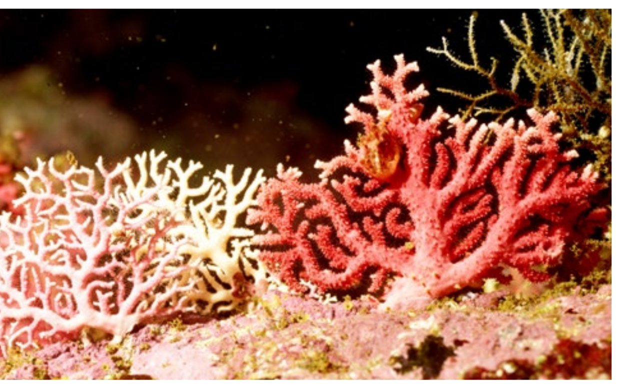

The state of knowledge of deep-sea corals in the New Zealand region

Di Tracey[1] and Freya Hjorvarsdottir[2]
(eds, comps)

Fisheries New Zealand
Tini a Tangaroa

Department of Conservation
Te Papa Atawhai

NIWA
Taihoro Nukurangi

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The state of knowledge of deep-sea corals in the New Zealand region

Di Tracey[1] and Freya Hjorvarsdottir[2]
(eds, comps)

[1] Fisheries Scientist, Deepsea Ecology and Fisheries, National Institute of Water and Atmospheric Research – Taihoro Nukurangi

[2] Previously Science Advisor, Conservation Services Programme, Marine Species & Threats, Biodiversity, Department of Conservation. Currently Senior Analyst, Fisheries New Zealand – Tini a Tangaroa, Ministry for Primary Industries – Manatū Ahu Matua

CONTENTS

Foreword: The State of Knowledge of Deep-Sea Corals in the New Zealand Region

Deep-sea corals create the most important biologically-structured habitats in the deep sea, and support ecosystems of astonishing variety and biodiversity. Deep-sea corals are also among the slowest growing and longest-lived animals in the ocean, with longevities of hundreds to thousands of years. These characteristics make deep-sea corals vulnerable to human activities that damage the seafloor or alter the surrounding environment. As a result, corals have become central to national and international deep-sea conservation efforts.

The State of Knowledge of Deep-Sea Corals in the New Zealand Region reviews how research over the last two decades is improving our understanding of the biology and ecology of deep-sea corals and the ecosystems they support in New Zealand waters and adjacent regions in the South Pacific. Written by the leading experts in the field, this report captures the richness of New Zealand's deep-sea coral species. For example, the approximately 110 deepwater coral species described from New Zealand represent around a sixth of the world's described species, and include the deepest reef-forming species, *Solenosmilia variabilis*. Individual sections and appendices on major deep-sea coral groups provide important information on these species. The report also describes how New Zealand scientists are combining mapping and oceanographic studies with new scientific approaches, such as population genetics and predictive habitat modelling to understand where corals occur and how they are likely to respond to impacts ranging from deep-sea mining to ocean acidification.

Building on this research, New Zealand has been at the forefront of efforts to conserve deep-sea corals. It was the first country to officially identify major groups of deep-sea corals as protected species. It has also been an international leader in protecting major portions of the nation's exclusive economic zone from impacts of bottom trawling. The report provides a brief overview of threats and New Zealand's forward-looking framework for management. The report also provides the first compilation of information on deep-sea corals from Antarctica's Ross Sea and the larger South Pacific Regional Fishery Management Organization region.

As an editor of the United States National Oceanic and Atmospheric Administration (NOAA) report on the State of Deep-Sea Coral and Sponge Ecosystems of the United States, I both appreciate the exceptional work that has gone into this report, and welcome the information and insights it offers into the understanding and management of these critical deep-sea ecosystems. This report sets the stage for future research and conservation, and will serve as an important reference for years to come.

Thomas Hourigan
Chief Scientist

NOAA Deep-Sea Coral Research &
Technology Program

EXECUTIVE SUMMARY

The need to understand the ecosystem role, function, and value of deep-sea corals and associated fauna has become a priority for researchers in the last decade. Deep-sea corals "no longer out of sight out of mind" are potentially under threat because of the increase of human activity, climate change, and use of deep-sea resources, which has outstripped the pace of scientific research. In order to manage and predict potential impacts on corals it is important to know a lot of basic biology and ecology: what species occur where, in what form, how resilient are they to disturbance, and can they recover from impact. The knowledge of these deep-dwelling corals is well summarised in Dennis Gordon's 2009 New Zealand Inventory of Biodiversity and has advanced substantially since the days of the *Astrolabe* and *Terra Nova* voyages and the early work by taxonomists such as Patricia Ralph, Donald Squires, Ian Keyes, and Stephen Cairns, but large knowledge gaps remain. Hence this State of Knowledge Report, prepared to provide a summary and update on what is now known about New Zealand's coral fauna, to highlight identified gaps that may require future research, but most importantly to support the development of initiatives and options for effective policy-setting and management of deep-sea corals. While the report focuses on the New Zealand Extended Continental Shelf area and the deep sea where many of the region's corals thrive in 800-1000 m, shallow-water corals are also covered in the report, including some information on the Kermadec region stony coral fauna.

An overview of the state of knowledge of corals in the New Zealand region is presented to provide an understanding of deep-sea corals – their distribution, biology, and the oceanographic and geological environment in which they are located. The relevance of the research to date describing biodiversity and coral productivity are detailed, along with descriptions of the risks facing coral species, the impacts, recovery rates, and the monitoring and protective management mechanisms in place. The need to understand and protect essential habitat is highlighted. An understanding of corals preferred habitat and habitat range, (depth and distribution), is slowly being understood. Predictive modelling maps are shown here as examples to show where corals may thrive and within the region, an understanding of where they occur in relation to the complex hydrography and complex submarine environment has developed. Most of the protected hard coral groups are on dense rubble, bedrock, and seamount features, in preferred areas of active oceanography thought to aid dispersal of larvae. In these environments however, the corals are also vulnerable to the path of bottom trawls targeting for example fish species aggregated over these features. Impacts including those from fishing and mining, and anthropogenic climate change and ocean acidification are described. Coral taxonomy and morphology including a description of functional traits, associated benthic species or communities, summarised for the first time, and evidence of endemism is presented for each key coral group. Where available, biological parameters and productivity data are presented to species level for each group.

In recent years various funding agencies have enabled deep-sea coral research to progress and the pool of data on age and growth and human impacts has grown. Nevertheless, as outlined in the gaps section of this report, several coral information research needs remain. Biogenic (living, habitat-forming) groups such as corals have been found to be particularly important habitat for some fish species including their juvenile state, and various invertebrate species, but we lack full understanding of their ecosystem role. We hope to build on addressing the gaps and research priorities acknowledging that effort needs to focus particularly on the ecosystem as a whole to ensure the sustainability of the protected coral groups.

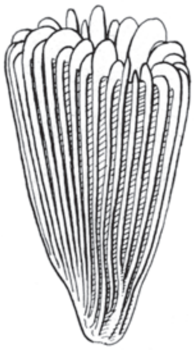
Acknowledgments

We thank Erika Mackay (NIWA) who designed and produced this report and we acknowledge her tremendous effort and artistic skills. We also acknowledge the support of the following for funding this project: the Department of Conservation (DOC), particularly Kath Blakemore, Kris Ramm, and Ian Angus, the National Institute of Water and Atmospheric Research (NIWA), principally Rosemary Hurst and Ian Tuck, and Fisheries New Zealand (FNZ), Ministry for Primary Industries (MPI) especially Richard Ford, Mary Livingston and Tiffany Bock. We also thank Mary Livingston for her thorough review and useful comments on the report, as well as co-authors Malcolm Clark and Debbie Freeman for their final read through of the document and Caroline Beamish (NIWA) for her editorial eye.

The scientific input to prepare the report was large, and we appreciate and thank the contribution of various researchers and science managers for their input to specific chapters.

New Zealand pioneers of deep-sea coral research in this region are acknowledged, particularly those whose early descriptions of coral fauna set the scene for today's research and provided the historical coral data records. These include early New Zealand Oceanographic Institute (NZOI) coral researchers Patricia Ralph, Senior lecturer in Zoology in 1959 and a reader in 1967, the first woman to hold such a position in the science faculty at Victoria University, Wellington, and whom we honour for her outstanding contribution to marine biology and descriptions of scleractinian corals in the region, along with other experts who have described New Zealand's coral fauna including: Donald Squires, Ian Keys, Ralph Grant, Fred Brook, Don McKnight, and Steve O'Shea. Ken Grange (NIWA, previously NZOI) carried out ground-breaking research on the Fiordland protected black corals. He, along with Karen Miller (now at AIMS, Perth) who worked on the Fiordland hydrocorals stylasteridae, were early coral researchers in this cold-water region. Importantly however, we acknowledge the input from international experts for their ongoing work on identifying New Zealand's diverse and abundant deep-sea coral fauna. These experts have shown dedication and passion over the decades, provided training, and descriptions of the region's diverse and abundant coral fauna. First and foremost, we thank Stephen Cairns, along with Helmut Zibrowius, Dennis Opresko, Gary Williams, Juan Sanchez, Luisa Duenas, Nestor Ardila, Santiago Herrera, Phil Alderslade, Kirrily Moore, Narissa Bax, Candice Untiedt, Marzia Bo, Tina Molodtsova, Mercer Brugler, Daphne Fautin, Jeremy Horowitz. [Affiliations are available on request].

The contribution of Lee Rauhina-August, NIWA's Wellington based Pou Ārahi – Māori Development Leader, is acknowledged for her Whakatauki (proverb) that reflects the community that has worked together to produce this report.



Cup coral *Spenotrochus ralphae*.

