NIWA
Taihoro Nukurangi

The distribution of protected corals in New Zealand waters

Prepared for DOC

February 2013

Authors/Contributors:
S.J. Baird, D. Tracey, S. Mormede, M. Clark

For any information regarding this report please contact:

S.J. Baird
Scientist
+64-4-386 0487
s.baird@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd

301 Evans Bay Parade, Greta Point

Wellington 6021

Private Bag 14901, Kilbirnie

Wellington 6241

New Zealand

Phone +64-4-386 0300

Fax +64-4-386 0574

NIWA Client Report No:	WLG2012-43
Report date:	February 2013 [Final]
NIWA Project:	DOC12303 / POP2011-06

Reef-forming stony branching coral *Madrepora oculata* colonised by a hydrocoral and various sponges. [*in situ* image taken in the New Zealand region using NIWA's Deep towed imaging system (DTIS)]

Contents

Tables

Figures

Reviewed by

Dr Mathew Dunn

Approved for release by

Dr Barbara Hayden

Executive summary

A wide variety of deepwater corals exist in New Zealand's Exclusive Economic Zone (EEZ). These corals are at risk from anthropogenic activities such as bottom trawling. This threat was recognised by the listing of all deepwater black corals, gorgonians, stony corals, and some hydrocorals, as protected species.

This report describes research to (1) expand recent work on identifying areas where deep sea corals are at highest risk of interactions with commercial fishing gear by using additional sources of information relevant to the distribution of corals, including mapping of likely coral distributions using predictive models, and (2) provide recommendations on any future research required to further improve the estimation of risk to protected corals from commercial fishing.

The sources of information considered were from research sampling (58%) and from commercial fishing effort where observers had been present (42%). The resulting dataset contained 7731 records, of which 46% were stony corals (56 genera from 15 families in Order Scleractinia), 33% were gorgonians (57 general from 8 families in Order Alcyonacea), 11% were hydrocorals (16 genera from one family in Order Anthoathecata), and 10% were black corals (26 families from 7 genera in Order Antipatharia). Coral records from the four orders were distributed throughout the Fishery Management Areas, though differences by area and depth were evident at the family and genus level, where lower taxonomic detail was available.

Corals were described and analysed in four functional groups. These groups recognised the structural differences that corals exhibit, and the potential biogenic habitat that different coral structures provide. The four groups were described as "tree-like", "reef-like", "solitary small", and "whip-like".

Boosted regression tree (BRT) analysis was used to predict the likely distribution of coral groups throughout the New Zealand 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 deepwater 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 between species were effectively lost.

Generally the areas predicted to have the greatest probability of conditions suitable for corals were outside the main fisheries areas, except for some deepwater fisheries that occurred on areas of steeper relief. The fisheries that pose the most risk to protected corals are the deepwater trawl fisheries for species such as orange roughy, oreo species, black cardinalfish, and alfonsino. In more shallow waters, scampi trawl fisheries appear to pose the greatest risk to corals in all protected orders. Bottom longline fisheries pose a risk to those corals that have a branching or bushy structure. Setnet fisheries may pose a risk in areas of hard substrate.

Recommendations for future research to inform the level of risk posed by fisheries to protected corals include: update and maintain the existing protected coral dataset; increase observer coverage to attempt to cover all fishery methods with seafloor contact, improve the quality of data collection and, in particular, coral identification; collect more biological information about local coral species to better understand their risk to anthropogenic disturbance; where biological information is lacking, review the international literature to identify relevant information; and investigate species associations and better quantify the value of corals as habitat.

1 Introduction

Deepwater corals in the New Zealand region are at risk from anthropogenic activities such as bottom trawling (Clark & O'Driscoll 2003, Clark & Rowden 2009, Williams et al. 2010), oil and gas exploration and extraction (Gass & Roberts 2006), the laying of cables and telecommunications links, and waste disposal (Kogan et al. 2003). Coldwater corals are also threatened by effects from ocean acidification which result in decreased calcification rates (for example, Caldeira & Wickett 2003, Guinotte et al. 2006, Turley et al. 2007).

For deepwater corals in New Zealand waters, the risk of damage or destruction by fishing activities was recognised in the 2010 amendment of Schedule 7A of the Wildlife Act 1953 when the list of protected corals was extended to include all deepwater hard corals in the orders Antipatharia (black corals), Gorgonacea (gorgonians), Scleractinia (stony corals), and Family Stylasteridae in Order Anthoathecata (hydrocorals). The Order Gorgonacea has recently been revised and all gorgonians are now in Order Alcyonacea (Watling et al. 2011). This change is reflected in this report.

Information on the distribution of corals within New Zealand waters comes from dedicated sampling during biodiversity surveys, opportunistic sampling from other research surveys including trawl surveys, and observed commercial fishing. The latter fishery-dependent information reported by government observers has improved in recent years since the introduction in October 2007 of added data collection directed at benthic bycatch, including corals.

Coral distribution data. A first step in characterising the extent of interactions is to describe the overlap in the distribution of fishing effort with that of corals. Tracey et al. (2011b) analysed the distribution of nine groups of protected corals based on bycatch records from observed trawl effort for 2007–08 to 2009–10. Coral catches were reported from a wide range of depths, with most from 800–1200 m in target fisheries for orange roughy (*Hoplostethus atlanticus*), black oreo (*Allocyttus niger*), smooth oreo (*Pseudocyttus maculatus*), and black cardinalfish (*Epigonus telescopus*). Estimated catches were highest from effort on underwater topographic features on the Chatham Rise, West Norfolk Ridge in northwestern waters of the EEZ, east of the Pukaki Rise, and on the Macquarie Ridge. Fewer reports of coral catch were reported from observed fisheries in waters shallower than 800 m, such as those for hoki (*Macruronus novaezelandiae*) and jack mackerels (*Trachurus* spp.).

Any characterisation of a species distribution is determined by the quantity and quality of the available data, including the extent of the sampling effort. Using observed commercial fishing activity as a data source to describe coral distribution has some recognised difficulties. Firstly, fishing gears are not good for sampling organisms such as corals which may be broken up and may not be retained in the gear (Parker et al. 2009); and the portion that is retained represents a colony of unknown size located somewhere along the trawl track. Secondly, there is likely an observer effect in the detection rate of corals in a landed catch. Thirdly, the extent of the depths and areas sampled is constrained by the target fishery being monitored by observers which results in uneven sampling distribution. Fourthly, the identification of the corals by observers is most useful at the higher taxonomic level of family or order, though this does depend on the type of coral (Tracey et al. 2011b). However, this is not such a major concern whilst corals are protected at the level of order (or family in one order).

A combined dataset of coral records from historic and recent scientific surveys with the observer records provides a larger dataset to describe the distribution of corals in areas within the EEZ, to determine the potential overlap between fisheries activities and protected corals. This distribution may also indicate areas where corals exist and are protected from fishing through various area restrictions in the EEZ, such as the seamount closures (19 seamounts were closed to trawling from 2001) and the Benthic Protected Areas (BPA, since 2007) (*see* http://www.mpi.govt.nz/fisheries/environmental).

The overlap of coral distribution with fishing effort can identify fishery areas where there is potential for removal of corals or modification of the biogenic structure provided by the types of corals protected in New Zealand waters. To identify areas beyond the known or current fishing effort, it is possible to describe the environmental preference of a coral (or group of corals) by a number of variables thought to be relevant to the coral and its location; and thus identify similar environments that have not been sampled, but in which deepwater corals may exist.

Species distribution models. In the absence of robust species distribution data, various species distribution models have been developed in recent years as tools to predict the distribution of species and species groups, generally as an aid to prioritise conservation needs (for example, Guisan et al. 2002, Elith & Leathwick 2009). These models may be limited in their prediction of biological patterns and occurrence by the type, amount, scale, and coverage of data, both for the response variable and the environmental variables.

Various papers evaluate the approaches and compare the advantages and disadvantages: for example, Guisan et al. (2002), Lehmann et al. (2002), Elith & Leathwick (2009), Palialexis et al. (2011).

Approaches are generally split into those that model either the probability of presence or abundance of species. Input environmental data may be based on multibeam-derived products that describe the “landscape” (depth, slope, aspect, rugosity), layers of environmental data that may be remotely-sensed (salinity, temperature anomaly, primary productivity) or modeled (currents and velocity), or “station” data associated with coral record data (latitude, longitude, depth, substrate). Methods used depend on the resolution of the data and the areal extent of analysis, and the data type, quality, and quantity.

Other methods have developed from the Ecological Niche Factor Analysis (ENFA) which uses species presence-only data. Guinan et al. (2009) developed further models to predict coldwater coral distributions at local and regional scales based on occurrence records and associated environmental data. Another method for presence-only data has been developed in the software program MaxEnt (Phillips et al. 2006, Elith et al. 2011). This method was found to be more flexible and perform better than the ENFA to predict habitat suitability for coldwater stony corals on seamounts at the global scale (Tittensor et al. 2009).

The use of regression trees to predict patterns and processes to classify environments suitable for species has developed over the last decade (De’ath & Fabricius 2000, De’ath 2007). One of the most widely used methods in New Zealand is the boosted regression tree (BRT) method developed by Elith et al. (2008) (for example, Leathwick et al. 2006; Davies & Guinotte 2011). An application of this method by Tracey et al. (2011c) identified depth and location relative to a seamount as consistently important factors influencing the probability of occurrence of five species of branching stony corals (in Order Scleractinia) in the New Zealand region.

Although model validation and the lack of environmental data and appropriately-scaled data were limitations in some models, these approaches provide ways of predicting coral habitat and potential distribution of corals in areas where knowledge of coral distribution is lacking.

Project objectives. The first objective of this project is *to expand recent work on identifying areas where deep sea corals are at highest risk of interactions with commercial fishing gear by using additional sources of information relevant to the distribution of corals*. Our approach to this work is to describe the distribution of protected corals based on the available coral records from both fishing and research sampling in relation to current fishing patterns and to model the coral data with available environmental data in a boosted regression tree analysis to predict coral distribution throughout the EEZ (after Tracey et al. 2011c). The coral data exist at varying taxonomic levels and it was agreed with the Department of Conservation to summarise and analyse the data on two levels — one at the management level (all families of black corals, gorgonians, and scleractinians, and the stylasterid family of hydrocorals) and one as "functional" groups where corals of similar structure are considered together.

The results from this first objective provide input into completion of the second objective: *to provide recommendations on any future research required to further improve the estimation of risk to protected corals from commercial fishing*. Risk assessment has developed rapidly in recent years as a technique to support resource management to identify, evaluate, and reduce the risk of undesirable consequences due to fishing (e.g., Francis & Shotton 1997, Fulton et al. 2005). The majority focus on ecological risk assessment (ERA) which is now increasingly seen as part of routine fisheries assessment around the world (e.g., Suter 2006), including in New Zealand. The quality and quantity of data used to estimate risk, for example to protected corals, are important determinants in the assessment methods used within the bounds of the management objective. Generally there will be less uncertainty (for both the component at risk and the components that pose the risk) in datasets in which there is good spatio-temporal coverage, relevant spatial resolution, a large number of data points, and measures of impact frequency and intensity.

2 Methods

2.1 Data sources and treatment

Four datasets were required for this work:

- a dataset of presence records for protected corals within the New Zealand EEZ — the **"**protected coral data**"**,
- a dataset of observed and research stations where samples were collected from the seafloor —"benthic stations data" — to provide a base set of stations for absences (to indicate where sampling had occurred but no coral catch was reported),
- a dataset of environmental variables considered relevant to deepwater corals — "environmental data" — to describe the distribution of various environmental parameters, and

- GIS layers of a 16-year (1989–90 to 2004–05) and 20-year (1989–90 to 2008–09) trawl footprint.

2.1.1 Protected coral data

This dataset was compiled to describe the diversity of deepwater corals and their distribution within the EEZ. Data from the primary sources of invertebrate records were extracted, combined, and standardised. Data included coral records and associated station records that provide location, date, and depth data. The extracts were from a number of databases including those that store taxonomic and related information for corals returned from sea and identified at NIWA, by various international taxonomists or by NIWA experts. Data were collated from:

- historic research surveys (*AllSeaBio* database);
- historic and recent research surveys and observed commercial fishing (NIWA's invertebrate collection database *Specify*);
- records from the Ministry for Primary Industries (MPI) databases: observer database (*cod*) and the research trawl and biodiversity databases (*trawl* and *biods*) where the identification was made at sea and no sample was returned;
- a stony coral dataset from NIWA Memoir records and unpublished voyage reports.

These data were restricted to those collected within the New Zealand 200 n. mile EEZ. The data were compared and, where possible, duplicate records were identified and removed. Coral records from the observer database were appended with the target species and gear type of the associated fishing record.

Observations of coral bycatch reported by observers and by scientists on research trawl surveys, but not verified by experts, were included because they were considered to be robust when used at the family or order level used in this analysis. Observers and researchers have used the Deepsea Invertebrate Guide (for example, see Tracey et al. 2011a) and the Coral Identification Guide (Tracey et al. 2008) for reference since 2005. The use of these guides has increased the taxonomic level to which samples are successfully identified at sea (Tracey et al. 2011b). The research survey trips from which coral data were recorded were staffed by researchers with a high level of expertise in the identification of corals.

The accuracy of the identification of the observer data collected over a 3-year period (based on fishing years between 1 October 2007 to 30 September 2010) was reviewed by

Tracey et al. (2011b), though the small numbers of samples of hydrocorals (Family Stylasteridae) — a family that is readily confused with the gorgonian precious coral Family Coralliidae — precluded any test of accuracy. For other protected corals, the accuracy of the observers' data recording was 90% for black corals (Order Antipatharia), 86% for the branching stony corals and 98% for the cup stony corals in Order Scleractinia, and 97% for bubblegum corals to genus and 85% for bamboo corals to family (previously Order Gorgonacea, now Order Alcyonacea). Overall, 73% of all the gorgonian corals were assigned to this order by observers; most of the remainder were mistakenly identified as belonging to other protected coral orders.

The location records for the coral samples were reported at different scales, depending on the dataset. For the observed trawl effort and research trawl survey data, the presence of coral is represented by the station record for when the net started fishing. However, the coral may have been caught at any stage along the seabed swept by the trawl. The length of a trawl track may vary from 2–3 km in an orange roughy or oreo hill tow to 20–30 km for a hoki tow (Clark & O'Driscoll 2003, Baird et al. 2011). A trawl survey tow is generally standardised at 3 n.mile long for middle depth species such as hoki and 1.5 n. mile long for deepwater species such as orange roughy and oreos. Shorter tows are made with the towed gears for biodiversity sampling (for example, benthic sleds and seamounts sleds) (Bowden 2011).

Taxonomic and group assignation

The taxonomic level of each protected coral data record was retained within the dataset; with corals represented at the order level only, through to the full species delineation. Within New Zealand waters, there are variations in the physical structure and composition between families in some protected orders (Tracey et al. 2008). For example, amongst the families represented in the gorgonian corals are the different forms represented by the bubblegum corals (Family Paragorgiidae), bamboo corals (Family Isididae), and golden corals (Family Chrysogorgiidae). Some corals have similar forms, but are in different orders (for example, the gorgonian precious corals and the hydrocorals of Family Stylasteridae in Order Anthoathecata (see Tracey et al. 2011a)).

To reflect the ecological importance of corals, coral records were assigned to one of four "functional" groups, based on overall form and size, with the implicit understanding that these groups are sufficiently different in their structure that they provide varying forms of habitat and associated value to other animals. Notwithstanding the likelihood of variation in morphology within each group, the main structural forms are broadly described as resembling a branch, a bush, a whip, or being of small stature and existing singly: that is "reef-like", "tree-like", "whip-like", and "solitary small", respectively. The main features of the corals in each group are given below, and some supporting images are presented in Figures A1–A4 in Appendix A.

"Reef-like" corals. "Reef-like" corals comprise over 10 genera in 3 families of branching stony corals that form 3-dimensional matrices (Cairns 1995). These corals produce relatively large colonies (up to about 1 m in height) that can form large reef-like structures (tens to hundreds of metres long) (Huehnerbach et al. 2007). Branching scleractinian corals are often associated with seamounts and other underwater topographical features, extending from the summit down the flank to the base region, or are found on other hard-bottom features on slope areas (Clark & Rowden 2009). The largest known deepwater coral reef within the New Zealand EEZ is on the Campbell Plateau; this covers 9.2 km^2 and mainly consists of the branching stony coral *Goniocorella dumosa* (Squires 1965, Mackay et al. (submitted)).

"Reef-like" species returned from observed fishing effort in the New Zealand EEZ include *Solenosmilia variabilis* and *Goniocorella dumosa* (Family Caryophylliidae), *Madrepora oculata* (and form 'vitae') and *Oculina virgosa* (Family Oculinidae), and *Enallopsammia rostrata* (Family Dendrophylliidae) (Tracey et al. 2011b). Other taxa assigned to this group, and present in New Zealand waters, include *E. marenzelleri*, *Dendrophyllia* spp., and *Euguchisammia* spp. (Family Dendrophylliidae).

These reef-forming scleractinians provide essential habitat and are thus ecologically important (Fosså et al. 2002). Fish species seen in close proximity to these corals may use them as sources of vertical relief, for refuge from predators, and may feed on the corals or associated animals (Stone 2006, Mortensen et al. 2008). Large aggregations of commercial fish species can occur above seamounts that support high densities of "reef-like" corals, but any direct linkages between the fish and coral are unknown. These corals also provide structure for other protected corals such as *Desmophyllum* spp. and some gorgonian corals (for example, the bamboo coral *Keratoisis* spp.) (Cairns & Bayer 2005).

"Tree-like" corals. The bushy "tree-like" group includes corals from at least 7 families of black corals and 9 gorgonian families. These corals exist in small to large colonies (about

5 cm to over 300 cm in height) that have a limited areal extent (about 5 cm to 100–200 cm in width). Individual colonies can be found grouped in patches.

The “tree-like” black corals include all genera with either bushy, branching, arborescent (tree-like), or umbellate (umbel-like) form (Opresko 1972). The gorgonian “tree-like” corals are described as branching, bushy, bottle-brush, fan-like, lyrate (lyre-like), and umbellate (Cairns & Bayer 2009). Some corals included in this group do not fit the “tree-like” description as clearly as others: for example, *Chrysogorgia* species have long whip-like stems with bushy branching at the tip.

“Tree-like” corals are thought to be important providers of fish and invertebrate habitat, in ways similar to those described above for the “reef-like” corals (Etnoyer & Morgan 2005, Stone 2006). Several overseas studies have shown the importance of the gorgonian corals to associated fish species (e.g., Mortensen & Buhl-Mortensen 2004, Miller et al. 2012).

“Whip-like" corals. This group comprises corals that have a whip-like form (Cairns & Bayer 2009) of limited extent (about 100 cm^2) and are relatively large in height (up to about 100 cm). Three genera are assigned to this group: one black coral in Family Antipathidae (*Stichopathes*) and two gorgonians in families Chrysogorgiidae and Primnoidae (*Radicipes* and *Primnoella*).

“Solitary small”corals. The “solitary small” corals include scleractinian cup corals belonging to 13 families and all the hydrocorals (Family Stylasteridae in Order Anthoathecata). The cup corals exist as solitary animals or may form small clumps of up to 10 individuals (Cairns 1995). The hydrocorals are small (about 10–20 cm in height and width) and fan-like or uniplanar in form (Cairns 1991).

2.1.2 Benthic stations data

A dataset was compiled from an extract from the NIWA database *marineDB* which stores data for all benthic research stations, including those with the potential to sample protected coral (for example, gear type was a benthic sled, bottom trawl, rock dredge), for all depths. These data were supplemented with a set of trawl fisheries observer data from October 2007 to December 2010. (These dates represent a three-year period following the introduction of benthic data forms.) No data from beyond the EEZ were retained, and any duplicates were removed. Duplication occurred for some observed effort where a sample had been returned from sea for identification and the associated station data had been recorded in the *marineDB* research database. Depth values for this combined dataset were extracted from the 250-m bathymetry grid (CANZ 2008).

2.1.3 Environmental data

Environmental data used in this work were originally prepared for the stony coral analyses undertaken by Tracey et al. (2011c). The environmental variable data were provided as individual tiffs, each with an extent that represented the Extended Continental Shelf. These data were loaded into ArcGIS 10 (ESRI 2011) using the Mercator 41 projection and a subset of each environmental data layer was created to represent the EEZ (the extent required for this work). The two occlusions within the outer EEZ boundary — one on the Chatham Rise and one near the Pukaki Rise — were retained as part of the EEZ.

The nine variables included are considered relevant to the distribution of protected coral orders (Tracey et al. 2011c) and represent modelled bio-chemico-physical properties of the EEZ waters, with values gridded at a resolution of 250 m. The environmental predictors included depth, slope, bottom water temperature residuals, dissolved organic matter, dynamic topography, tidal current speed, sea surface temperature gradient, surface water primary productivity, and particulate organic carbon flux (see Table B1 & Figures B1–B3 in Appendix B).

The use of other environmental data was investigated. A measure of orbital velocity was excluded because it had very little or no discrimination in waters relevant to deepwater corals. Data for salinity, phosphorus, nitrates, and silicates at the seafloor showed strong positive correlations with depth and were not retained. Temperature is also highly correlated with depth. However, a depth-independent measure of temperature was included, bottom water temperature residuals, obtained from a model that normalised temperature in relation to depth (*see* Leathwick et al. 2012). The resulting residuals represent the difference (in degrees) at each 250-m grid cell from the mean temperature at depth at each location. Cooler waters are indicated by values less than zero and warmer waters by positive values (Leathwick et al. 2008).

Environmental data may relate to the response variable (the corals) in different ways. They could directly influence the probability of occurrence or act as proxies for more complex environmental relationships or as surrogates for variables not included (Pinkerton et al. 2010). For example, depth will be a measure for changes in variables such as salinity, temperature, pressure, and nutrients, all of which influence the distribution of benthic organisms in the deep sea (Thistle 2003). Temperature (measured here independent of depth) affects distribution because of its (taxa-specific) influence on physiological processes (Dodds et al. 2007), for example, reproduction and thus dispersal potential. The EEZ-wide distributions shown in Figures B1–B3 suggest that the variation in tidal current speed and dissolved organic matter is largely delineated by the continental shelf and the presence of the Sub-Tropical Front. Tidal currents are likely to be important in delineating areas where organisms are structurally strong enough to survive and where sessile organisms require a regular food supply (Leathwick et al. 2012). Surface water primary production provides a food source for organisms on the seafloor and is considered important in influencing biological distributions of benthic organisms (Levin et al. 2001). While primary productivity is a useful measure of the amount of potential food for seafloor organisms, particulate organic matter flux and dissolved organic matter are more direct measures of the food available to suspension feeding animals such as corals (Duineveld et al. 2004).

The delivery of such food to benthic organisms depends in part upon currents. Dynamic topography (relative sea surface height) was used as a proxy for surface current velocity, and tidal current speed was used to evaluate the influence of near seabed currents. Corals have been shown to be more abundant where strong currents increase the rate of food delivery (Thiem et al. 2006). Sea surface temperature gradients reflect the location of frontal zones between two water masses. Fronts are features where primary productivity can be concentrated or particulate matter flux enhanced, and which may provide barriers to larval dispersal and thereby influence species distribution patterns (Watling & Gerken 2005). Slope is considered useful to this analysis because of the influence it may have on more localised processes, especially water flow, food supply, and sedimentation (Reveillaud et al. 2008). Slope may also be a rough proxy for substratum type; broad areas of relatively low slope may accumulate soft sediment, whereas areas of relatively high slope may experience less sediment accumulation and offer more exposed hard substratum for attachment.

The locations of “seamounts” (hills, knolls, pinnacles, and seamounts) as elements of underwater topography likely to provide hard substrate and desirable conditions for deepwater corals (Genin et al. 1986) were also available and represented the known locations from the NIWA *seamount* database (*see* Rowden et al. 2008, Mackay 2007) converted to a grid format.

2.1.4 Final merged datasets

The protected coral dataset, the benthic stations dataset, and the environmental data layers were loaded into a PostgreSQL relational database that allowed spatial queries in the Mercator 41 projection. The gridded variable data provided base data from which variable values were extracted and appended to the point locations in the benthic stations and the protected coral datasets.

A new combined dataset of all the background EEZ environmental data was created to use as the prediction background data. Because of the extent of the EEZ (about 4.1 million km^2 (*see* Baird & Wood 2012)), these data were resampled to a 1-km grid, to provide a 'smaller' prediction dataset more consistent with the range of variation around the 'true' sampling locations (which varied from point locations through to the length of a commercial trawl).

The three datasets were exported and loaded into R statistical package (R Development Core team 2011) and ArcGIS 10 for analysis and visualisation. For the prediction modelling (see section 2.2), and the description of coral distribution relative to commercial fishing activity, subsets of all datasets were created by restricting each dataset to the depths fished by the deepwater vessels, 200–2000 m, though the deepest effort is likely to be at less than 1600 m (Baird et al. 2011). The depths used to restrict the datasets were the depths derived from the base gridded bathymetry data (CANZ 2008) because we were unsure of what the depth values in the coral data represented (minimum/maximum, start/finish) and a proportion were not able to be assigned a depth value. Generally, for the coral orders, there was good correlation where comparisons could be made between the reported depths and the depth value extracted from the bathymetry grid, though some reported depth records for the gorgonian corals and stony corals appeared to be slightly shallower than the derived values in 1000–1500 m depth range. This may result from sampling on underwater features such as hills or knolls, or in areas of steep relief where localised elevation is not represented in the 250-m gridded data.

2.1.5 Fishing-related information

The focus of this study is deepwater protected corals that may be at risk from damage by commercial fishing, specifically in 200–2000 m. The observed fishing data provide presence/absence data for coral bycatch, but the observer coverage of fisheries by method and by target (and by implication, depth) is variable (see Abraham & Thompson 2011).

Observed trawl fisheries provide most of the coral bycatch records (Tracey et al. 2011b). With permission from the Ministry for Primary Industries, we have chosen to use the trawl footprint GIS layers that cover 16 years (see Baird et al. 2011) and 20 years (provided by J. Black, GNS) to indicate where trawl fishing has contacted the seafloor within the EEZ. These footprints do not indicate areas where trawling intensity is relatively high or relatively low. Baird et al. (2011) showed that many areas were repeatedly trawled each year as fishers returned to favoured fishing grounds, and that the 16-year footprint included areas where trawling occurred for several years, then decreased markedly, as different stocks or species were targeted. The 20-year trawl footprint is comparable to the 16-year version and provides a current assessment.

We compared the trawl footprint layers with the coral distributions, with reference to areas where there are restrictions to commercial fishing that contacts the seafloor (the seamount closures and the BPAs). We reviewed the available information in various reports analysing commercial fisheries to further describe the patterns of fishing for those fisheries known to have coral bycatch and those that may be conducted in areas where protected corals exist (for example, fisheries described by Anderson 2011, Anderson & Dunn 2012, Baird et al. 2011, Ballara & O'Driscoll 2012, Tuck 2009).

2.2 Predicted distribution analysis

Boosted regression tree (BRT) analysis was chosen as a method to predict the distribution of the coral orders and functional groups (*after* Tracey et al. 2011c). This approach 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 of the four coral orders and of the four functional groups. 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, the number of interactions that determine a split ("tree complexity") was set to a moderate level of 3, where 1 is no interactions. Several models were run with different levels of interactions. Allowing interactions reflects the understanding that at least some of these variables create an environment that may be preferred by the response variable. The relative performance of the environmental predictor variables is presented as their relative contribution (%), with contributions summing to 100, and the responses are plotted for interpretation. Various cross-validation measures were estimated within the model: the percentage deviance explained and the Area Under Curve (AUC) value for which 0.5 shows that the model has no discriminatory power and a value of 1 indicates that the model correctly identifies the occurrence. A model with an AUC of greater than 0.7 is considered “useful” (Swets 1986). Where an environmental variable was shown to have very little or no effect on the presence of a coral order or functional group, it was not offered to the model for that response variable. All other settings required used the defaults given in *gbm* (Ridgeway 2006).

For this analysis, we assumed that the coral records represented the full sample identified from each station and that a null record for a coral order/functional group was an absence for that order or group. The combination of the coral records dataset and the benthic stations dataset provided an EEZ-wide dataset of presence and absence. This dataset and the full EEZ dataset of variables were restricted to records within the 200–2000 m depth range to predict within the depths that deepwater corals occur and are vulnerable to impact from commercial fishing.

Cells with environmental variable values outside the range in each of the coral datasets were excluded. When displayed in GIS, these excluded cells were restricted to shallow waters close to land. The *predict.gbm* function in R was used to generate a dataset of the probability of the occurrence of the preferred environmental or suitable habitat for each coral order and functional group within the EEZ, using the background environmental variable dataset. These prediction datasets were exported and displayed in GIS for interpretation.

3 Results

Figures and tables relating to the diversity and distribution of protected corals are given in Appendix C. The distribution of environmental variables for the coral orders and functional groups, the benthic stations dataset, and the full background variable dataset are shown in Appendix D, along with the modelling results for the functional groups. Figures and tables relevant to fishery interactions with protected corals are given in Appendix E.

3.1 Protected coral diversity and distribution

The full benthic stations dataset describes the sampling effort and included 62 144 records. It extends from about 30° S to 55° S and 162° E to 172° W within the New Zealand 200 n. mile EEZ (Figure 3-1). The sampling effort is generally concentrated at the edge of the continental shelf and in areas of steeper relief, with a higher proportion of records in waters shallower than 500 m (Figure C1 in Appendix C). Relatively few samples were from beyond 2000 m.

The distribution of the 7731 protected coral records was bounded by similar limits, though there were relatively few records from more southerly latitudes and from waters west of the main islands (Figure 3-1, Figure C1).

Areas that show the highest density of coral records are generally those where there has been repeated sampling during research surveys, especially where known seamounts exist; for example, the Graveyard complex on the northern Chatham Rise around 180°, southeast of the Chatham Islands, the Macquarie Ridge southwest of the South Island, and in northern waters such as along the Kermadec Ridge that extends northeast from the Bay of Plenty coastline. Highest densities seen in waters deeper than 1000 m east of Pukaki Rise and from 500–1000 m waters on the western slope of the Bounty Platform represent coral records reported by fisheries observers (Figure C2).

Protected coral orders. Stony corals (Order Scleractinia) and the gorgonians in Order Alcyonacea were the most commonly recorded and accounted for 46% and 33% of the coral records, respectively (Table C1). Another 11% were attributed to Family Stylasteridae in Order Anthoathecata (hydrocorals) and 10% to Order Antipatharia (black corals). The depth distributions of gorgonians and black corals were similar, with most in 750–1250 m, and a smaller peak in shallower waters (Figure C1). The hydrocorals and stony corals were found throughout the depth range with peaks in 200–500 m and about 1000 m, and the stony corals appeared to have a wider depth range in the deepest waters. [Note that these depths are from the 250-m gridded bathymetry data].

