for estimating inherent optical properties of New Zealand continental shelf waters from satellite ocean colour measurements. *N.Z. Journal of Marine and Freshwater Research 40*: 227–247.

R Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Ramm, K. (2012a). Conservation Services Programme Observer Report: 1 July 2009 to 30 June 2010 Final Report. Conservation Services Programme, Department of Conservation. 130 p.

Ramm, K. (2012b). Conservation Services Programme Observer Report: 1 July 2010 to 30 June 2011. FINAL REPORT. Conservation Services Programme, Department of Conservation, November 2012.

Rengstorf, A.; Grehan, A.; Yesson, C.; Brown, C. (2012). Towards high resolution habitat suitability modelling of vulnerable marine ecosystems in the deep-sea: Resolving terrain attribute dependencies. *Mar. Geod. 35(4)*: 343–361.

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.

Rengstorf, A.N.; Mohn, C.; Brown, C.; Wisz, M.S.; Grehan, A.J. (2014). Predicting the distribution of deep-sea vulnerable marine ecosystems using high-resolution data: Considerations and novel approaches. *Deep-Sea Research I 93*: 72–82.

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.

Richard, Y.; Abraham, E.R.; Filippi, D. (2011). Assessment of the risk to seabird populations from New Zealand commercial fisheries. Final Research Report for Ministry of Fisheries projects IPA2009/19 and IPA2009/20. (Unpublished report held by the Ministry of Fisheries, Wellington). 66 p.

Richard, Y.; Abraham, E.R. (2013). Application of Potential Biological Removal methods to seabird populations. New Zealand Aquatic Environment and Biodiversity Report No. 108. 30 p

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.

Roleda, M.Y.; Boyd, P.W.; Hurd, C.L. (2012). Before Ocean Acidification: Calcifier Chemistry Lessons. *Journal of Phycology. 47*, 4 p. DOI: 10.1111/j.1529-8817.2012.01195.x

Rowden, A.A.; Guinotte, J.M.; Baird, S.J.; Tracey, D. M.; Mackay, K.A.; Wadhwa, S. (in press). Predictive modelling of the distribution of vulnerable marine ecosystems in the South Pacific Ocean region. Draft New Zealand Aquatic Environment and Biodiversity Report.

Rowe, S. (2010). Level 1 risk assessment for incidental seabird mortality associated with New Zealand fisheries in the NZ EEZ. Unpublished report. Department of Conservation. 75 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.

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

Townsend, A.J.; de Lange, P.J.; Duffy, C.A.J.; Miskelly, C.M.; Molloy, J.; Norton, D.A. 2008: New Zealand Threat Classification System manual. Department of Conservation, Wellington. 35 p.

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.; Bostock, H.; Currie, K.; Mikaloff-Fletcher, S.; Williams, M.; Hadfield, M.; Neil, H.; Guy, C.; Cummings, V. (2013). The potential impact of ocean acidification on deep-sea corals and fisheries habitat in New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report* No. 117. 101 p. Manuscript 2695 ISBN 978-0-478-42099-9 (o) https://fs.fish.govt.nz/Page.aspx?pk=113&dk=23494

Tracey D.; Mackay, E.; Cairns, S.; Opresko, D.; Alderslade, P.; Sanchez, J.; Williams, G. (2014). Coral Identification Guide 2nd Version, Department of Conservation, Wellington. 16 p. http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/fishing/coral-id-guide-updated.pdf

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.

Uddstrom, M.J.; Oien, N.A. (1999). On the use of high resolution satellite data to describe the spatial and temporal variability of sea surface temperatures in the New Zealand region. *J Geophys Res 104*: 20729–20751

Walters, R.A.; Goring, D.G.; Bell, R.G. (2001). Ocean tides around New Zealand. *NZ J. Mar Freshw. Res. 35*: 567–579

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.

Yesson, C.; Taylor, M.L.; Tittensor, D.P.; Davies, A.J.; Guinotte, J.; Baco, A.; Black, J.; Hall-Spencer, J. M.; Rogers, A.D. (2012). Global habitat suitability of cold-water octocorals. Journal of Biogeography doi:10.1111/j.1365-2699.2011.02681.x.