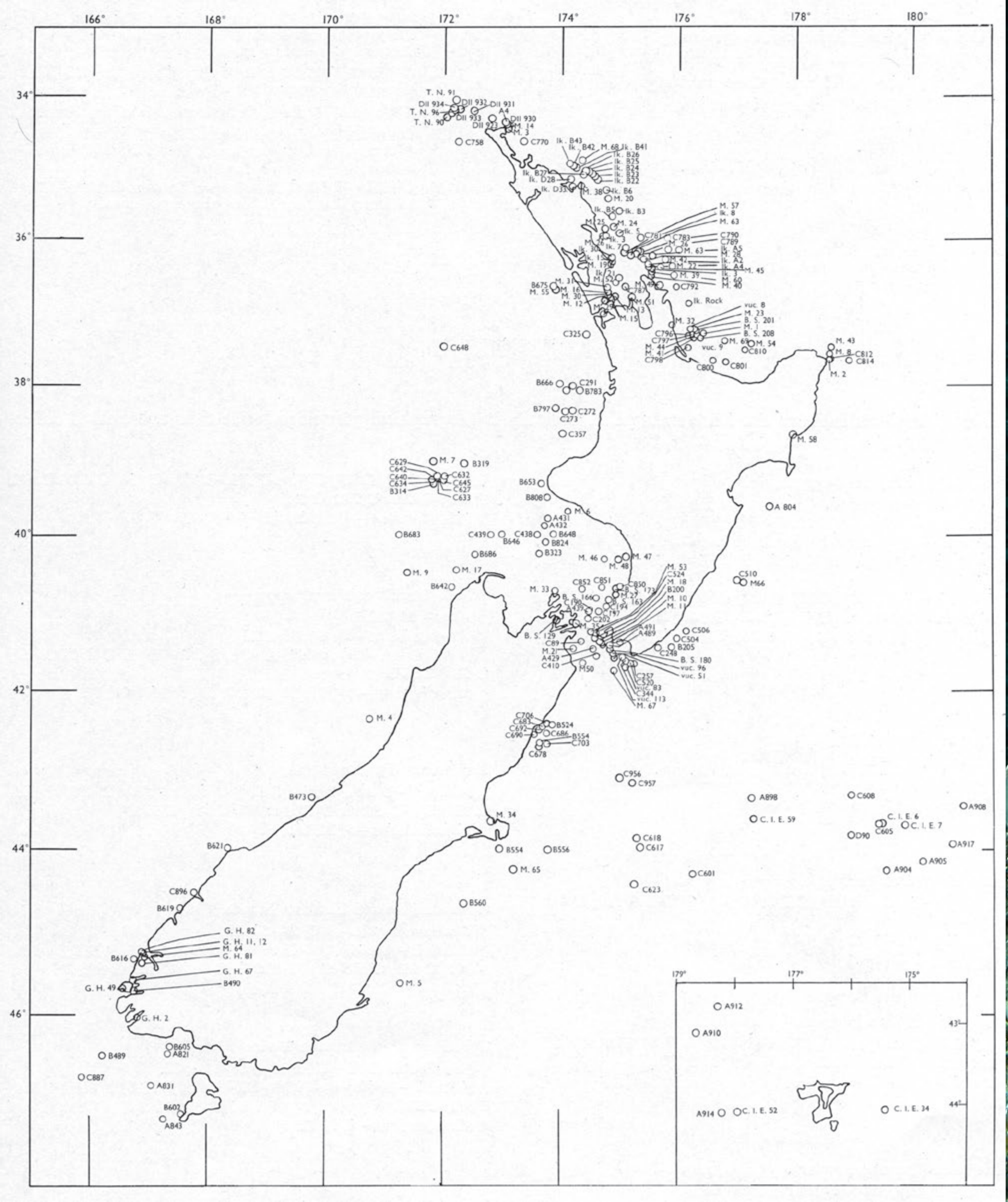
This and *Caryophyllia ralphae* were two species named in honour of Patricia Marjorie Ralph (1920-1995), for her outstanding contribution to marine biology including the description of corals for the region.

He waka kōtuia kāhore e tukutukua ngā mimira

A canoe that is interlaced will not become separated at the bow

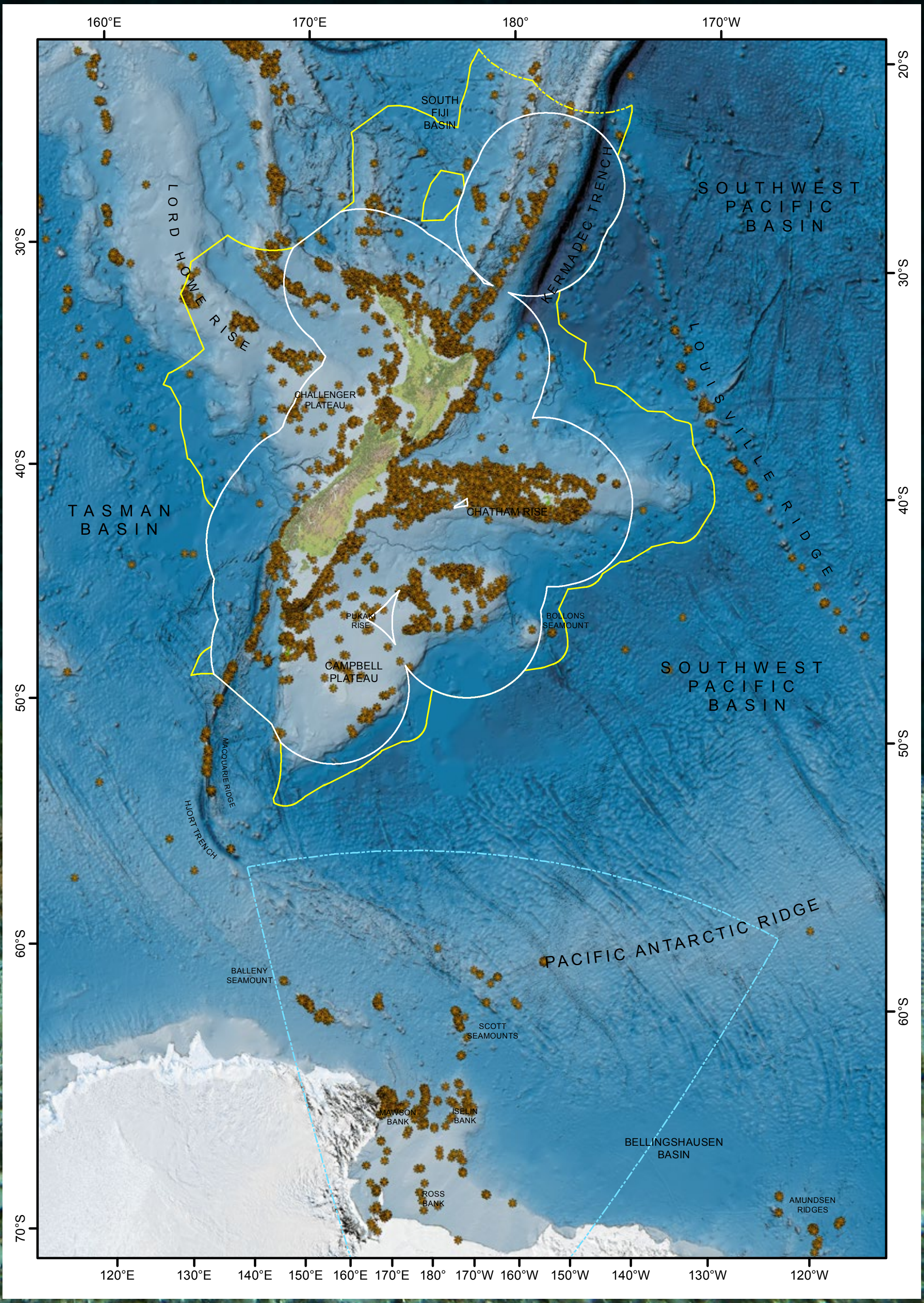
Map of the New Zealand region showing the distribution of all stations 'that yielded corals'.

Taken from Squires & Keys (1967)



Map of the New Zealand region showing the distribution of all coral samples.

Data taken from the pooled dataset prepared for Anderson *et al.* (2017) and for the Ross Sea region from NIWA Invertebrate Collection Specify database *niwainvert.*

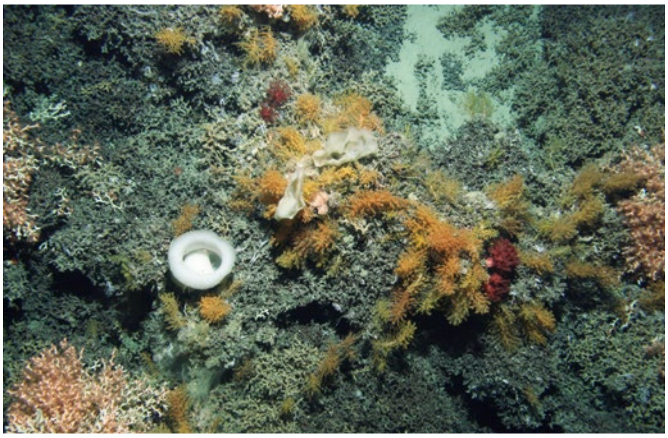


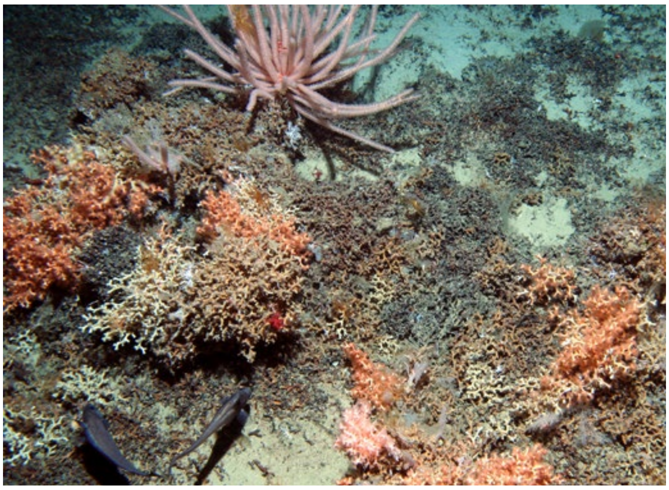
Introduction (overview)

Di Tracey

Coral is used as a general term to describe several different groups of animals in the Phylum Cnidaria and are an ecologically important group located in ocean environments of the world oceans. New Zealand's large marine realm supports an abundant and diverse coral fauna in shallow-waters to well over 2000 m (Cairns *et al*. in Gordon 2009). Corals are distinguished from their soft bodied relatives (anemones, jellyfish, and hydroids) by hard, often calcified skeletons. There are exceptions, for example sea pens, stoloniferans, some zoanthids, and soft corals do not have hard skeletons.

The focus of this report is on the deep-sea hard corals that are found primarily in waters over 200 m depth, and that belong to the coral groups that are protected under Schedule 7A of the Wildlife Act 1953 and a later (2010) amendment to the Act. These protected coral groups include orders Antipatharia (black corals), Alcyonacea (the gorgonian octocorals known previously as those corals in Order Gorgonacea), Scleractinia (stony corals), and family Stylasteridae (hydrocorals). Additional protection is provided for corals located within marine reserves (e.g., for the shallow cold-water corals in Fiordland Marine Reserves), closed seamounts, and Benthic Protection Areas (BPAs). Several unique deep-sea corals are found throughout the region (Sanchez 2005; Cairns 2007; 2012; 2016; Opresko 2014), with the gorgonian octocoral assemblage perhaps the most diverse of any country in the world (Sánchez & Rowden, 2006).





Coral species within the New Zealand region are widespread and are found on the continental shelf region both on slope margins, ridges and underwater topographical features such as seamounts, knolls, and drop-offs and principally at depths of 800–1000 metres. Several species extend into the wider Pacific region, including along the Louisville Seamount Chain, throughout the Southern Ocean, including along the Macquarie Ridge, and into the Ross Sea. Some of the same species are found in the deep sea and in the west coast South Island fiords. While 'deep-sea' in the New Zealand region is defined as 200 m or more, several corals have a shallow minimum depth distribution and some habitat suitability modelling studies use a 50 m cut-off in the depth data for this group (Tracey *et al*. 2011).