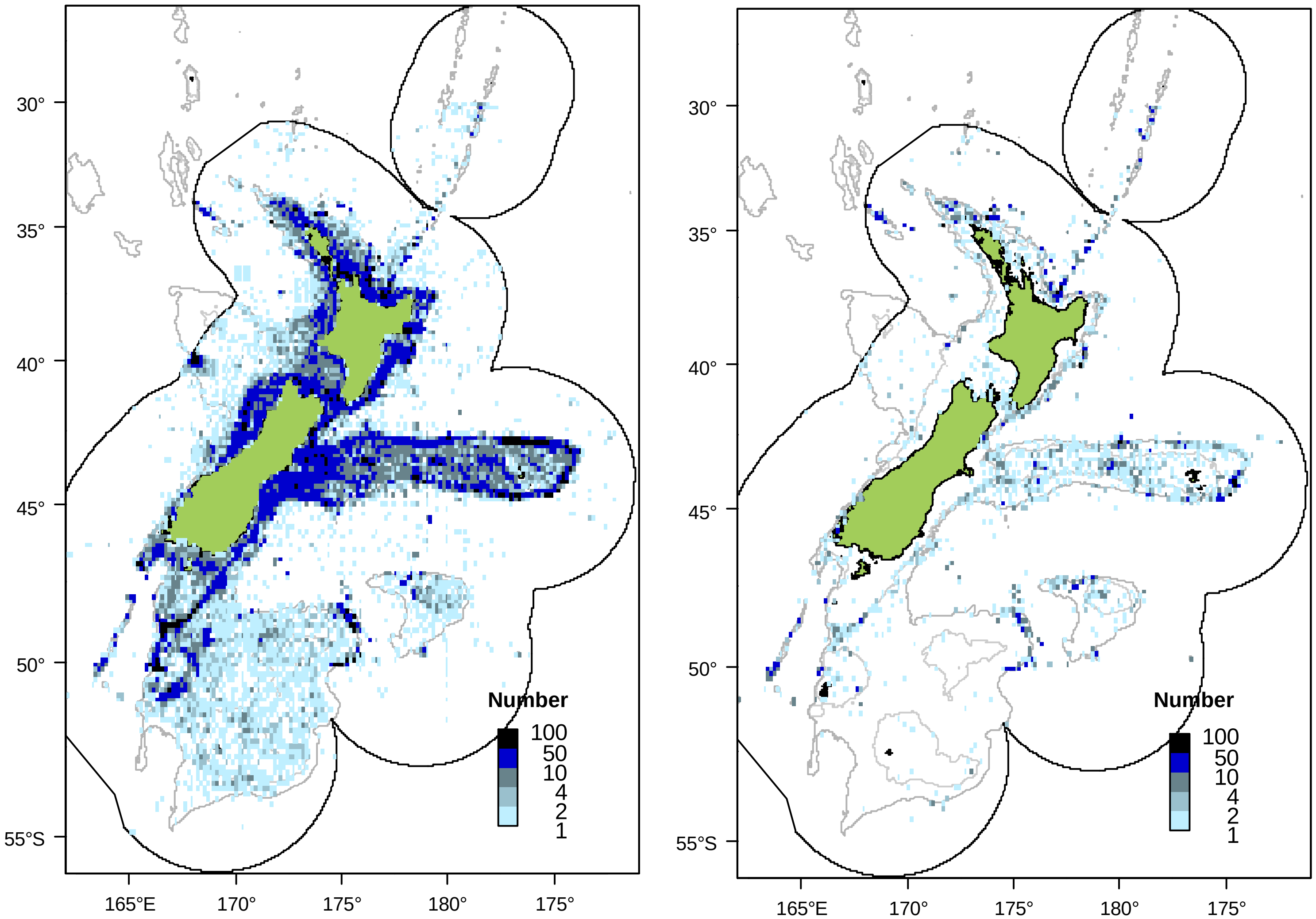

Figure 3-1:Density of benthic station data (*n* = 62 144) (left) and of the coral records (*n* = 7331) (right) displayed in 0.15° cells, within the New Zealand 200 n. mile EEZ. The 500 m, 1000 m, and 1500 m depth contours are shown.

Sampling from historic surveys (since 1954) and trawl and biodiversity surveys (up to 30 April 2011) contributed to 58% of all protected coral records. Observer data collected between January 1996 and 30 September 2011 provided the remaining 42%. The observer data accounted for 22% of the hydrocorals, 40% of the stony corals, 47% of the gorgonians, and 55% of the black corals. The numbers of records for each coral order, by Fishery Management Area (FMA, see Figure C2), are shown in Figure 3-2 for the survey sampling and observer sampling. Survey sampling had similar numbers of records from northern (FMAs 1, 2, 8–10) and southern FMAs (FMAs 3–7), whereas 70% of the observer records were from the southern FMAs.

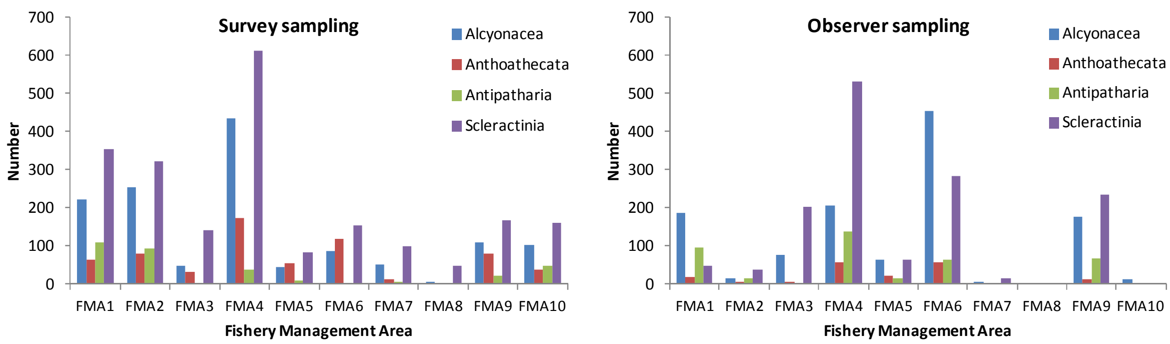

Figure 3-2: Numbers of coral records for each order from historic sampling and research surveys (n = 4510) (left) and from observed fishing effort (n = 3221) (right), by FMA.

Corals from all four orders were recorded from each of the FMAs, with consistently larger numbers of stony corals and gorgonians from most FMAs. Few corals were reported from FMAs 7, 8, and 10. At the family level, in all orders except Order Anthoathecata, there are differences in the geographic spread, with some families within an order reported from most FMAs and others restricted to one or two FMAs (*see* Table C1). Similarly, the distribution of the genera, by FMA, varies within each family of an order (Table C2). These differences reflected northern or southern distributions for some genera.

The most diversity within each order was evident in the gorgonians and the stony corals: 57 genera were identified from the 8 families of gorgonians; 56 genera from the 15 stony coral families; 26 genera from the 7 families of black coral; and 16 genera from the protected hydrocoral family (Table C2).

Almost 17% of the gorgonian records were not identified to family level. Of the nine families that were distinguished, the distribution of two families was represented in only one FMA, whereas the other seven families were found in at least 8 FMAs (Table C2). Eight FMAs had records from at least seven of the families, one (FMA 7) had five families, and the one family found in FMA 8 was represented by a single genus (*Acanthogorgia*) that was reported from throughout the EEZ (Table C2). In contrast to this, the one record for *Ctenocella* (the only genus in Family Ellisellidae) was found in FMA 1. For other families, the distribution of genera varied widely, with some genera found in one or two FMAs whereas others were more widespread.

Hydrocorals were reported from each of the FMAs, though the one record from FMA 8 was not reported by genus. The 16 identified genera showed variation in the extent of their distribution within the EEZ, with 8 genera recorded from at least 6 FMAs and remainder from 1 to 3 FMAs.

Of the 746 black coral records, 33% were not identified to family. The records for the black coral genera were more restricted in their occurrence by FMA than other orders, with most genera present in 1–4 FMAs. FMA 1 had the largest number of black coral genera and the most northern area, FMA 10, was the only area from where records for 6 genera representing two families (Aphanipathidae and Myriopathidae) were reported.

About 14% of the 3577 stony coral records were not identified to genus. Five of the stony coral genera had records located in all 10 FMAs: three from Family Caryophylliidae, one from Flabellidae, and one from Oculinidae. Relative to the other coral orders, the stony coral genera were more likely to be located in either a small number of FMAs or at least 8 FMAs, across northern and southern latitudes.

Functional groups. The allocation of the families of each order into the four functional groups based on structure is given in Table C3. The main effect of this split is the separation of the branching and cup corals in Order Scleractinia. The cup corals are combined with the hydrocorals in the “solitary small” group and the three main families (in terms of numbers of records — Caryophylliidae, Flabellidae, and Stylasteridae) that contribute to this functional group were reported from throughout the EEZ, with presence in all 10 FMAs (Table C4, Figure C3). The locations of other “solitary small” coral families were more scattered. The depth distribution for “solitary small” corals peaked in waters shallower than 500 m and at about 1000 m.

The three branching stony coral families designated “reef-like” were reported from all the FMAs (Table C4), either in waters shallower than 500 m or in about 750–1500 m (Figure C3). The black corals and gorgonian corals were combined into the “tree-like” group, except for 3 genera which constitute the small group of “whip-like” corals. Thus, the “tree-like” distribution is very similar to those shown individually for black and gorgonian corals (Figures C1 & C3). The “whip-like” corals represent just three families, with a generally shallower distribution than the other groups.

3.2 Protected coral distribution relative to environmental variables, in 200–2000 m

The 200–2000 m depth restriction reduced the coral dataset by 5% to 6965 records: 94% of the gorgonian records were retained, as were 94% of black corals, 88% of stony corals, and 85% of hydrocorals (Tables D1 & D2 in Appendix D). The benthic stations dataset was reduced by 32% to 42 515 sampling stations in 200–2000 m.

The frequency distributions for the coral order and functional group data in relation to the reported latitude and the gridded environmental data are shown in Figures D1–D4. Similar figures are presented for the 200–2000 m benthic stations and the gridded EEZ datasets in Figure D5. Boxplots in Figures D6–D9 show the median and first and third quartiles of these variables by family within each order or functional group. It is evident that for some variables there are some marked differences in the distributions between orders and functional groups (for example, compare the values for *dynoc* and *poc* (dynamic topography and particulate organic carbon flux, *see* Table B1)). In some the differences are more subtle, but comparisons are confounded by the much greater numbers of records for the stony and gorgonian corals compared with the other two orders. The black coral records were more northern in their distribution compared with the other orders. The benthic station data and the EEZ were skewed to more southern latitudes, as would be expected for the latter especially due to the larger southern and eastern extent of the outer EEZ boundary relative to the North Island and South Island.

Some orders show moderately strong variation between families for some environmental variables, in the median values or the range preferred by the corals in each family (Figures D6 & D7). Within the functional groups there are few differences between the families in the “reef-like” group, but there are some clear differences in distribution in the “whip-like” group

(Figures D8 & D9). Overall, the range of values for each of the environmental variables shown in the coral and benthic stations datasets and the background data are very similar.

3.3 Predicted distribution

The cross-validation measures of the AUC suggest that the models do moderately well in modelling the probability of presence for all the orders and the functional groups — though less well for the hydrocorals and the stony corals and for the "solitary small" and "whip-like" functional groups (Table 3-1). The best performing model was for the "reef-like" corals where, for any two random points, there is about 86% probability that the model will correctly assign them in terms of presence or absence.

Nine continuous environmental variables and one categorical variable (seamount or not) were provided for model fitting (*see* Table B1). No predictions were made where values fell outside the range in the response dataset. The fitted functions of the coral orders or functional groups for each of the variables are plotted in Figures 3-3 & 3-4 and Figures D10 & D11, respectively. These plots indicate the relative similarities between the patterns in the environmental space represented by the presence data for each response variable and that of the environmental data.

Table 3-1: Predictive performance of the BRT models for protected coral orders and functional groups. The models were family Bernoulli, with 2 interactions allowed, and over 1000 trees.

"model"	Deviance explained	AUC
Order Alcyonacea	0.20	0.81
Order Anthoathecata	0.15	0.70
Order Antipatharia	0.21	0.84
Order Scleractinia	0.16	0.76
"Reef-like"	0.29	0.86
"Solitary small"	0.11	0.73
"Tree-like"	0.21	0.81
"Whip-like"	0.19	0.73

The lack of smoothness in the occurrence distribution indicates the large variation in the preferences of different species or genera within each order or group. Similarly, when an order or a group is associated with both high and low values of a variable, it probably corresponds to two species/families with different niches.

There appeared to be a pattern in the variables considered to have the most influence on the distribution of the orders and functional groups. Generally, the following variables contributed more than 10% to the prediction of presence, though the order at which they appeared differs: dynamic topography, particulate organic carbon flux, depth, bottom temperature residuals, and the tidal current speed.

Importance of variables by order. Dynamic topography, with its strong north-south distribution (see Figure B1) is likely to be a proxy for other environmental variables, with both high and low values having a positive relationship with occurrence. This factor is the most important contributor for all the orders except stony corals, where it is the fourth most important variable. Gorgonians and stony corals appear to prefer a wider range of this value than the hydrocorals, which prefer relatively low and relatively high values, and black corals which prefer relatively moderately high values.

The gorgonians were also associated with low levels of particulate organic carbon flux, relatively deeper waters, and both cool water masses (where bottom temperature residuals were under 0) and warm water masses. Gorgonians were associated with relatively low values of dissolved organic matter and tidal current speed, a range of slopes (up to about 22°), relatively low primary production, relatively high sea surface temperature gradient, and with the presence of seamounts.

Several of the environmental variables for the hydrocorals had very little or no discernible effect, or were explained by other variables, and were not included in the final model: depth, particulate organic carbon flux, and sea surface temperature gradient. Hydrocorals were associated with low tidal current speed; a range of water temperatures, though a tendency to be in cooler temperatures; a range of slopes between 2° and 20°; and relatively low levels of dissolved organic matter and primary productivity. These corals were strongly associated with seamounts.

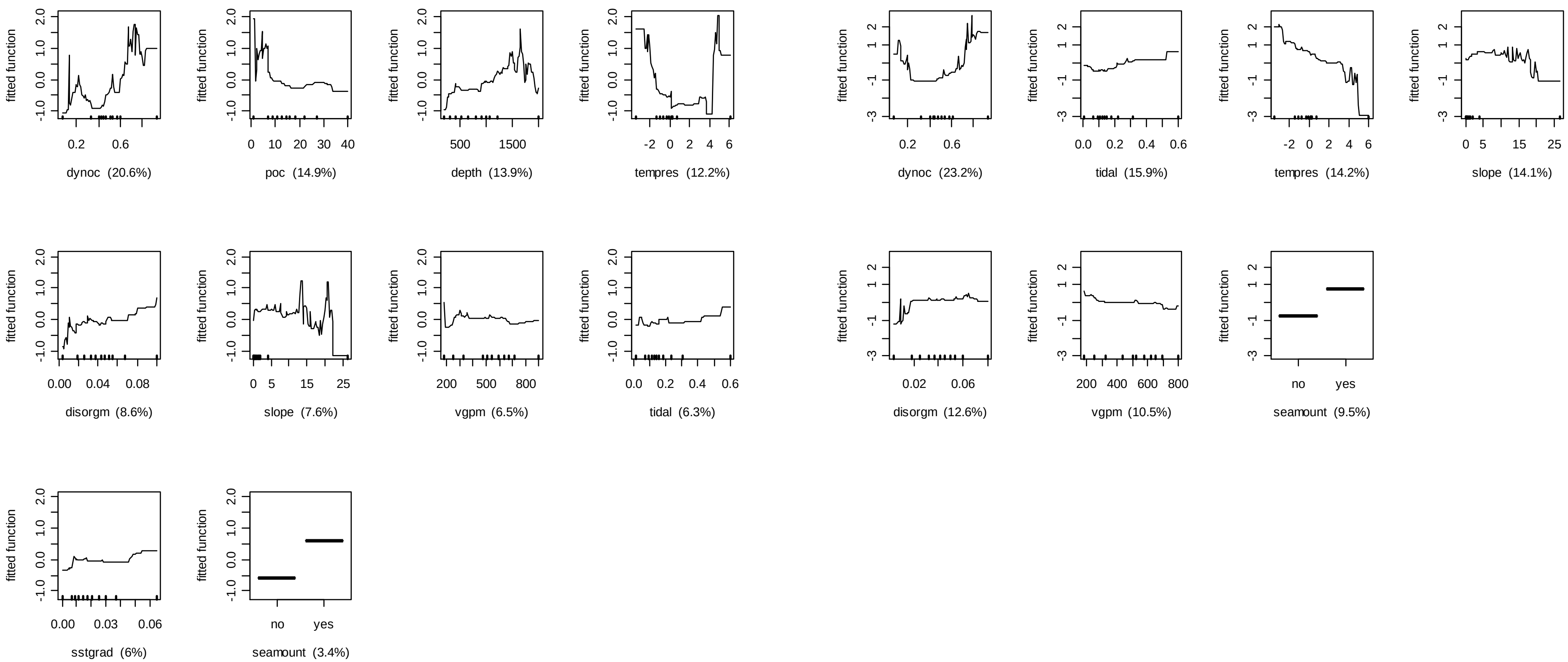

Figure 3-3: The BRT model results showing the occurrence, by variable, for the gorgonians (Alcyonacea) (left) and the hydrocorals (Anthoathecata) (right). The occurrence is plotted on the y-axis on a logit scale with a zero mean over the data distribution. The distribution of the benthic datset across the variable is shown as 'rugs' on each x-axis, with each representing 10% of the data. The variable names are explained in Table B1.

The factors that contributed most to the gorgonian occurrence were similar to those describing the presence of black corals, though there were differences between the two orders in importance and association. Black corals were associated with a smaller range of low particulate organic carbon flux values and showed a weaker relationship with both cool and warm water masses. They were associated with relatively low values of tidal current speed, dissolved organic matter, and primary production. Black corals were most strongly associated with slopes of about 2–15° and had only a weak association with seamount presence. They appeared to prefer a more restricted range of low sea surface temperatures compared with gorgonians.

Particulate organic carbon flux was the highest contributor for stony corals, which were associated with relatively very low values and moderately low values. They also occurred in waters with relatively low tidal current speed and primary productivity; across the ranges for depth, slope (2–20°), and dynamic topography; and in waters characterised mainly by relatively cool temperatures. Stony corals were also associated with moderate-high gradients of sea surface temperature, as were gorgonian corals, suggesting a preference for waters where mixing occurs.

Importance of variables by functional group. The main influences for the “reef-like” group came from variables for tidal current speed, particulate organic carbon flux, depth, and primary production (Figure D10). In contrast, for the “solitary small” group (cup corals and hydrocorals) and dynamic topography, dissolved organic matter, tidal current, particulate organic carbon flux, and bottom temperature residuals were important (Figure D11). All the gorgonians except two genera and all black corals except one genus were assigned to the “tree-like” functional group in this analysis, for which the largest contributors were particulate organic carbon flux, dynamic topography, depth, and the bottom temperature residuals (Figure D10). Comparison of the occurrence plots for the two orders and the “tree-like” functional group indicates the influence of the gorgonians in driving the “tree-like” presence distribution.

Tidal current speed and warm water masses were the greatest contributors in the “whip-like” model (Figure D11). These corals seem to prefer a small range of relatively low levels of particulate organic carbon flux, relatively gentler slopes, low and high values of dissolved organic matter, and were present in areas of relatively low and high values for dynamic topography. The “whip-like” corals had a very strong association with seamounts.

Prediction distribution. Deep waters (over 1000 m) were predicted as the most likely to support gorgonian corals (Figure 3-5). Some of these areas corresponded with the corals records from areas of steeper slopes and deeper water. For example, the waters between the Pukaki Rise and Bounty Platform in FMA 6; known seamount complexes on the Chatham Rise; high relief areas in northern waters (such as on the West Norfolk Ridge to the northwest); and along the ridges to the northeast in FMA 10. However, there was little discrimination in the Bay of Plenty waters southwest of the seamount closures, in the shallower waters of the Chatham Rise, or the southern edge of the Stewart-Snares shelf, from where there were gorgonian records.

Similarly, the spatial prediction for hydrocorals was very patchy and limited to deep water and high relief – in areas from where hydrocorals were reported (Figure 3-6). However, as with the gorgonians, there was little discrimination across the Chatham Rise and shelf edge areas in shallower waters where hydrocoral records were located. The spatial prediction for black corals was also very patchy, with black corals most likely to be in 1250–2000 m in northern waters, on the northern and eastern extreme of the Chatham Rise, and the edge of the southern plateau (Figure 3-7). The spatial prediction for stony corals was similar to that for gorgonians, though the stony coral distribution showed more discrimination on the Chatham Rise than was seen for gorgonians (Figure 3-8). For comparison, spatial predictions by functional group are shown in Figures D12 and D13 in Appendix D.

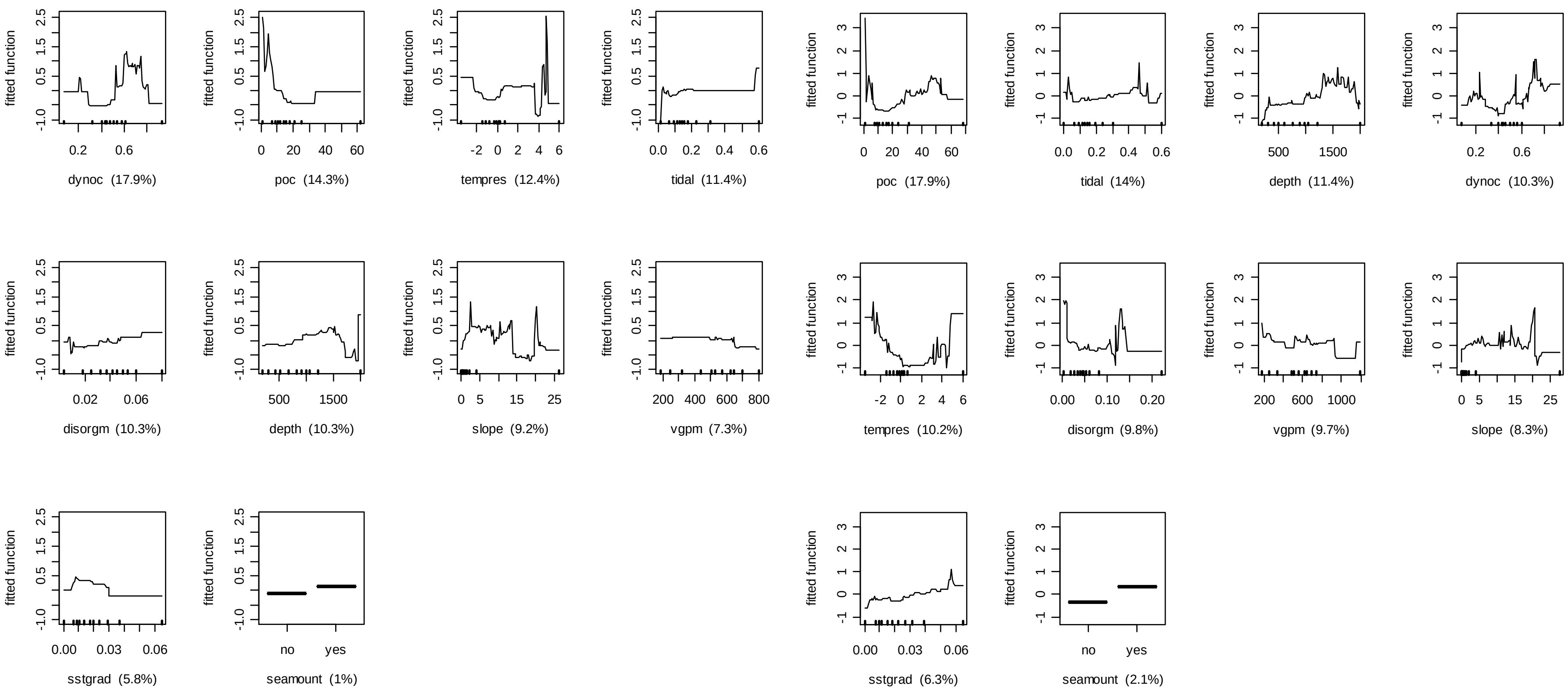

Figure 3-4: The BRT model results showing the occurrence, by variable, for the black corals (Antipatharia) (left) and the stony corals (Scleractinia) (right). The occurrence is plotted on the y-axis on a logit scale with a zero mean over the data distribution. The distribution of the benthic dataset across the variable is shown as 'rugs' on each x-axis, with each representing 10% of the data. The variable names are explained in Table B1.

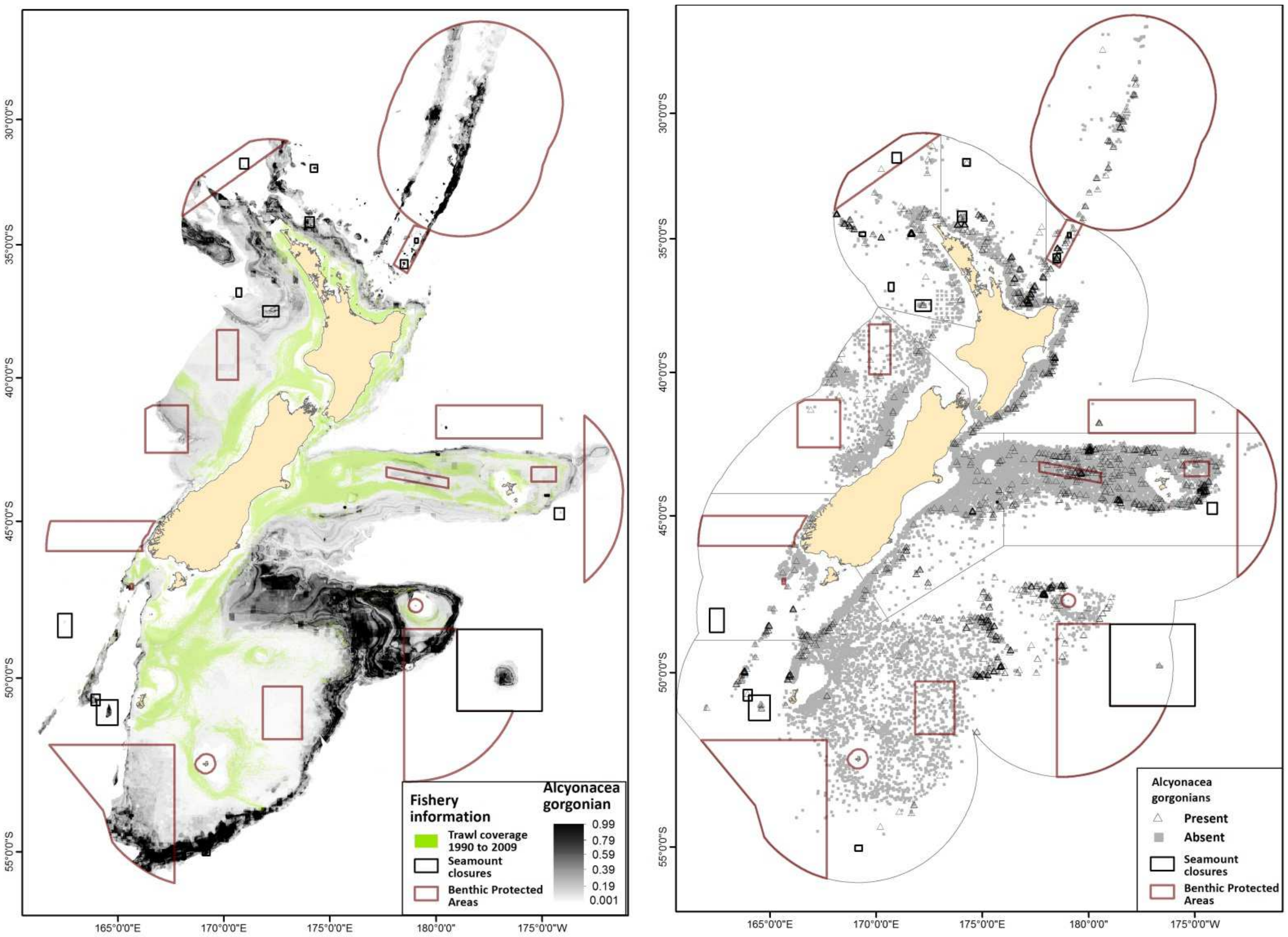

Figure 3-5: Predicted distribution (left) and location of coral presence/absence data records (right) for gorgonian corals in Order Alcyonacea. The predicted distribution is shown relative to the 20-year trawl footprint (1989-90 to 2008-09), seamount closures introduced in 2001, and Benthic Protected Areas introduced in 2007. FMAs are shown in Figure 3-1.