Appendix A Partial dependence plots for BRT model variables

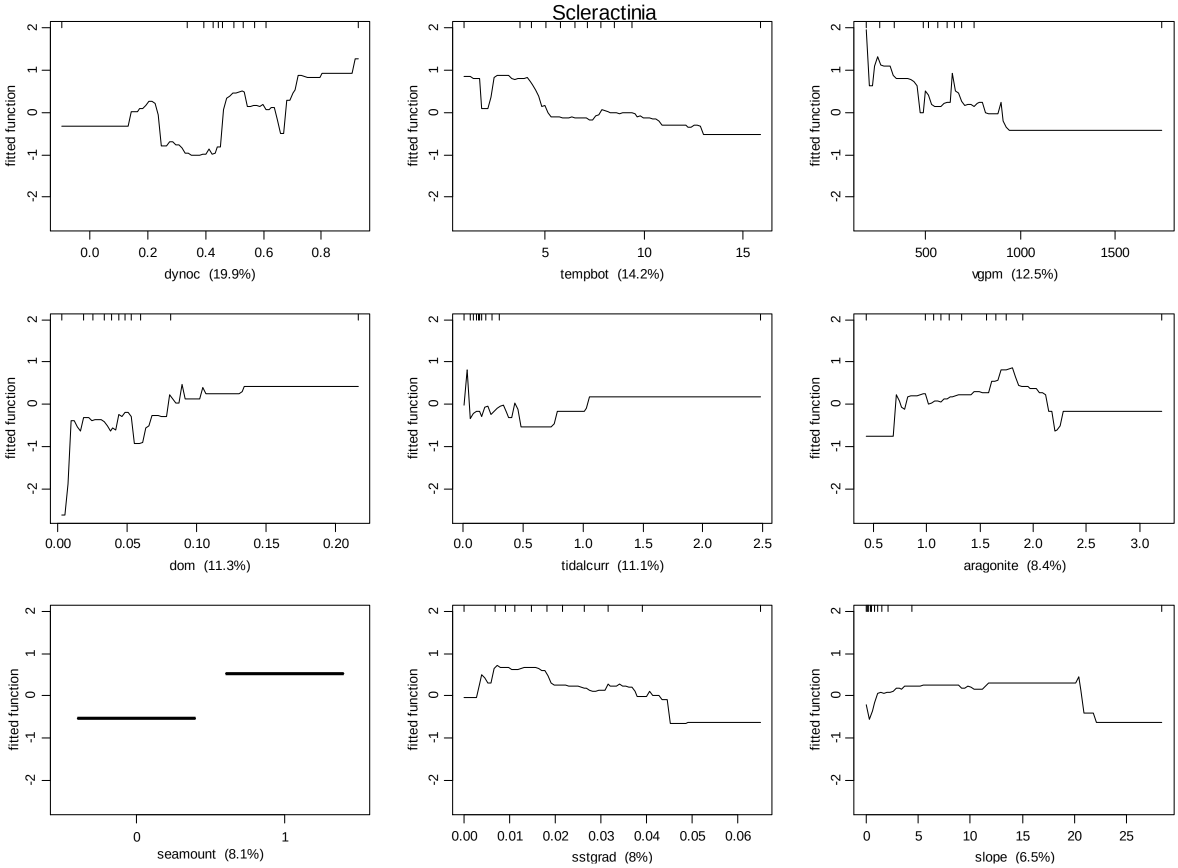


Figure A-1: Partial dependence plots showing the marginal effect of each variable in the BRT model for Scleractinia. See Table 2-2 for an explanation of the variables. The y-axis (fitted functions) are on the logit scale, centred to have zero mean over the data distribution. The distributions of all presence and absence sites across each variable are shown as a rugplots below the top axis, in deciles.

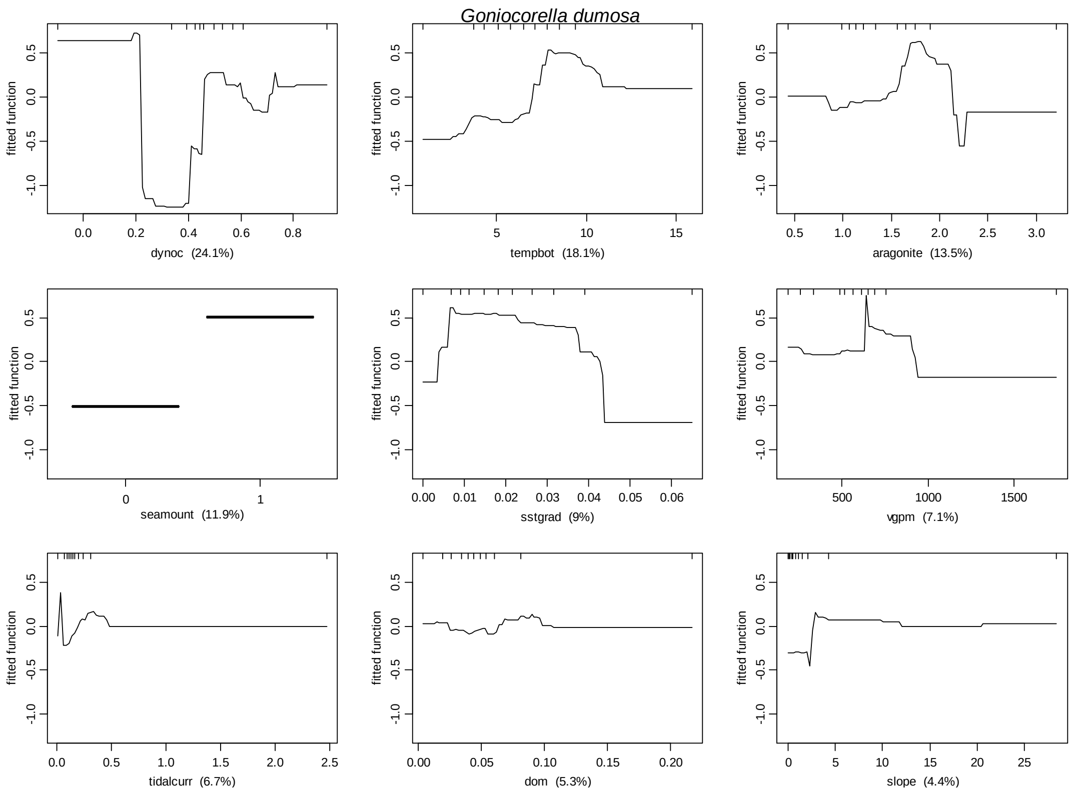


Figure A-2: Partial dependence plots for each variable in the BRT model for *Goniocorella dumosa*. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