The scleractinian corals include the shallow warm-water hermatypic (zooxanthellate) stony corals. These have symbiotic microalgae for photosynthesis. Of the 17 hermatypic species in New Zealand, all but one is found on the Great Barrier Reef, Australia (Brooks 1999), and they are at or near their southernmost limit at shallow depths around Rangitāhua or Kermadec Islands (e.g., *Tubinaria*, *Pocillopora*). Ahermatypic, azooxanthellate cold- water corals occur throughout the region's deeper waters and are also referred to as cold-water or deep-sea corals.

Deep-sea corals fall at the natural confluence of biology, hydrography, and geology (Roberts *et al*. 2009), and within the New Zealand region an understanding of their spatial distribution, preferred bottom substrate in what is a complex submarine environment and dynamic ocean environment, has developed. The oceanography that aids dispersal is well understood, less so their reproductive strategies and dispersal mechanisms

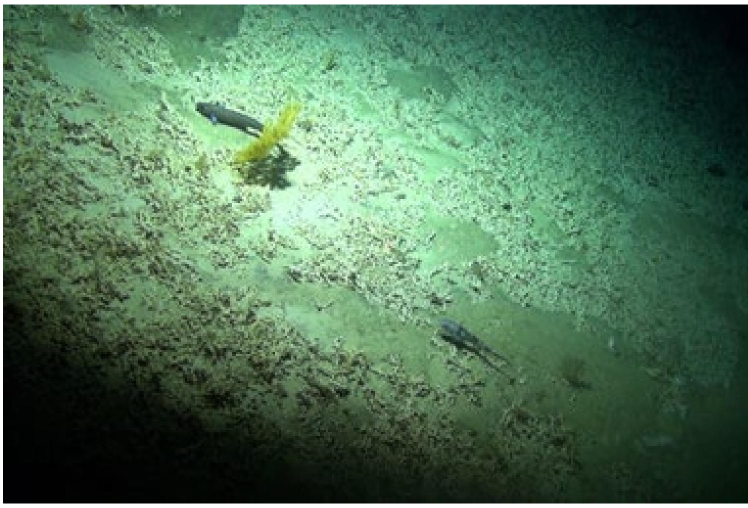
Despite their hidden nature, we know that corals are key components of deep-sea bottom ecosystems in the region (Clark *et al*. 2010). They provide important habitat complexity and a variety of ecosystem services to the species and communities they support. Corals are often associated with a high biodiversity of fish and invertebrates, providing vertical relief, nursery areas, refuge and shelter (Fosså *et al*. 2002; Buhl–Mortensen & Mortensen, 2004). Biogenic coral structures occur in coastal and deep waters (Jones *et al*. 2018; Tracey *et al*. 2011; Anderson *et al*. 2019), and support high levels of biodiversity, and are likely to be important fish habitat, including nursery habitat. To date only an unpublished report by Simmons (2016), has begun to explore fish species associations with deep-sea corals in New Zealand waters.

The ability to carry out deep-sea exploration on deep-sea corals has been limited by technology, however in the last decade or so, knowledge has built up of some of the key fauna found in the New Zealand region as well as an understanding of their biodiversity and ecology. This has been made possible by using data obtained from numerous biodiversity research samples and video images (e.g., see Clark *et al*. 2010; 2014a; Jones *et al*. 2018), fisheries research trawl surveys (O'Driscoll 2018; Stevens *et al*. 2018), as well as from the identification of coral bycatch taken from research trawl and observed commercial vessel fishing activity (e.g., see Mills *et al*. 2013; Tracey & Mills 2016; 2017; Macpherson *et al*. 2017).

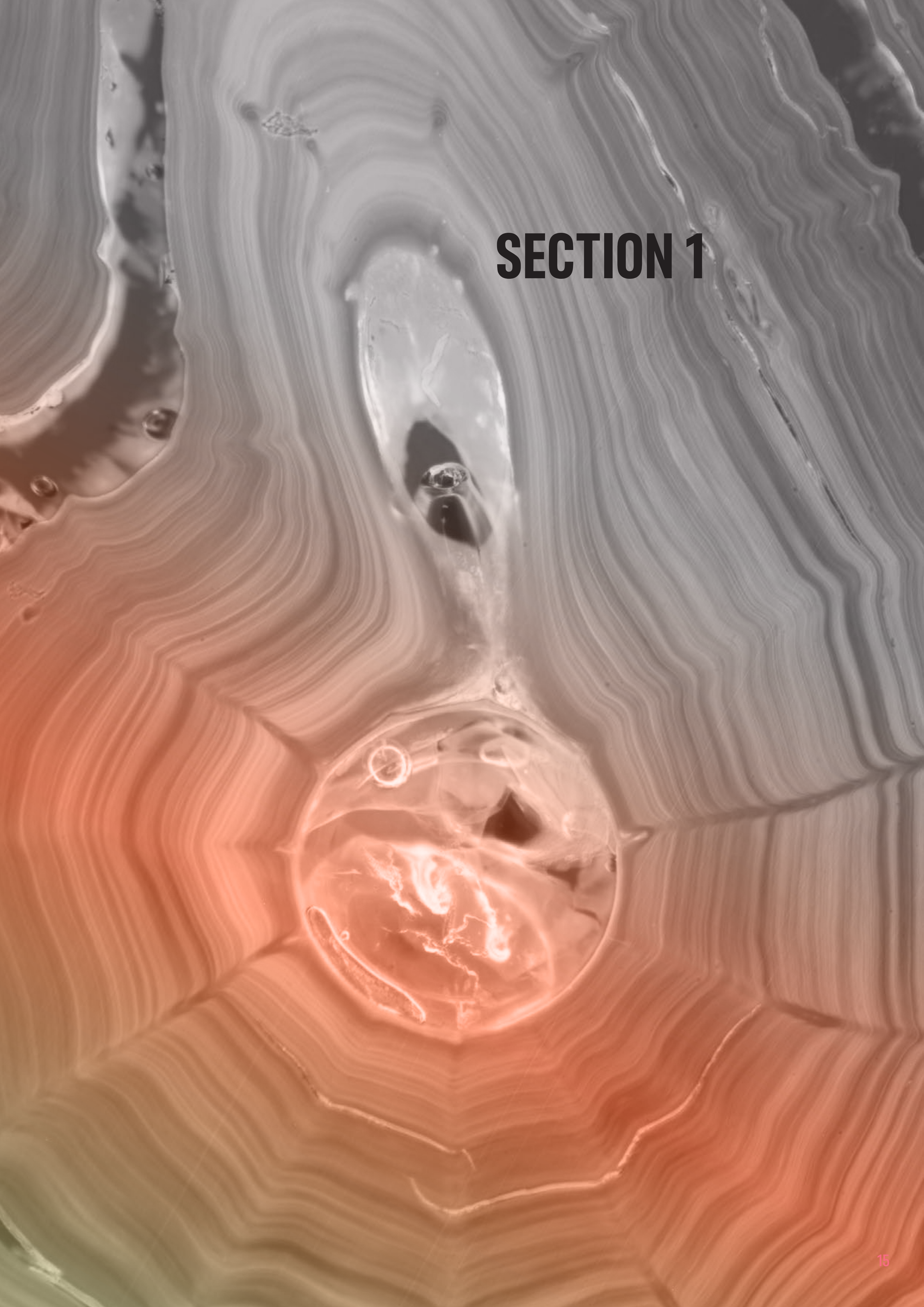
Most protected corals are delicate, slow growing and extremely long-lived, and several contain records of a wide range of human activities that can be used to reconstruct baseline ocean dynamics (Sinclair *et al*. 2011; Komugabee *et al*. 2014). The fragility of their structures makes them vulnerable to physical disturbance with resultant slow recovery from physical damage (see review in Tracey *et al*. 2013). This means that deep-sea corals are at risk from activities such as bottom trawling, oil and gas exploration, and extraction (Clark *et al*. 2016), the laying of cables and telecommunications links, plastics (Chapron *et al*. 2018), waste disposal (e.g., Ramirez-Llodra *et al*. 2011), as well as from anthropogenic climate change and ocean acidification (Gammon *et al*. 2018).

Corals are defined as vulnerable marine ecosystem indicator taxa (Parker *et al*. 2009), and their vulnerability to anthropogenic impacts highlights the need for their conservation. The key threatening processes identified by the Department of Conservation (DOC) for marine invertebrates including corals were fishing and land-use associated impacts such as sedimentation (Freeman *et al*. 2010). The Conservation Services Programme (CSP) DOC Annual Research Summary provides a summary of commercial effort, observer effort, and protected species bycatch provided by Fisheries Management Area for commercial fisheries in the New Zealand Exclusive Economic Zone (EEZ). The main focus of CSP is to report on impacts of trawling on protected corals, particularly on the Chatham Rise for deep-sea fisheries such as orange roughy (*Hoplostethus atlanticus*) and the oreo species (e.g., black oreo *Allocyttus niger* and smooth oreo *Pseudocyttus maculatus*) (Hjorvarsdottir 2017). In order to refine and understand the overlap between commercial fishing effort and corals, and to assess potential fishing impacts across their distribution, the spatial extent of corals in relation to these impacts are regularly quantified (e.g., see Anderson *et al*. 2014).

The following Chapters provide a "national overview" of the state of knowledge of New Zealand's corals and expand on the review by Consalvey *et al*. (2006). The focus is on the protected corals and the deep-sea regions where most of the research was carried out. This is not a literature review, rather a summary of New Zealand research carried out to date with some reference to overseas studies where appropriate. Gaps in knowledge for this group are highlighted to help inform future coral research and management.



SECTION 1



Chapter 1: Taxonomic Coral Classification

Sadie Mills, Di Tracey, Jaret Bilewitch (NIWA), with input from experts Frederic Sinniger (University of the Ryukyus, Okinawa, Japan); Stephen Cairns and Dennis Opresko (Smithsonian Institute, Washington DC, US), Marcelo Kitahara (Universidade Federal de São Paulo, Brazil)

The Class Anthozoa contains ~7,500 extant species of soft corals, sea fans, stony corals (Figure 1), black corals (Figure 2), and also sea pens and anemones, (Daly *et al*. 2007), and New Zealand hosts a very abundant and diverse coral fauna within this Class. These include the important reef-forming stony corals, large tree-like black corals found both in cold fiordic waters and the deep-sea, numerous gorgonian octocoral families including one of the largest known marine invertebrates (the bubblegum coral *Paragorgia arborea*) (Figure 3), and the endemic *Taiaroa tauhou* – the only extant octocoral that lives as a single, solitary polyp (Bayer & Muzik, 1976). Table 1 presents the cnidarian taxonomy as used in this report, showing the primary coral groups (subclasses Octocorallia and Hexacorallia, and the various Orders), and numbers represented for these groups in the New Zealand region. The classification is based on the World Register of Marine Species (WoRMS) taxon list.

Figure 1: Structure forming stony branching deep-sea coral *Solenosmilia variabilis* with a white primnoid octocoral (*Narella* spp.) attached to the matrix (NIWA DTIS image).