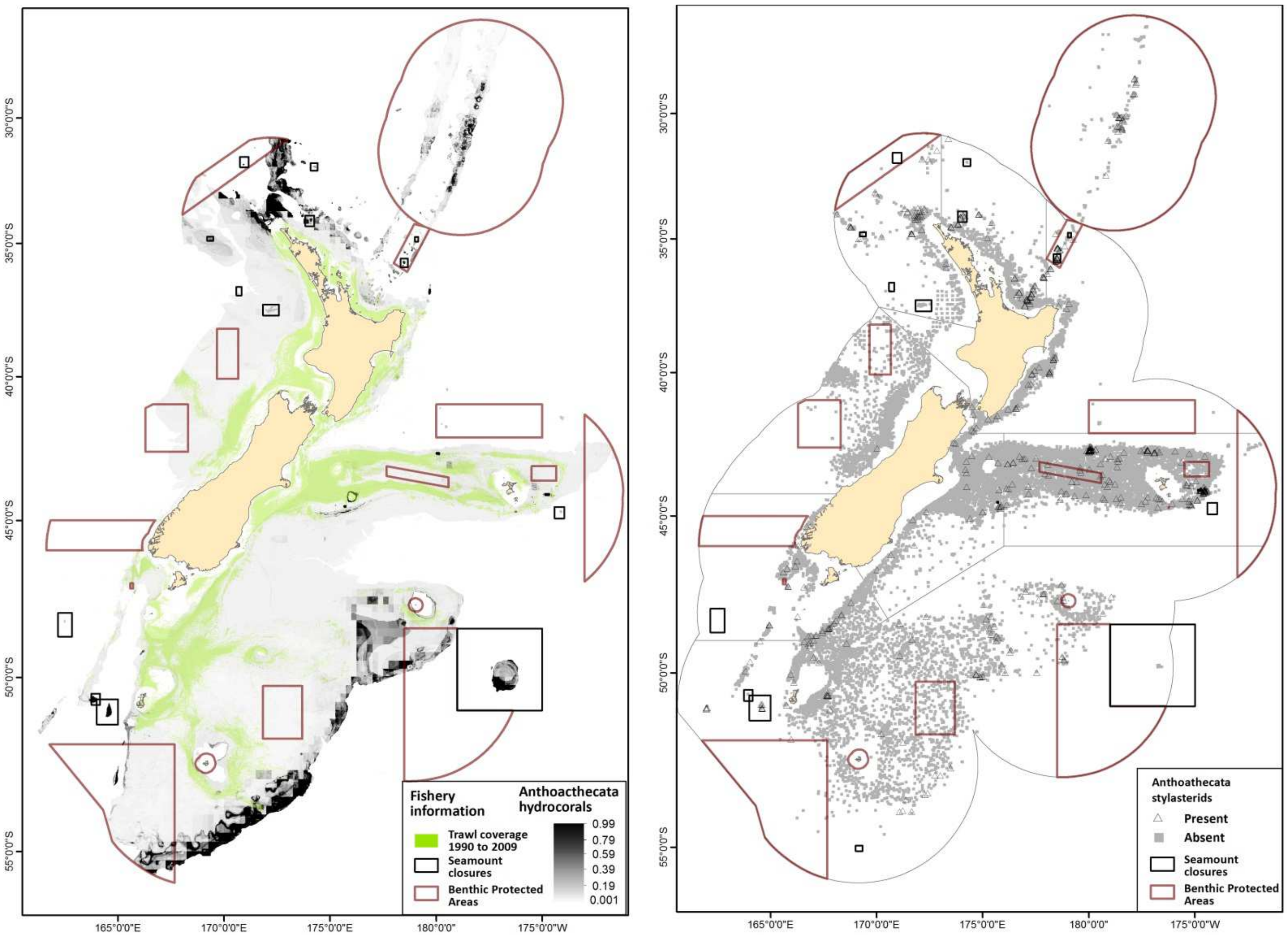

Figure 3-6: Predicted distribution (left) and locations of coral presence/absence records (right) for hydrocorals in Order Anthoathecata. The predicted distribution is shown relative to the 20-year trawl footprint (1989-90 to 2008-09), seamount closures introduced in 2001, and Benthic Protected Areas introduced in 2007. FMAs are shown in Figure C2.

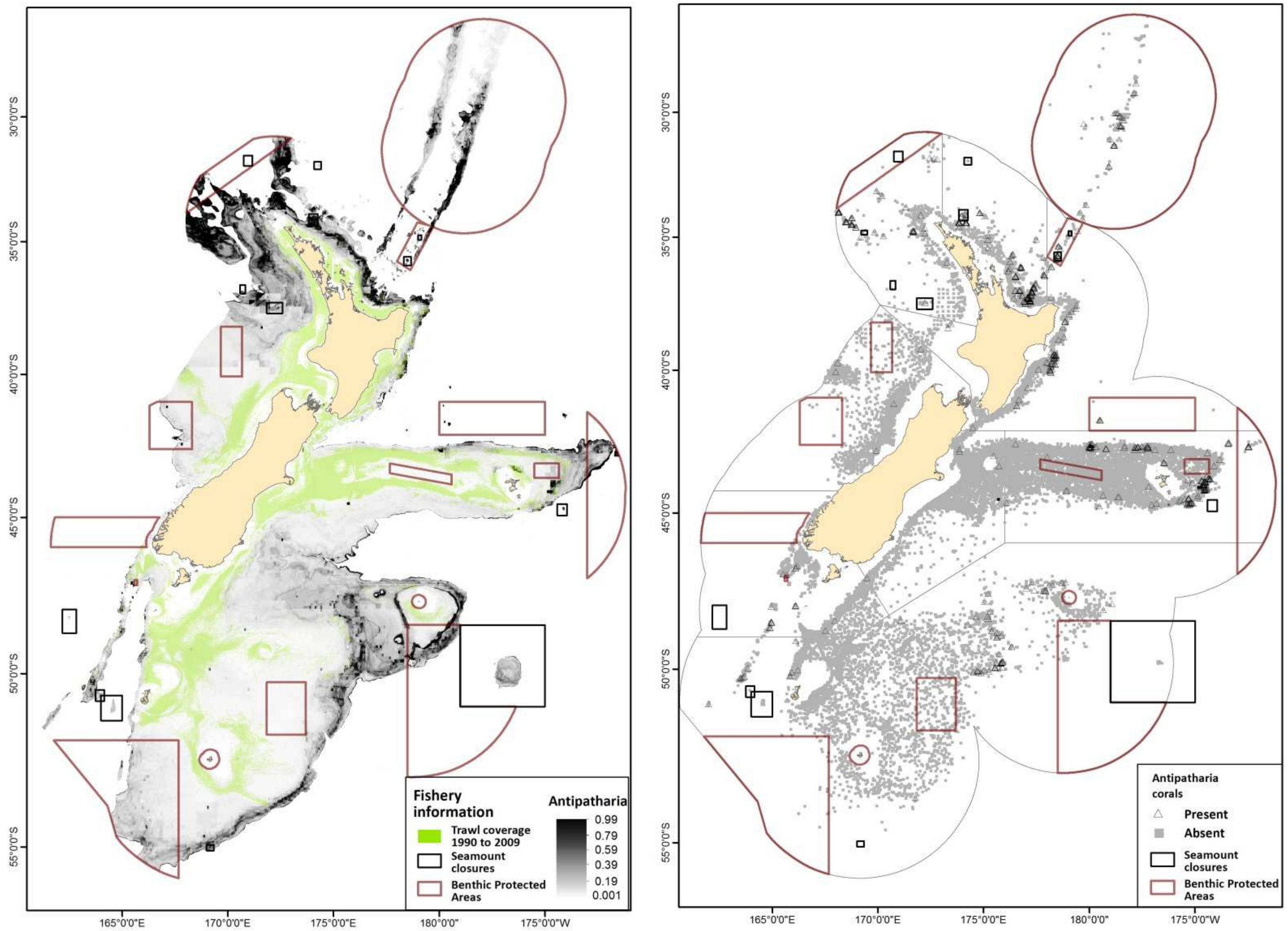

Figure 3-7: Predicted distribution (left) and locations of coral presence/absence records (right) for black corals (Order Antipatharia). The predicted distribution is shown relative to the 20-year trawl footprint (1989-90 to 2008-09), seamount closures introduced in 2001, and Benthic Protected Areas introduced in 2007. FMAs are shown in Figure C2.

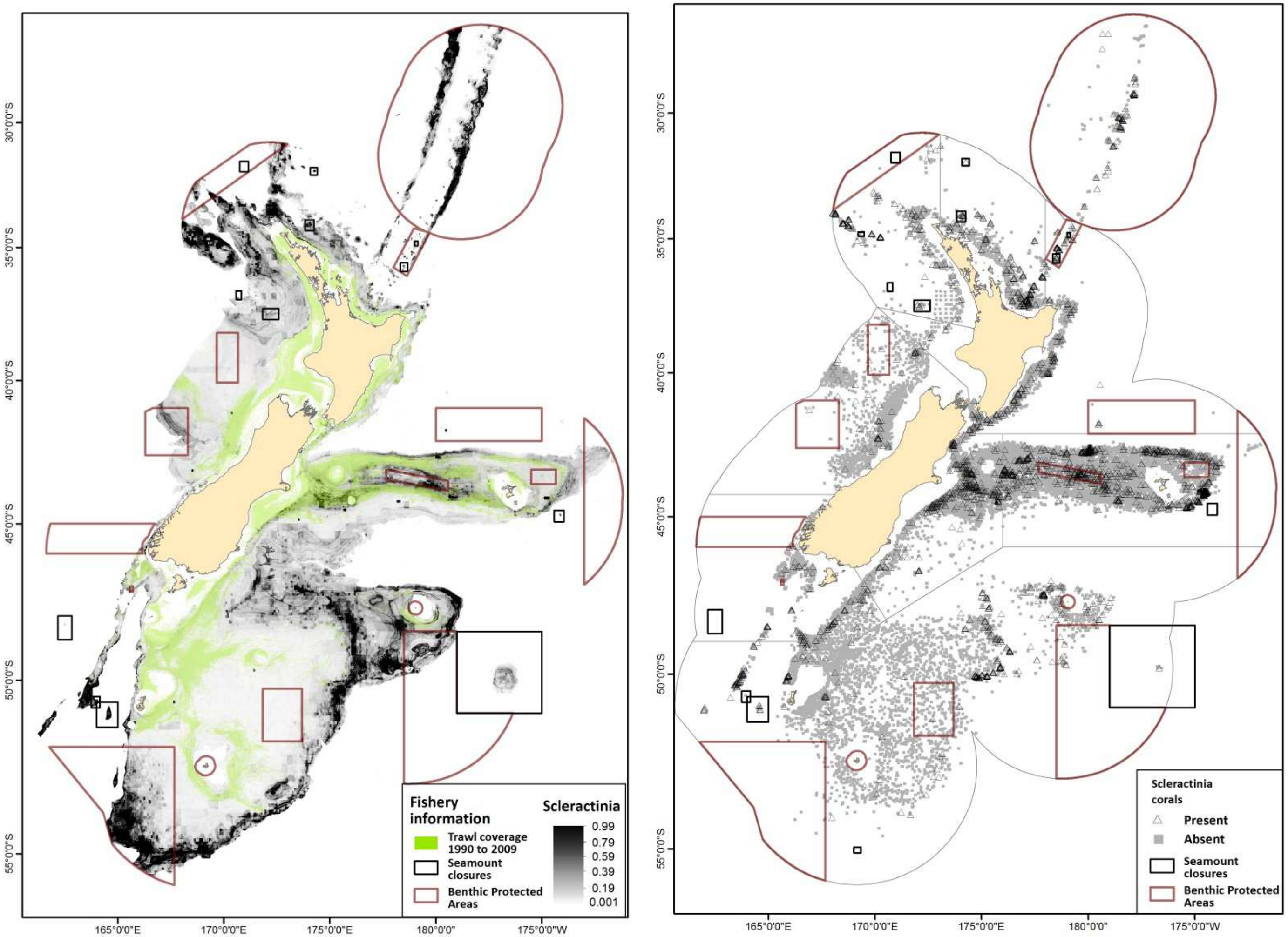

Figure 3-8: Predicted distribution (left) and locations of coral presence/absence records (right) for stony corals (Order Scleractinia). The predicted distribution is shown relative to the 20-year trawl footprint (1989-90 to 2008-09), seamount closures introduced in 2001, and Benthic Protected Areas introduced in 2007. FMAs are shown in Figure C2.

3.4 Distribution in relation to fishing

3.4.1 Observed distribution

Trawl effort. Coral records from observed commercial fishing are plotted with the 20-year trawl fishing footprint, the seamount closures, and the Benthic Protected Areas in Figure E1 in Appendix E. Many of the coral records are from areas where the footprint appears to relatively small, mainly because they represent areas where short tows are made on underwater features; for example, east of Pukaki Rise and northwest of the Bounty Platform. Although bottom trawling is prohibited in the closed areas, there has been little or no bottom trawling in most of the areas (over the period since 1989–90 for when there are adequate fishing effort data), as shown by the lack of overlap (see Figure E1).

One effect of changing effort patterns was evident in an 'eyeball' comparison of the EEZ-wide 16-year footprint with the 20-year version that encompasses data up to the end of September 2009. An extension of effort immediately east of 176° E and south of 43°20' S on the Chatham Rise (see Figures E1 & E2) was evident in the recent footprint. The observed coral bycatch reported from this effort indicated that this was an area that had been exploited in recent years with scampi as the target. This observed effort was part of the three-year benthic data collection to specifically look at protected corals (see Tracey et al. 2011b), and resulted in 85 stony corals (branching and cup), 8 hydrocorals, 2 black corals, and one gorgonian.

The observed coral records were from all areas except FMA 8 (Table 3-2), and a wide range of target species was reported for the observed effort with protected coral catch (Table 3-3). The highest numbers were returned from fishing in FMA 4 and FMA 6 and to a lesser extent from the northern waters of FMA 1 and FMA 9. Few were recorded from observed effort in FMA 7. Bottom trawl effort that targeted orange roughy accounted for almost half the observed records (Table 3-3), and catches represented corals from all four orders and functional groups (Tables E1 & E2). These catches accounted for most coral records from the northern, eastern, and southeastern slopes of the Chatham Rise (FMA 4), most records in FMAs 1 & 9, the deeper records in FMA 2, with the remainder from southern waters. Coral bycatch from deepwater fisheries for oreo species were from the southern FMAs in waters between 42° and 54° S.

Table 3-2: Numbers of observed coral records, by coral order and functional group, for each Fishery Management Area. FMAs are shown in Figure C2.

Order/Group	Fishery Management Area										
	1	2	3	4	5	6	7	8	9	10	All
Anthoathecata	18	5	7	57	18	35	1	0	12	0	153
Antipatharia	92	17	3	136	16	65	1	0	66	4	400
Gorgonacea	185	16	76	205	59	453	3	0	176	13	1 186
Scleractinia	48	40	203	527	59	275	17	0	235	0	1 404
All	343	78	289	925	152	828	22	0	489	17	3 143
Reef-like	44	24	38	327	33	249	0	0	226	0	941
Solitary small	22	20	172	256	44	60	18	0	20	0	612
Tree-like	276	33	79	340	75	518	4	0	242	17	1 584
Whip-like	1	0	0	1	0	0	0	0	0	0	2
Unassigned	0	1	0	1	0	1	0	0	1	0	4
All	343	78	289	925	152	828	22	0	489	17	3 143

Table 3-3: Common and scientific names for target species codes and numbers of corals reported from observed effort in 200-2000 m, by FMA.

Target code	Common name	Scientific name	Fishery Management Area									
			1	2	3	4	5	6	7	9	10	All
BAR	Barracouta	*Thyrsites atun*	0	0	0	1	0	0	0	0	0	1
BNS	Bluenose	*Hyperglyphe antarctica*	1	0	1	9	0	0	0	1	0	12
BOE	Black oreo	*Allocyttus niger*	0	0	24	14	1	239	0	0	0	278
BYX	Alfonsino	*Beryx* spp.	24	10	0	10	0	0	0	15	0	59
CDL	Black cardinalfish	*Epigonus telescopus*	30	19	0	0	0	0	0	0	0	49
HAK	Hake	*Merluccius australis*	0	0	4	0	9	3	18	0	0	34
HOK	Hoki	*Macruronus novaezelandiae*	2	1	140	45	21	15	3	0	0	227
LIN	Ling	*Genypterus blacodes*	0	0	18	9	0	5	0	0	0	32
MDO	Mirror dory	*Zenopsis nebulosus*	0	0	0	0	0	0	0	1	0	1
OEO	Oreo species		0	0	7	10	34	146	0	0	0	197
ORH	Orange roughy	*Hoplostethus atlantica*	280	15	1	658	3	84	1	469	3	1514
PTO	Patagonian	*Dissostichus eleginoides*	0	0	0	0	0	5	0	0	0	5
RBY	Rubyfish	*Plagiogeneion rubiginosum*	0	4	0	0	0	0	0	1	0	5
SBO	Southern boarfish	*Pseudopentaceros richardsoni*	0	0	0	0	0	0	0	1	0	1
SBW	Southern blue	*Micromesistius australis*	0	0	0	0	0	2	0	0	0	2
SCI	Scampi	*Metanephrops challengeri*	6	29	4	96	0	0	0	0	0	135
SQU	Squid	*Nototodarus gouldi*	0	0	4	1	62	2	0	0	0	69
SSO	Smooth oreo	*Pseudocyttus maculatus*	0	0	65	63	9	327	0	0	0	464
SWA	Silver warehou	*Seriollela punctata*	0	0	21	8	3	0	0	0	0	32
TAR	Tarakihi (king)	*Nematodactylus*sp.	0	0	0	0	0	0	0	0	14	14
WWA	White warehou	*Seriollela caerulea*	0	0	0	0	10	0	0	0	0	10
UNI	unidentified		0	0	0	0	0	0	0	1	0	1
All			343	78	289	924	152	828	22	488	17	3141

Corals reported from deepwater targets included those with strong associations with seamounts (gorgonians and hydrocorals) (Tables E1 & E2). The stony corals caught in these fisheries were mainly branching corals in the “reef-like” group, with a relatively weaker response to seamount presence, as have black corals. All coral orders were caught in black cardinalfish tows in waters off the east coast of the North Island between about 41° 40’ S and 35° S.

Coral bycatch from observed effort that targeted alfonsino was from 430–770 m waters north of about 44°, with the catch from FMA 4 (southeast of the Chatham Islands and on the northern Chatham Rise), off the east coast of the North Island to about 34° S in FMAs 1 & 2, and in north-western waters on the West Norfolk Ridge in FMA 9. All orders except for the hydrocorals were represented in this bycatch.

Stony corals were the main bycatch from fisheries that targeted middle depths species with bottom trawls: hoki, ling, hake, silver warehou, and white warehou. Gorgonians, and comparatively small numbers of black corals and hydrocorals, were also caught in middle depth tows. Most captures were from the Chatham Rise and at about 500 m depths around the South Island. The most southern records were from southeast of the Campbell Rise. Although all coral orders were represented in the hoki bycatch, about 80% were stony corals, in particular stony cup corals (see Tables E1–E3). A similar pattern was seen for most other middle depths species, though the numbers were much smaller. A gorgonian and stony cup corals were reported from ling tows.

Species targeted in waters shallower than about 300 m had few coral records. Squid-targeted tows were the main contributor to coral bycatch in shallower waters, especially off the southeastern and southern Stewart-Snares shelf, but also north of the Auckland Islands – the main squid trawling areas. Corals were also caught off the east coast of the South Island where squid is targeted. All coral orders were represented in these areas, though there were few black corals reported by observers. All but one of the stony corals were branching “reef-like” corals.

The scampi fishery provided a dataset of corals from depths of 320–440 m in the Chatham Rise area mentioned above as well as from the northern fisheries off the east coast of the North Island between 41° 30’ S and 39° 30’ S and in the Bay of Plenty between 35° 30’ S and 37° 30’ S. Similar numbers of cup and branching stony corals were reported from these tows, and the other coral orders were represented in the overall bycatch, though the numbers were low in some areas.

Bottom trawling in FMA 10 has been prohibited since 2007. However, prior to this, 17 corals were reported from one observed trip targeting orange roughy and tarakihi along the Kermadec Ridge in 1998. These corals were all “tree-like”, with 13 gorgonians and 4 black corals. From five observed tows, 13 genera were identified, mostly from the shallower tows. Other shallow water fisheries with observed coral bycatch included rubyfish (black corals and one gorgonian), a stony cup coral from a barracouta net, and a gorgonian from a mirror dory-targeted tow (see Table E3).

Other methods. This observed coral dataset includes 5 records of corals caught during bottom longline fishing for Patagonian toothfish and these are in the group of southernmost records displayed in Figure E1 (see Table E3). Corals from all the orders except black corals were identified and the two stony corals were branching corals. Other observed bottom longlines targeted ling and bluenose. All protected coral orders except black corals were caught on ling longlines in 300–600 m and gorgonians and hydrocorals were reported from bluenose sets in 280–450 m. Fifteen stony corals (branching and cup corals) were returned from observed setnet activity for ling in 200–500 m off the Kaikoura coast at about 42° 30’ S.

3.4.2 Predicted distribution

The overlay of the trawl footprint on the predicted distributions for the coral orders and the four functional groups (*see* Figures 3-5–3-8, D12 & D13) suggests that fishing is conducted in areas where there is generally a lower probability of environmental conditions suitable for protected corals – the exceptions being underwater features that are currently fished, areas of steeper slope and higher relief, and southern flanks and top of the Chatham Rise – the latter mainly for stony corals and the “solitary small” group. Many of the closed areas are in waters deeper than 2000 m and therefore outside the fishing footprint; however, some include areas where protected corals may occur.

3.4.3 Closed areas

The corals recorded from sampling in the areas that are now designated seamount closures or BPAs represent 27 families from the four protected orders, and of the 107 identified genera in the closed areas, 23 are the only records for those genera in the dataset used in this study. About 4% of the benthic stations were in the closed areas.

4 Discussion

Data input. The addition of records from research trawl surveys and other biodiversity sampling to those from observed commercial fishing operations has provided a wider dataset from waters within the main trawling footprint and beyond to 2000 m. The main difference between the datasets was the method in which the coral data were collected. The biodiversity surveys used specialised gear to sample the seafloor (for example, Rowden & Clark 2010, Bowden 2011) and the positioning of the gear and the length of tow was generally designed to maximise the collection of the ‘target’ taxa or habitat. In contrast, the sampling efficacy of corals by trawl nets during a research trawl survey and observed fishing effort will vary with the target species, vessel size, gear used, and the area or substrate of the seafloor.

When fishers target species close to the seafloor the aim is to get the gear as close as possible to the seabed, whilst avoiding snagging the gear (coming fast) and thereby losing or damaging the gear. The different designs of the part of the gear contacting the seabed (ground gear) will change the nature of the damage a trawl does to the seafloor. The use of large bobbins and rockhopper gear, necessary to fish on hard substrates, will tend to break and crush coral structure. The ‘hop’ effect of rockhopper gear, which was introduced to allow fishing over rougher ground, keeps the bottom of the net (fishing line) further from the seabed, and so may prevent the net from catching coral and coral fragments. The size of the mesh used in trawl nets and cod-ends may be too large to effectively retain coral bycatch, unless the coral is large or is one of the branching or bushy corals which gets caught in the mesh itself. Thus, the coral bycatch described and analysed in this report will be biased to some extent, and so does not fully represent the true coral distribution. Unfortunately, there is little that can be done about this bias in catching ability of the nets, and without directed research experiments the magnitude of this bias cannot be easily estimated.

Nevertheless, the collection of coral bycatch records returned from observed fishing has vastly improved in recent years with concerted efforts to collect these data and the production of identification guides to aid at-sea identification. This data collection has identified coral bycatch from new fishery areas or from areas where the fishing has extended beyond the historic grounds.

Adverse effects to coral structure, such as the matrix-forming stony corals, has been observed after relatively few tows (Clark et al. 2011), but the overall effect will depend on the overlap of the trawl path (including the smothering effect), the type of coral structure, and the distribution of corals. When samples are obtained from trawls, it will be unknown at what point of the trawl path the coral was actually damaged and caught, or whether it represented an isolated patch or was part of a larger habitat structure. The severity of the damage will be unknown, and may range from slight damage with pieces being broken off to removal of the organism or smothering by remains of the damaged coral.

Species distribution and model evaluation. This study combined coral occurrence (compiled in diverse taxonomic orders and 'functional' groups) and modelled environmental variables. The data did not allow any determination of species abundance, rarity, or importance within a community, rather a description of species distribution based on best available data. By pooling the corals by their taxonomic orders and by "functional" groups that reflected similarities in habitat structure, we have effectively incorporated a wide variety of species (and their individual habitat preferences) within each order or group.

The choice of environmental variables is fundamental to distribution modelling. In this study, the environmental data were limited to those that were available and that had indicated some discriminatory potential in earlier work (Tracey et al. 2011c). However, critical variables such as seafloor substrate and ocean chemistry data were not available for this study, but such data layers are under development. Under an MPI-led project on ocean acidification and deep sea fisheries (ZBD201041), opportunistic water samples being collected from NIWA-led voyages are being analysed for alkalinity and dissolved inorganic carbon. These two carbonate parameters can be used to calculate the aragonite saturation horizon (ASH) and calcite saturation horizon (CSH). To provide improved detailed coverage of the ASH and CSH around New Zealand which will take into account the complex topography and currents, NIWA has developed algorithms to estimate the carbonate parameters from the commonly measured hydrographic parameters – temperature, salinity, and oxygen.

In addition, data that describe the mineral composition for the key habitat-forming stony branching corals and gorgonian genera are now available. These data will help inform whether corals such as the stony branching corals are restricted by the carbonate ion concentration in the intermediate and deep sea, and whether they will be affected by future ocean acidification – a process that further reduces the aragonite saturation state.

The scale at which the environmental data were resolved did not match the scale of the sampling or the localised scale at which the corals may exist. Many of the localised topographic features that are likely to be of hard substrate and therefore offer attachment and habitat for these corals may not be recognised in the datasets due to both scale and the resolution of sampling.

The BRT modelling identified potential environmental influences on coral distribution, and was then used to predict where a coral may occur, based on the distribution of those influences. Depth and presence of seamounts were the most important variables for 5 species of branching stony corals within the New Zealand Extended Continental Shelf, though there were differences between species (Tracey et al. 2011c). Two species were found in deep waters and two in shallow waters, thus there was more discrimination between the environments, particularly in primary production, tidal current speed, and slope. The general similarity in predicted distributions of the coral groups in this study may be real, or it may be because potentially many species were included within each analysis group. The data available did not allow analysis at a more disaggregated level. Individual species within groups may show distinct distributions which are masked when groups of corals are analysed together.

Another impact on the prediction was the uneven distribution of the sampling stations within the 200–2000 m waters. The very large number of absences on the Chatham Rise relative to the number of presences appeared to heavily influence the ability of the model to predict occurrence in areas where corals were known to exist, other than at the areas of highest relief and deep waters where research sampling had been concentrated.

Fisheries risk. All protected coral orders occur in areas where middle depths and deepwater species are targeted, particularly in areas of higher seabed relief, with concentrations evident on features such as seamounts and on the shelf breaks. Certain areas appear to have less coral catch, particularly off the west coasts of the North and South Islands, but this could be an artefact of the sampling distribution.

In many areas where commercial fishing was concentrated, for example on much of the Chatham Rise, the reported coral by-catch and so predicted coral occurrence was low. The fisheries for which protected corals are at most risk are primarily the deepwater trawl fisheries and those that target scampi. Many of the locations with coral bycatch match specific orange roughy fishery features described by Anderson & Dunn (2012). The one orange roughy fishery area (now closed) with no reported coral catch was the Cook Canyon fishery in ORH 7B off the west coast of the South Island. Coral bycatch from deepwater fisheries for oreo species were from all known oreo fishery areas in the southern FMAs in waters between 42° and 54° S (see Anderson 2011). Most of these coral data were collected in recent years from relatively new small fishery areas. In the area east of Pukaki Rise the fishery activity for orange roughy and black oreos was generally more intensive in this area during the last 10 years and at least one new fishery was established in the late 2000s (see Anderson & Dunn 2012, Anderson 2011).

Corals reported from fisheries targeting deepwater fishes included those with strong associations with seamounts (gorgonians and hydrocorals) (see Tables E1–E3). The stony corals caught in these fisheries were mainly branching corals in the "reef-like" group, with a relatively weaker response to seamount presence, as have black corals. All coral orders were represented in the bycatch from black cardinalfish tows in eastern waters between about 35° S and 41° 40' S in the main target fishery areas (Dunn & Bian 2009). The risk to corals from the black cardinalfish fishery is now greatly reduced following the substantial reduction in the Total Allowable Commercial Catch for this species.

Bottom longline fisheries also operate in areas where protected corals are found but the catch from these fisheries is not well understood. The coral catch from setnet fishing activity has highlighted another fishing method previously not associated with coral bycatch in New Zealand waters. The corals caught by this method are likely to have particular environment requirements that may differ from those further offshore in more oceanic water masses.

5 Recommendations for future research

The second objective of this project is to provide recommendations on any future research required to further improve the estimation of risk to protected corals from commercial fishing. To explore this and develop recommendations, we first describe some general background to risk estimation within New Zealand, provide some examples of possible assessment methods, and identify the information/data required. Informed by the Objective 1 work, we are able to provide recommendations on research to fill gaps in data and/or knowledge.

5.1 Risk assessment

Risk assessment has developed rapidly in recent years as a technique to support fisheries management (e.g., Francis & Shotton 1997, Fulton et al. 2005). There are many definitions of risk, and many approaches to risk assessment that relate to fisheries (e.g., Lackey 1994, Burgman 2005, IEC/ISO 2009). Some include social and economic aspects, but the majority focus on Ecological Risk Assessment (ERA) which is now increasingly recognised as part of routine fisheries assessment around the world (e.g., Suter 2006), including in New Zealand.

General assessment frameworks have been the most widely used in fisheries ERA (Rowden et al. 2008) and have been applied in New Zealand situations by Campbell & Gallagher (2007) for deepwater fisheries; Sharp et al. (2009) for Antarctic benthos; Parker (2008) for South Pacific High Seas fisheries; Rowe (2010), Baird & Gilbert (2010), and Richard et al. (2011) for seabird bycatch; Clark et al. (2011) for seamount habitat, and MacDiarmid et al. (2012) for a variety of New Zealand marine habitats.

Evaluation of ecological risk requires consideration of several aspects.

- Definition of risk in the relevant management context (i.e., risk to what from what).
- Clear management objectives, which enable appropriate parameters to be identified, and criteria assigned to determine risk threshold levels at the resolution required to inform management.
- An ERA framework under which various methods can be applied that are tailored to the particular situation.
- Adequate data to enable a sufficiently comprehensive and robust ERA.

A widely accepted definition is that risk is the chance of not achieving or meeting management objectives (e.g., ANZ Standards 2009, Hobday et al. 2011). This definition is recommended also by Clark et al. (submitted) in their development of a general approach and methodology for carrying out ERAs of New Zealand's deepwater fisheries. It ensures that the output from any ERA is directly useable by management agencies. Hence, early definition of clear management objectives is a critical element of planning for an ERA.

It is also important to know if there are specific threats to be considered. For example, if fishing is the main human activity then the risks that would be evaluated could differ from those assessed if the ERA was to include other threats such as seabed mining or climate change. In this project, commercial fishing is clearly the main activity that poses threats to protected corals, but in considering data and general methodology we also keep in mind the developing potential of seabed mining. Below we provide some discussion on two semi-quantitative approaches, and their associated data, that could be applied to determine relative risk to deepwater corals from commercial fishing.

The Ecological Risk Assessment for the Effects of Fishing (ERAEF) approach. This Australian approach detailed by Hobday et al. (2007, 2011) incorporates Productivity-Susceptibility-Analysis (PSA). This method was trialled successfully by Clark et al. (2011) who determined the relative risk to the benthic habitat of a group of New Zealand seamounts from bottom trawling for orange roughy. The “Habitat” component examined as the basis for this ERA was effectively biogenic habitat created by stony corals (*Solenosmilia variabilis* and *Madrepora oculata*) which formed reef-like structures on the summit and flank areas of the Graveyard complex of small seamount features on the northern Chatham Rise.