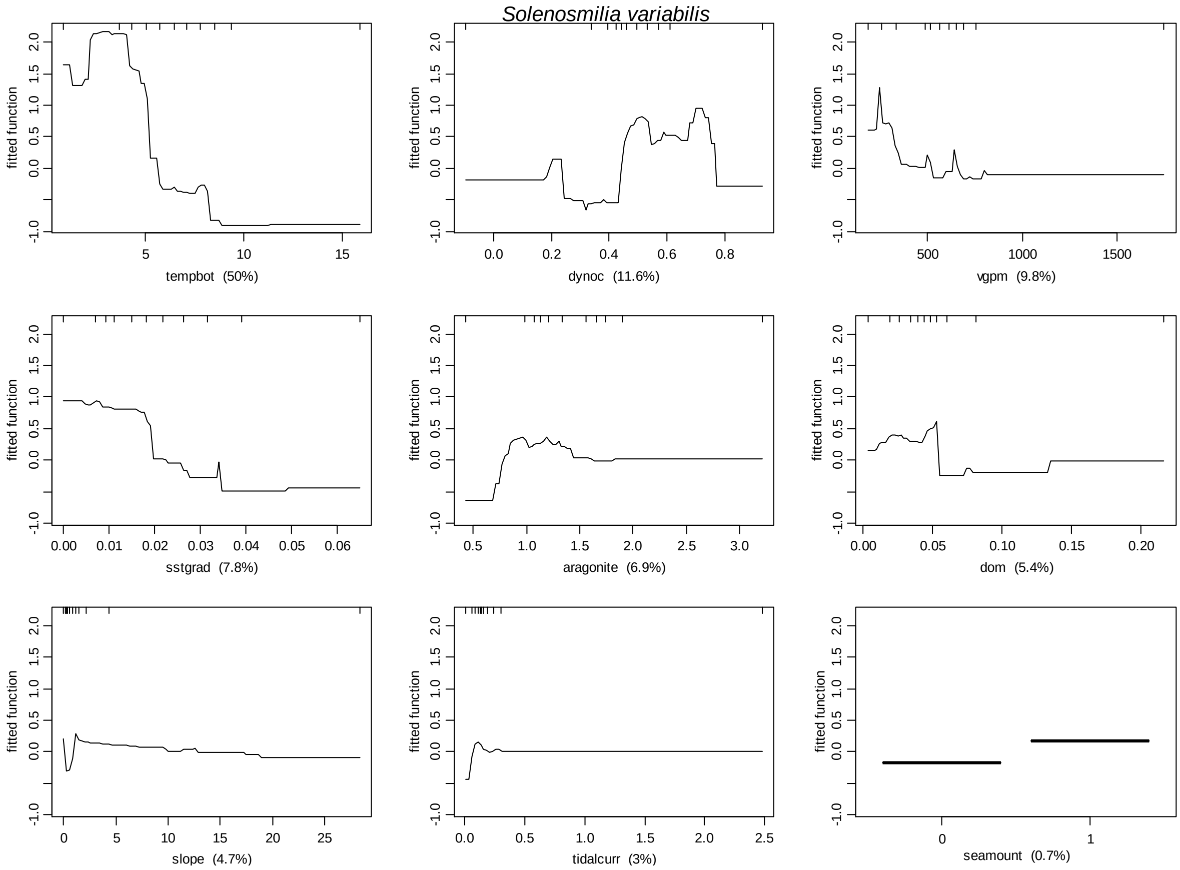


Figure A-3: Partial dependence plots for each variable in the BRT model for *Solenosmilia variabilis*. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

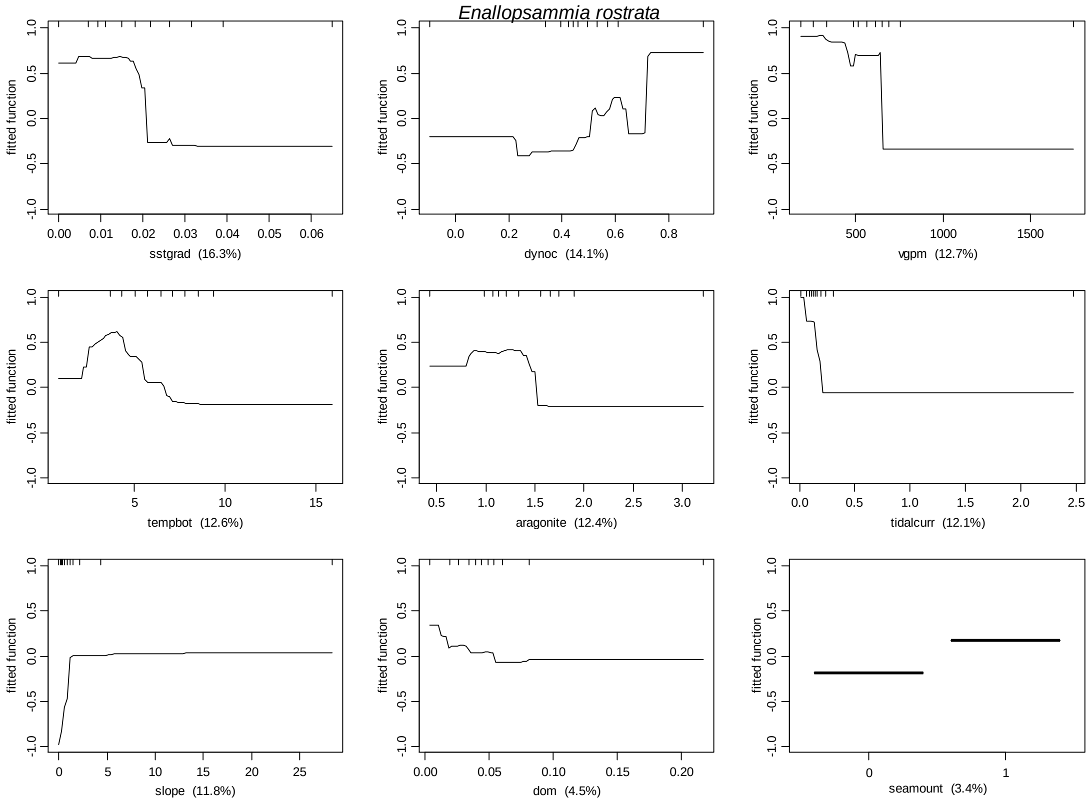


Figure A-4: Partial dependence plots for each variable in the BRT model for *Enallopsammia rostrata*. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