Table 1: Taxon list for Phylum Cnidaria within the New Zealand Exclusive Economic Zone (NZ EEZ), High Seas adjacent to the EEZ, and in the Ross Sea, as at October 2018, and described in this report. All except the true soft corals, zoantharians, and sea pens are protected under Schedule 7A of the Wildlife Act 1953. Numbers represent counts of described species only.

Taxon list	NZ EEZ	High Seas	Ross Sea
Class Anthozoa – corals, sea anemones, sea pens			
Subclass Hexacorallia – sea anemones, stony and black corals			
Order **Scleractinia** – stony corals (the most important families containing deep-sea, structure-forming stony corals are Carophylliidae, Dendrophylliidae, and Oculinidae)	116	36	9
Order **Zoantharia** – zoanthids (family Parazoanthidae, *Kulamanamana haumeaae* and *Savalia* sp.)	2	1	0
Order Corallimorpharia			
Order **Antipatharia** – black corals	33	18	3
Subclass Octocorallia – octocorals			
Order **Alcyonacea** – soft corals, stoloniferans, sea fans, sea whips, bubblegum corals (there are at least 12 families containing deep-sea structure-forming gorgonian octocorals)	114	50	23
Order **Pennatulacea** – sea pens	13	3	3
Class Hydrozoa – hydroids and hydromedusae			
Order **Anthoathecata** – (Stylasteridae: stylasterids, lace corals)	56	30	8

Included in Table 1 is the unique 'gold' coral, a rare zoantharian that secretes a hard skeleton. Two species are found in the New Zealand region, *Kulamanamana haumeaae* a species that secretes a golden/brown skeleton and is found in deep waters, and *Savalia* sp. (previously known as *Gerardia*) which is found between 10 and 300 m. *Savalia* sp. creates a hard, black skeleton (Frederic Sinniger pers. comm).

Specimens of the 'Gold coral' *Kulamanamana haumeaae*

Appendix 1 provides a list of described and undescribed species for the New Zealand region (Table 1), Ross Sea (Table 2); and High Seas (Table 3), as selected from the NIWA Invertebrate Collection (NIC) Specify Database *niwainvert*. Australian records from Macquarie Ridge region are not included, nor are 'undetermined' records of which there are number held in the NIC. Shallow-water specimens are under-represented. (see chapter on shallow coral fauna). Depth range data and where possible the 'Species Authority' and a 'Reference or Source expert' information is provided by species. Each Chapter in Section 2 summarises the key species for each taxonomic group.

Data sources for taxonomic studies

Accurate taxonomic identification improves the understanding of the distribution and population sizes of species, which can inform assessments of species prevalence for conservation initiatives and management decisions. Identification in turn depends upon access to a sufficient breadth of specimens for study and documentation of each species or taxon. The collection of specimens for taxonomic identification, by Government Observers as part of commercial fisheries bycatch or from research trawl and numerous biodiversity surveys, has been ongoing and has enabled descriptions by taxonomists to species-level for many of the deep-sea corals in the region (e.g., Sanchez 2005; Cairns 2012; 2016; Opresko 2014).

Several research projects have been funded to use expert advice to examine and identify or verify the identifications of bycatch specimens of protected corals that are difficult to identify at sea (see Tracey *et al*. 2017b). For over a decade, all benthic samples returned from observed vessels and from research trawl surveys were identified to the lowest taxon possible – regularly to species– and these data are recorded in NIWA's Invertebrate Collection (NIC) Specify Database *niwainvert* (e.g., see Tracey & Mills 2016; Tracey *et al*. 2017). Recently funded work has included the identification of observer digital images collected at sea (Macpherson *et al*. 2017). Identification of non-protected corals (e.g., of seapens, zoanthids, and soft corals) is undertaken as a part of other taxonomic identification projects of fisheries bycatch.

Researchers and taxonomists typically examine samples or voucher specimens of the corals to confirm or revise identifications to a lower taxonomic level, revise species descriptions, and to take subsamples for genetic analysis. Recently >200 black corals were identified or had identifications confirmed. A specimen of the genus *Heteropathes* – previously known only from Mauritius region – was recorded for the first time in New Zealand (D. Opresko pers. comm. Nov 2012). A potential new black coral genus *Diplopathes* (Figure 2) was recently discovered (Opresko *et al*. in prep).

Figure 2: This black coral "cf *Telopathes*" is most likely a new genus, *Diplopathes*, and was discovered recently on Diabolical Seamount in the Graveyard Seamount Complex at ~1000 m. (Credit NIWA).

Funding for taxonomic support has enabled coral identification to be ongoing thus providing ecological factor values for risk assessments e.g., 'Special ecological value – Endemic or rare species' is a value factor regularly used in Ecological Risk Assessments (ERA). The identifications are a priority research area for conservation managers as the information from identification of coral bycatch provides:

- vital baseline data that can help to better inform research underpinning marine protection planning such as predictive species distribution modelling (Tracey *et al*. 2011a, b; Baird *et al*. 2013; Anderson *et al*. 2014), benthic risk assessments for the effects of bottom trawling (Clark *et al*. 2014b), and management of benthic marine protected species;
- information on the interaction between commercial fishing vessels and protected cold-water corals in New Zealand waters (e.g., see Roux *et al*. 2014); and
- it allows for a more comprehensive mitigation framework to be implemented in the future in order to protect cold-water corals in New Zealand waters.

New coral species continue to be identified by global taxonomic experts and a significant driver for this is that the commercial and research vessels are not just revisiting and sampling repeatedly from the same areas, but new areas are being fished and or surveyed, and therefore species not seen before are being encountered.

To date a reliable time series of data for most areas is not available, but historic data from some areas can be used to help determine changes over time.

Production of Guides

To help improve coral identifications (particularly at sea) various guides and flip-sheets were developed for use by researchers and Government Observers (see Tracey *et al*. 2011c; 2014; Williams *et al*. 2014; Opresko *et al*. 2014), South Pacific Regional Fisheries Management Organisation (SPRFMO) (Tracey et al. 2008), and Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), (CCAMLR 2009).

Endemism

Evidence of extensive coral endemism within the New Zealand EEZ was highlighted by Cairns *et al*. in Gordon (2009) and is updated and summarised for key coral groups in Table 2. Unique to the region is the solitary soft coral *Taiaroa tauhou* (Family Taiaroidae; Bayer & Muzik, 1976), Figure 3. Other endemic species include various Flabellum cup corals, several black corals, and the red hydrocoral *Errina novaezelandiae* (Figure 3).

At sea Guides

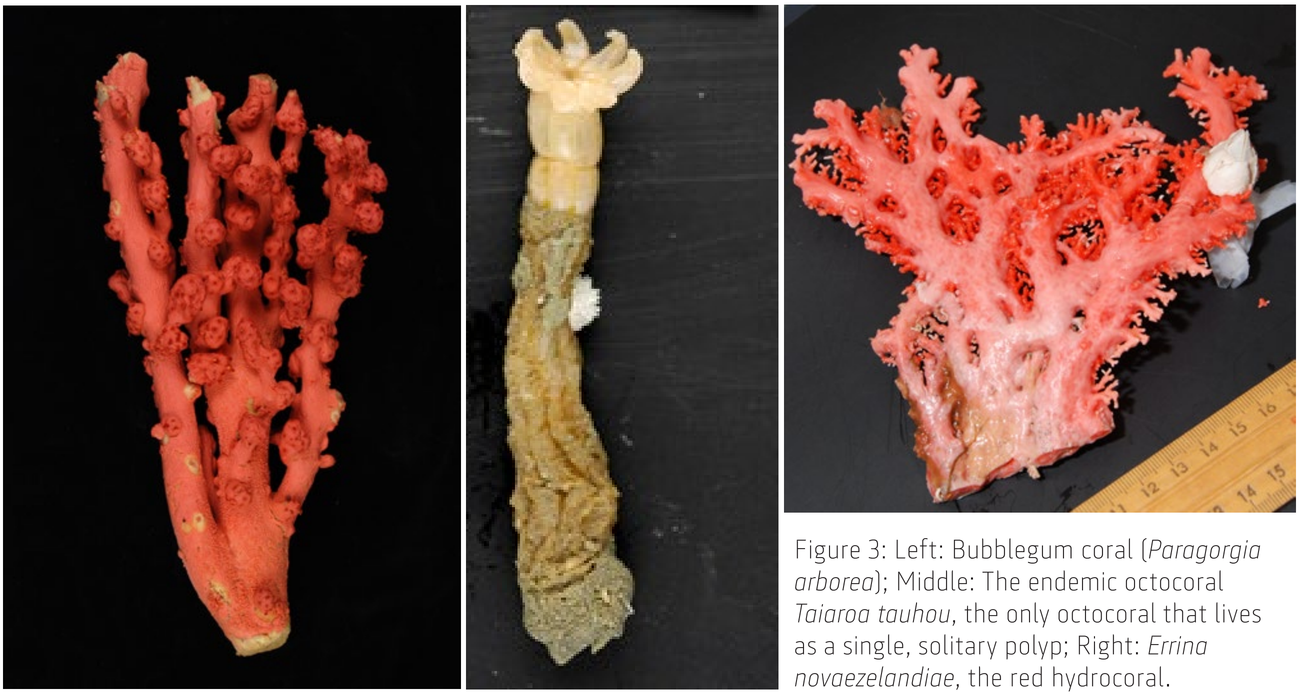


Figure 3: Left: Bubblegum coral (*Paragorgia arborea*); Middle: The endemic octocoral *Taiaroa tauhou*, the only octocoral that lives as a single, solitary polyp; Right: *Errina novaezelandiae*, the red hydrocoral.

The unusual coral-like anemone or jewel anemone *Corallimorphus niwa* (Order Corallimorpharia) (Figure 4) was recently described as an endemic species (Fautin 2011). This order, that falls between anemones and stony corals, is, along with the soft forms of Cnidaria – sea pens, zoanthids, anemones, and soft corals, not currently protected in New Zealand waters.

Table 2 summarises the endemic coral species in the New Zealand region (from Cairns *et al*. in Gordon 2009). A thorough literature review of papers published since Gordon (2009) is required to update this list. For the purposes of this report however, the numbers were revised based on recent work by Cairns (2012; 2016), who noted 20 endemic primnoid octocorals for the region and from Kitahara (*unpubl*. data), who revised down the number of endemic scleractinian species to 14 and listed one genus as endemic *Pedicellocyathus*. *Flabellum knoxi* (Figure 4, bottom image), was previously thought to be endemic but was reported in Australia by Wallace *et al*. (2009), and *Oculina virgosa* is now known not to be endemic. It is important to recognise that further sampling, and application of multiple or more sophisticated taxonomic identification tools may change estimates of endemism.

Figure 4: *Corallimorphus niwa,* in situ (left), dorsal and ventral specimen images (right) and *Flabellum* cup coral (bottom).

Table 2: Summary of endemic coral species in the New Zealand EEZ updated in part (from Cairns *et al*. in Gordon 2009; Opresko pers. comm).