For this type of ERA, a number of variables are considered. These describe the susceptibility of the coral habitat to trawling and the productivity of the corals (effectively their resilience to impact). Four main factors are evaluated: Availability, Encounterability, Selectivity, and Productivity. Each has a series of attributes which provide the basis for setting criteria, thresholds, and risk scores. Some examples are given below.

Factor & attributes	**Relevant coral data**
Availability	
Spatial overlap	Overlap of fishery with habitat (geography and depth)
Level of current protection	Some areas are closed
Distance to port	Areas close to port will be more accessible for fishing
Encounterability	
Depth zone	Detailed depth zonation of corals
Geographical area	Detailed geographical distribution of corals
Ruggedness	Rough terrain may mean trawling is difficult and will not occur
Selectivity	
Removability/mortality of m morphotypes	Growth form of corals (erect, inflexible, delicate, rugose, etc.)
Reduction of faunal diversity	Species association with corals (high diversity with reef-forming, lower for solitary forms)
Special ecological value	Endemic or rare species
Biogenic habitat area	Areal extent of various biogenic taxa
Removability of substratum	
Substratum hardness	Soft substrate will not have high densities of certain coral taxa
Seabed slope	Higher levels of structural fauna and densities of filter-feeders in steep flank and summit areas
Productivity	
Regeneration of fauna	Recovery of fauna, based on intrinsic growth and reproductive rates
Natural disturbance	Shallow corals will be subject to storm events above 100 m. Deep corals near active seamounts may be subject to catastrophic events (though rarely)
Naturalness	Historic level of trawl impact
Proximity	Surrogate for connectivity if no genetic/larval dispersal information available
Export production to seafloor	Flux of organic matter to seafloor, reflecting production potential.

Where trawling has already taken place, damage to corals has occurred. Therefore it can be argued that risk of further damage is reduced and is lower than in areas where fishing has not disturbed the coral distribution. Clark et al. (2010a) showed that stony coral cover on the summit and upper flanks of seamounts can be considerably reduced after as few as 10 trawls. Clark & Tittensor (2010) developed a risk index that discounted risk where heavy trawling had already taken place. Their approach then assessed the relative risk of impact from fishing on seamounts that were largely unfished, combining the suitability of a seamount for trawling of target species (geography and depth of the fish) with the habitat suitability of the seamount for stony corals.

Many of these attributes can be estimated from existing datasets on the distributions of species and trawling effort. The habitat suitability modelling enables prediction of species distribution, though it is limited to presence/absence. More data on relative abundance and densities of coral taxa would enable improved prediction of high density areas which are likely to have a higher vulnerability to damage by trawling.

The list given above highlights the need for further research on a number of productivity parameters. Very little is known about recovery rates; previous surveys on the Graveyard seamounts suggest this is very slow (Williams et al. 2010). Research has been carried out in New Zealand on the bamboo corals (e.g., Tracey et al. 2007), but more work is required on the age and growth characteristics of most taxa, because these are generally poorly known (Mortensen & Bulhl-Mortensen 2005). Genetic connectivity, and the ability of damaged areas to be recolonized, is another key parameter.

Existing data can be used to highlight particular coral groups that may be less resilient to fishing pressure. Size and flexibility data can be used to assess the selectivity attribute of “removeability/mortality” which would immediately help inform an ERA. The table below, from Clark et al. (2010b) demonstrates the sort of expert judgement that can be applied.

Table 2 Examples of megabenthic taxa on seamounts that appear more resilient to trawling impacts

Taxon	Ecological traits and observations
Hydrocorals: *Stylaster* sp.[a] *Calyptopora reticulata*[b] *Lepidotheca fascicularis*[b]	Small size (≲100 mm height)[a,b]; many (most) species brood with possibly continuous or protracted spawning; possibly short-lived larvae; most slow growing [d], but some (emergent) species fast growing[c]; ubiquitous in survey areas[a,b]
Gold corals: *Chrysogorgia* spp.[a,f]	Small size (≲200 mm height), compact (bottle-brush), and flexible[c]
Chrysogordidae (undescribed species)[a]	Small size (≲300 mm height), whiplike, robustly stiff but flexible[c]; abundant on heavily fished seamount in 1997 and 2007 surveys[c]
Bryozoan: *Lagenipora* sp.[b]	Small encruster considered opportunistic in disturbed environments[b]
Anemone: ?Actinernidae[c]	Anemones have capacity for local-scale mass colonization by larvae or brooded juveniles; not colony forming but have propensity for clustered distributions in shallow water[f]; on a single heavily trawled seamount, uncommon in 1993 but highly abundant in 2008[c]

[a]F. Althaus, A. Williams, T.A. Schlacher, R.J. Kloser, M.A. Green, unpubl. paper; [b]Clark & Rowden 2009; [c]A. Williams (CSIRO), unpubl. data; [d]Brooke & Stone 2007; [e]Miller et al. 2003; [f]K. Gowlett-Holmes (CSIRO), pers. commun.

The New Zealand FERA. Carrying out a full PSA can be time-consuming, and potentially expensive. A simpler approach is possible using the method proposed by Clark et al. (submitted) and termed the New Zealand Fisheries Ecological Risk Assessment (NZ FERA). This method, like the ERAEF, assesses a separate ‘Habitats’ component, by evaluating the threats of fishing activities on habitat type and habitat structure and function categories. It uses data on coral distribution and productivity to determine risk on a 4-level scale. It is not as detailed as a PSA, yet focuses on the same key elements of risk from fishing. The two tables below give an idea of the type of decisions on which this ERA is based. Thresholds of change are determined in consultation with management agencies to ensure they are appropriate to meet the management objectives.

Subcomponent	Consequence Category Score			
	1	2	3	4
Habitat types	No detectable impact on spatial extent of habitat type since start of fishery activity under consideration (based on catch data and MEC/BOMEC where appropriate and/or defined spatial extent)	Spatial extent of impact on habitat type no more than X% since start of fishery activity under consideration (based on catch data and MEC/BOMEC where appropriate and/or defined spatial extent)	Spatial extent of impact on habitat type no more than XX% since start of fishery activity under consideration (based on catch data and MEC/BOMEC where appropriate and/or defined spatial extent)	Spatial extent of impact on habitat type more than XX% since start of fishery activity under consideration (based on catch data and MEC/BOMEC where appropriate and/or defined spatial extent)

Subcomponent	Consequence Category Score			
	1	2	3	4
Habitat structure & function	No detectable change to the internal dynamics of the habitat type.	Where the spatial scale of impact on Habitat Type scores 3, or 4, there will likely be a detectable impact on habitat structure and function. Time to recover to pre-disturbed state on the scale of days to months, regardless of spatial scale.	Where the spatial scale of impact on Habitat Type scores 3, or 4, there will likely be a detectable impact on habitat structure and function. Time to recover to pre-disturbed state on the scale of years to a decade, regardless of spatial scale.	Where the spatial scale of impact on Habitat Type scores 3, or 4, there will likely be a detectable impact on habitat structure and function. Time to recover to pre-disturbed state on the scale of decades, regardless of spatial scale.

5.2 Recommendations for future research to support a risk assessment

(1) Research to better understand the distribution of protected corals.

Update and maintain the protected coral dataset. The dataset should be updated annually from data collected by research surveys and observed commercial fisheries and be summarised to highlight new information. Accurate taxonomic identification of samples should be updated as often as possible.

Increase observer coverage. The only form of coral data collection available from commercial fisheries is through the observer programme. Increased observer coverage, especially for those methods with bottom contact (including bottom longline, setnet, and various trawl fisheries), is needed to accurately identify the depths, areas, and methods that result in coral bycatch.

Improve the quality of observer data. Collaboration with observers, for example in an annual workshop on coral identification and the value of the coral bycatch data (and as carried out previously with CSP), would provide an opportunity to improve protected coral data collection. Observers would benefit by being informed about how the data are used, and would improve their skills at identifying and collecting samples and by-catch data. A workshop would also provide researchers with information and feedback from observers that could also benefit data analyses and interpretation. Observer briefings similar to those used for CCAMLR observers could occur on a regular basis.

Improve identification of protected corals. Some coral genera may be geographically localised, whereas others are more widely distributed. Where corals are only broadly identified, this information is lost. For understanding the diversity of deepwater corals, and as an input to risk assessment, it is important to understand distributions at a more detailed taxonomic level.

In the full coral dataset in this study, there were 51 species identified in Order Anthoathecata, 33 in Order Antipatharia, 43 species of gorgonian corals in Order Alcyonacea, and 101 species identified in Order Scleractinia. Just over 85% of all coral records were identified to family, 56% to genus, and 33% to species. The level of identification to species level would increase if samples could be returned from observed fishing in the future.

Further, morphological and molecular description of samples that currently exist in the NIWA collection (and are represented in the protected coral dataset used for this study) would result in higher numbers of corals identified to a more detailed taxonomic level.

(2) Research to better understand coral biology.

Collect information on coral age and growth, and size and form. Additional age and growth studies of important habitat forming corals are required to allow some determination of productivity and thus some measure of recoverability. Currently, validated age and growth data for the region are available only for three protected coral species: two gorgonian corals and one branching stony coral (Tracey et al. 2007; Neil et al. in prep). There is a better, though patchy, understanding of the size and form of protected corals. This information helps to assess the availability and encounterability for a coral to damage from fishing gear, and the subsequent removeability or mortality. A coral sample collection programme using observers, and initially designed to focus on specific corals, would provide a valuable dataset on various biological parameters for analysis. This data collection would also provide samples for morphological and molecular descriptions (see above) and to understand the level of genetic connectivity (see below).

Review international literature with regard to biological parameters. A review of the international literature, with relevance to deepwater corals found in the New Zealand region, would summarise what is known about size, age, growth and reproductive capacity. A description of the habitat structure should also be provided within this review.

Connectivity is another critical aspect in understanding recoverability and recommendations from the review should also address this issue and the methods used such as genetics to determine links between corals in a particular area and “source” populations. Any current research within New Zealand could also be highlighted as part of this review.

Species associations. A revised sampling collection regime could provide a more holistic view of the value of corals as habitats by identifying species associations, for example, through sampling and identification of animals that are found in the matrix of stony corals (such as polychaetes (marine worms) and galatheids (squat lobsters)), or those wrapped around the skeleton of gorgonians (e.g., ophiuroids (brittle stars)).

(3) Additional environmental data layer useful for modelling the distribution of protected corals

Once the ocean ASH and CSH are defined under MPI Project ZBD201041 (completion date June 2013), the ocean climatology from the CSIRO Atlas of Regional Seas (CARS) database can be used to produce detailed map layers of the aragonite and calcite saturation horizon states for use in further prediction modelling.

6 Acknowledgements

We thank the government observers and science researchers for their ongoing sample collection. We thank MPI for the use of observer data and of the trawl footprint (with thanks to J. Black of GNS for provision of the 20-year footprint layer). We acknowledge that many government- and industry-funded programmes have provided the coral data used here. Leverage from MPI-funded projects contributed to the data extracts (Projects ZBD201040, ZBD201041). Coral data and station data were extracted by NIWA colleagues: Kareen Schnabel (*Specify*), Brian Sanders (*cod*), Brent Wood (*trawl, biods*), and Kevin Mackay (*AllSeaBio*), and Fred Wei (*marineDB*). Tanya Compton provided the data layers prepared as part of the CO1X0028, CO1X0224 programmes and we thank her for these and for her initial advice.

Thanks also to NIWA colleagues Mark Hadfield, James Sturman, Helen Bostock, and Brent Wood for expert advice and support and Ashley Rowden and Matthew Dunn for helpful comments and review of the final document. The funding for this work was from the Department of Conservation (Project DOC12303/ POP2011-06).

7 References

Abraham,E.R.; Thompson, F.N. (2011). Summary of the capture of seabirds, marine mammals, and turtles in New Zealand commercial fisheries, 1989–99 to 2008–09. *New Zealand Aquatic Environment and Biodiversity Report No. 80.* 170 p.

Anderson, O.F (2011). Descriptions of the black oreo and smooth oreo fisheries in OEO 1, OEO 3A, OEO 4, and OEO 6 from 1977–78 to 2009–10.*New Zealand Fisheries Assessment Report 2011/55*. 92 p.

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.

Baird, S.J.; Gilbert, D.J. (2010). Initial assessment of risk posed by trawl and longline fisheries to selected seabird taxa breeding in New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report No. 50*. 99 p.

Baird, S.J.; Wood, B.A.(2012). Extent of coverage of 15 environmental classes within the New Zealand EEZ by commercial trawling with seafloor contact. *New Zealand Aquatic Environment and Biodiversity Report No.89*. 43 p.

Baird, S.J.; Wood, B.A.; Bagley, N.W. (2011). Nature and extent of commercial fishing effort on or near the seafloor within the New Zealand 200 n. mile Exclusive Economic Zone, 1989–90 to 2004–05. *New Zealand Aquatic Environment and Biodiversity Report No. 73.* 46 p plus appendices.

Ballara, S.L.; O’Driscoll, R.L. (2012). Catches, size, and age structure of the 2010–11 hoki fishery, and a summary of input data used for the 2012 stock assessment. *New Zealand Fisheries Assessment Report 2012/23.* 117 p.

Bowden, D.A. (2011). Benthic invertebrate samples and data from the Ocean Survey 20/20 voyages to Chatham Rise and Challenger Plateau, 2007. *New Zealand Aquatic Environment and Biodiversity Report No.65*. 46 p.

Burgman, M.A. (2005). *Risks and decisions for conservation and environmental management*. Cambridge University Press, Cambridge, UK. 488 p.

Cairns, S.D. (1991). The Marine Fauna of New Zealand: Stylasteridae (Cnidaria: Hydroida). *New Zealand Oceanographic Institute Memoir 98*. 179 p.

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

Cairns, S.D.; Bayer, F.M. (2005). A review of the Genus *Primnoa* (Octocorallia;Gorgonacea: Primnoidae), with the description of two new species. *Bulletin of Marine Science, 77(2):* 225-256.

Cairns, S.D.; Bayer, F.M. (2009). A generic revision and phylogenetic analysis of the Primnoidae (Cnidaria: Octocorallia). Smithsonian Contributions to Zoology No. 629. 79 p.

Caldeira, K.; Wickett, M.E. (2003). Anthropogenic carbon and ocean pH. *Nature 425*: 365.

Campbell, M.L.; Gallagher, C. (2007). Assessing the relative effects of fishing on the New Zealand marine environment through risk analysis. *ICES Journal of Marine Science 64*: 256–270.

CANZ (2008). New Zealand Region Bathymetry, 1:4 000 000, 2nd Edition. NIWA Chart, Miscellaneous Series No. 85.

Clark, M.R.; Bowden, D.A.; Baird, S.J.; Stewart, R. (2010a). Effects of fishing on the benthic biodiversity of seamounts of the “Graveyard” complex, northern Chatham Rise. *New Zealand Aquatic Environment and Biodiversity Report No. 46.* 40 p.

Clark, M.R.; Rowden, A.A.; Schlacher, T.; Williams, A.; Consalvey, M.; Stocks, K.I.; Rogers, A.D.; O’Hara, T.D.; White, M.; Shank, T.M.; Hall-Spencer, J. (2010b) The ecology of seamounts: structure, function, and human impacts. *Annual Review of Marine Science 2*: 253–278.

Clark, M.R.; Tittensor, D.P. (2010). An index to assess the risk to stony corals from bottom trawling on seamounts. *Marine Ecology 31(suppl 1)*: 200–211.

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 submitted to MPI as part of DEE201004.

Clark, M.; O'Driscoll, R. (2003). Deepwater fisheries and aspects of their impact on seamount habitat in New Zealand. *Journal of Northwest Atlantic Fishery Science 31*: 441–458.

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

Davies, A.J.; Guinotte, J.M. (2011). Global habitat suitability for framework-forming cold-water corals. *PLoS ONE* 6(4): e18483. doi:10.1371/journal.pone.0018483.

De'ath, G. (2007). Boosted trees for ecological modeling and prediction. *Ecology 88(1)*: 243–251.

De'ath, G.; Fabricius, K.E. (2000). Classification and regression trees: a powerful yet simple technique for ecological data analysis. *Ecology 81(11)*: 3178–3192.

Dodds, L.A.; Roberts, J.M.; Taylor, A.C.; Marubini, F. (2007). Metabolic tolerance of the cold-water coral *Lophelia pertusa* (Scleractinia) to temperature and dissolved oxygen change. *Journal of Experimental Marine Biology and Ecology 349*: 205–214.

Duineveld, G.C.A.; Lavaleye, M.S.S.; Berghuis, E.M. (2004). Particle flux and food supply to a seamount cold-water coral community Galicia Bank, NW Spain. *Marine Ecology Progress Series 277*: 13–23.

Dunn, M.R.; Bian, R. (2009). Analysis of catch and effort data from New Zealand black cardinalfish (*Epigonus telescopus*) fisheries to the end of the 2007–08 fishing year. *New Zealand Fisheries Assessment Report 2009/40.* 53 p.

Elith, J.; Leathwick, J.R. (2009). Ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics 40*: 677–697.

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.

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

Elith, J.; Phillips, S.J.; Hastie, T.; Dudik. M.; Chee, Y.E.; Yates, C.J. (2011). A statistical explanation of MaxEnt for ecologists**.** *Diversity and Distributions 17*: 43–57.

ESRI (2011). ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Etnoyer, P.; Morgan, L.E. (2005) Habitat forming deep-sea corals in the Northeast Pacific Ocean, pp. 331–343, *in* Freiwald, A., Roberts, J.M. (eds) Cold-water corals and ecosystems. Springer-Verlag,Heidelberg,

Fosså, J.H.; Mortensen, P.B.; Furevik, D.M. (2002). The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. *Hydrobiologia 471*:1–12.

Francis, R.I.C.C.; Shotton, R. (1997). "Risk" in fisheries management: a review. C*anadian Journal of Fish and Aquatic Sciences 54*: 1699–1715.

Fulton, E.A.; Smith, A.D.M.; Punt, A.E. (2005). Which ecological indicators can robustly detect effects of fishing? *ICES Journal of Marine Science 62*: 540–551.

Gass, S.E.; Roberts, J.M. (2006). The occurrence of the cold-water coral *Lophelia pertusa* (Scleractinia) on oil and gas platforms in the North Sea: Colony growth, recruitment and environmental controls on distribution. *Marine Pollution Bulletin 52*: 549–559.

Genin, A.; Dayton, P.K.; Lonsdale, P.F.; Spiess, F.N. (1986). Corals on seamount peaks provide evidence of current acceleration over deep-sea topography. *Nature 322*: 59–61.

Guinan, J.; Brown, C.; Dolan, M.F.J.; Grehan, A.J. (2009**).** Ecological niche modelling of the distribution of cold-water coral habitat using underwater remote sensing data. *Ecological Informatics 4*: 83–92.

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 deep-sea scleractinian corals? *Frontiers in Ecology and the Environment 4*: 141–146.

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.

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. *Fisheries Research 108(2–3)*: 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

IEC/ISO International Standard (2009). Risk management-risk assessment techniques. IEC/ISO 31010: 2009. IEC, Switzerland. 90 p. (English and French available).

Kogan, I.; Paull, C.K.; Kuhnz, L.; Burton, E.J.; Von Thun, S.; Greene, H.G.; Barry, J.P. (2003) Environmental impact of the ATOC/Pioneer seamount submarine cable. Report prepared by the Monterey Bay Aquarium Research Institute (MBARI) in partnership with the National Oceanic and Atmospheric Administration - Oceanic and Atmospheric Research (NOAA-OAR) and National Ocean Service (NOAA-NOS). 84 p. Available online at http://montereybay.noaa.gov/research/techreports/cablesurveynov2003.pdf.

Lackey, R.T. (1994). Ecological risk assessment. *Fisheries 19(9)*: 14–19.

Leathwick, J.R.; Dey, K.; Julian, K. (2006). Development of a marine environment classification optimised for demersal fish.NIWA Client report HAM2006-063 prepared for the Department of Conservation. 21 p.

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.; Rowden, A.; Nodder, S.; Gorman, R.; Bardsley, S.; Pinkerton, M.; Baird, S.J.; Hadfield, M.; Currie, K.; Goh, A. (2012). A Benthic-optimised Marine Environment Classification (BOMEC) for New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report No. 88*. 54 p.

Lehmann, A.; Overton, J.M.; Leathwick, J.R. (2002). GRASP: generalized regression analysis and spatial prediction. *Ecological Modelling 157*: 189–207.

Levin, L.;A.; Etter, R.J.; Rex, M.A.; Gooday, A.J.; Smith, C.R.; Pineda, J.; Stuart, C.T.; Hessler, R.R.; Pawson, D. (2001). Environmental influences on regional deep-sea species diversity. *Annual Review of Ecology and Systematics 32*: 51–93.

MacDiarmid, A. A.; McKenzie, A.; Sturman, J.; Beaumont, J.; Mikaloff-Fletcher, S.; Dunne, J. (2012). Assessment of Anthropogenic Threats to New Zealand Marine Habitats. *New Zealand Aquatic Environment and Biodiversity Report No. 93*. 255 p.

Mackay, K.A. (2007). Database documentation: seamount. NIWA Internal Report available from the NIWA library in Wellington. 42 p.

Mackay, K.; Bostock, H. Tracey, D.M.; Rowden, A.A. (submitted). Revisiting "Squires' Coral Coppice", Campbell Plateau, New Zealand". Deep-Sea Research Part I.

Miller, R.J.; Hocevar, J.; Stone, R.P.; Fedorov, D.V. (2012). Structure-forming corals and sponges and their use as fish habitat in Bering Sea submarine canyons. *PloS ONE 7(3)*: e33885.doi:10.1371/journal.pone.0033885.

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.

Mortensen, P.B.; Buhl-Mortensen, L. (2005). Deep-water corals and their habitats in The Gully, a submarine canyon off Atlantic Canada, pp. 247–277, *in* Freiwald, A., Roberts, J.M. (eds). Cold-water Corals and Ecosystems. Springer-Verlag Berlin Heidelberg.

Mortensen P.B., Buhl-Mortensen, L.; Gebruk, A.V.; Krylovab, E.M. (2008). Occurrence of deepwater corals on the Mid-Atlantic Ridge based on MAR-ECO data. *Deep-Sea Research Part II 55*: 142–152.

Neil, H.; Tracey, D.; Clark, M.; Marriott, P. (in prep). Age and growth of habitat-forming *Solenosmilia variabilis* – an assessment of recovery potential.

Opresko, D.M. (1972). Redescriptions and reevaluation of the Antipatharians described by L.F. de Pourtalès. *Biological Results of the University of Miami Deep-Sea Expeditions 97*: 950–1015.

Palialexis, A.; Georgakarakos, S.; Karakassis, I.; Lika, K.; Valavanis, V.D. (2011). Prediction of marine species distribution from presence-absence acoustic data: comparing fitting efficiency and the predictive capacity of conventional and novel distribution models. *Hydrobiologia 670*: 241–266.

Parker, S. (2008). Development of a New Zealand High Seas bottom fishery impact assessment standard for evaluation of fishing impacts to vulnerable marine ecosystems in the South Pacific Ocean. Final Research Report to Ministry of Fisheries for project IFA2007-04. Objectives 3 and 4. (unpublished report held by Ministry of Fisheries).

Parker, S.J.; Penney, A.J.; Clark, M.R. (2009). Detection criteria for managing trawl impacts to Vulnerable Marine Ecosystems in high seas fisheries of the South Pacific Ocean. *Marine Ecology Progress Series 397*: 309–317.

Phillips, S.J.; Anderson, R.P.; Schapire, R.E. (2006). Maximum entropy modeling of species geographic distributions**.** *Ecological Modelling 190*: 231–259.

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.

Pinkerton, M.H.; Smith, A.N.H.; Raymond, B.; Hosie, G.W.; Sharp, B.; Leathwick, J.R.; Bradford-Grieve, J.M. (2010). Spatial and seasonal distribution of adult *Oithona similis* in the Southern Ocean: predictions using boosted regression trees. *Deep-Sea Research Part 1 57*: 469–485.

R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. http://www.R-project.org.

Reveillaud, J.; Freiwald, A.; Van Rooij, D.; Le Guilloux, E.; Altuna, A.; Foubert, A.; Vanreusel, A.; Olu, K.; Henriet, J. (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.

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.

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 No. 27.* 50 p.

Rowden, A.A.; Clark, M.R. (2010). Benthic biodiversity of seven seamounts on the southern end of the Kermadec volcanic arc, northeast New Zealand. *New Zealand Aquatic Environment and Biodiversity Report No. 62.* 31 p.

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.

Sharp, B.R.; Parker, S.J.; Smith, N. (2009). An impact assessment framework for bottom fishing methods in the CCAMLR Convention Area. *CCAMLR Science 16*: 195–210.

Squires, D.F. (1965) . Deep water coral structure on the Campbell Plateau, New Zealand. *Deep-Sea Research 12(6)*: 785–788.

Stone, R.P. (2006). Coral habitat in the Aleutian Islands of Alaska: depth distribution, fine-scale species associations, and fisheries interactions. *Coral Reefs 25*: 229–38.

Swets, J. A. (1986). Indices of discrimination or diagnostic accuracy: Their ROCs and implied models. *Psychological Bulletin 99*: 100–117.

Suter, G.W. (ed) (2006). Ecological risk assessment. 2nd edition. CRC Press/Taylor & Francis. 643 p.

Thiem, Ø.; Ravagnan, E.; Fosså, J.H.; Bersten, J. (2006) Food supply mechanisms for coldwater corals along a continental shelf edge. *Journal of Marine Systems 60*: 207–219.

Thistle, D. (2003). The deep-sea floor: an overview. *In* Tyler, P.A. (ed.), Ecosystems of the World 28. Elsevier Science pp. 5–37.

Tittensor, D.P.; Baco, A.R.; Brewin, P.E.; Clark, M.R.; Consalvey, M.; Spencer, J.H.; Rowden, A.A.; Schlacher, T.; Stocks, K.I.; Rogers, A.D. (2009) Predicting global habitat suitability for stony corals on seamounts. *Journal of Biogeography 36(6)*: 1111–1128.

Tracey, D.; Mackay, E.; Gordon D.; Sanchez, J.; Opresko, D. (2008). A Guide to Deepsea Coral. Report prepared for CSP Unit, Department of Conservation, DOC08309 Project (Objective 3). 15 p.

Tracey, D.M.; Anderson, O.F.; Naylor, J.R. (Comps.) (2011a). A guide to common deepsea invertebrates in New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report No. 86.* 317 p.

Tracey, D.; Baird, S.J.; Sanders, B.M.; Smith, M.H. (2011b). 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.; Neil, H.; Marriott, P.; Andrews, A.H.; Cailliet, G.M.; Sanchez, J.A. (2007). Age and growth of two genera of deep-sea bamboo corals (Family Isididae) in New Zealand waters. Bulletin of Marine Science 81: 393–408.

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

Tuck, I. (2009). Characterisation of scampi fisheries and the examination of catch at length and spatial distribution of scampi in SCI 1, 2, 3, 4A, and 6A. *New Zealand Fisheries Assessment Report 2009/27.* 102 p.

Turley, C.M.; Roberts, J.M.; Guinotte, J.M. (2007). Corals in deepwater: Will the unseen hand of ocean acidification destroy cold-water ecosystems? *Coral Reefs 26*: 445–448.

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

Watling, L.; Gerken, S. (2005). The Cumacea of the Faroes Islands region: water mass relationships and North Atlantic biogeography*. BIOFAR Proceedings 2005:* 137–149.

Williams, A.; Schlacher, T.A.; Rowden, A.A.; Althaus, F.; Clark, M.R.; Bowden, D.A.; Stewart, R.; Bax, N.J.; Consalvey, M.; Kloser, R.J. (2010) Seamount megabenthos assemblages fail to recover from trawling impacts. *Marine Ecology 31 (supp 1)*: 183–199.

Appendix A Images showing structure of corals by functional group

Figure A1: "Reef-like" branching stony corals *in situ*. Left, *Solenosmilia variabilis*; right, *Madrepora oculata*.

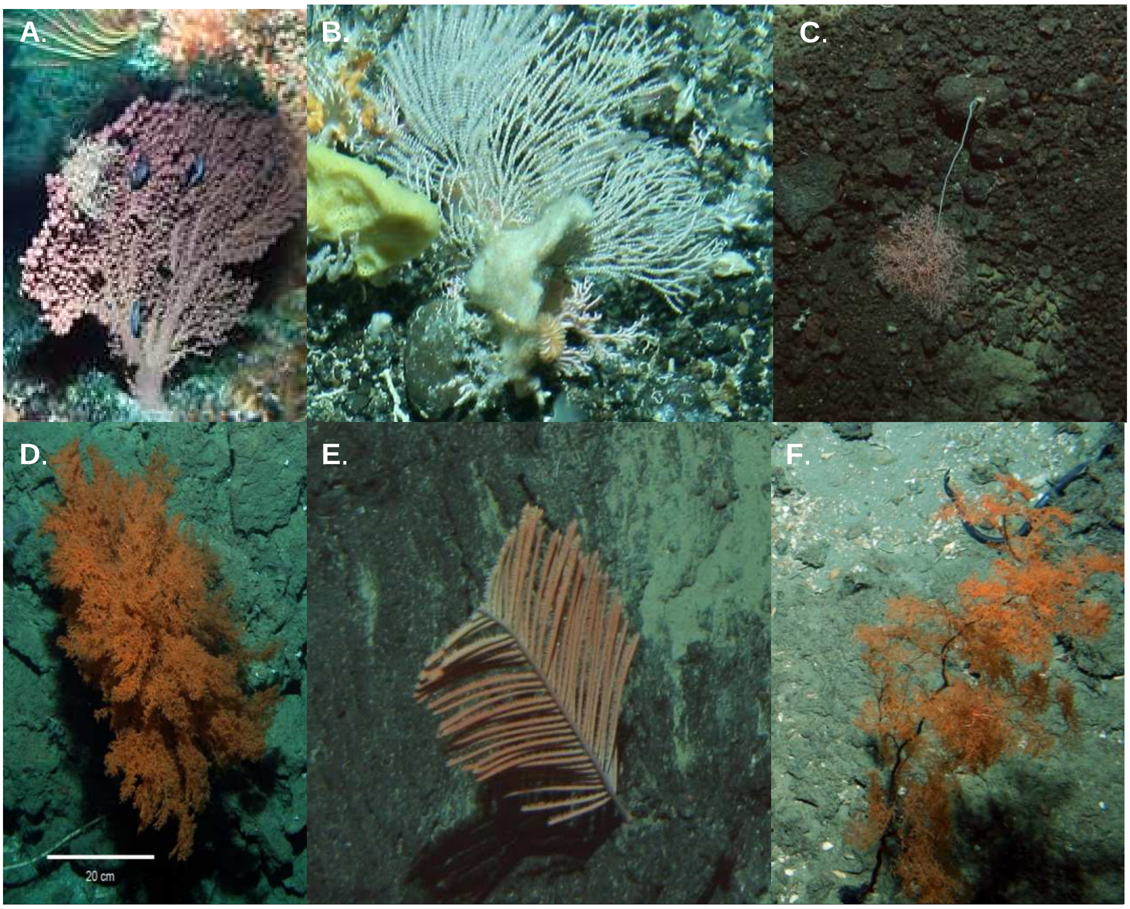

Figure A2: "Tree-like" corals. Upper left to right: gorgonian corals *in situ* — A. *Paragorgia arborea*, bubblegum coral; B. *Callogorgia* spp., primnoid sea fan; C. *Metallogorgia* spp., golden coral. Lower left to right: black corals *in situ* — D. *Antipathes* spp.; E. *Bathypathes* spp.; and F. *Leiopathes* spp.