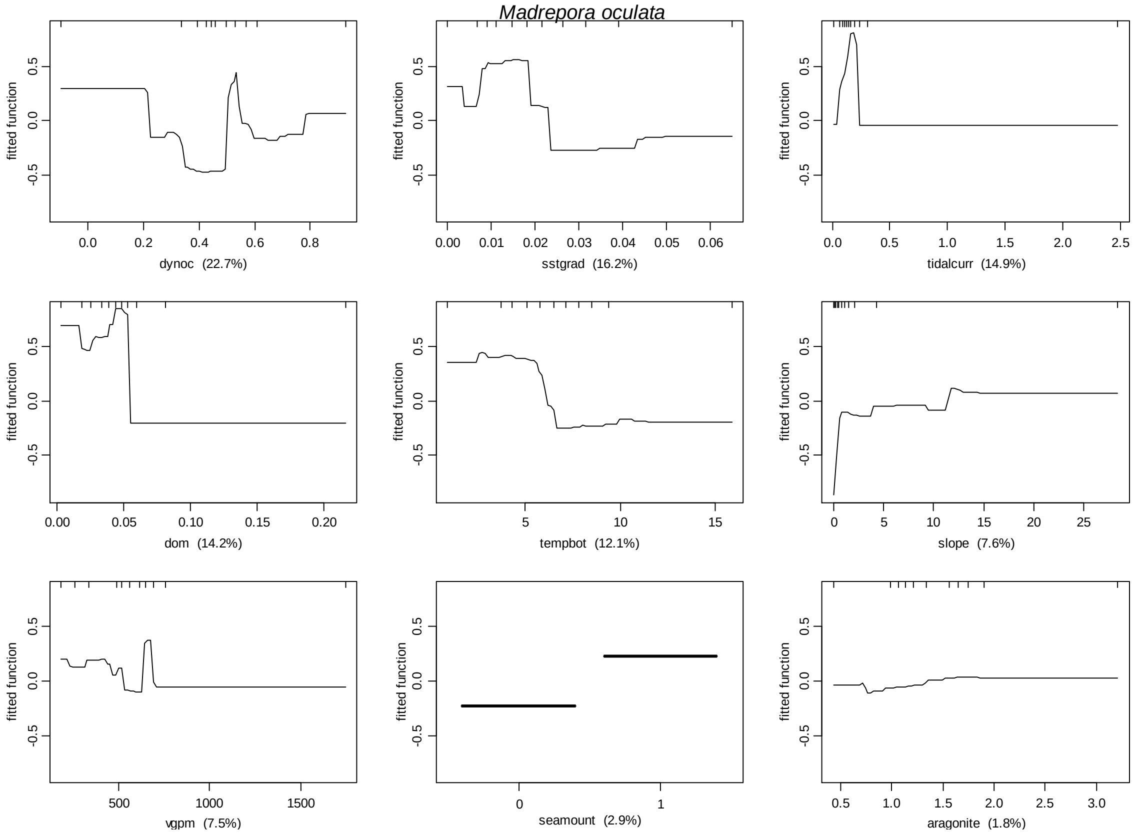


Figure A-5: Partial dependence plots for each variable in the BRT model for *Madrepora oculata*. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