Taxon Cnidaria	**Described living species**	**Known undescribed, undet. species**	**Estimate unknown species**	**Endemic species**	**Endemic genera**
Anthozoa	279	270	140	~111	5
Alcyonacea	46	166	70	~58	4
Pennatulacea	12	19	5	0	0
Scleractinia	124	5	10	16	4
Corallimorpharia	5	0	3	2	0
Antipatharia	28	~80	~52	~20	1
Hydrozoa	454	28	75	121	7
Leptothecata	234	14	30	77	2
Anthoathecata	138	12	20	43	5
Total	**~1320**	**~594**	**~363**	**~196**	**~28**

Chapter 2: Coral Biology

Di Tracey, Peter Marriott, Helen Bostock, Jaret Bilewitch (NIWA), Aimée Komugabee-Dixson, Lyndsey Holland (FNZ); Nicholas Hitt (PhD Student NIWA/Victoria University of Wellington)

Age and growth data for New Zealand's deep-sea corals are summarised to aid assessment of the likely 'recovery time' for habitat-forming species such as the reef-forming corals that are impacted by bottom-contacting fishing gear. Information on mineralogy that allows us to determine if corals are restricted by the carbonate ion concentrations and their susceptibility to ocean acidification (OA) or otherwise are described, along with some information on deep-sea corals reproductive strategies.

Age, growth rates

Several deep-sea corals are typically characterised by both long life and slow growth. Various ageing methods have revealed that some corals are thousands of years old and continue to grow today. In the New Zealand region a growth rate of 3.9 cm y^{-1} was obtained for the shallow (fiord) cold-water black coral *Antipathes aperta* (Grange & Singleton 1988). Table 3 summarises age and growth studies for deep-sea corals (from Tracey *et al*. 2018). Results show overall slow growth and extreme longevity.

Recent and ongoing work on the region's corals includes:

- Obtaining radiocarbon ages and growth data black coral species *Bathypathes patula*. In this study both coarse and fine zone counts on thin section preparations of the main-stem of ten specimens were obtained and four of the specimens were also sampled for radiocarbon assay. The ^{14}C age results showed *B. patula* to be a slow-growing long-lived species, attaining ages in excess of 385 years (Figure 5). The ^{14}C did not verify the zone counts.
- Ascertaining annually-decadally resolved radiocarbon reservoir ages in black coral species *Leiopathes secunda*; *Antipathella fiordensis*; and the genus *Antipatharia*), (Hitt *et al*. 2018; in press). Maximum ^{14}C ages of 2905 years were produced and growth rates vary between species.
- Various black corals and gorgonian octocorals such as bamboo corals are currently being analysed to reconstruct baseline ocean dynamics in New Zealand waters (Ashley Davis PhD Student under Dan Sinclair VUW, Di Tracey and Eric Behrens (NIWA).

Figure 5: 385 year old black coral specimen *Bathypathes patula*.

These projects will develop marine proxy records that will 'extend the window of perception out several centuries or more by using long-lived, deep-sea corals as a marine archive' (Sinclair *et al*. 2011; Komugabee *et al*. 2014; Hitt *et al*. 2018; in press) and produce additional estimates of deep-sea coral growth rates for a range of genera, invaluable information for coral ecologists seeking to understand deep coral ecosystems. For more details see Tracey *et al*. (2018) and Marriott *et al*. 2019)

Radiogenic isotope methods such as radiocarbon (^{14}C), Uranium–Thorium, and lead 210 (210Pb–226Ra) dating are increasingly being used to obtain colony age of habitat-forming deep-sea corals. These methods are particularly important to apply when assumed annual growth zones are not visible in the branch cross-section of the skeleton, or when growth is unable to be observed in situ. By applying these methods, various studies on branching scleractinian corals and tree-like gorgonian octocorals are able to determine growth as linear extension rates or radial thickening respectively. There is however a need to consider the complexities of the ocean environment in order to understand age data for deep-sea corals. For radiocarbon dating, interpreting the resultant ^{14}C age data requires knowledge of regional ocean circulation and the radiocarbon age of the water i.e., the "marine reservoir age", as well as how errors in the reservoir age can modify age estimates. Altered levels of ^{14}C can also occur due to localised upwelling events and productivity blooms.

For black corals the skeleton is proteinaceous, and this coral group derives its ^{14}C from the particulate organic matter (POM) that it feeds on. The POM falls as planktonic detrital rain from the surface waters. Marriott *et al*. (2019) provided radiocarbon measurements of the black coral *Bathypathes* where the carbon from these corals skeletons comes from the surface, hence they have a surface radiocarbon

Table 3: Summary of protected coral age data for the New Zealand and adjacent regions (revised from Appendix A: in Tracey *et al*. 2018). The table is divided by coral group. A small amount of age data is included for Australian studies. Location and depth of collection, age (in years), growth (in mm/yr) where available, growth parameter measured (e.g., linear, radial), ageing method, and a citation reference are provided for each coral species. New age data for black corals and two species of stony corals are included from Hitt *et al*. (2018), Marriott *et al*. (2019).

PROTECTED CORAL GROUPS							
Coral species	**Location of collection (with depth in metres (m) of collection)**	**Depth (m)**	**Age (years old)**	**Growth (mm/yr)**	**Growth parameter measured**	**Method**	**Reference**
Stony Corals (Scleractinia)							
Solenosmilia variabilis	Tasmanian seamounts, Australia, South Pacific Ocean	958–1454	75–120 (47400 colony)	0.84–1.25 0.27	Linear extension Accumulation rate	Growth zone counts; ^{14}C dating	Fallon *et al.* 2014
Solenosmilia variabilis	Louisville Seamount chain	910–1448	–	0.53–3.068	Linear extension	Observation in live aquaria over 1 year	Tracey *et al.* 2016, Gammon 2016
Solenosmilia variabilis	Chatham Rise	1019–1250	160–300	0.3–1.3	Linear extension	^{14}C dating	Neil *et al.* in review
Solenosmilia variabilis	Louisville Seamount chain	1019–1250	84–271 (516–10,744 colony	0.2–0.8	Linear extension	^{14}C dating	Neil *et al.* in review
Madrepora oculata	Chatham Rise	890–1233	752–1123	0.31–0.80	Linear extension	^{14}C dating	Marriott *et al.* 2019
Madrepora oculata	Bay of Plenty	760–960	921	0.68	Linear extension	^{14}C dating	Marriott *et al.* 2019
Goniocorella dumosa	Chatham Rise	261–420	372–422	0.48	Linear extension	^{14}C dating	Marriott *et al.* 2019
Black corals (Antipatharia)							
Black coral (no species name)	Norfolk Ridge, Tasman Sea	560	300–330	0.002–0.1	Radial growth	^{14}C dating; U/Th dating	Komugabe *et al.* 2014
Black coral (no species name)	Norfolk Ridge, Tasman Sea	490	283–307	0.049	Radial growth	U/Th dating	Komugabe-Dixson *et al.* 2016
Antipatharia	Chatham Rise	870	909–2672			^{14}C dating	Hitt *et al.* 2018
Antipatharia	Fiordland	35	263–present			^{14}C dating	Hitt *et al.* 2018
Antipathella fiordensis	Fiordland	34	129–present			^{14}C dating	Hitt *et al.* 2018
Antipathes	Chatham Rise	~300–500	380–present			^{14}C dating	Hitt *et al.* 2018
Leiopathes secunda	Chatham Rise	758	35–1269			^{14}C dating	Hitt *et al.* 2018
Leiopathes secunda	Bay of Plenty	750	506–1960			^{14}C dating	Hitt *et al.* 2018
Leiopathes spp.	Bay of Plenty	758	289–2901			^{14}C dating	Hitt *et al.* 2018
Bathypathes patula	Chatham Rise	758–810	211–481; 120–310			Growth band counts; ^{14}C dating	Marriott *et al.* 2019
Bathypathes patula	Bay of Plenty	949	176–380			Growth band counts; ^{14}C dating	Marriott *et al.* 2019

Table 3 cont.

Gorgonian octocorals (Alyconacea)							
Bamboo coral							
Keratoisis spp.	Cascade Plateau of Tasmania, Australia, South Pacific Ocean	1000	316–400	0.005	Radial growth	^{14}C dating; 210Pb dating; U/Th dating; Mg:Ca ratios Ck ages for all methods	Thresher *et al.* 2004
Keratoisis spp.	Urry Knoll, Chatham Rise, New Zealand, South Pacific Ocean	594–770	305	0.4	Linear extension	^{14}C dating	Noe & Dullo 2006
Keratoisis spp.	Snares Shelf, Campbell Plateau, New Zealand, South Pacific Ocean	935	38	0.22	Radial growth	Growth band counts (SEM)	Tracey *et al.* 2007
Keratoisis spp.	Chatham Rise, New Zealand, South Pacific Ocean	680		0.23–0.64 5	Linear extension Vertical growth	Growth band counts; ^{14}C dating	Noe *et al.* 2008
Keratoisis spp.	Antarctica	2119–2592		0.0155		^{14}C dating	Thresher *et al.* 2009
Lepidisis sp.	New Zealand seamounts, South Pacific Ocean	638–1030	7–58	0.15–0.32 21.5–57	Radial growth Linear extension	Growth band counts (SEM); 210Pb dating Growth band counts (SEM)	Tracey *et al.* 2007
Bubblegum coral							
Paragorgia arborea	New Zealand seamounts, South Pacific Ocean	no depth data available	300–500	15–25	Radial growth	^{14}C dating	Tracey *et al.* 2003

signature and not an at-depth radiocarbon value. Some samples exhibited a fraction modern ($F^{14}C$) of greater than 1 from the growing branch tips and main branch surface. This indicates the coral has ingested material with the bomb signal in it thus helping support the conclusion that the corals food source is from the surface. The deep, ambient water that these corals are living in however, has much lower ^{14}C values, and the post-bomb testing elevated ^{14}C values found in the New Zealand surface waters are yet to filter down to the deep sea.

Several factors need to be considered when radiocarbon dating these and other marine organisms - the food source, the rate of fall of prey through the water column, and the carbonate form of the corals, be it one with an organic (proteinaceous) matrix, a carbonate structure (as with the scleractinian stony corals that get the carbon at depth), or even a mix of both organic and carbonate (e.g., the bamboo corals).

Uranium–Thorium (U-Th) dating assumes that radioactive decay of U and Th occurs in a closed system within the coral (Edwards *et al*. 2003). For most living corals, there is limited exchange between the skeletal carbonate and ambient water masses, therefore ages are typically accurate after correcting for detrital thorium isotopes in the water column. The U–Th results might need further interpretation for fossil corals that might have undergone diagenetic processes which alter the ratios for U-Th.

Mineralogy

There are three forms of calcium carbonate found in nature; Aragonite, Calcite and High Mg Calcite, and a large number of deep-sea corals form calcium carbonate skeletons comprising these various forms. Bicarbonate and/or CO_2 are the important variables in calcification. An increased level of CO_2 in the oceans affects formation of calcium carbonate shells and skeletons. The water's suitability for carbonate formation is determined by the saturation state (represented by the Greek letter omega, Ω). As Ω goes down, growth for certain organisms becomes increasingly difficult, ultimately threatening an organism's survival.