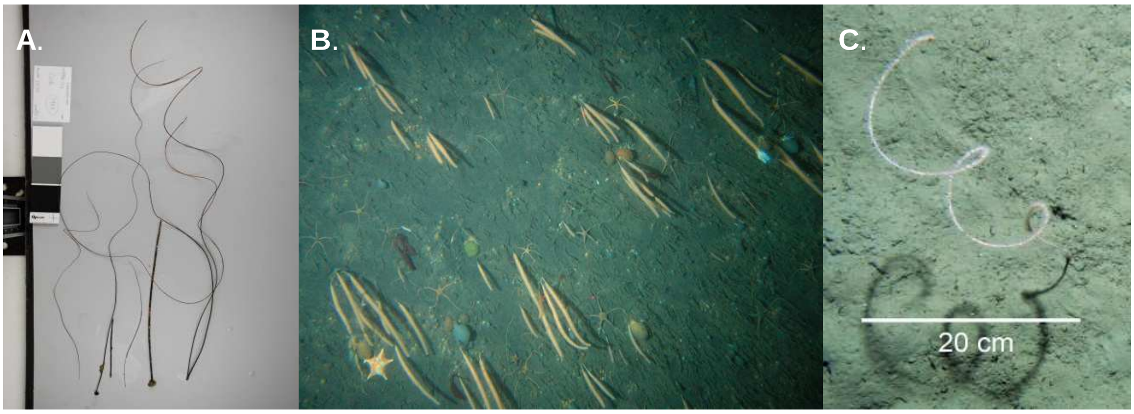

Figure A3: "Whip-like" corals. A. black coral *Stichopathes* spp., and *in situ* B. numerous *Primnoella* spp. gorgonian corals and C. golden coral *Radicipes* spp.

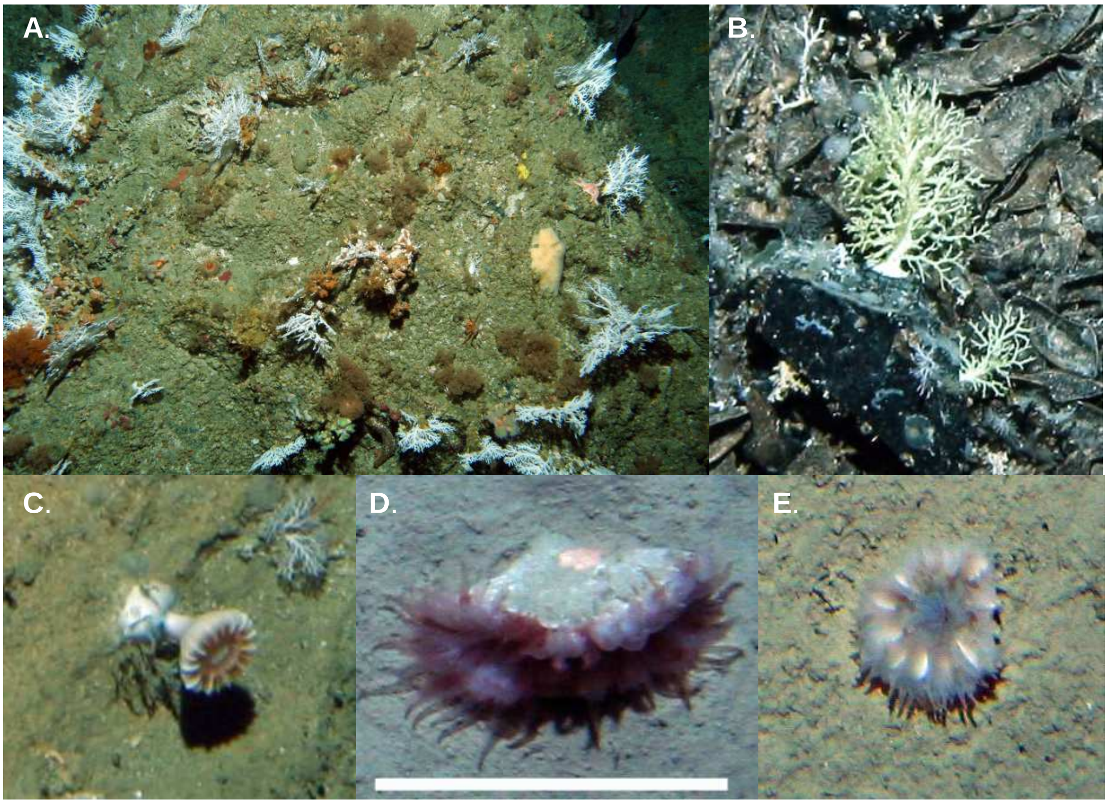

Figure A4: "Solitary small" corals (that sometimes exist in clumps). Small hydrocorals and cup corals *in situ*. Top left to right, stylasterid hydrocorals A.*Calyptopora* spp. and B. *Lepidotheca* spp. Bottom left to right, cup corals C. *Caryophyllia* spp., D. *Flabellum knoxi*, and E. *Stephanocyathus* spp.

Appendix B Derivation and distribution of environmental variables

Table B1: Brief description of environmental data layers (from Tracey et al. 2011b). Abbreviations used in relevant figures are given in italics.

Variable	Description and data source	Units	Reference
Depth *depth*	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 *seamount*	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 *disorg*	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.	*a*DOM (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 *tempres*	Residuals from a GLM relating bottom water temperatures to depth using natural splines.	–	CARS (2009); Leathwick et al. (2012)
Tidal current speed *tidal*	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.	$^{o}C\ km^{-1}$	Uddstrom & Oien (1999), Hadfield et al.
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)

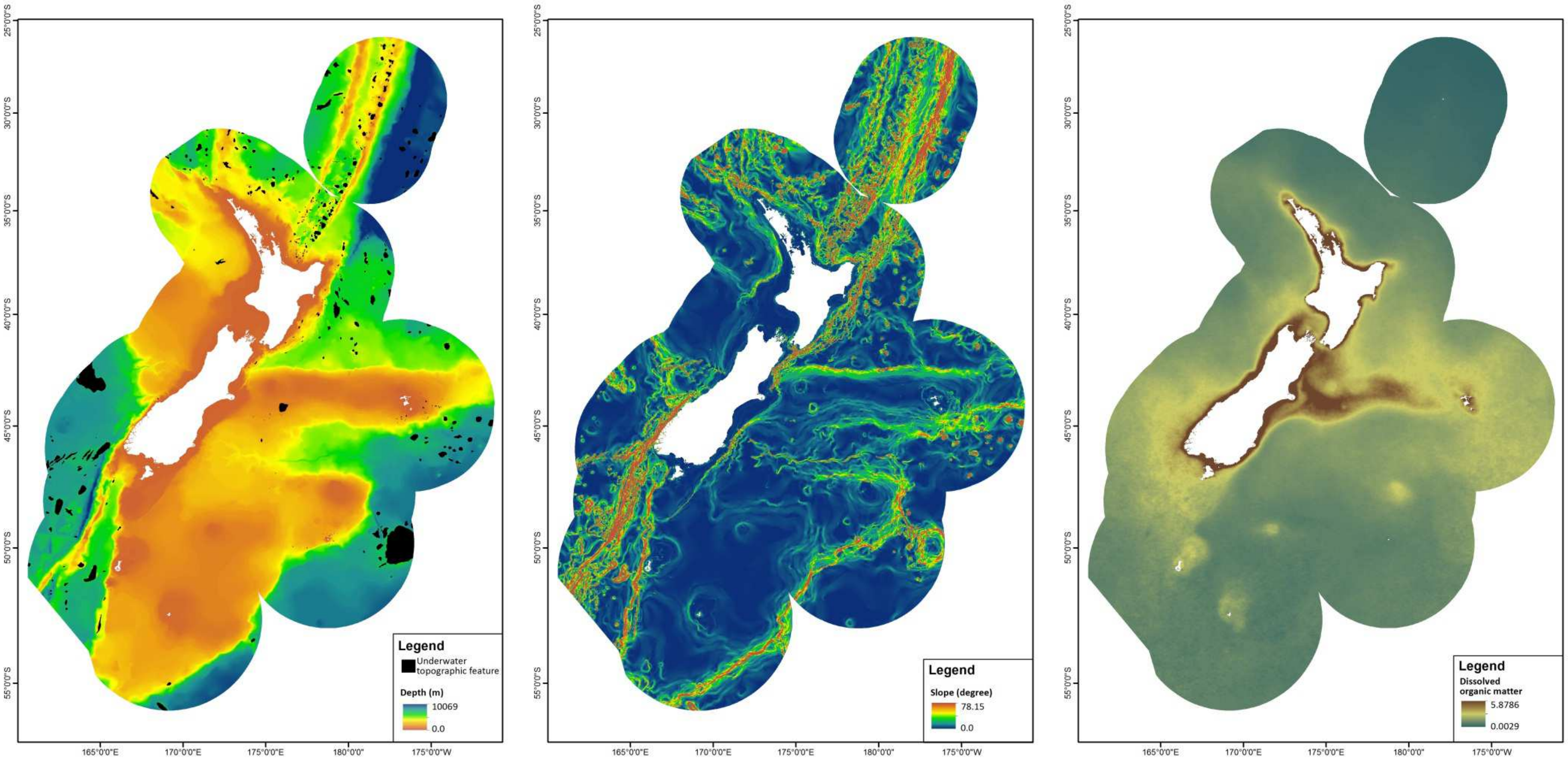

Figure B1: Distribution of environmental layers (on a 250 x 250 m grid) used in the predictive modelling: depth (m) and location of underwater topographic features (left), slope (°) (centre), and dissolved organic matter ($^{a}_{DOM}$ (443) m^{-1}) (right).

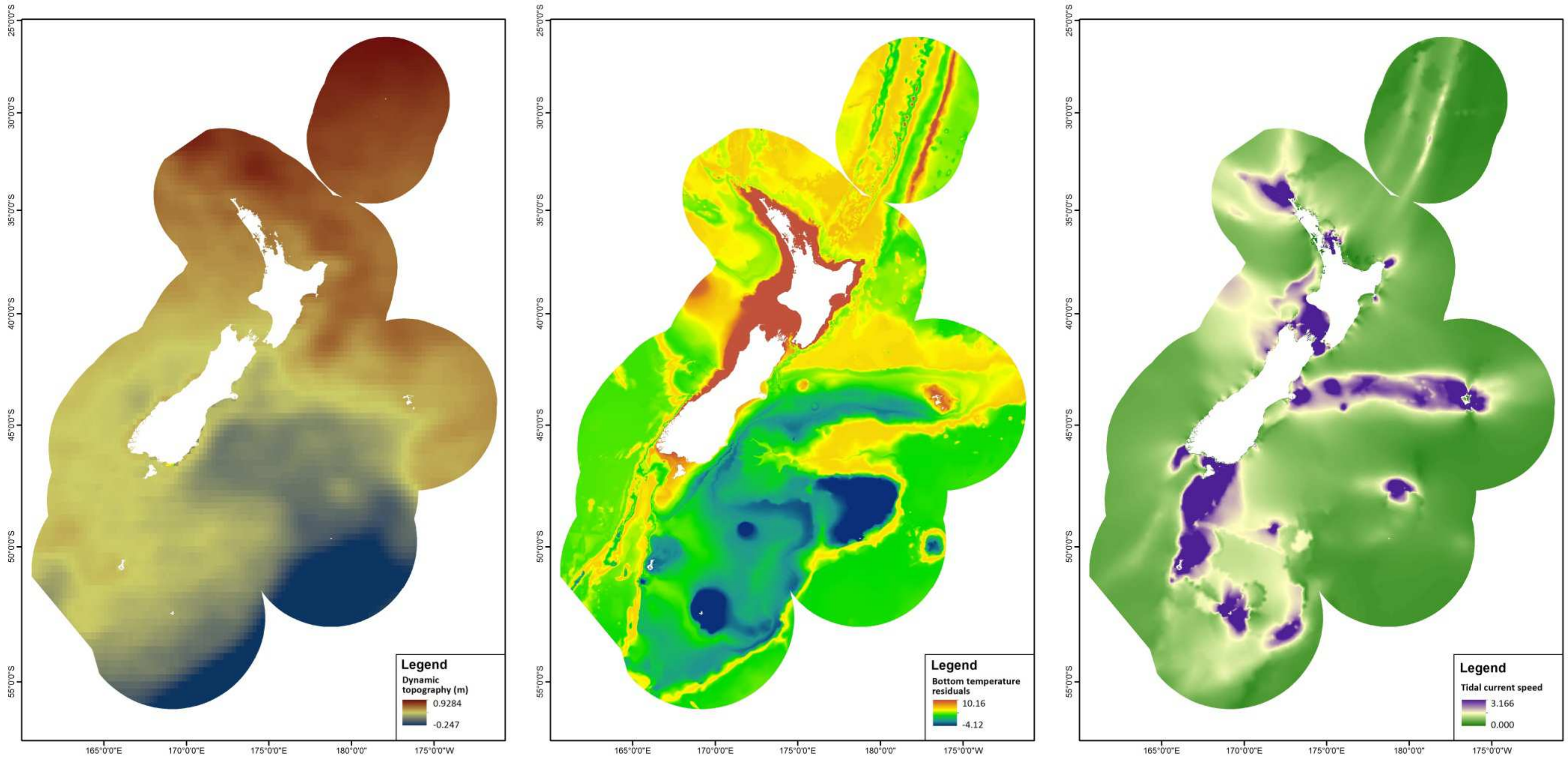

Figure B2: Distribution of environmental layers (on a 250 x 250 m grid) used in the predictive modelling: dynamic topography (m) (left), bottom water temperature residuals (centre), and tidal current speed (m s^{-1}) (right).

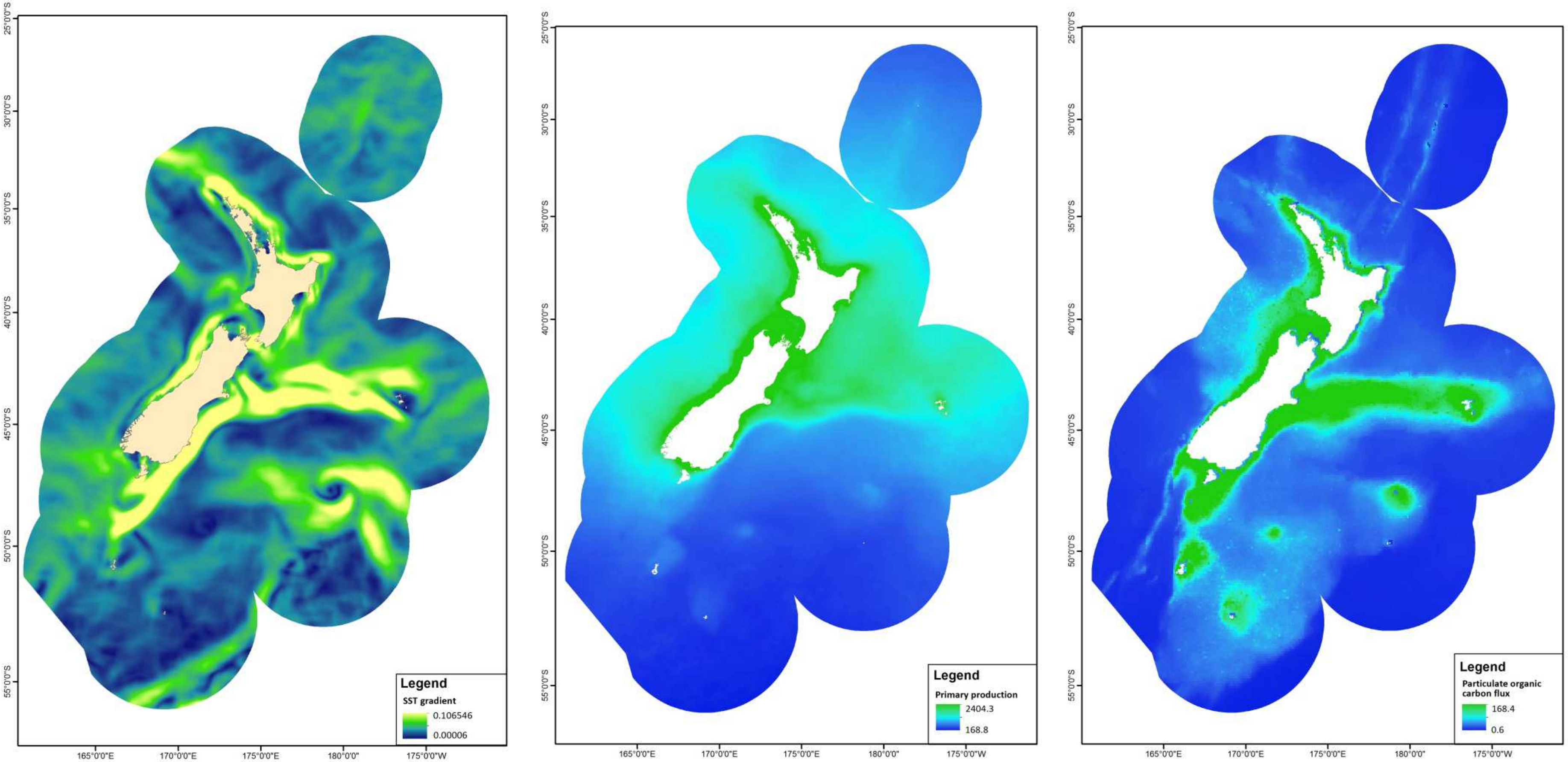

Figure B3: Distribution of environmental layers (on a 250 x 250 m grid) used in the predictive modelling: SSTgradient ($^{o}C\ km^{-1}$) (left), surface water ductivity ($mg\ C\ m^{-2}\ d^{-1}$) (centre), and particulate organic carbon flux ($mg\ C_{org.}m^{-2}\ d^{-1}$) (right).

Appendix C Protected coral distribution

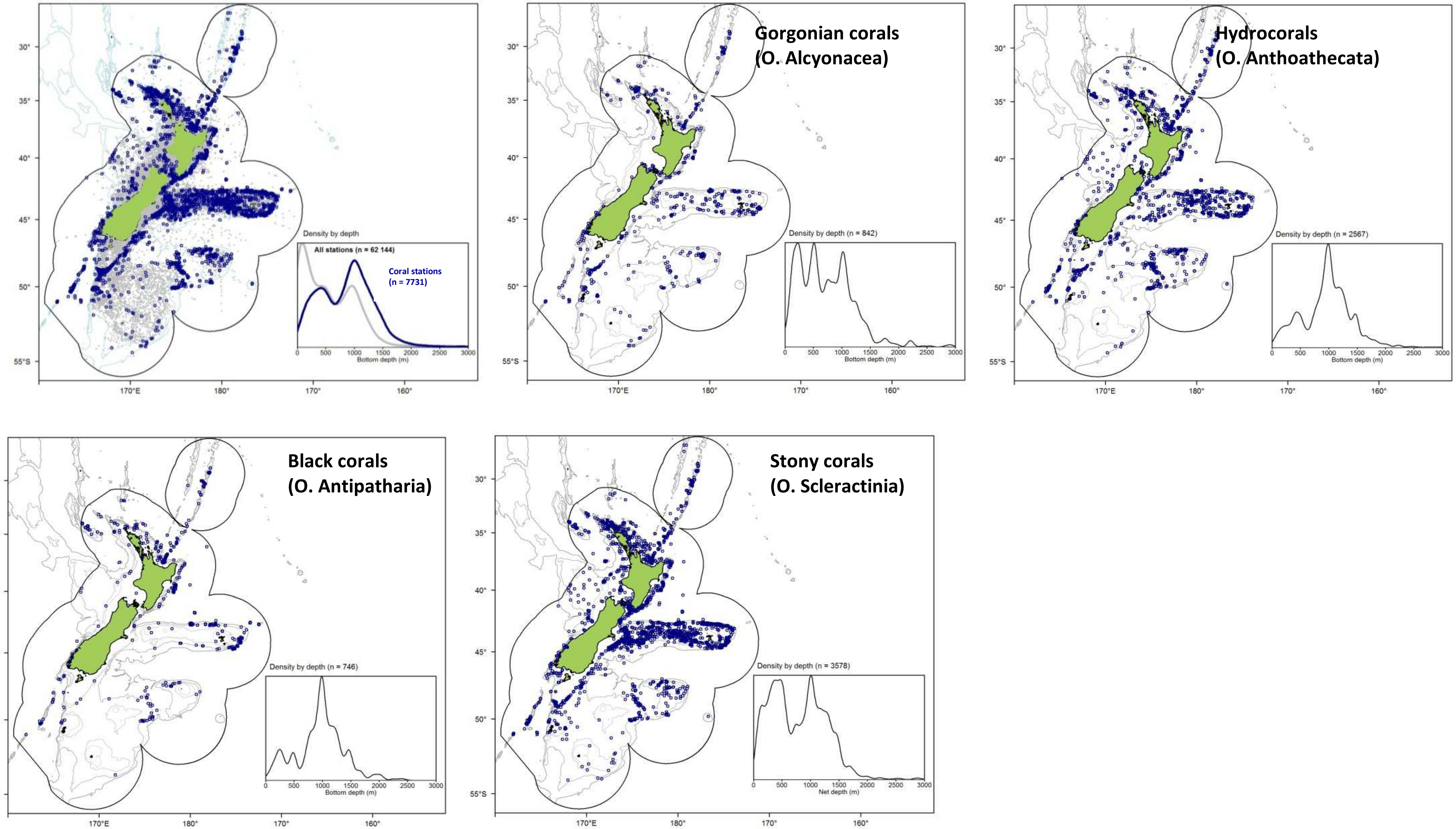

Figure C1: Location of benthic stations (■) and coral records (○) and their depth distribution (top left), and locations of coral records by the four protected orders, within the New Zealand 200 n. mile EEZ. The 500 m, 1000 m, and 1500 m depth contours are shown.

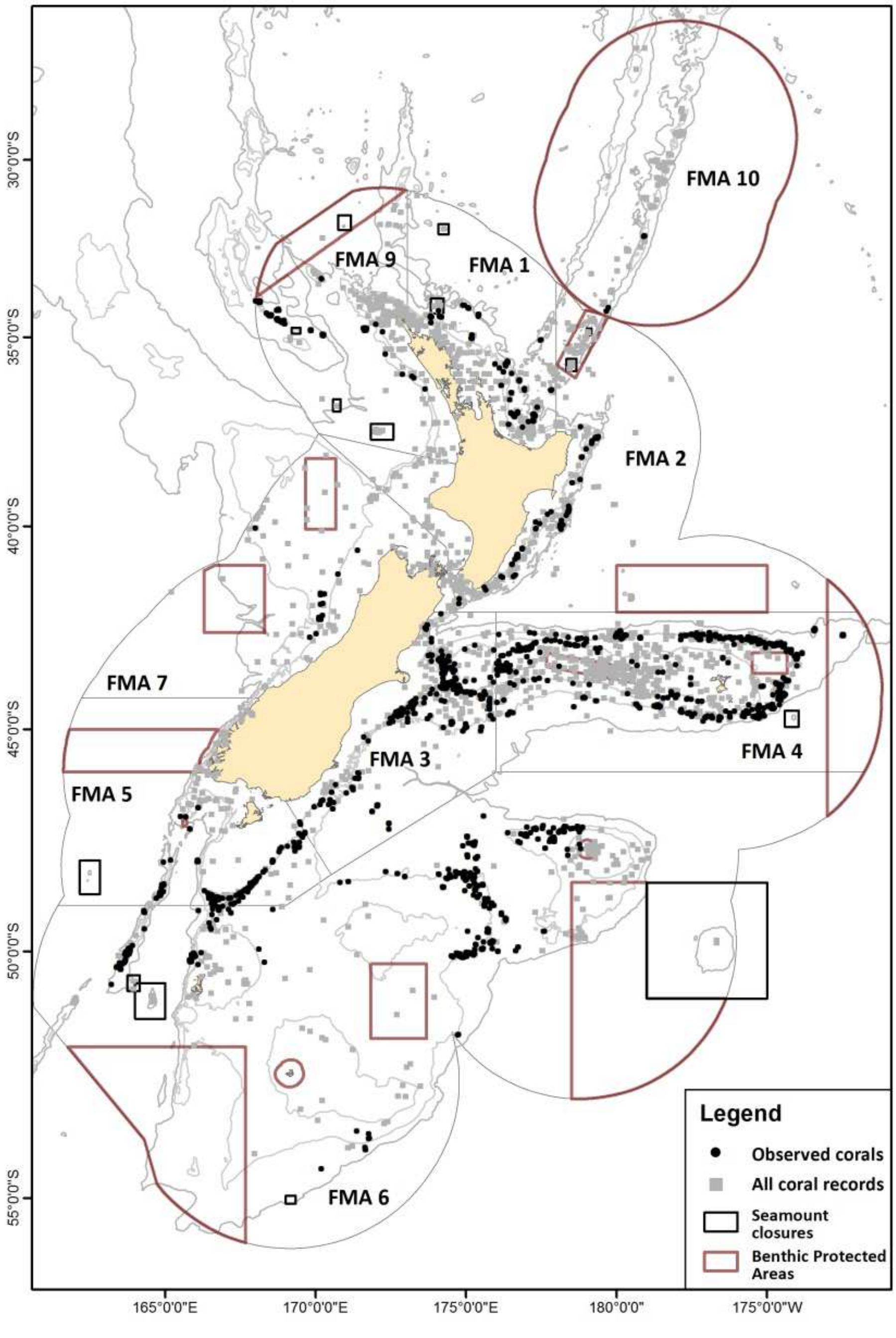

Figure C2: Location of protected coral records within the New Zealand 200 n. mile EEZ. The map shows the 10 Fishery Management Areas (FMAs) within the EEZ, the fishery closures relevant to seafloor contact, and the 500 m, 1000 m, and 1500 m depth contours.

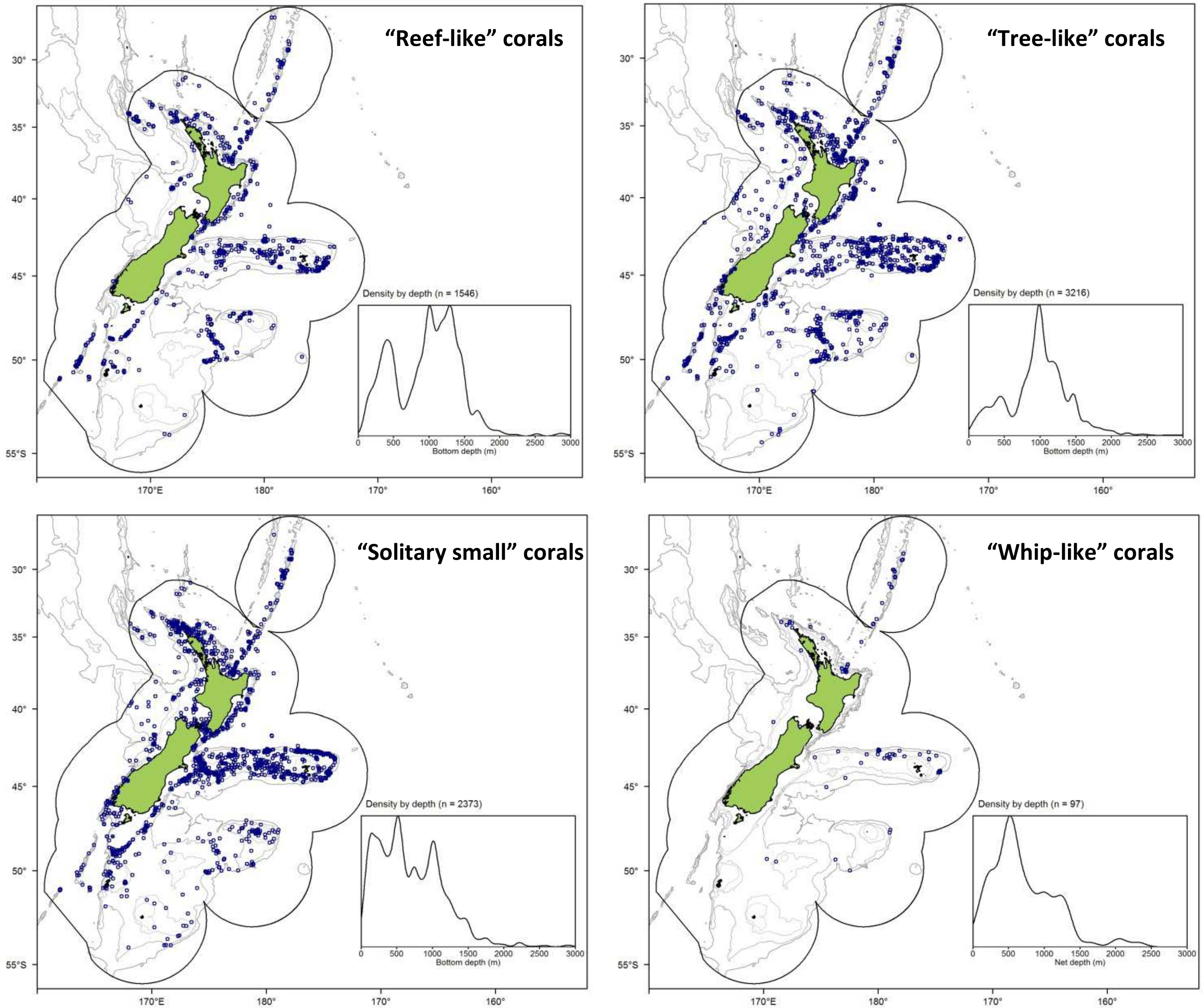

Figure C3: Location of coral records (○) and their depth distribution, within the New Zealand 200 n. mile EEZ, by the four functional groups. The 500 m, 1000 m, and 1500 m depth contours are shown.