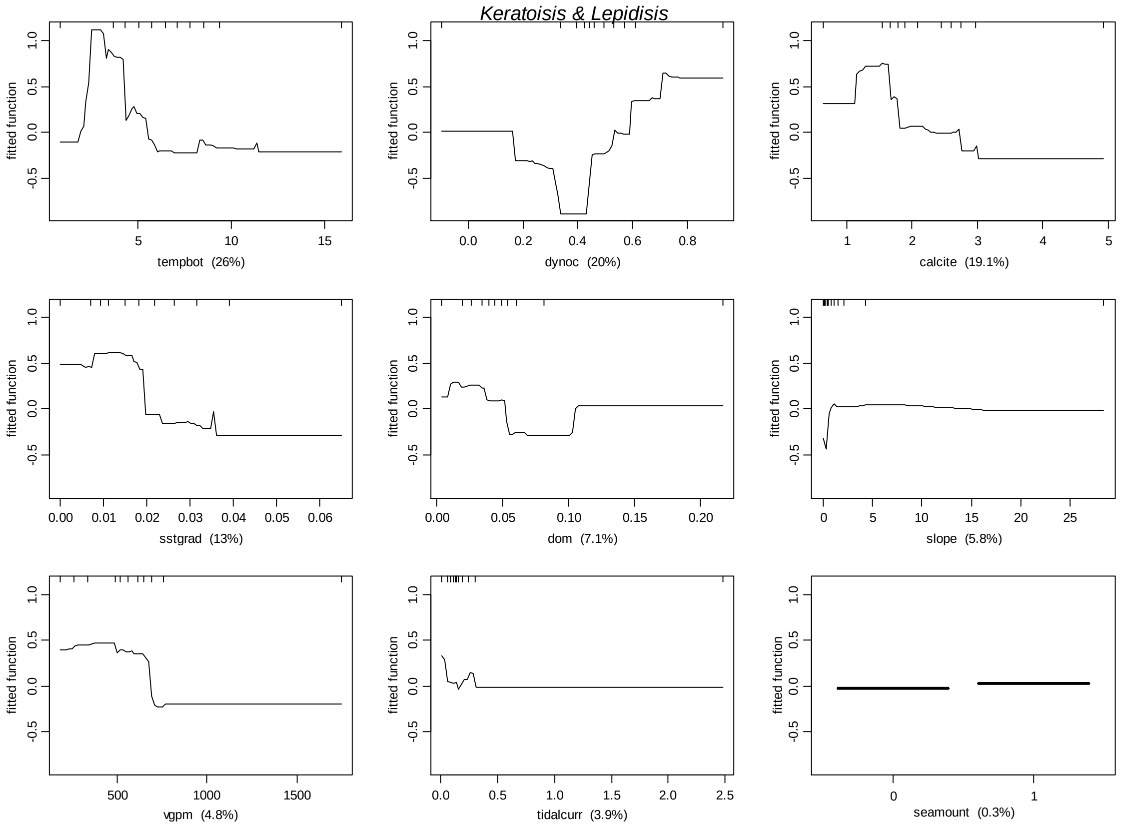


Figure A-6: Partial dependence plots for each variable in the BRT model for *Keratoisis* spp. & *Lepidisis* spp. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

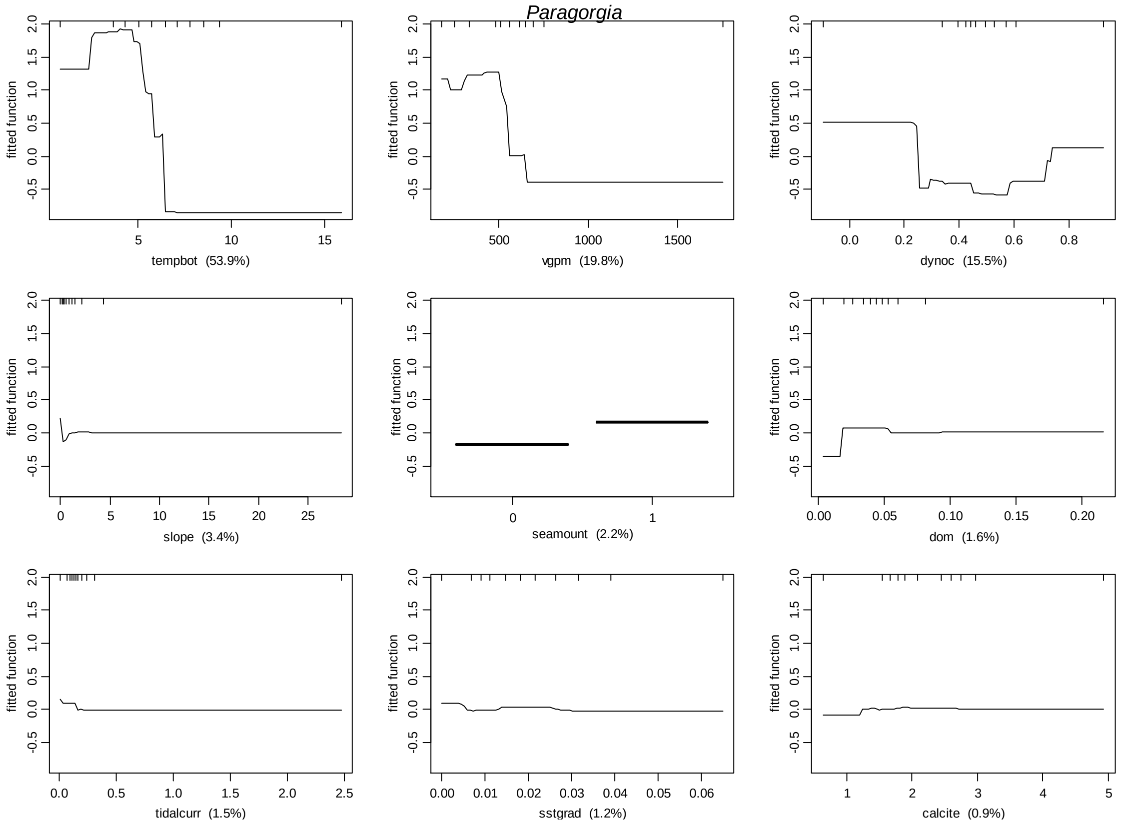


Figure A-7: Partial dependence plots for each variable in the BRT model for *Paragorgia* spp. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