Like their tropical, shallow-water counterparts, the deepwater scleractinian corals are all made of aragonite (Guinotte *et al*. 2006; Thresher *et al*. 2011b; Bostock *et al*. 2015). Knowledge of coral mineralogy helps determine if they are restricted in their distribution by the carbonate ion concentrations in intermediate and deep-sea waters and if they will be affected by future ocean acidification (OA). Chapter 8 describes in more detail the adverse effects of OA impacts on the skeletons of corals.

Some minerals such as aragonite are more soluble than others and thus more susceptible to dissolution, as a result of reductions in carbonate ion concentrations caused by OA. Trace element data help to determine how much magnesium (Mg) is in the calcite, also important for determining the solubility and susceptibility to OA.

Globally 95% of scleractinians were reported from above the Aragonite Saturation Horizon (ASH; Guinotte *et al*. 2006). In the New Zealand region 85% of the habitat-forming scleractinia (*Solenosmilia variabilis*, *Enallopsammia rostrata*, *Goniocorella dumosa*, *Madrepora oculata* and *Oculina virgosa*) are found above the ASH, which sits between depths of 1050 – 1250 m (shallower south of Chatham Rise and deeper north of Chatham Rise; Bostock *et al*. 2015). Some species of habitat-forming scleractinian corals appear to be more resilient to undersaturation than others, e.g., *S. variabilis* is found below the ASH.

The majority of Alcyonacea corals (e.g., gorgonian octocorals and true soft corals), have high Mg calcite with 8–11 mol% $MgCO_3$ (Weinbauer *et al*. 2000; Dauphin, 2006; Thresher *et al*. 2011b; Vielzeuf *et al*. 2013). The bamboo corals *Keratoisis* spp. and *Lepidisis* spp. have the lowest Mg/Ca ratios of 8.5–8.8 mol% $MgCO_3$. The bubblegum coral *Paragorgia* spp. has an average of 9.7mol% $MgCO_3$. *Primnoa* sp. (Figure 6) is trimineralic and has both low and high Mg calcite (11mol% $MgCO_3$) and aragonite (Thresher *et al*. 2011b; Bostock *et al*. 2015). The amount of Mg incorporated into the calcite is important as it was shown experimentally to affect the solubility of the coral skeleton, with >12mol% $MgCO_3$ being equally soluble to aragonite (Walter & Morse, 1984; Bischoff *et al*. 1987; Morse *et al*. 2006; Andersson *et al*. 2008), and thus the vulnerability to OA.

Currently 95% of the predominantly Mg calcite gorgonian octocorals are also found above the ASH in the New Zealand region (Bostock *et al*. 2015). This suggests that the carbonate chemistry is having a strong control on the distribution of these gorgonians. Even some of the soft coral have small sclerites which are a combination of organic matter and calcium carbonate. These are made of high Mg Calcite with 5–10mol% $MgCO_3$ (Rahman & Oomori, 2008). Some species of gorgonian were found to have different minerals for different parts of their skeleton, e.g., the holdfast versus the axis, with 8–16mol% $MgCO_3$ (Bayer &Macintyre, 2001). Gorgonians were also found to have amorphous carbonate hydroxylapatite present in combination with aragonite and high Mg calcite (Bayer & Macintyre, 2001).

Several other deep-sea coral genera such as those in the family Corallidae (Dauphin 2006), are high Mg calcite, *Corallium rubrum* is high Mg Calcite with 9–15mol% $MgCO_3$ (Vielzeuf *et al*. 2013). The hydrocoral Stylasteridae, including some from the New Zealand region, are primarily aragonitic, but with 7 in 4 hydrocoral genera calcitic, and several species bimineralic and contain both aragonite and high Mg calcite with 6.5–10mol% $MgCO_3$ (Cairns & Macintyre 1992). Black coral *Leiopathes* and *Bathypathes*, and gold corals (e.g., the species *Kulamanamana haumeaae* found in Hawaii but also in the New Zealand region), were proteinaceous (Prouty *et al*. 2017). Clearly there is some variability and teasing out the mineralogy for corals is important before responses to OA can be fully understood.

Figure 6: The trimineralic *Primnoa* sea fan sampled as bycatch from a New Zealand observed commercial fishing vessel trip (Image Fisheries New Zealand Observer).

Reproduction

There is little information on deep-sea coral reproduction for the New Zealand region, which generally parallels a global data gap in terms of understanding the extent of sexual vs. asexual reproduction, the variability in reproductive methods, gamete sizes, fecundities, and reproductive periodicity. Larval settlement is also poorly understood.

From work in the early 2000s on however, it is thought that most deep-sea corals are gonochoric broadcast-spawners that produce lecithotrophic planulae (i.e., single-sex colonies with post-release fertilisation in the water column, and larvae that feed on yolk as opposed to plankton). There are also coral groups that are brooders, in which larval maturation occurs within a coral polyp (Waller *et al*. 2002, Waller 2005, Waller & Tyler 2005, Rogers *et al*. 2007, Waller & Baco-Taylor 2007).

Consalvey *et al*. (2010) provided a summary of reproductive studies for the New Zealand region. Reproduction in the stony corals *Solenosmilia variabilis*, *Enallopsammia rostrata*, *Goniocorella dumosa*, and *Madrepora oculata* has been determined to involve seasonal, gonochoristic broadcast spawning with fertilization occurring in April/May, coinciding with the end of summer biomass accumulation (Burgess & Babcock 2005). There is an apparent high degree of synchrony between seamounts In *E. rostrata*, the large size of oocytes suggests it produces lecithotrophic larvae (Rogers *et al*. 2007 and references therein).

A recent study by Fountain *et al*. (2019) describes the international research that has set the stage in investigating the relationships between sexual reproduction and growth for the deep-sea octocorals. *Primnoa resedaeformis* and *Paramuricea placomus*, have been identified as gonochoristic and both genera occur in New Zealand waters. Calculated age at first reproduction, 7.6–19.8 years for *P. resedaeformis* and 20.7–37 years for *P. placomus*, which may be dependent on sex of the colony, provides a metric for estimating the amount of time these coral habitats will take to recover (Fountain *et al*. 2019).

For black corals, it is thought that *Bathypathes patula*, like most black corals, is likely to be gonochoristic which explains philopatric settlement (i.e., back to their natal area) and limited dispersal (Brugler *et al*. 2013 and references therein, Wagner *et al*. 2011). Miller (1996) worked on the shallow fiordic black coral *Antipathes fiordensis* and determined it to also be gonochoristic with annual reproduction (most likely towards the end of summer). Miller (1997; 1998) went on to report *A. fiordensis* to have a restricted larval dispersal with larvae being negatively buoyant, weak swimming and short-lived (Parker *et al*. 1997).

The stylasterid hydrocoral *Errina novaezelandiae* has been determined to be dioecious with male and female gametes developing in the skeletal cavities and internal fertilisation. Brooded planulae are hypothesised to crawl on the surface of adults before settling on the substrate below (P. Stratford, pers. comm. to Miller *et al*. 2004). *E. novaezelandiae* recruitment may be variable in space and time (Underwood and Fairweather 1989; Miller *et al*. 2004).

Little new information has emerged for the region since Consalvey *et al*.'s review. However, new genetic data provide further evidence of sexual reproduction strategies for deep-sea corals (e.g., *Desmophyllum dianthus*, Miller & Gunasekera 2017, Holland *et al*. 2019), and many species of primnoid octocorals in the region have now been described as brooders (Susana Soto de Matos-Pita, pers. comm Cairns submitted).

Disentangling factors that affect the dispersal and recruitment of coral larvae, including life history strategies, larval longevity, relevant settlement cues and substrate suitability, is all important information to understand coral productivity. An ecological risk assessment (Clark *et al*. 2014b) considered various sources of information on the biological data available for corals such as age, growth, reproduction, colonisation, and dispersal. These aspects were used to rank the overall "productivity" of a coral species or group, which then hypothetically reflects its capacity to recover from trawling. The productivity value factor scoring in the risk assessment was 'low' highlighting the lack of knowledge of these key biological data for deep-sea corals. The global research and scattered studies in the region carried out thus far provide context for larger scale reproductive ecology work and potentially for comparative studies to take place in the New Zealand region.

Chapter 3: Coral Population Connectivity

Lyndsey Holland (FNZ)

Determining population differences and assessing to what extent these differences are governed by import and export of individuals can be achieved by assessing the 'connectivity' of a coral species. Connectivity may be defined as 'the extent to which populations in different parts of a species' range are linked by exchange of larvae, recruits, juveniles or adults' (Palumbi 2003). As connectivity is logistically challenging to measure in a marine context, migration patterns and population divergence can be inferred genetically, by measuring the extent of the exchange of genes between populations (for reviews see Cowen & Sponaugle 2009, Weersing & Toonen 2009). Understanding the role that life history and different reproductive strategies have in dispersal is also important knowledge to help infer connectivity, and to inform productivity parameters in coral risk assessments.

In New Zealand, coral genetic connectivity research has primarily used two molecular methods; DNA sequencing, whereby a specific DNA region (locus and or loci) is aligned and compared, or fragment analysis (e.g., microsatellites), whereby DNA fragment lengths and frequencies at several loci are compared between populations. The various studies carried out for the region are summarised in Appendix 2, where species, sample sizes, sample sites, and the markers used to show connectivity or otherwise are referenced. More recent genetic methodologies that facilitate comparison of 1000s of loci (i.e., 'next-generation sequencing'), have not been applied to corals in New Zealand in a population genetics context, primarily due to the temporal and fiscal commitment to such methods. Improved marker development is one avenue for future coral connectivity research or for molecular-based taxonomy (e.g., Herrera & Shank 2016).

Of the protected coral groups in the region, the majority of connectivity research has focused on stony corals, although data are available for some black corals, octocorals, and hydrocorals (Appendix 2). Connectivity patterns are not uniform within each of these groups, and in some cases differ at the species level, vary between studies, molecular markers applied, or areas examined. For example, low connectivity was observed for Solenosmilia variabilis with local structure noted between seamounts (Miller & Gunasekera 2017), in contrast to regional-level differences elsewhere for the same species (Zeng *et al.* 2017). High connectivity was observed at very large spatial scales such as between the Kermadec Ridge region and the Louisville Seamount chain for some species (*Desmophyllum dianthus*, Holland *et al.* 2019), but not others (*Solenosmilia variabilis*, Zeng *et al.* 2017). It is likely that local and regional currents drive some larval dispersal routes and there has been some effort to reconcile predictive hydrodynamic models with genetic data (Holland *et al.* 2019). Conflicting genetic connectivity patterns at the species-level demonstrate that connectivity should be examined on a species-by-species basis and generalising likely routes of connectivity broadly across taxa or geographic area may be unreliable. However, as more data become available, there are some emergent patterns. The Chatham Rise and the Kermadec Ridge were both identified as areas of unique genetic diversity (Zeng *et al.* 2017, Holland *et al.* 2019), and the former showed some degree of genetic isolation. There is also increasing evidence that the Antarctic Circumpolar Current (ACC) is a barrier to dispersal for the corals tested (octocorals and black corals, Duenas *et al.* 2016 and Holland *et al.* 2019 respectively).