Table C1: Number of records of protected corals in the full dataset (*n* = 7731 records), by family in each of the four protected coral orders, by Fishery Management Area within the New Zealand 200 n. mile EEZ (see Figure C2).

	Fishery Management Areas										
	1	2	3	4	5	6	7	8	9	10	All
Order Alcyonacea (previously Order Gorgonacea)											
Acanthogorgiidae	10	19	2	21	3	8	5	2	3	14	87
Anthothelidae	–	–	–	–	1	–	–	–	–	–	1
Chrysogorgiidae	66	25	10	28	3	38	3	–	44	3	220
Coralliidae	15	12	2	7	1	17	–	–	2	21	77
Ellisellidae	1	–	–	–	–	–	–	–	–	–	1
Isididae	175	59	34	184	25	182	19	–	120	9	807
Paragorgiidae	8	8	14	43	6	98	–	–	19	1	197
Plexauridae	21	38	2	15	3	26	3	–	7	15	130
Primnoidae	81	64	21	219	22	107	6	–	58	33	611
Unknown	33	45	41	125	44	66	21	7	34	19	435
All	410	270	126	642	108	542	57	9	287	115	2566
% total by FMA	16.0	10.5	4.9	25.0	4.2	21.1	2.2	0.4	11.2	4.5	100.0
Order Anthoathecata											
Stylasteridae	82	84	39	232	78	177	15	1	94	40	842
All	82	84	39	232	78	177	15	1	94	40	842
% total by FMA	9.7	10.0	4.6	27.6	9.3	21.0	1.8	0.1	11.2	4.8	100.00
Order Antipatharia											
Antipathidae	36	2	–	2	1	–	2	–	4	23	70
Aphanipathidae	–	–	–	–	–	–	–	–	–	7	7
Cladopathidae	5	7	–	4	4	1	–	–	1	–	22
Leiopathidae	38	16	–	33	2	3	–	–	22	1	115
Myriopathidae	4	–	2	2	–	–	–	–	–	16	24
Schizopathidae	41	40	1	45	4	32	–	1	12	2	178
Stylopathidae	24	6	–	16	–	1	1	–	2	4	54
Unknown	60	39	4	72	14	32	5	3	47	–	276
All	208	110	7	174	25	69	8	4	88	53	746
% total by FMA	27.9	14.7	0.9	23.3	3.4	9.2	1.1	0.5	11.8	7.1	100.0
Order Scleractinia											
Agariciidae	–	–	–	–	–	–	–	–	–	3	3
Anthemiphylliidae	–	–	–	–	–	–	–	–	–	2	2
Caryophylliidae	174	210	69	719	89	294	54	16	249	60	1934
Dendrophylliidae	59	18	5	50	11	39	13	–	21	34	250
Flabellidae	62	67	182	108	27	39	23	21	42	16	587
Fungiacyathidae	2	5	–	–	–	–	1	–	1	4	13
Fungiidae	2	–	–	–	–	–	–	–	–	–	2
Gardineriidae	–	–	–	–	–	1	–	–	–	2	3
Guyniidae	10	5	–	3	1	4	–	2	4	5	34
Micrabaciidae	2	–	–	–	–	–	–	–	3	3	8
Oculinidae	17	12	10	73	6	20	11	4	18	7	178
Pocilloporidae	–	–	–	–	–	–	–	–	–	1	1
Poritidae	–	–	–	2	–	–	–	–	–	–	2
Rhizangiidae	3	1	–	–	–	–	2	–	1	–	7
Turbinoliidae	23	3	–	2	1	3	–	1	32	1	66
Unknown	47	42	81	188	15	40	14	5	33	22	487
All	401	363	347	1145	150	440	118	49	404	160	3577
% total by FMA	11.2	10.1	9.7	32.0	4.2	12.3	3.3	1.4	11.3	4.5	100.0
All protected corals	1101	827	519	2193	361	1228	198	63	873	368	7731

Table C2: Genera represented in each family in each of the four protected orders (where Order Gorgonacea has been included under Order Alcyonacea) and the Fishery Management Areas from which the protected corals were reported. See Figures C1 & C3 for coral locations by order and Figure C2 for areas.

	Fishery Management Area									
	1	2	3	4	5	6	7	8	9	10
O. Alcyonacea: F.	■	■	■	■	■	■	■	■	■	■
Acanthogorgia	■	■	■	■	■	■	■	■	■	■
O. Alcyonacea: F. Anthothelidae					■					
Anthopodium					■					
O. Alcyonacea: F.	■	■	■	■	■	■	■		■	■
Chrysogorgia	■	■		■	■	■			■	■
Iridogorgia	■						■			■
Isidoides	■	■								
Metallogorgia	■	■		■						
Pseudochrysogorgia	■									
Radicipes	■		■	■		■	■			
O. Alcyonacea: F. Coralliidae	■	■	■	■	■	■			■	■
Corallium	■	■	■	■	■	■			■	■
Paracorallium										■
O. Alcyonacea: F. Ellisellidae	■									
Ctenocella	■									
O. Alcyonacea: F. Isididae	■	■	■	■	■	■	■		■	■
Acanella	■	■	■	■	■	■	■		■	■
Chathamisis	■			■						
Circinisis									■	
Echinisis				■		■			■	
Isidella					■	■			■	
Karakaisis						■				
Keratoisis	■	■	■	■	■	■	■		■	■
Lepidisis	■	■	■	■	■	■			■	■
Lissopholidisis							■			
Minuisis	■	■	■	■		■			■	
Muricellisis									■	
Peltastisis				■			■			
Primnoisis				■						
Sclerisis	■									
O. Alcyonacea: F. Paragorgiidae	■	■	■	■	■	■			■	■
Paragorgia	■	■	■	■	■	■			■	
Sibogagorgia	■									■
O. Alcyonacea: F. Plexauridae	■	■	■	■	■	■	■		■	■
Bebryce	■									
Dentomuricea		■								
Euplexaura	■								■	
Muriceides		■		■						
Paracis	■		■				■			■
Paramuricea	■	■		■		■				
Placogorgia	■	■								
Psammogorgia					■					
Scleracis	■									■
Swiftia	■					■				
Trachymuricea		■								
Villogorgia		■		■						■

Table C2: ***continued***

	Fishery Management Area									
	1	2	3	4	5	6	7	8	9	10
Order Alcyonacea: Family	■	■	■	■	■	■	■		■	■
Callogorgia	■	■				■			■	■
Callozostron		■								
Calyptrophora	■			■					■	■
Candidella	■	■				■				
Dasystenella		■								
Fanellia										■
Narella	■	■		■		■			■	■
Narelloides										
Paracalyptrophora	■								■	■
Parastenella				■		■				
Perissogorgia										
Plumarella	■	■	■	■			■			
Primnoa			■	■	■	■	■			
Primnoella	■			■		■			■	■
Pterostenella	■			■						
Thouarella	■	■	■	■	■	■	■		■	■
Tokoprymno		■	■	■	■	■				

	Fishery Management Area									
	1	2	3	4	5	6	7	8	9	10
O. Anthoathecata: F. Stylasteridae	■	■	■	■	■	■	■		■	■
Adelopora									■	
Allopora					■	■				
Bathelia		■								
Calyptopora	■	■	■	■	■	■	■			■
Conopora	■	■	■	■	■	■			■	■
Crypthelia	■	■		■	■	■			■	■
Distichopora					■	■				
Errina	■	■		■	■	■	■		■	■
Inferiolabiata	■			■	■	■			■	■
Lepidopora	■			■		■			■	■
Lepidotheca	■			■	■	■			■	■
Sporadopora					■	■			■	
Stellapora					■	■				
Stenohelia	■			■		■				
Stephanohelia				■						
Stylaster	■	■	■	■	■	■			■	■

	Fishery Management Area									
	1	2	3	4	5	6	7	8	9	10
O. Antipatharia: F. Antipathidae	■	■		■	■		■		■	■
Antipathes	■	■			■				■	■
Cirrhipathes	■			■						
Stichopathes	■						■		■	■
O. Antipatharia:Fam. Aphanipathidae										■
Acanthopathes										■
Asteriopathes										■
Rhipidipathes										■
O. Antipatharia: F. Cladopathidae	■	■		■	■	■			■	
Cladopathes		■			■	■				
Sibopathes	■	■		■						
Trissopathes	■	■		■					■	
O. Antipatharia: F. Leiopathidae	■	■		■	■	■			■	■
Leiopathes	■	■		■	■				■	■

Table C2: *continued.*

	Fishery Management Area									
	1	2	3	4	5	6	7	8	9	10
O. Antipatharia: F. Myriopathidae	■		■	■						■
Antipathella	■		■	■						■
Cupressopathes										■
Myriopathes										■
Plumapathes										■
O. Antipatharia: F. Schizopathidae	■	■	■	■	■	■			■	■
Bathypathes	■	■	■	■	■	■			■	■
Dendrobathypathes	■	■				■				
Dendropathes	■	■				■			■	
Lillipathes	■									
Parantipathes	■	■		■	■	■			■	
Saropathes	■									
Schizopathes	■					■				
Stauropathes	■				■	■				■
Umbellapathes	■	■								
O. Antipatharia: F. Stylopathidae	■	■		■		■	■		■	■
Stylopathes	■	■					■		■	■
Triadopathes	■	■		■		■				
Tylopathes	■									

	Fishery Management Area									
	1	2	3	4	5	6	7	8	9	10
O. Scleractinia: F. Agariciidae										■
Leptoseris										■
O. Scleractinia: F. Anthemiphylliidae										■
Anthemiphyllia										■
O. Scleractinia: F. Caryophylliidae	■	■	■	■	■	■	■	■	■	■
Anomocora										■
Aulocyathus	■	■		■	■				■	■
Bourneotrochus										■
Caryophyllia	■	■	■	■	■	■	■	■	■	■
Coenocyathus										■
Conotrochus	■									■
Crispatotrochus		■	■	■	■					■
Cyathoceras							■			
Dasmosmilia	■								■	
Deltocyathus		■								■
Desmophyllum	■	■	■	■	■	■	■	■	■	■
Goniocorella	■	■	■	■	■	■	■	■	■	■
Hoplangia	■			■						
Labyrinthocyathus		■		■	■	■				■
Paracyathus		■					■			
Polycyathus										■
Solenosmilia	■	■	■	■	■	■			■	■
Stephanocyathus	■	■		■	■	■	■	■	■	■
Tethocyathus	■									■
Trochocyathus				■						■
Vaughanella		■								■
O. Scleractinia: F. Dendrophylliidae	■	■	■	■	■	■	■		■	■
Balanophyllia	■	■			■		■		■	■
Dendrophyllia	■	■		■	■	■	■		■	■
Eguchipsammia	■	■		■					■	■
Enallopsammia	■	■	■	■	■	■			■	■
Endopachys										■
Leptopsammia										■

Table C2: ***continued***

	Fishery Management Area									
	1	2	3	4	5	6	7	8	9	10
O. Scleractinia: F. Flabellidae	■	■	■	■	■	■	■	■	■	■
Flabellum	■	■	■	■	■	■	■	■	■	■
Javania	■	■				■			■	■
Monomyces	■	■	■	■	■	■	■	■	■	
Placotrochides		■								
Polymyces	■	■								■
Rhizotrochus	■									■
Truncatoflabellum	■	■					■			■
O. Scleractinia: F. Fungiacyathidae	■	■					■		■	■
Fungiacyathus	■	■					■		■	■
O. Scleractinia: F. Fungiidae	■									
O. Scleractinia: F. Gardineriidae						■				■
Gardineria						■				■
O. Scleractinia: F. Guyniidae	■	■		■	■	■		■	■	■
Pedicellocyathus	■	■							■	
Stenocyathus	■	■		■	■	■		■	■	■
Truncatoguynia										■

	Fishery Management Area									
	1	2	3	4	5	6	7	8	9	10
O. Scleractinia: F.	■								■	■
Letepsammia	■								■	■
Stephanophyllia									■	
O. Scleractinia: F. Oculinidae	■	■	■	■	■	■	■	■	■	■
Madrepora	■	■	■	■	■	■	■	■	■	■
Oculina	■	■			■				■	■
O. Scleractinia: F.								■		
Madracis										■
O. Scleractinia: F. Poritidae			■							
Goniopora				■						
O. Scleractinia: F.	■	■					■		■	
Astrangia	■									
Culicia	■	■					■		■	
O. Scleractinia: F.	■	■		■	■	■		■	■	■
Cryptotrochus									■	
Kionotrochus	■	■							■	
Notocyathus		■		■						
Peponocyathus		■		■	■	■			■	
Pleotrochus									■	
Sphenotrochus								■	■	
Thrypticotrochus										■

Table C3: The number of coral records in each order and functional group, by family.

		"Reef-like"	"Solitary small"	"Tree-like"	"Whip-like"
Order Anthoathecata hydrocorals					
Stylasteridae	–	–	842	–	–
Order Antipatharia					
Unassigned	–	–	–	276	–
Antipathidae	–	–	–	30	40
Aphanipathidae	–	–	–	7	–
Cladopathidae	–	–	–	22	–
Leiopathidae	–	–	–	115	–
Myriopathidae	–	–	–	24	–
Schizopathidae	–	–	–	178	–
Stylopathidae	–	–	–	54	–
Order Alcyonacea gorgonians					
Unassigned	–	–	–	435	–
Acanthogorgiidae	–	–	–	87	–
Anthothelidae	–	–	–	1	–
Chrysogorgiidae	–	–	–	191	29
Coralliidae	–	–	–	77	–
Ellisellidae	–	–	–	1	–
Isididae	–	–	–	807	–
Paragorgiidae	–	–	–	197	–
Plexauridae	–	–	–	130	–
Primnoidae	–	–	–	583	28
Order Scleractinia*					
Unassigned	484	–	3	–	–
Agariciidae	–	–	3	–	–
Anthemiphylliidae	–	–	2	–	–
Caryophylliidae	17	1118	799	–	–
Dendrophylliidae	–	250	–	–	–
Flabellidae	–	–	587	–	–
Fungiacyathidae	–	–	13	–	–
Fungiidae	–	–	2	–	–
Gardineriidae	–	–	3	–	–
Guyniidae	–	–	34	–	–
Micrabaciidae	–	–	8	–	–
Oculinidae	–	178	–	–	–
Pocilloporidae	–	–	1	–	–
Poritidae	–	–	2	–	–
Rhizangiidae	–	–	7	–	–
Turbinoliidae	–	–	66	–	–

* Family Caryophylliidae in Order Scleractinia are split into two different functional groups representing the branching forms (“reef-like”) and the cup form (“solitary small”). Those undefined were identified to family only.

Table C4: Number of records of protected corals in the full dataset, by family in each functional group.

	Fishery Management Area										
	1	2	3	4	5	6	7	8	9	10	All
"Reef-like"											
Caryophylliidae	71	83	35	407	43	234	12	8	221	4	111
Dendrophylliidae	59	18	5	50	11	39	13		21	34	250
Oculinidae	17	12	10	73	6	20	11	4	18	7	178
All	147	113	50	530	60	293	36	12	260	45	154
"Tree-like"											
Acanthogorgiidae	10	19	2	21	3	8	5	2	3	14	87
Anthothelidae	–	–	–	–	1	–	–	–	–	–	1
Antipathidae	12	2	–	2	1	–	1	–	2	10	30
Aphanipathidae	–	–	–	–	–	–	–	–	–	7	7
Chrysogorgiidae	65	24	8	6	3	36	2	–	44	3	191
Cladopathidae	5	7	–	4	4	1	–	–	1	–	22
Coralliidae	15	12	2	7	1	17	–	–	2	21	77
Ellisellidae	1	–	–	–	–	–	–	–	–	–	1
Isididae	175	59	34	184	25	182	19	–	120	9	807
Leiopathidae	38	16	–	33	2	3	–	–	22	1	115
Myriopathidae	4	–	2	2	–	–	–	–	–	16	24
Paragorgiidae	8	8	14	43	6	98	–	–	19	1	197
Plexauridae	21	38	2	15	3	26	3	–	7	15	130
Primnoidae	80	64	21	207	22	103	6	–	52	28	583
Schizopathidae	41	40	1	45	4	32	–	1	12	2	178
Stylopathidae	24	6	–	16	–	1	1	–	2	4	54
Unknown	93	84	45	197	58	98	26	10	81	19	711
All	592	379	131	782	133	605	63	13	367	150	321
"Solitary small"											
Agariciidae	–	–	–	–	–	–	–	–	–	3	3
Anthemiphylliidae	–	–	–	–	–	–	–	–	–	2	2
Caryophylliidae	96	122	34	310	46	57	42	8	28	56	799
Flabellidae	62	67	182	108	27	39	23	21	42	16	587
Fungiacyathidae	2	5	–	–	–	–	1	–	1	4	13
Fungiidae	2	–	–	–	–	–	–	–	–	–	2
Gardineriidae	–					1	–			2	3
Guyniidae	10	5	–	3	1	4	–	2	4	5	34
Micrabaciidae	2	–							3	3	8
Pocilloporidae	–									1	1
Poritidae	–			2	–						2
Rhizangiidae	3	1	–				2	–	1	–	7
Stylasteridae	82	84	39	232	78	177	15	1	94	40	842
Turbinoliidae	23	3	–	2	1	3	–	1	32	1	66
Unknown	–				3	–					3
All	282	287	255	657	156	281	83	33	205	133	237
"Whip-like"											
Antipathidae	24	–	–	–	–	–	1	–	2	13	40
Chrysogorgiidae	1	1	2	22	–	2	1	–	–	–	29
Primnoidae	1	–	–	12	–	4	–	–	6	5	28
Unknown	54	47	81	190	12	43	14	5	33	22	501
All	26	1	2	34	–	6	2	–	8	18	97
Unassigned	54	47	81	190	12	43	14	5	33	22	501

Appendix D Distribution of environmental variables and prediction results

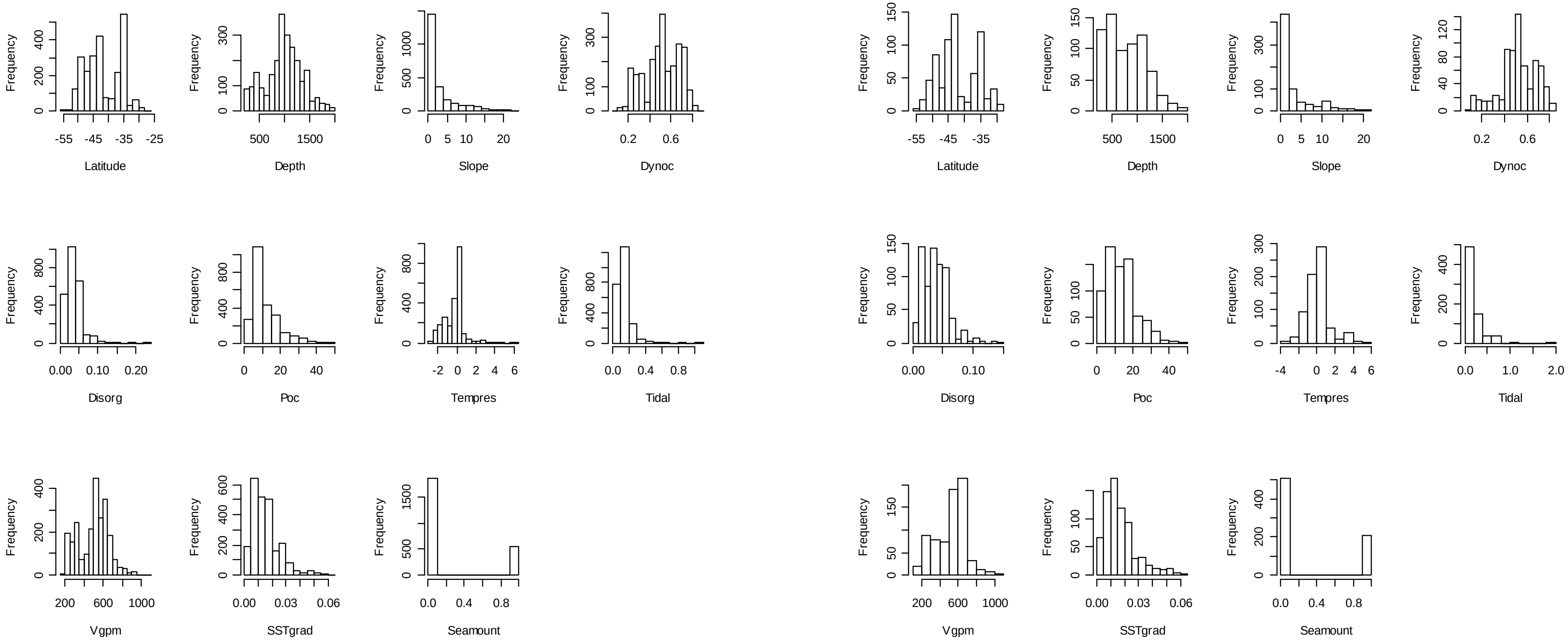

Figure D1: Frequency of gorgonian corals in Order Alcyonacea (left) and hydrocorals in Order Anthoathecata corals (right) in 200–2000 m, by latitude (° S), depth, slope, dynamic topography , dissolved organic matter, particulate, bottom temperature residuals, tidal current, primary production, SST gradient, and underwater topographic feature (seamount). See Table B1 for units and description of environmental variables.

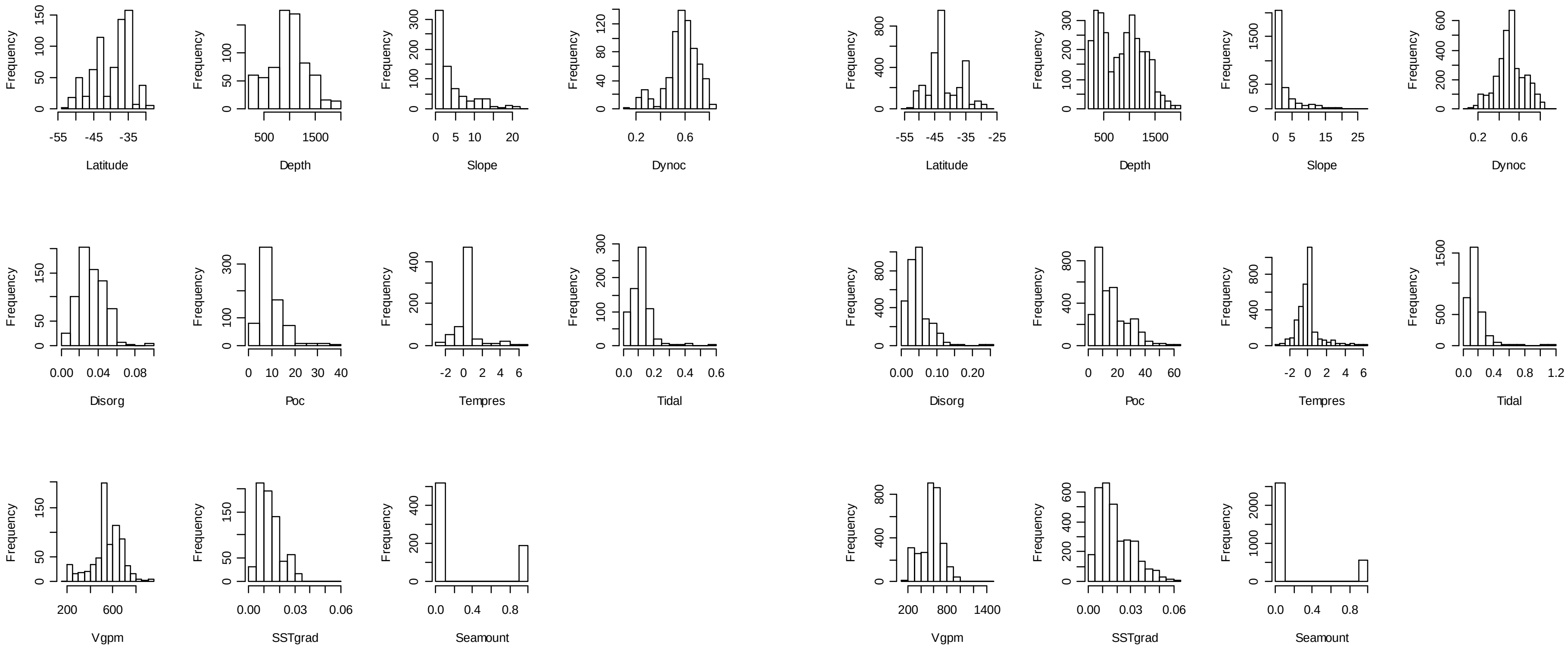

Figure D2: Frequency of black corals in Order Antipatharia (left) and stony corals in Order Scleractinia corals (right) in 200–2000 m, by latitude (° S), depth, slope, dynamic topography, dissolved organic matter, particulate, bottom temperature residuals, tidal current, primary production, SST gradient, and underwater topographic feature (seamount). See Table B1 for units and description of environmental variables.

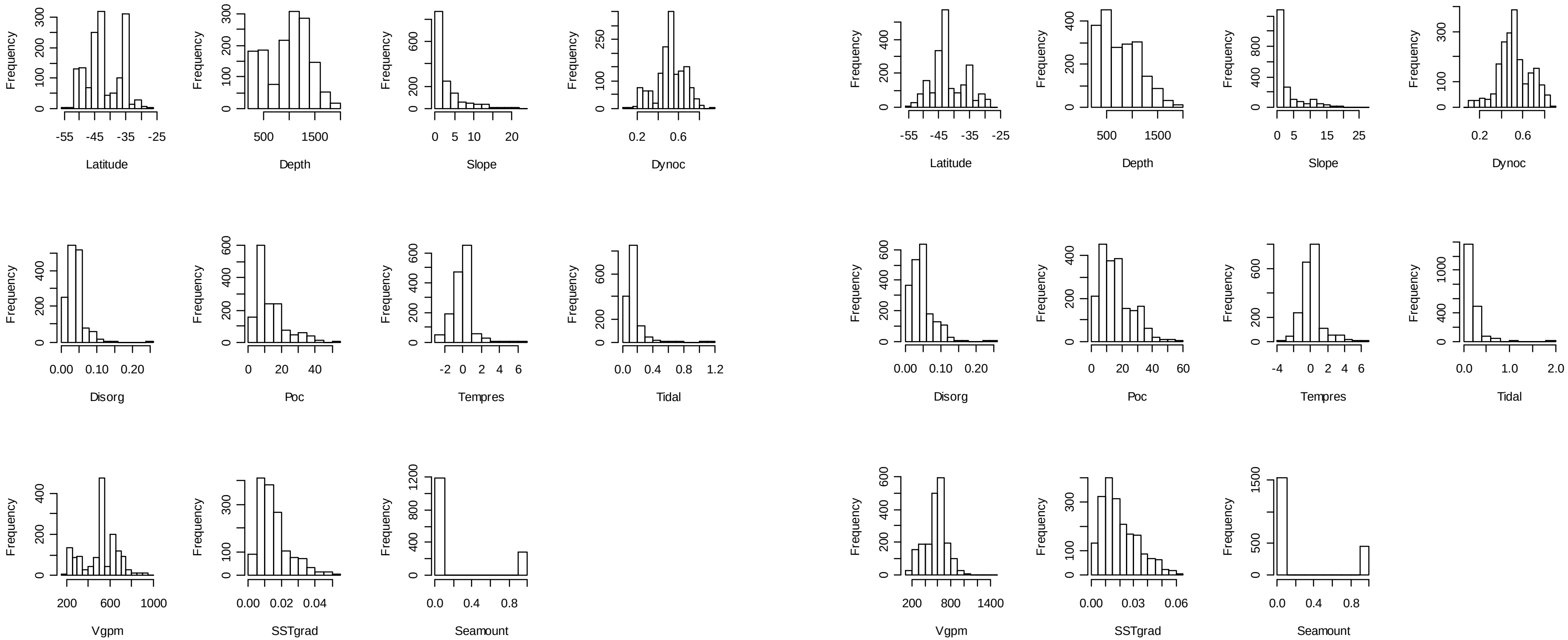

Figure D3: Frequency of "reef-like" corals (left) and "solitary small" corals (right), by latitude (° S), depth, slope, dynamic topography , dissolved organic matter, particulate, bottom temperature residuals, tidal current, primary production, SST gradient, and underwater topographic feature (seamount). See Table B1 for units and description of environmental variables.

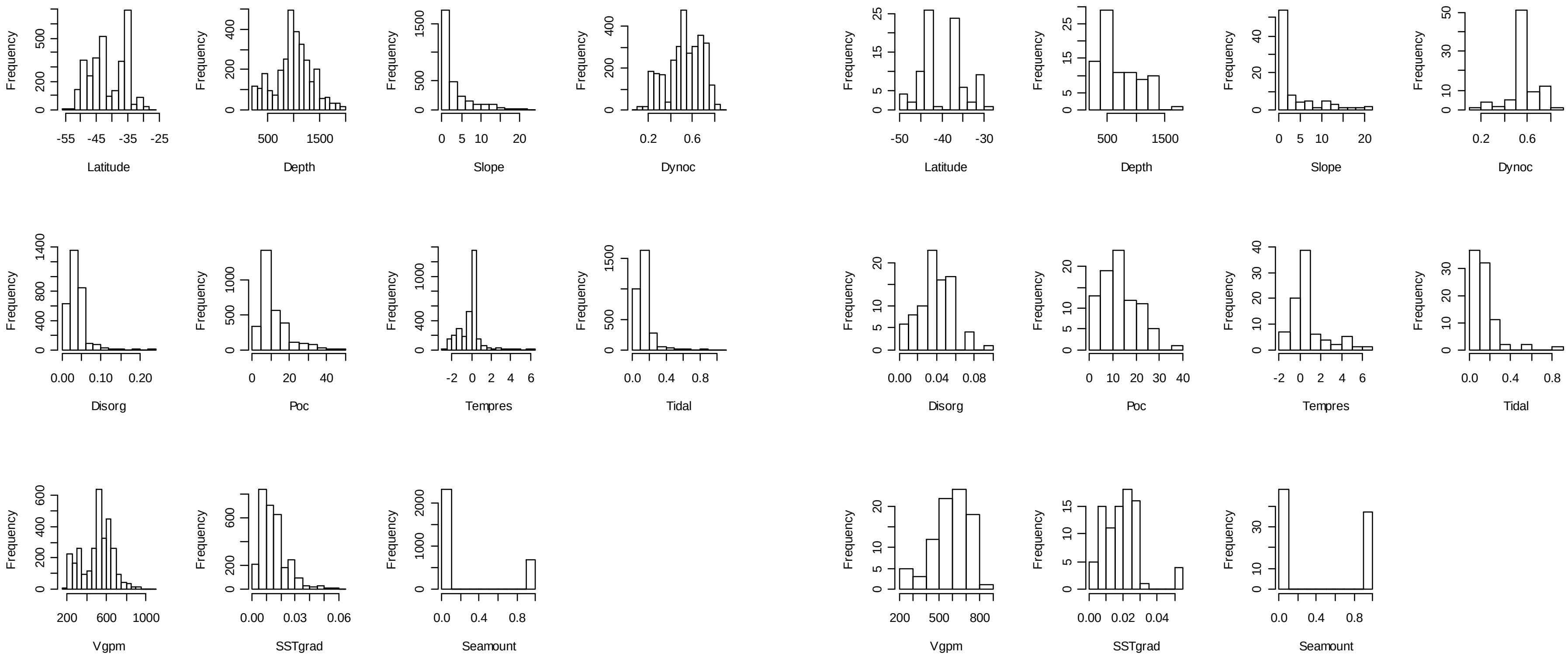

Figure D4: Frequency of "tree-like" corals (left) and "whip-like" corals (right), by latitude (° S), depth (m), slope, dynamic topography , dissolved organic matter, particulate , bottom temperature residuals, tidal current, primary production, SST gradient, and underwater topographic feature (seamount). See Table B1 for units and description of environmental variables.