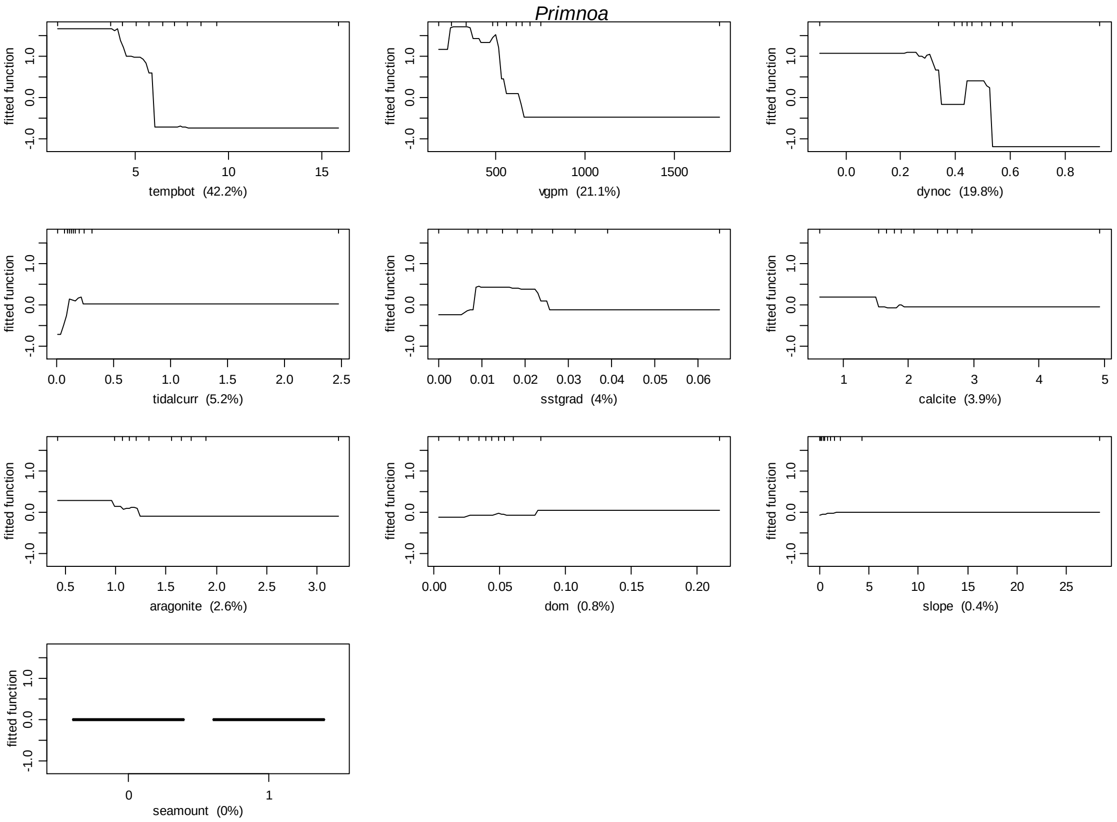


Figure A-8: Partial dependence plots for each variable in the BRT model for *Primnoa* spp. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

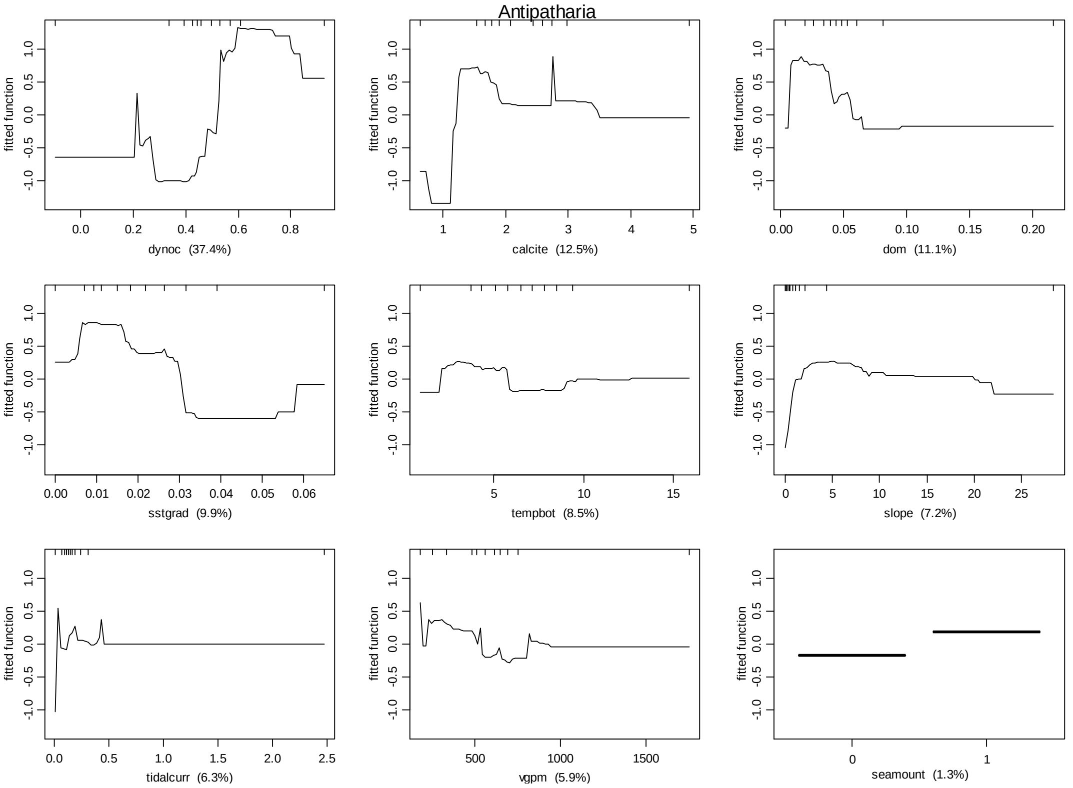


Figure A-9: Partial dependence plots for each variable in the BRT model for Antipatharia. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