There is increasing evidence of genetic structuring by depth (*Desmophyllum dianthus* Miller *et al.* 2011, Miller & Gunasekera 2017). Bathymetrically–separated populations may have important management implications under scenarios of changing aragonite saturation horizons or when considering adverse fishing impacts relative to species/population distributions.

Coral Genetic Diversity

In some cases, genetic diversity of corals provides an indication of population resilience; low genetic diversity is detrimental to the long-term survival likelihood of a population or species (Reed & Frankham 2003, Bradshaw & Holzapfel 2008, Wright *et al.* 2008). Genetic diversity was found to vary by coral species and/or area, e.g.:

- lower for *Solenosmilia variabilis* than *Desmophyllum dianthus* in the same area (Miller & Gunasekara 2017),
- is higher in particular areas across several species (e.g., the Kermadec ridge region and the Chatham Rise, Holland *et al.* 2019).

Chapter 4. Species Associations with Deep Coral Communities

Kareen Schnabel, Sadie Mills (NIWA) (Invertebrates); Malcolm Clark, Ashley Rowden, Peter McMillan, Di Tracey, David Bowden, Alan Hart, Peter Marriott (NIWA), Jess Simmons (previously Bangor University), Laura Londono (University of Western Australia, previously Universidad de los Andes, Bogota, Colombia). (Fish)

Deep-sea coral communities are a highly diverse group and can form biogenic hot spots of biodiversity in the deep ocean, being associated with many species, including various invertebrates and fish, including commercially important species.

Corals provide habitat, refuge, sanctuary, and nursery areas for a broader set of benthic communities (Rogers, 1999; Krieger & Wing, 2002; Stone 2006; Mortensen *et al*. 2008; D'Onghia *et al*. 2010). The large thicket or reef-like, stony coral forms are often referred to as the engineers of the deep and their living and dead coral matrices provide structure, refuge, and shelter for numerous other species (e.g., other corals, sponges, bryozoans, various crustaceans, and echinodermata including ophiuroids, echinoids, holothurians). The field of fish association with corals has developed more recently, and while there has been an increase in literature examining deep-sea demersal fish-habitat relationships in the last decade many questions still remain. Here for the first time, information has been compiled for several invertebrate and fish species associations with deep-sea corals in the New Zealand region.

Figure 7: Polychaete *Eunice* species on *Solenosmilia variabilis.*

Invertebrate associates

Kareen Schnabel, Sadie Mills (NIWA)

Deep-sea corals provide important habitat for many invertebrate species and detailed inventories of coral associates have highlighted diverse communities of macro– and megafauna living with cold-water corals in the northern Atlantic (e.g., Rogers 1999; Buhl-Mortensen & Mortensen, 2004; 2005) and the northern Pacific (e.g., Krieger & Wing 2002). With the absence of research submersibles or remotely operated vehicles (ROV) in the New Zealand region, comparably little is known about faunal associations through direct observations here. Using the NIWA Deep-Towed Imaging System (DTIS), large sessile and mobile fauna such as brittle stars and squat lobsters can be seen perched on deep-sea corals (Figure 8, composite), but interactions of smaller fauna or those within the matrix are deduced indirectly on board the ship during sorting of physical samples or subsequently during the examination of the preserved specimen(s).

Overall, NIWA'S Invertebrate Collection (NIC) database records include references to associates for 23 coral genera in 14 families. Knowledge of invertebrate associates with corals are summarised here for the first time.

Many species of sessile suspension feeders such as sponges (e.g., Farreidae cornflake sponges), hydroids or other corals (e.g., Stylasteridae or Caryophyllidae cup corals) are often seen attached to the top of the living and dead coral matrix, taking advantage of the elevated vantage point that the coral matrix provides. Specific associations of sessile cnidarians with corals are notable such as two species of the unusual ring anemones in the genus *Peronanthus* that are only found on a *Keratoisis* bamboo coral and an *Anthothela* gorgonian, respectively (Ocaña *et al*. 2004). Also, the zoanthid *Kulamanamana haumeaae* only encrusts living gorgonian octocorals such as bamboo primnoid species (Sinniger *et al*. 2013). Other zoanthids such as the striking yellow *Parazoanthus elongatus* or *Epizoanthus karenae* frequently encrust e.g., the Fiordland black coral, but are also found on a range of other organisms from coralline algae, gorgonian corals and sponges throughout the southern Pacific (Philipp & Fautin 2009, Sinniger & Häusserman 2009).

Many mobile species are considered obligatory or facultative associates of deep-sea corals. In some cases, the associate modifies the morphology of the host to create a permanent home, e.g., commensal polynoid polychaetes alter the branching patterns of stylasterid hydrocorals to form tunnels and/or trenches along the coral axis that they move around on; Cairns (1991) reported six species of hydrocorals in four genera that always had an associated polynoid. Cairns (2012, 2014) also reported polynoids on eight species of primnoid corals in five genera. Gordon (2009) noted at least three species of polynoid worms as commensals of the deepwater black corals *Antipathes* and *Parantipathes*.

Polychaetes of the family Eunicidae form parchment-like tubes in the 3-D matrix of branching corals (e.g., of *Solenosmilia variabilis* Figure 7), and at least three unnamed morphological *Eunice* species (of about 16 New Zealand species for the genus) are known so far. Their flexible tubes can be subsequently calcified by the coral host, and although nothing is yet known on calcification enhancement effects for New Zealand species, Northern hemisphere experimental aquarium studies on *Eunice norvegica* living on the Norwegian cold-water coral *Lophelia pertusa* showed a four-fold increase in the weight of coral calcification of the host when a *Eunice* associate was present, thus enhancing the development and persistence of the natural coral ecosystem (Mueller *et al*. 2013).

Ophiuroidea (snake stars, basket stars and brittle stars) are common associates of corals. Most species of snake stars in the Order Euryalida and some species in the family Ophiacanthidae have arm-spines modified into hooks, or with extra spinelets, which they use to grasp onto the corals. Ophiuroids have not been documented to eat the corals, but it is assumed that they use the structure of the coral as either a means of gaining height up off the sea floor to suspension feed, avoid predation, or feed off deposits landing on the coral. A common and well-documented association is the aptly-named *Ophiocreas oedipus* with the gold coral species *Metallogorgia melanotrichos*. *Ophiocreas oedipus* is obligately associated to *M. melanotrichos* and lives alone on the coral for its whole life, suspension feeding from the top of its bushy perch with no evidence that the coral benefits from this pairing (Mosher & Watling, 2009). New Zealand records reflect this association with *Metallogorgia*, but also a pairing between *O. oedipus* and the similar shaped gold coral *Pseudochrysogorgia bellona* at Otara Knoll, in the Bay of Plenty.

The variably-coloured snake star species *Astrobrachion constrictum* lives tightly wound around the branches of *Antipathella fiordensis* (Grange, 1990; Figure 8). During the day, and at night it unwinds to feed using various methods: it either catches organisms floating past in the water column or sweeps up detritus that lands on the mucus layer of the coral surface (Stewart 1998). This doesn't harm the coral and aids in keeping it clean and healthy, safe from potential negative impacts in areas of heavy sedimentation or in catastrophic landslide events (Grange 1991). Evidence for the benefit to the coral of this ophiuroid cleaning action was seen in the Gulf of Mexico following the Deepwater Horizon blowout event. Girard *et al*. (2016) found that the colonies of octocoral *Paramuricea biscaya* that carried one or more ophiuroids (*Asteroschema clavigerum*) were on average less visibly impacted by the oil spill than corals that did not host any.

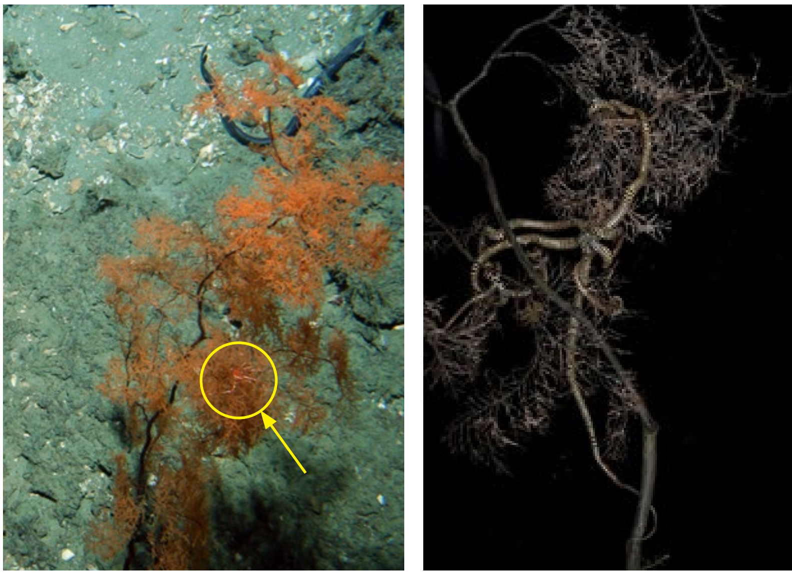


Figure 8: Left: Deep-sea *Leiopathes* black coral with a small squat lobster nestled in the branchlets of a black coral (yellow circle and arrow). Right: The ophiuroid, *Astrobrachion constrictum* on the black coral *Antipathella* from the Bay of Islands at 101 m. (Credit: Images, NIWA DTIS towed-camera).

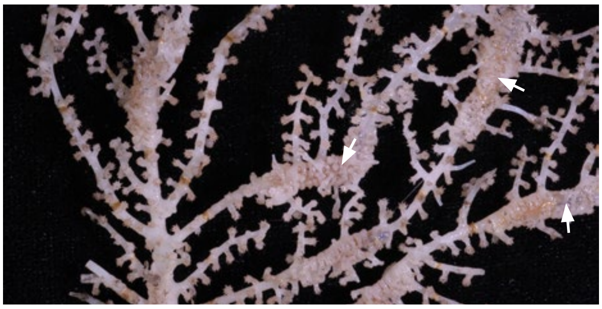


Figure 9: Polyps of the bamboo coral *Sclerisis* sp. arching over an unidentified polynoid scaleworm (Soto pers. comm from Clark *et al* 2009).

Many echinoderms are regularly seen perched on live coral assemblages, but little is known about their direct relationship with coral.

Many arthropods, primarily Crustacea, are observed and/or collected with deep-sea corals, but these are suspected to drop off their host most quickly considering the typical collection techniques used.

While anecdotal evidence shows some pycnogonid sea spiders on live coral and a number of species are collected with live coral, nothing is known about their relationship with coral in New Zealand.

Obligate coral symbionts include the coral–inhabiting barnacles in the family Pyrgomatidae and can create galls on corals. Stalked barnacles and acorn barnacles are frequently attached to live and dead corals sampled in the New Zealand region, but this relationship has not been formally examined.