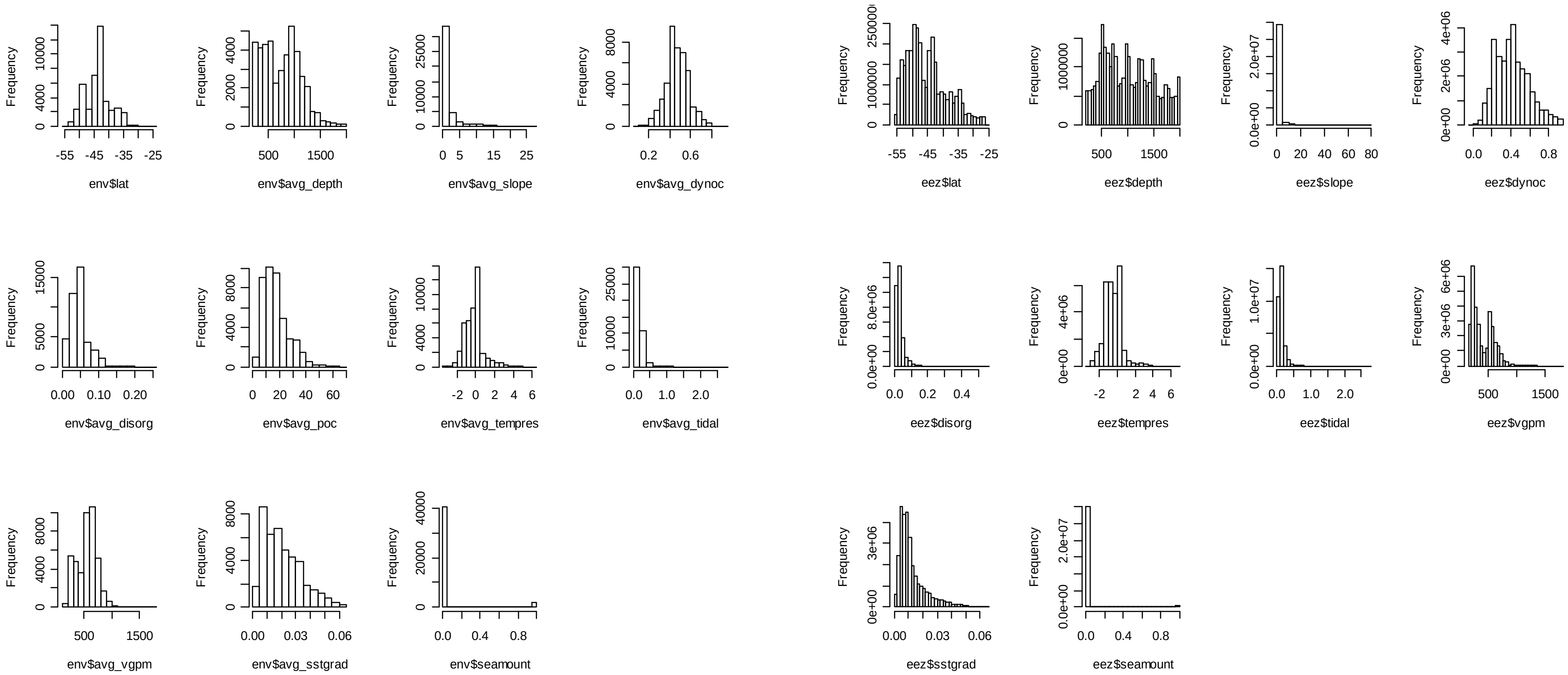

Figure D5: Frequency of benthic stations (left) and background EEZ 250 x 250 m cells (right) in 200–2000 m, by latitude (° S), depth, slope, dynamic topography , dissolved organic matter, particulate organic carbon flux, bottom temperature residuals, tidal current, primary production, SST gradient, and underwater topographic feature (seamount). See Table B1 for units and description of environmental variables.

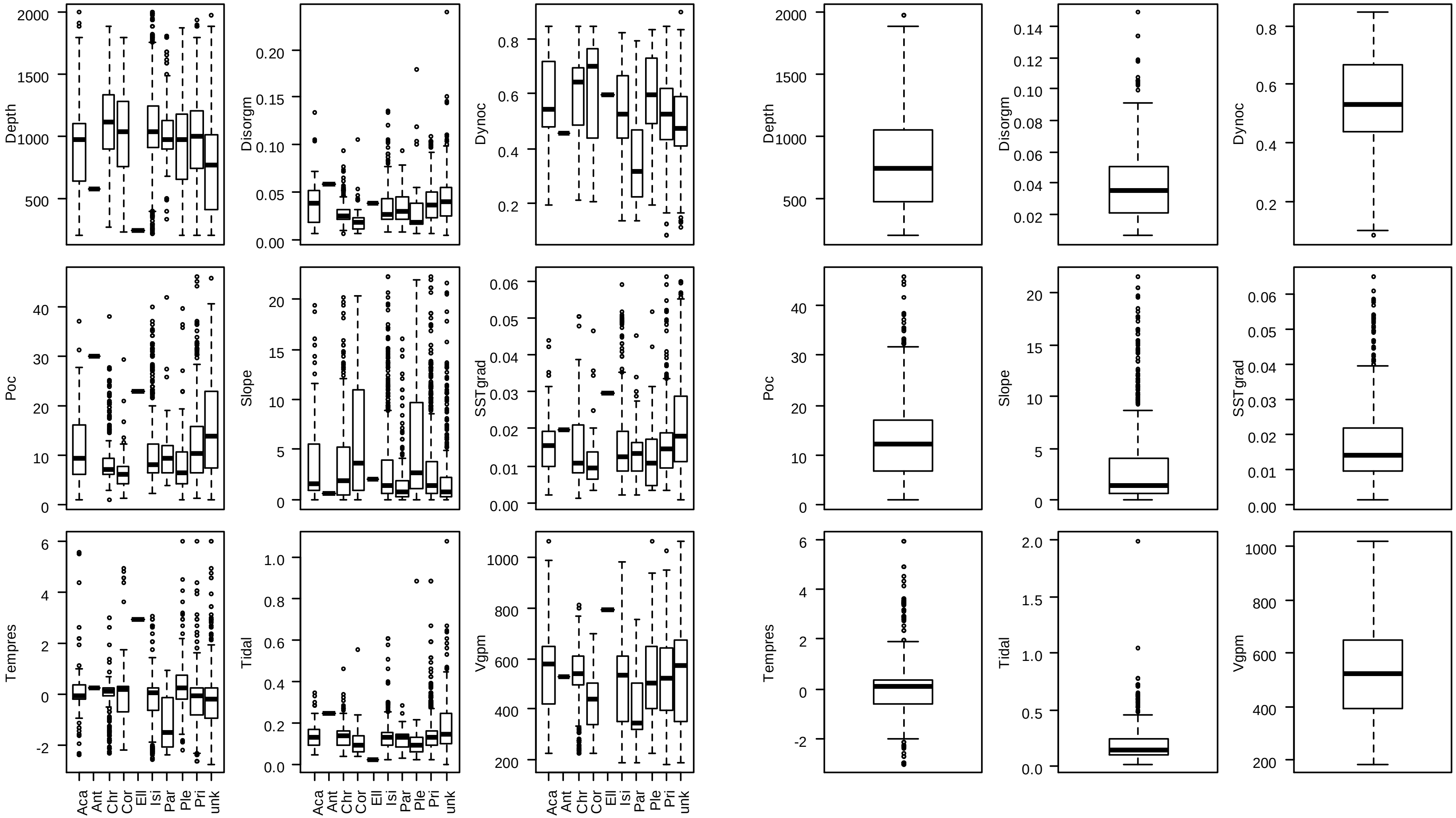

Figure D6: Distribution of environmental variables by gorgonian family in Order Alyconacea (left) and by Family Stylasteridae in Order Anthoathecata (right). See Table B1 for variable name and units and Table C1 for full family names.

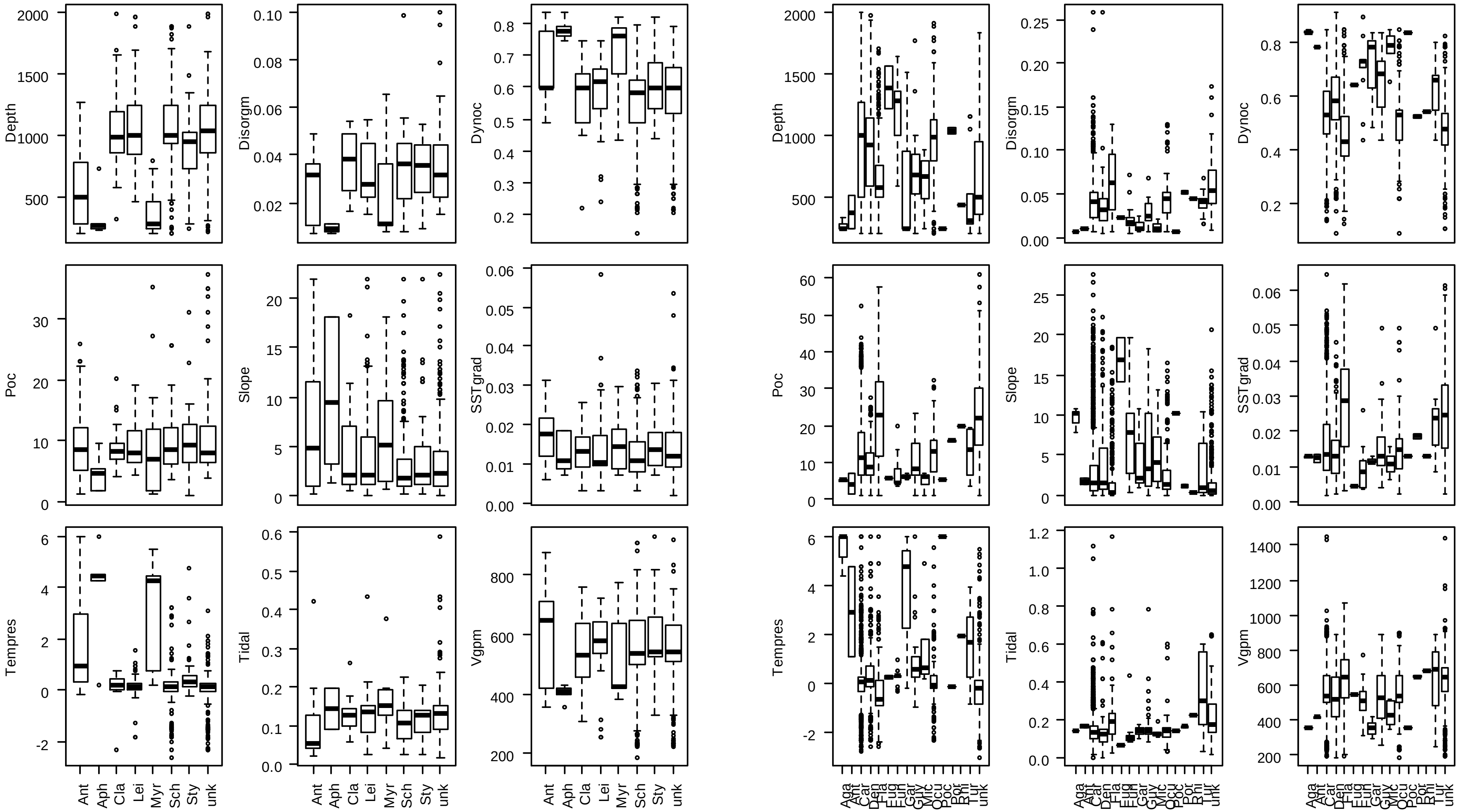

Figure D7: Distribution of environmental variables by family in Order Antipatharia (left) and by family in Order Scleractinia (right). See Table B1 for variable name and units and Table C1 for full family names.

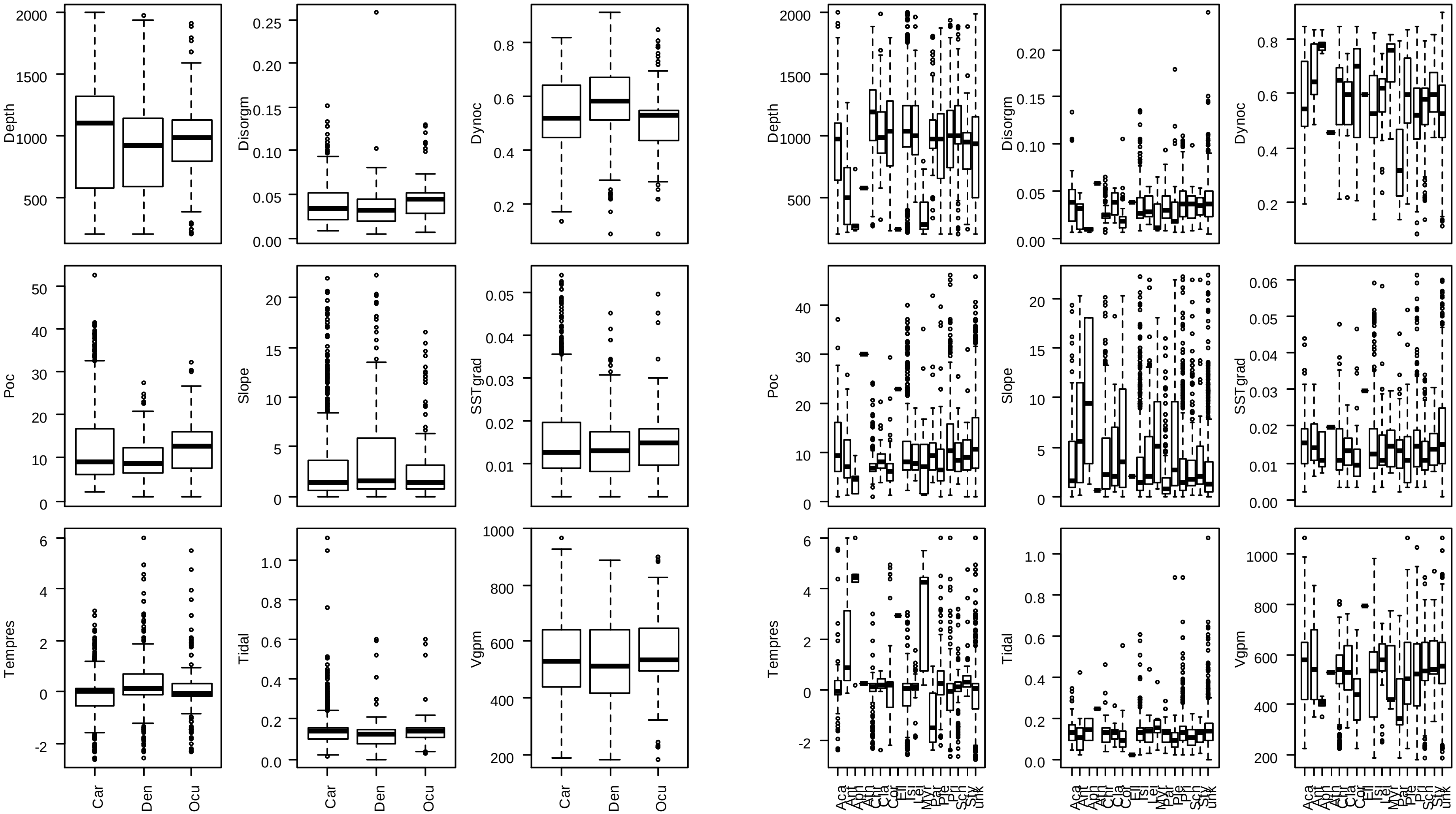

Figure D8: Distribution of environmental variables by family in “reef-like” functional group (left) and by family in “tree-like” functional group (right). See Table B1 for variable name and units and Table C4 for full family names.

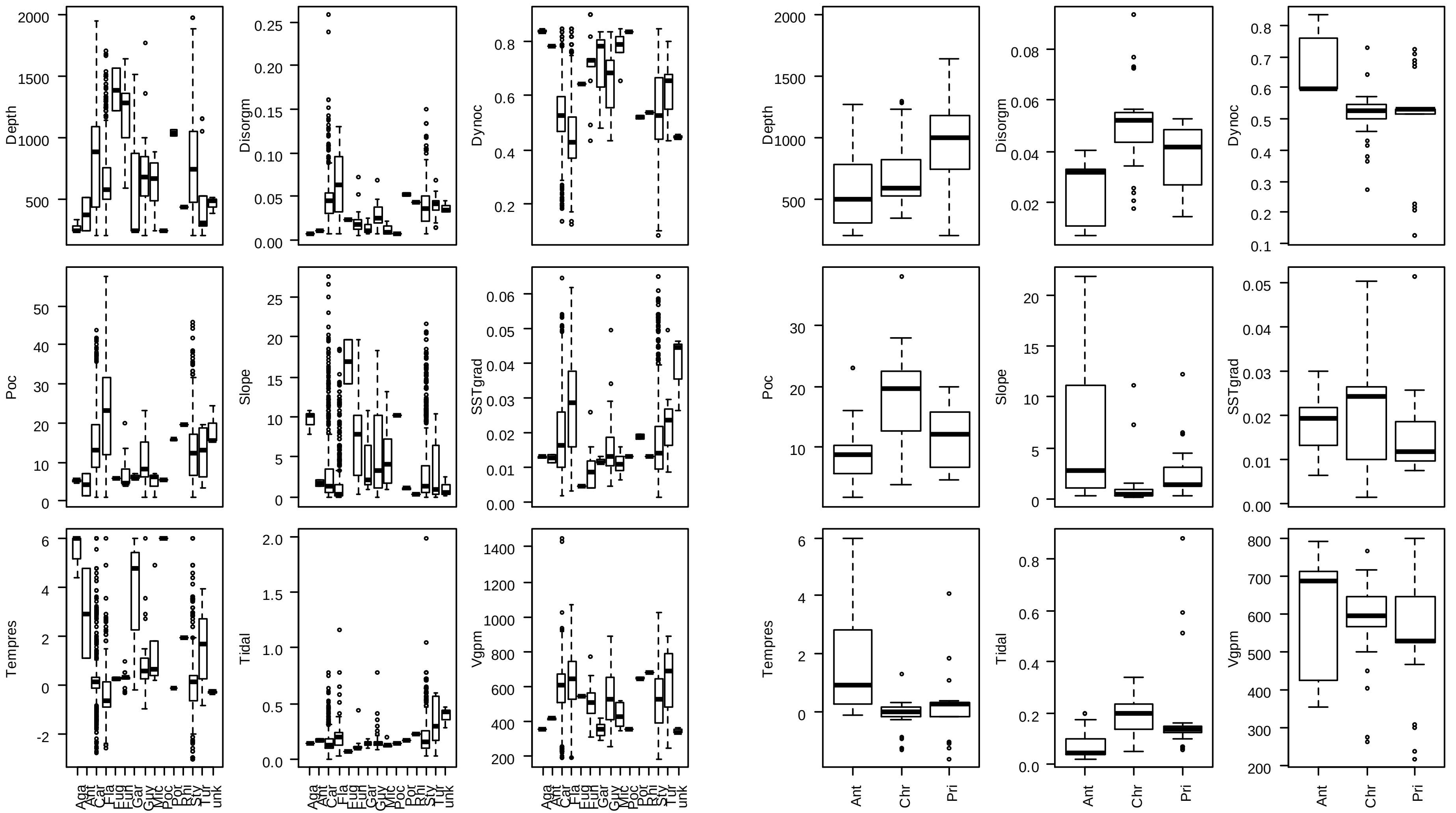

Figure D9: Distribution of environmental variables by family in “solitary small” functional group (left) and by family in “whip-like” functional group (right). See Table B1 for variable name and units and Table C4 for full family names.

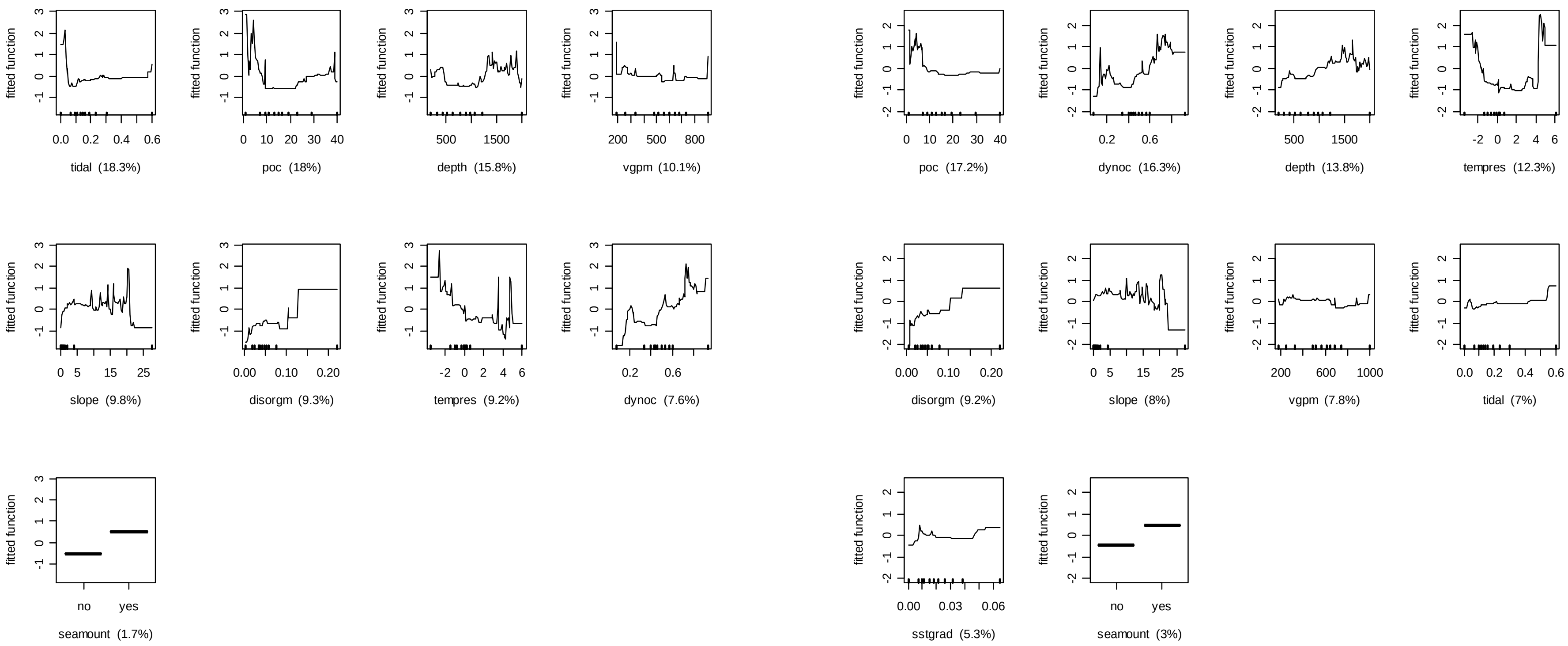

Figure D10: The BRT model results showing the occurrence, by variable, for "reef-like" corals (left) and "tree-like" corals (right). The occurrence is plotted on the *y*-axis are on the logit scales with a zero mean over the data distribution. The distribution of the benthic dataset across the variable is shown as 'rugs' on each *x*-axis, with each representing 10% of the data. The variable names are explained in Table B1.

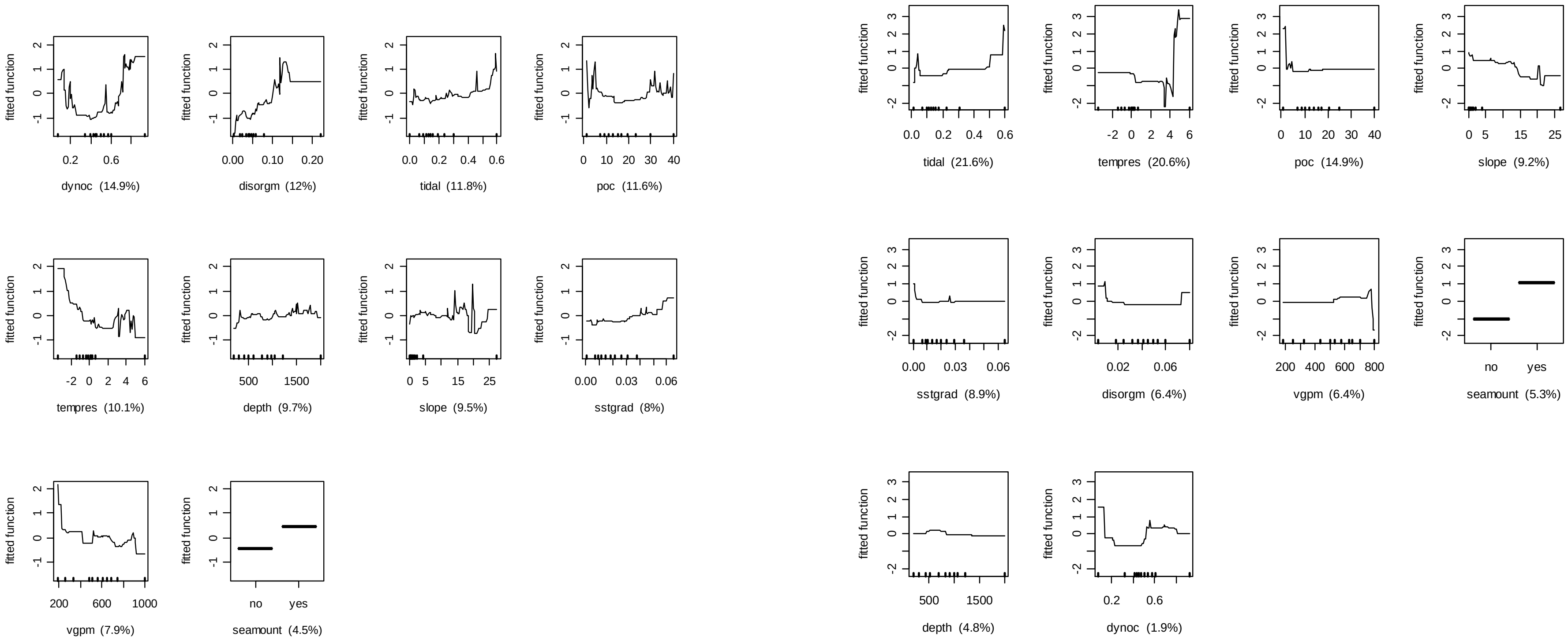

Figure D11: The BRT model results showing the occurrence, by variable, for "solitary small" corals (left) and "whip-like" corals (right). The occurrence is plotted on the *y*-axis are on the logit scales with a zero mean over the data distribution. The distribution of the benthic dataset across the variable is shown as 'rugs' on each *x*-axis, with each representing 10% of the data. The variable names are explained in Table B1.

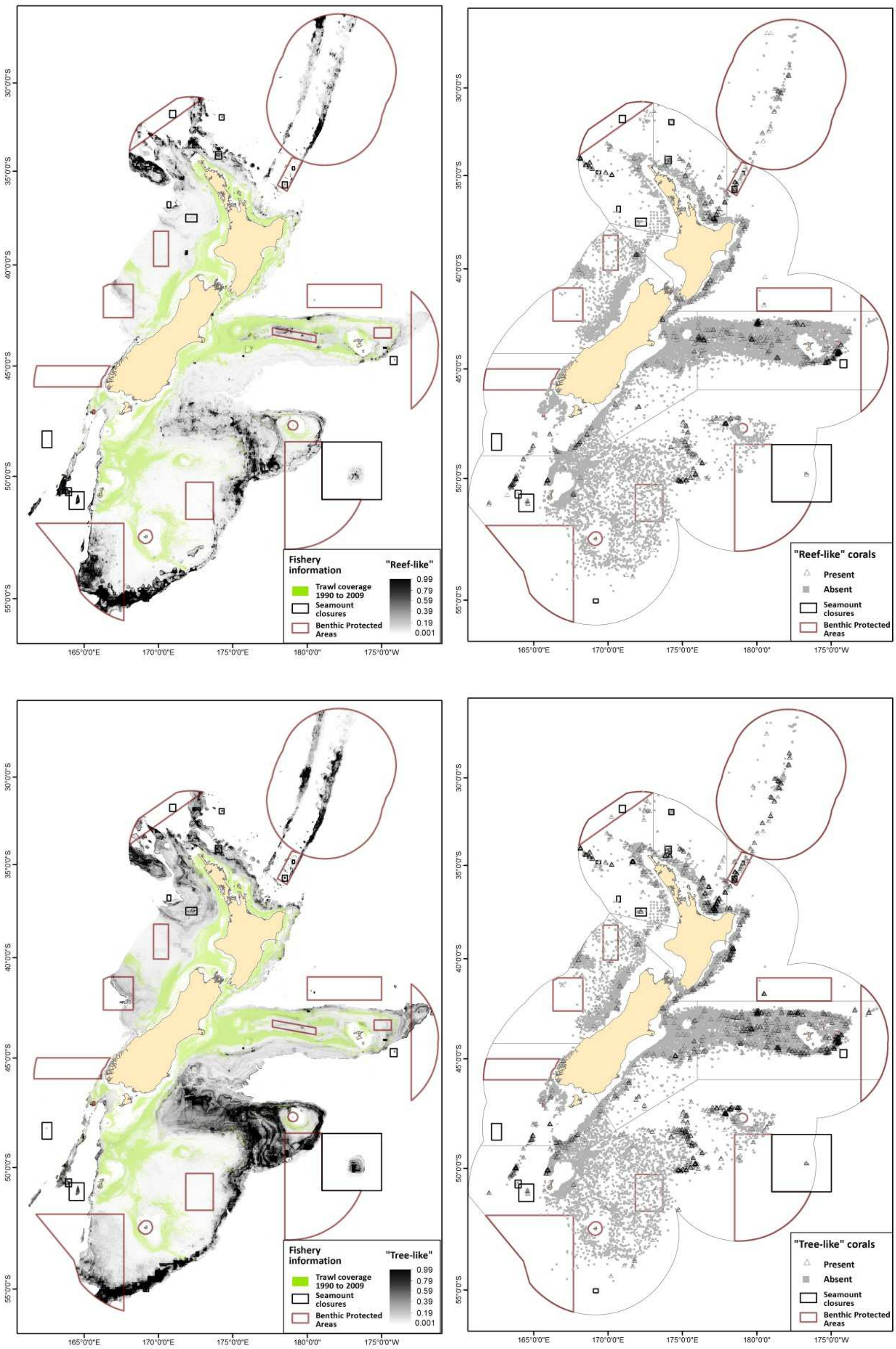

Figure D12: Predicted distributions (left) and location of coral presence/absence data records within the EEZ (right) for "reef-like" corals (upper) and "tree-like" corals (lower), relative to the 20-year trawl footprint (1989–90 to 2008–09) and seamount closures introduced in 2001 and Benthic Protected Areas introduced in 2007. FMAs of the EEZ are shown in Figure C2.