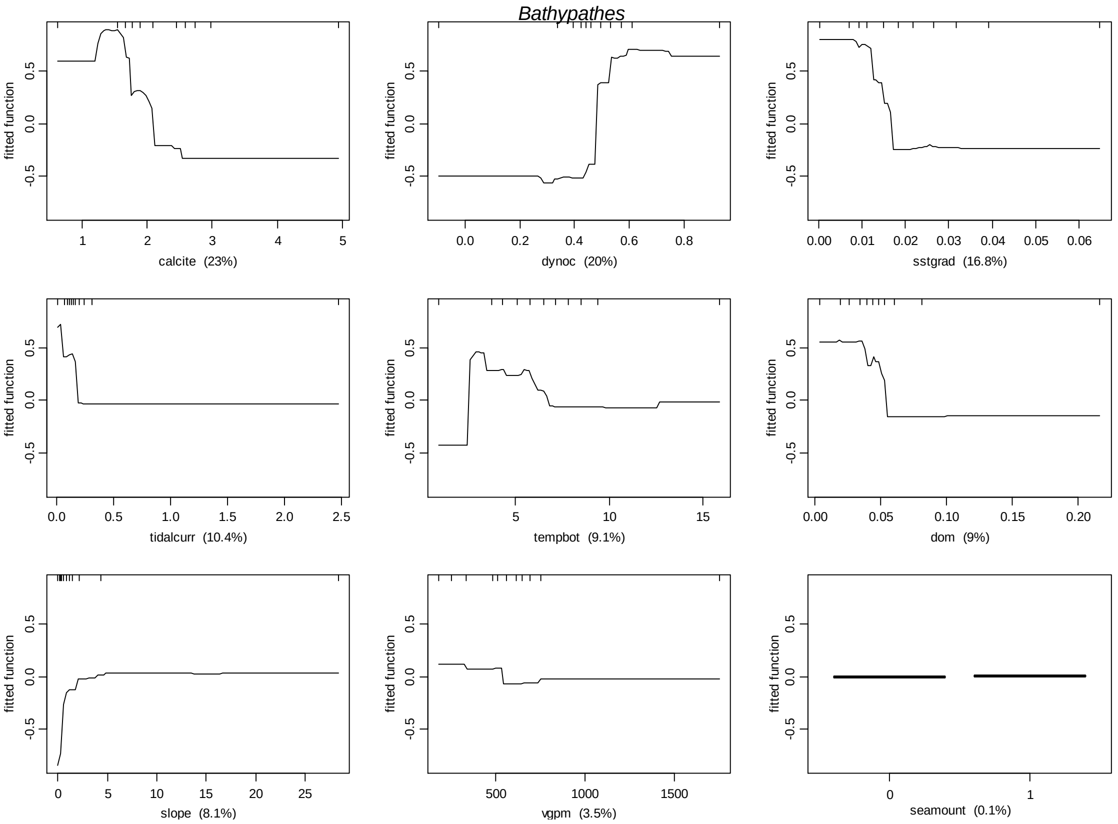


Figure A-10: Partial dependence plots for each variable in the BRT model for *Bathypathes* spp. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

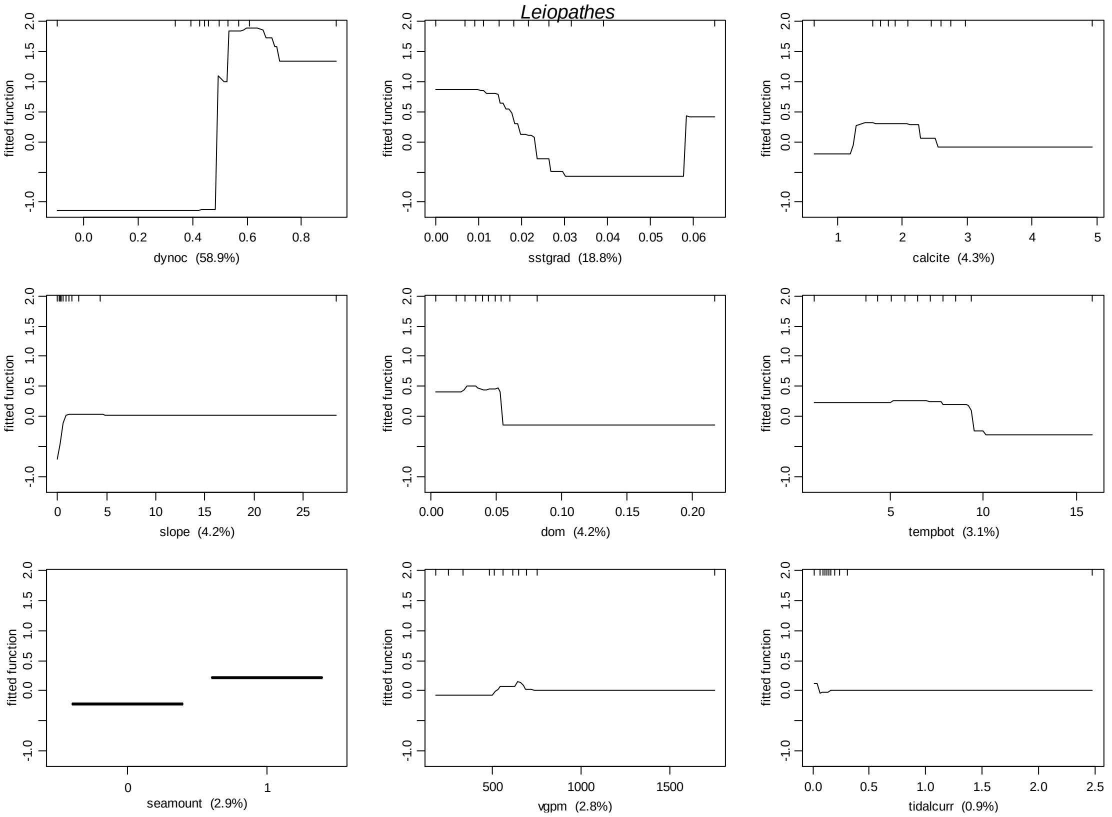


Figure A-11: Partial dependence plots for each variable in the BRT model for *Leiopathes* spp. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