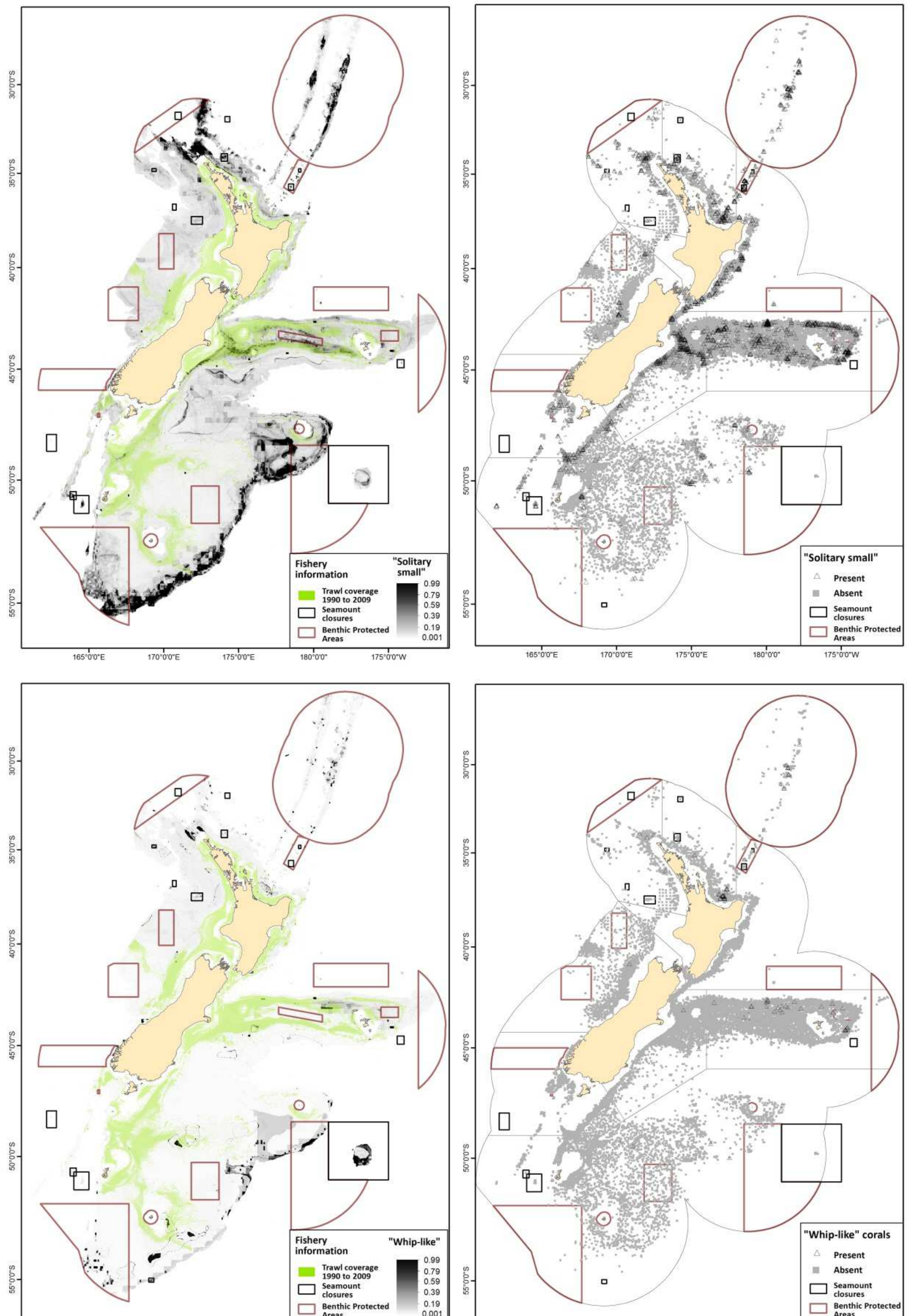

Figure D13: Predicted distributions (left) and location of coral presence/absence data records within the EEZ (right) for "solitary small" corals (upper) and "whip-like" corals (lower), relative to the 20-year trawl footprint (1989–90 to 2008–09) and seamount closures introduced in 2001 and Benthic Protected Areas introduced in 2007. FMAs of the EEZ are shown in Figure C2.

Table D1: Coral data in 200–2000 m waters, by functional group and Fishery Management Area.

	Fishery Management Area										
	1	2	3	4	5	6	7	8	9	10	All
"Reef-like"											
Caryophylliidae	69	77	34	407	36	223	11	4	219	4	1084
Dendrophylliidae	53	16	5	50	7	39	13	–	15	30	228
Oculinidae	10	11	10	69	4	20	11	2	11	7	155
All	132	104	49	526	47	282	35	6	245	41	1467
"Tree-like"											
Acanthogorgiidae	9	19	2	21	3	8	4	1	2	14	83
Anthothelidae	–	–	–	–	1	–	–	–	–	–	1
Antipathidae	9	2	–	2	–	–	1	–	2	9	25
Aphanipathidae	–	–	–	–	–	–	–	–	–	6	6
Chrysogorgiidae	64	21	8	6	3	34	2	–	44	3	185
Cladopathidae	3	7	–	4	4	1	–	–	1	–	20
Coralliidae	13	11	2	7	1	17	–	–	2	20	73
Ellisellidae	1	–	–	–	–	–	–	–	–	–	1
Isididae	170	53	33	184	25	178	19	–	116	8	786
Leiopathidae	38	16	–	33	2	3	–	–	22	1	115
Myriopathidae	3	–	1	2	–	–	–	–	–	13	19
Paragorgiidae	7	8	14	43	6	98	–	–	19	1	196
Plexauridae	20	38	2	15	1	26	3	–	1	14	120
Primnoidae	74	62	20	205	22	101	6	–	25	28	543
Schizopathidae	38	39	1	45	4	32	–	1	10	2	172
Stylopathidae	22	6	–	15	–	1	1	–	2	4	51
Unknown	82	80	33	193	35	91	19	5	72	13	623
All	553	362	116	775	107	590	55	7	318	136	3019
"Solitary small"											
Agariciidae	–	–	–	–	–	–	–	–	–	3	3
Anthemiphylliidae	–	–	–	–	–	–	–	–	–	2	2
Caryophylliidae	59	112	27	309	37	53	40	7	23	51	718
Flabellidae	29	54	178	107	18	39	14	1	14	15	469
Fungiacyathidae	2	5	–	–	–	–	1	–	1	4	13
Fungiidae	2	–	–	–	–	–	–	–	–	–	2
Gardineriidae	–	–	–	–	–	1	–	–	–	2	3
Guyniidae	8	5	–	3	1	3	–	2	2	5	29
Micrabaciidae	1	–	–	–	–	–	–	–	1	3	5
Pocilloporidae	–	–	–	–	–	–	–	–	–	1	1
Poritidae	–	–	–	2	–	–	–	–	–	–	2
Rhizangiidae	–	–	–	–	–	–	1	–	–	–	1
Stylasteridae	72	82	25	223	57	132	3	–	82	40	716
Turbinoliidae	1	3	–	2	–	2	–	–	9	–	17
Unknown	–	–	–	–	3	–	–	–	–	–	3
All	174	261	230	646	116	230	59	10	132	126	1984
"Whip-like"											
Antipathidae	24	–	–	–	–	–	–	–	1	10	35
Chrysogorgiidae	1	1	2	22	–	2	1	–	–	–	29
Primnoidae	1	–	–	12	–	4	–	–	3	1	21
Unknown	26	1	2	34	–	6	1	–	4	11	85
Unassigned	25	35	78	187	8	31	10	2	21	13	410
Total	910	763	475	2168	278	1139	160	25	720	327	6965

Table D2: Coral data in 200–2000 m waters, by order and Fishery Management Area.

	Fishery Management Area										
	1	2	3	4	5	6	7	8	9	10	All
Anthoathecata											
Stylasteridae	72	82	25	223	57	132	3	–	82	40	716
All	72	82	25	223	57	132	3	–	82	40	716
Antipatharia											
Antipathidae	33	2	–	2	–	–	1	–	3	19	60
Aphanipathidae	–	–	–	–	–	–	–	–	–	6	6
Cladopathidae	3	7	–	4	4	1	–	–	1	–	20
Leiopathidae	38	16	–	33	2	3	–	–	22	1	115
Myriopathidae	3	–	1	2	–	–	–	–	–	13	19
Schizopathidae	38	39	1	45	4	32	–	1	10	2	172
Stylopathidae	22	6	–	15	–	1	1	–	2	4	51
Unassigned	58	38	3	71	9	31	4	1	44	–	259
All	195	108	5	172	19	68	6	2	82	45	702
Gorgonacea											
Acanthogorgiidae	9	19	2	21	3	8	4	1	2	14	83
Anthothelidae	–	–	–	–	1	–	–	–	–	–	1
Chrysogorgiidae	65	22	10	28	3	36	3	–	44	3	214
Coralliidae	13	11	2	7	1	17	–	–	2	20	73
Ellisellidae	1	–	–	–	–	–	–	–	–	–	1
Isididae	170	53	33	184	25	178	19	–	116	8	786
Paragorgiidae	7	8	14	43	6	98	–	–	19	1	196
Plexauridae	20	38	2	15	1	26	3	–	1	14	120
Primnoidae	75	62	20	217	22	105	6	–	28	29	564
Unassigned	24	42	30	122	26	60	15	4	28	13	364
All	384	255	113	637	88	528	50	5	240	102	2402
Scleractinia											
Agariciidae	–	–	–	–	–	–	–	–	–	3	3
Anthemiphylliidae	–	–	–	–	–	–	–	–	–	2	2
Caryophylliidae	3	5	–	2	–	1	–	–	–	–	11
Caryophylliidae_br	69	77	34	407	36	223	11	4	219	4	1084
Caryophylliidae_cup	59	112	27	309	37	53	40	7	23	51	718
Dendrophylliidae	53	16	5	50	7	39	13	–	15	30	228
Flabellidae_cup	29	54	178	107	18	39	14	1	14	15	469
Fungiacyathidae_cup	2	5	–	–	–	–	1	–	1	4	13
Fungiidae	2	–	–	–	–	–	–	–	–	–	2
Gardineriidae	–	–	–	–	–	1	–	–	–	2	3
Guyniidae	8	5	–	3	1	3	–	2	2	5	29
Micrabaciidae_cup	1	–	–	–	–	–	–	–	1	3	5
Oculinidae_br	10	11	10	69	4	20	11	2	11	7	155
Pocilloporidae	–	–	–	–	–	–	–	–	–	1	1
Poritidae	–	–	–	2	–	–	–	–	–	–	2
Rhizangiidae_cup	–	–	–	–	–	–	1	–	–	–	1
Turbinoliidae	1	3	–	2	–	2	–	–	9	–	17
Unassigned	22	30	78	185	11	30	10	2	21	13	402
All	259	318	332	1136	114	411	101	18	316	140	3145
All	910	763	475	2168	278	1139	160	25	720	327	6965

Appendix E Fishery interactions with protected corals

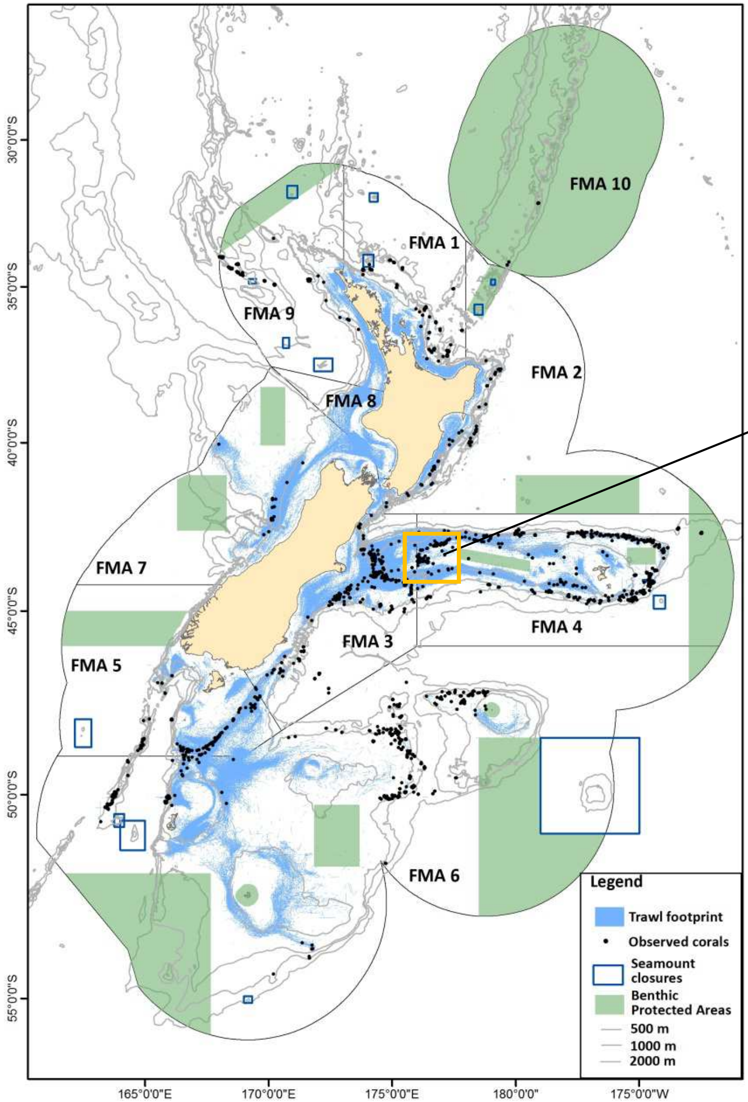

Figure E1: Location of coral records (200–2000 m) relative to the 20-year trawl fishing footprint, showing the Fishery Management Areas, the Benthic Protected Areas (since 2007), and the seamount closures introduced in 2001. The 500 m, 1000 m, 1250 m, and 1500 m depth contours are shown.

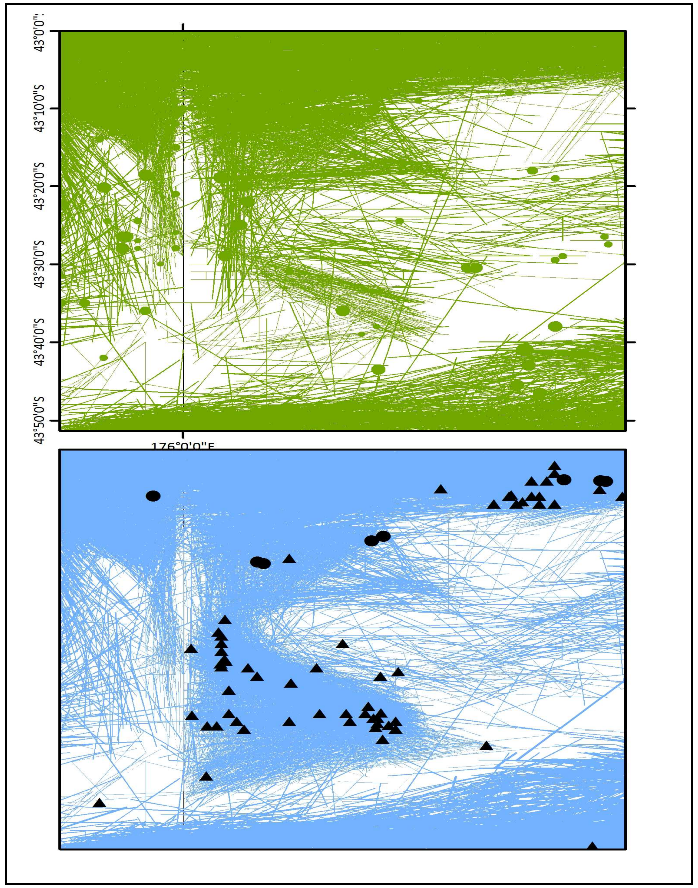

Figure E2: This represents a close-up of the area shown by the orange box on the Chatham Rise in Figure B2. The top box shows the 1989–90 to 2004–05 trawl footprint (Baird et al. 2011, Baird & Wood 2012) in this area southeast of the Mernoo Bank. The lower plot shows the 1989–90 to 2008–09 trawl footprint (GNS 2012) and includes locations of observed coral catches, for data that match the top footprint (●) and for observed coral data collected since October 2005 (▲).

Table E1: Target species for observed fishing effort where corals from orders Alcyonacea, Anthoathecata, Antipatharia, and Scleractinia were reported. Codes are defined in Table 3-3 and Fishery Management Areas are shown in Figure C2.

	Fishery Management Area									
	1	2	3	4	5	6	7	9	10	All
Order Alcyonacea (gorgonian families only)										
BNS	1	0	0	1	0	0	0	0	0	2
BOE	0	0	15	7	0	119	0	0	0	141
BYS	8	2	0	0	0	0	0	8	0	18
BYX	3	4	0	2	0	0	0	0	0	9
CDL	8	2	0	0	0	0	0	0	0	10
HAK	0	0	0	0	2	0	1	0	0	3
HOK	0	0	5	17	6	7	1	0	0	36
LIN	0	0	1	3	0	2	0	0	0	6
MDO	0	0	0	0	0	0	0	1	0	1
OEO	0	0	3	9	23	81	0	0	0	116
ORH	163	6	0	128	0	60	1	166	2	526
PTO	0	0	0	0	0	2	0	0	0	2
RBY	0	1	0	0	0	0	0	0	0	1
SBW	0	0	0	0	0	2	0	0	0	2
SCI	2	1	1	1	0	0	0	0	0	5
SQU	0	0	0	1	18	0	0	0	0	19
SSO	0	0	50	35	3	180	0	0	0	268
SWA	0	0	1	0	1	0	0	0	0	2
TAR	0	0	0	0	0	0	0	0	11	11
UNI	0	0	0	0	0	0	0	1	0	1
WWA	0	0	0	0	6	0	0	0	0	6
Order Anthoathecata (hydrocoral family only)										
BNS	0	0	1	4	0	0	0	0	0	5
BOE	0	0	2	1	0	11	0	0	0	14
CDL	1	0	0	0	0	0	0	0	0	1
HAK	0	0	0	0	1	1	0	0	0	2
HOK	0	0	3	0	0	2	1	0	0	6
LIN	0	0	0	0	0	2	0	0	0	2
OEO	0	0	0	0	0	6	0	0	0	6
ORH	17	1	0	41	0	1	0	12	0	72
PTO	0	0	0	0	0	1	0	0	0	1
SCI	0	4	0	8	0	0	0	0	0	12
SQU	0	0	1	0	15	1	0	0	0	17
SSO	0	0	0	3	2	10	0	0	0	15

	Fishery Management Area									
	1	2	3	4	5	6	7	9	10	All
Order Antipatharia										
BOE	0	0	0	0	1	27	0	0	0	28
BYS	2	1	0	1	0	0	0	2	0	6
BYX	3	0	0	3	0	0	0	2	0	8
CDL	15	9	0	0	0	0	0	0	0	24
HAK	0	0	0	0	0	0	1	0	0	1
HOK	1	0	0	0	1	3	0	0	0	5
OEO	0	0	1	0	7	8	0	0	0	16
ORH	69	4	1	123	3	5	0	60	1	266
RBY	0	3	0	0	0	0	0	1	0	4
SBO	0	0	0	0	0	0	0	1	0	1
SCI	2	0	0	2	0	0	0	0	0	4
SQU	0	0	0	0	1	1	0	0	0	2
SSO	0	0	0	7	2	21	0	0	0	30
SWA	0	0	1	0	0	0	0	0	0	1
WWA	0	0	0	0	1	0	0	0	0	1
Order Scleractinia										
BAR	0	0	0	1	0	0	0	0	0	1
BNS	0	0	0	4	0	0	0	1	0	5
BOE	0	0	7	6	0	82	0	0	0	95
BYS	2	1	0	0	0	0	0	2	0	5
BYX	6	2	0	4	0	0	0	1	0	13
CDL	6	8	0	0	0	0	0	0	0	14
HAK	0	0	4	0	6	2	16	0	0	28
HOK	1	1	132	28	14	3	1	0	0	180
LIN	0	0	17	6	0	1	0	0	0	24
OEO	0	0	3	1	4	51	0	0	0	59
ORH	31	4	0	366	0	18	0	231	0	650
PTO	0	0	0	0	0	2	0	0	0	2
SCI	2	24	3	85	0	0	0	0	0	114
SQU	0	0	3	0	28	0	0	0	0	31
SSO	0	0	15	18	2	116	0	0	0	151
SWA	0	0	19	8	2	0	0	0	0	29
WWA	0	0	0	0	3	0	0	0	0	3

Table E2: Target species for observed fishing effort where corals from functional groups “reef-like”, “tree-like”, “solitary small”, and “whip-like” were reported. Codes are defined in Table 3-3 and Fishery Management Areas are shown in Figure C2. One “tree-like” record from FMA 9 had no target code.

	Fishery Management Area									
	1	2	3	4	5	6	7	9	10	All
"Reef-like"										
BNS	0	0	0	4	0	0	0	1	0	5
BOE	0	0	5	3	0	78	0	0	0	86
BYS	2	1	0	0	0	0	0	2	0	5
BYX	5	1	0	4	0	0	0	1	0	11
CDL	6	5	0	0	0	0	0	0	0	11
HOK	1	1	5	1	0	1	0	0	0	9
LIN	0	0	11	4	0	0	0	0	0	15
OEO	0	0	2	1	2	44	0	0	0	49
ORH	28	4	0	250	0	18	0	222	0	522
PTO	0	0	0	0	0	2	0	0	0	2
SCI	2	12	1	43	0	0	0	0	0	58
SQU	0	0	0	0	27	0	0	0	0	27
SSO	0	0	13	12	2	106	0	0	0	133
SWA	0	0	1	5	1	0	0	0	0	7
WWA	0	0	0	0	1	0	0	0	0	1
"Tree-like"										
BNS	1	0	0	1	0	0	0	0	0	2
BOE	0	0	15	7	1	146	0	0	0	169
BYS	10	3	0	1	0	0	0	10	0	24
BYX	6	4	0	5	0	0	0	2	0	17
CDL	23	11	0	0	0	0	0	0	0	34
HAK	0	0	0	0	2	0	2	0	0	4
HOK	1	0	5	17	7	10	1	0	0	41
LIN	0	0	1	3	0	2	0	0	0	6
MDO	0	0	0	0	0	0	0	1	0	1
OEO	0	0	4	9	30	89	0	0	0	132
ORH	231	10	1	250	3	65	1	226	3	790
PTO	0	0	0	0	0	2	0	0	0	2
RBY	0	4	0	0	0	0	0	1	0	5
SBO	0	0	0	0	0	0	0	1	0	1
SBW	0	0	0	0	0	2	0	0	0	2
SCI	4	1	1	3	0	0	0	0	0	9
SQU	0	0	0	1	19	1	0	0	0	21
SSO	0	0	50	42	5	201	0	0	0	298
SWA	0	0	2	0	1	0	0	0	0	3
TAR	0	0	0	0	0	0	0	0	14	14
WWA	0	0	0	0	7	0	0	0	0	7

	Fishery Management Area									
	1	2	3	4	5	6	7	9	10	All
"Solitary small"										
BAR	0	0	0	1	0	0	0	0	0	1
BNS	0	0	1	4	0	0	0	0	0	5
BOE	0	0	4	4	0	14	0	0	0	22
BYX	1	1	0	0	0	0	0	0	0	2
CDL	1	3	0	0	0	0	0	0	0	4
HAK	0	0	4	0	7	3	16	0	0	30
HOK	0	0	130	27	14	4	2	0	0	177
LIN	0	0	6	2	0	3	0	0	0	11
OEO	0	0	1	0	2	13	0	0	0	16
ORH	20	1	0	156	0	1	0	20	0	198
PTO	0	0	0	0	0	1	0	0	0	1
SCI	0	15	2	50	0	0	0	0	0	67
SQU	0	0	4	0	16	1	0	0	0	21
SSO	0	0	2	9	2	20	0	0	0	33
SWA	0	0	18	3	1	0	0	0	0	22
WWA	0	0	0	0	2	0	0	0	0	2
"Whip-like"										
ORH	1	0	0	1	0	0	0	0	0	2

Table E3: Number of corals reported by family from observed fishing effort up to 30 September 2011. Codes are defined in Table 3-3 and Fishery Management Areas are shown in Figure C2.

Target	FMA	Order only	Acanthogorgiidae	Antipathidae	Aphanipathidae	Caryophylliidae	Caryophylliidae_br	Caryophylliidae_cup	Chrysogorgiidae	Cladopathidae	Coralliidae	Dendrophylliidae	Flabellidae	Isididae	Leiopathidae	Myriopathidae	Oculinidae	Paragorgiidae	Plexauridae	Primnoidae	Schizopathidae	Stylasteridae	Stylopathidae	All
TWL		295	7	4	1	1	774	244	128	8	23	82	205	513	85	3	68	173	36	207	87	145	13	3102
BAR	FMA4							1																1
BNS	FMA1													1										1
	FMA4						4																	4
	FMA9						1																	1
BOE	FMA3	2					2	1	1			1	1	7			2	5				2		24
	FMA4							3						1			3	3		3		1		14
	FMA5	1																						1
	FMA6	39	1				62	3	10		5	10		32	1		6	16	9	20	14	11		239
BYS	FMA1	3					2		1					5						1				12
	FMA2						1								1			1	1					4
	FMA4	1																						1
	FMA9	3					1		2			1		5										12
BYX	FMA1	1					4	1				1		3	2									12
	FMA2						1	1						3						1				6
	FMA4	3					4							1	1									9
	FMA9	2					1																	3
CDL	FMA1	5					5		2			1		6	10							1		30
	FMA2	9					4	3	1								1	1						19
HAK	FMA3												4											4
	FMA5	3						3						1						1		1		9
	FMA6							2														1		3
	FMA7			1				16						1										18
HOK	FMA1	1					1																	2
	FMA2						1																	1
	FMA3	1					5	2					125	2				1		1		3		140
	FMA4							4	1				23	14			1			2				45
	FMA5	1											14		1					5				21
	FMA6	3					1						2	2						2	2	2	1	15
	FMA7	1						1														1		3
LIN	FMA4							1						1										2
	FMA6												1											1
MDO	FMA9	1																						1
OEO	FMA3	1					2		1				1					1		1				7
	FMA4						1							2				6		1				10
	FMA5	2	2				2	2		4				5				5		9	3			34
	FMA6	7					37	6	3		6	3	1	38			4	11	10	10	4	6		146
ORH	FMA1	43	1	1			19	2	36		2	9	1	102	18			3		15	9	17	2	280
	FMA10													1	1					1				3
	FMA2	5					4							4						1		1		15
	FMA3																				1			1
	FMA4	51	1	2		1	194	112	4	3	3	27	3	53	27		29	14	4	43	36	41	10	658
	FMA5	3																						3
	FMA6	6					13		4			5		34				10	1	10		1		84
	FMA7																			1				1
	FMA9	42					207	6	37		1	8	2	90	20		7	19		13	5	12		469
RBY	FMA2	3																		1				4
	FMA9	1																						1
SBO	FMA9	1																						1
SBW	FMA6																	2						2
SCI	FMA1	1					2							1		1			1					6
	FMA2	1					12	11											1			4		29
	FMA3						1	1					1							1				4
	FMA4	2					43	38					4							1		8		96
SQU	FMA3												3									1		4
	FMA4																			1				1
	FMA5	11					26	1			1	1		5						2		15		62
	FMA6	1																				1		2
SSO	FMA3	11	1				7	2	6		1	3		18			3	4		9				65
	FMA4	5					9	6				1		11			2	14		9	3	3		63
	FMA5	1					1		1					1			1	1			1	2		9
	FMA6	16					87	10	16	1	4	10		57	2		9	56	5	35	9	10		327
SWA	FMA3	1					1						18	1										21
	FMA4						5	2					1											8
	FMA5						1	1	1															3
TAR	FMA10		1		1											2			4	6				14
UNI	FMA9								1															1
WWA	FMA5							2				1		5	1					1				10

Table E3: *continued*

Target	FMA	Order only	Acanthogorgiidae	Antipathidae	Aphanipathidae	Caryophylliidae	Caryophylliidae_br	Caryophylliidae_cup	Chrysogorgiidae	Cladopathidae	Coralliidae	Dendrophylliidae	Flabellidae	Isididae	Leiopathidae	Myriopathidae	Oculinidae	Paragorgiidae	Plexauridae	Primnoidae	Schizopathidae	Stylasteridae	Stylopathidae	All
BLL							6	1				1		3			1	1		3		8		24
BNS	FMA3																					1		1
	FMA4													1								4		5
LIN	FMA3						2							1										3
	FMA4						4	1						1				1						7
	FMA6																			1		2		3
PTO	FMA6											1					1			2		1		5
NA														1				1						2
LIN	FMA6																	1						1
NA	FMA4													1										1
SN							4	6									5							15
LIN	FMA3						4	6									5							15
All		295	7	4	1	1	784	251	128	8	23	83	205	517	85	3	74	175	36	210	87	153	13	3143