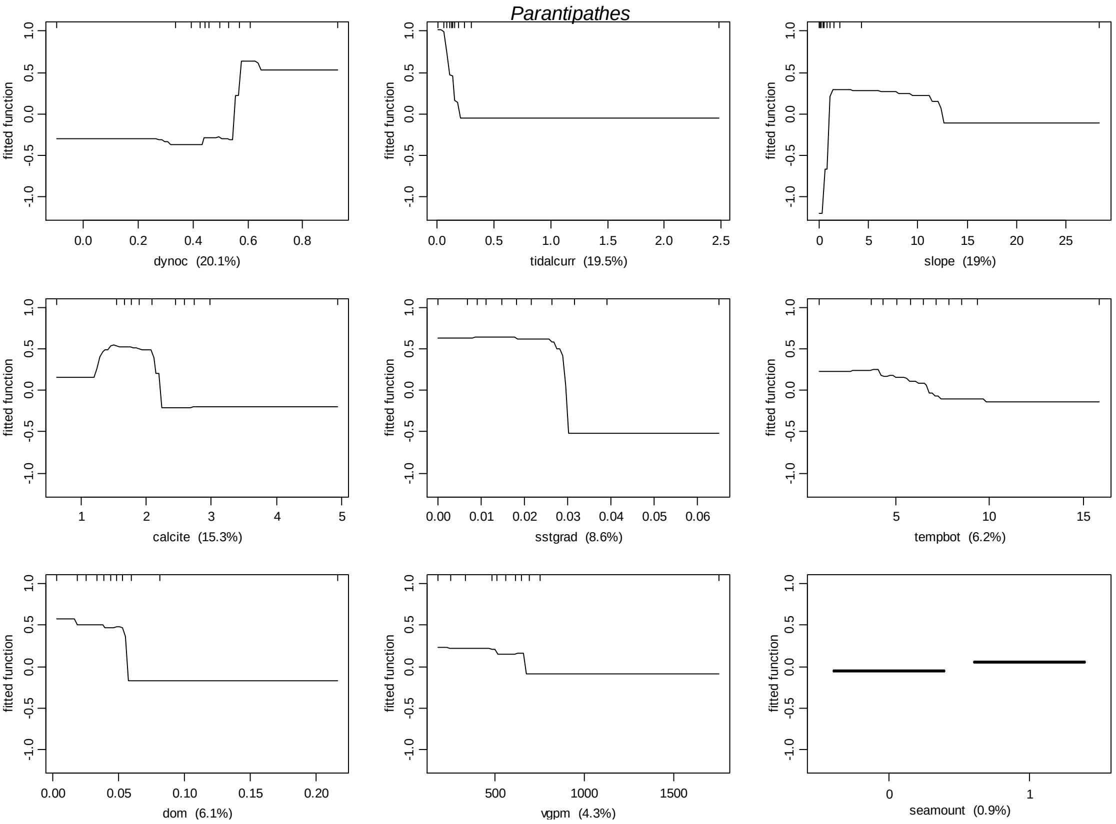


Figure A-12: Partial dependence plots for each variable in the BRT model for *Parantipathes* spp. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.

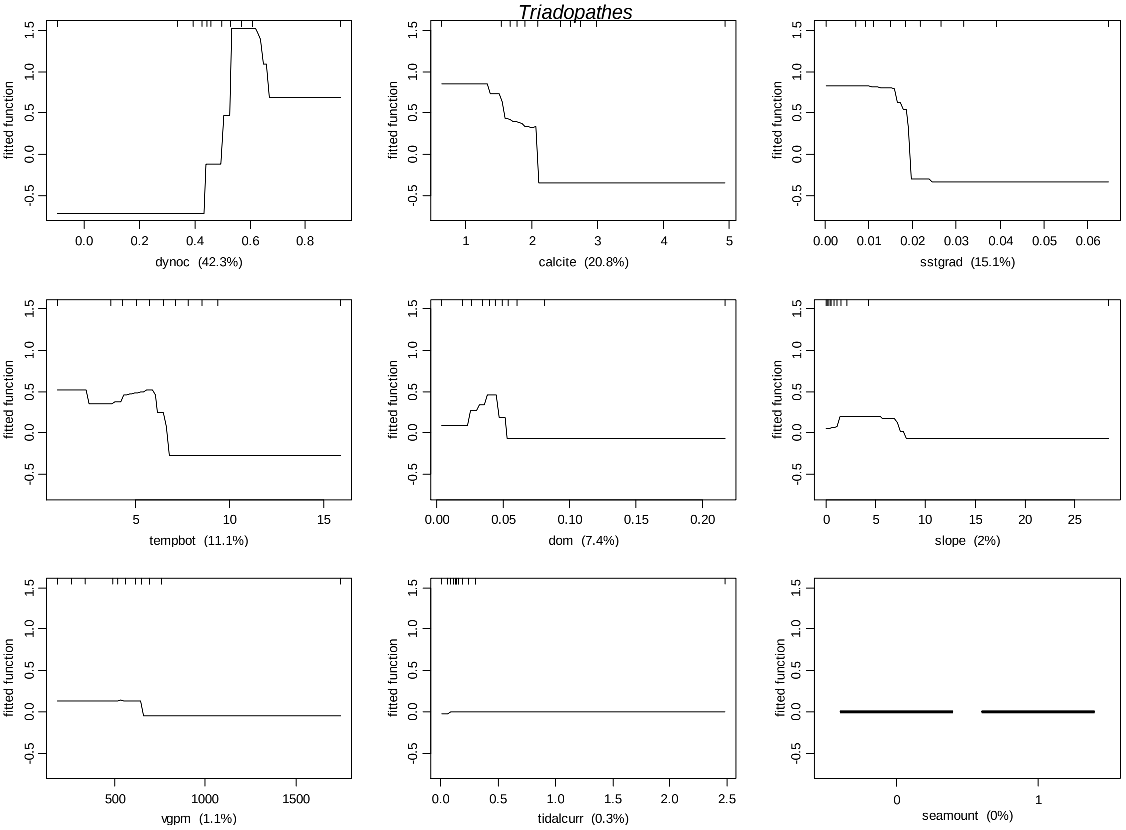


Figure A-13: Partial dependence plots for each variable in the BRT model for *Triadopathes* spp. See Table 2-2 for an explanation of the variables and Figure A-1 caption for more details.