Most recently, 23 species of chirostyloid squat lobsters in three families were reported with corals in the region by Schnabel (in press), 18 of which belong to the genus *Uroptychus*. Species of this genus are regularly collected deeply buried within the matrix of gorgonian gold corals, bushy bamboo corals or black corals (Figure 8) and it is generally assumed that members of this genus are associated with anthozoans (see review by Baeza, 2011). The large 'football crab', now *Sternostylus rogeri* (Baba, 2000), is always seen perched on large gorgonian and black corals similar to detailed in situ observations of another *Sternostylus* species by Le Guilloux *et al*. (2010) which showed a strong preference for large *Leiopathes* black coral in the northern Atlantic.

The galatheoid squat lobsters, which includes the ubiquitous *Munida* species are frequently encountered in all deep-sea habitats, but some species, such as *M. isos* (Ahyong & Poore, 2004) were found to be a distinctly 'seamount associated' species (Rowden *et al*. 2010). They are seen in sometimes high abundances in both live and dead coral framework as well as the extensive fields of coral rubble at the base of the reef.

Important associates of corals to consider are also corallivore predators, such as the Hippasterinae starfish. Four species of *Hippasteria* and one species of *Evoplosoma* are known in the New Zealand region and the notorious crown–of–thorns starfish (*Acanthaster planci*) is present on shallow-water corals around the Kermadec Islands (Richards & Liggins 2015).

Concluding remarks: There are few New Zealand in situ observations of invertebrate associations with deep-sea corals, most of the information available is indirect evidence and for megafauna. Macro and meiofaunal associations were not examined in the region, these associates are difficult to recover intact, and many animals simply detach or swim away when the colony is lifted from the seabed.

Fish and corals

Malcolm Clark, Ashley Rowden, Peter McMillan, Di Tracey, David Bowden, Alan Hart, Peter Marriott (NIWA), Jess Simmons (previously Bangor University), Laura Londono (University of Western Australia, previously Universidad de los Andes, Bogota, Colombia).

Elevated numbers or densities of fish are often observed in association with topography or habitats where deep-sea corals occur (e.g., Auster 2007, Costello *et al*. 2005, Tracey *et al*. 2004) and a broad range of global studies suggest deepwater corals may influence fish distribution. Fish species seen in close proximity to corals (Figure 10) 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; D'Onghia *et al*. 2010). Large aggregations of commercial fish species (such as orange roughy, alfonsino, black cardinalfish) can occur above seamounts that support high densities of "reef-like" corals, but direct linkages between the fish and coral are uncertain. The reef-like coral structures create biogenic habitat and provide structure for other protected corals such as *Desmophyllum* spp. and some gorgonian corals (for example, the bamboo coral *Keratoisis* spp.) (Cairns & Bayer 2005) as well as feeding, spawning and nursery sites for numerous organisms (Husebo *et al*. 2002; Purser *et al*. 2013; Morrison *et al*. 2014; Clark & Dunn 2012; Jones *et al*. 2016).

Vulnerable Marine Ecosystems are characterised by the presence of fragile, unique and rare taxa, alongside species and communities that can form specific habitats or increase the structural complexity (FAO, 2009). Several studies have focussed upon investigating the relationship between scleractinian corals and deep-sea fish using: in situ imagery (e.g., see

Figure 10: Giant morid cods (genus *Lepidion*) frequently observed in close proximity to coral matrix, Graveyard Knolls, Chatham Rise (NIWA).

Du Preez and Tunicliffe, 2011; Söeffker *et al*. 2011; Baker *et al*. 2012; Kutti *et al*. 2015; Milligan *et al*. 2016); fisheries surveys (D'Onghia *et al*. 2010; Kutti *et al*. 2014, Pham *et al*. 2015); or a combination of the two (Ross and Qauttrini, 2007). More and more studies such as these are revealing clear associations between fish and coral habitat and while these vary due to factors such as depth and sub-stratum type (Biber *et al*. 2013; Milligan *et al*. 2016), the reef matrix is clearly an important habitat for certain fish species.

There has been limited research in New Zealand on the extent, as well as functional nature, of associations between fish and corals. A recent Bangor University project (Simmons, 2016) carried out in collaboration with NIWA, used video image data available from six Graveyard Knoll seamounts, to examine how the demersal fish may be using the various habitats including that of corals within a seamount feature. Over 4000 individual fish were recorded from the towed camera and 88% of the individuals observed were identified to species or genus level. The three most common species observed were orange roughy, *Hoplostethus atlanticus*, (n=1467), four-rayed rattail, *Coryphaenoides subserrulatus* (n=634) and deep-sea cardinalfish species, *Epigonus* spp., (n=388); with *Halargyreus* spp. (n=125) and small headed cod, *Lepidion microcephalus* (n=86) commonly occurring deep-sea morids. Aspects such as distance from coral, and fish behaviour, were noted to determine function, not just association. The georeferenced information accompanying the fish images (n=644) in the seamount region (e.g., seamount, depth) by species, was subsequently annotated onto the individual fish image files in order to enable an efficient search enquiry and to easily locate specific fish species images for further analyses (Londono 2016). The final results of this work are not yet available and the large resource of video and still image data needs to be further explored, however the deep-sea coral reef matrix is clearly an important habitat for certain fish species.

Chapter 5. Geological and Oceanographic setting

Helen Bostock, Grace Frontin-Rollet (NIWA)

Within the New Zealand region, we are slowly building an understanding of what bottom substrate corals occur and of their preferred ocean environment. Most corals are found located on hard substrate – e.g., on dense rubble, bedrock, and on seamount features, drop-offs, and in canyons. Some species prefer the soft sediment – particularly a number of solitary scleractinian cup coral genera, as well as most sea pens. The geomorphology and bathymetry of a region determine whether there is appropriate habitat at the right water depths for deep-sea corals to live. Here the geological, bathymetric, and oceanographic setting are briefly described for the region. Recently published sediment texture and carbonate maps are shown to help provide for the first time, coral distribution in relation to substrate. These data need to be analysed by coral groups to show their preferred habitat. the first step of which is shown in Figure 3 where the sediment texture and carbonate maps (from Bostock *et al*. 2018) are overlain with coral presence for the region including an inset for the Chatham Rise. Clearly sediment cores are unable to sample in hard bottom regions and as multibeam data are not available for the entire region the maps can only serve as a proxy for the preferred habitat for corals – that of seamounts and hard bottom – ideal substrate for corals to attach. Where high density of soft sediment occurs, coral densities are low.

Geology and Bathymetric setting

The geological history and tectonic activity in the region has resulted in a complex submarine environment composed of a number of distinct bathymetric features (Figure 11), including: plateaux, rises, volcanic ridges, seamounts, deep troughs, submarine canyons and channels, and abyssal basin plains. Descriptions of the region's main bathymetric features are labelled on Figure 12.

Oceanographic setting

Oceanographic currents influence deep-sea corals by providing a steady flow of food and dispersal of larvae. Consequently, these currents also influence the availability of prey and distribution of deep-sea corals. While deep-sea corals are most affected by the bottom water currents that flow over them and influence the distribution of sediments, they are also affected by the surface water currents which influence primary productivity and thus the food supply that rains down to the deep-sea coral on the seafloor.

The New Zealand landmass sits at the cross roads between warm, nutrient-poor, subtropical surface waters flowing in from the north, and cool, nutrient-rich, subantarctic surface waters flowing in from the south. The complex bathymetry of the

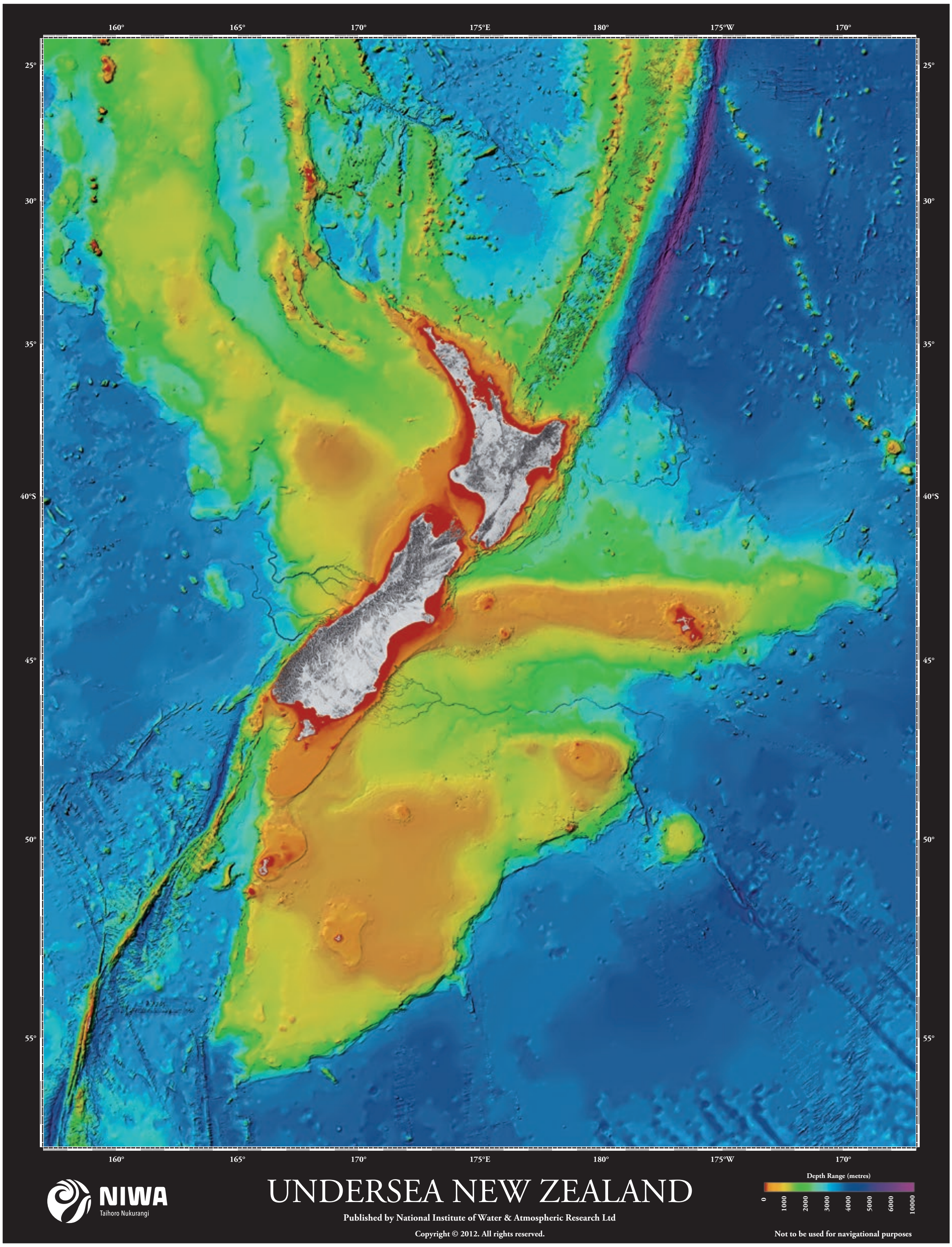
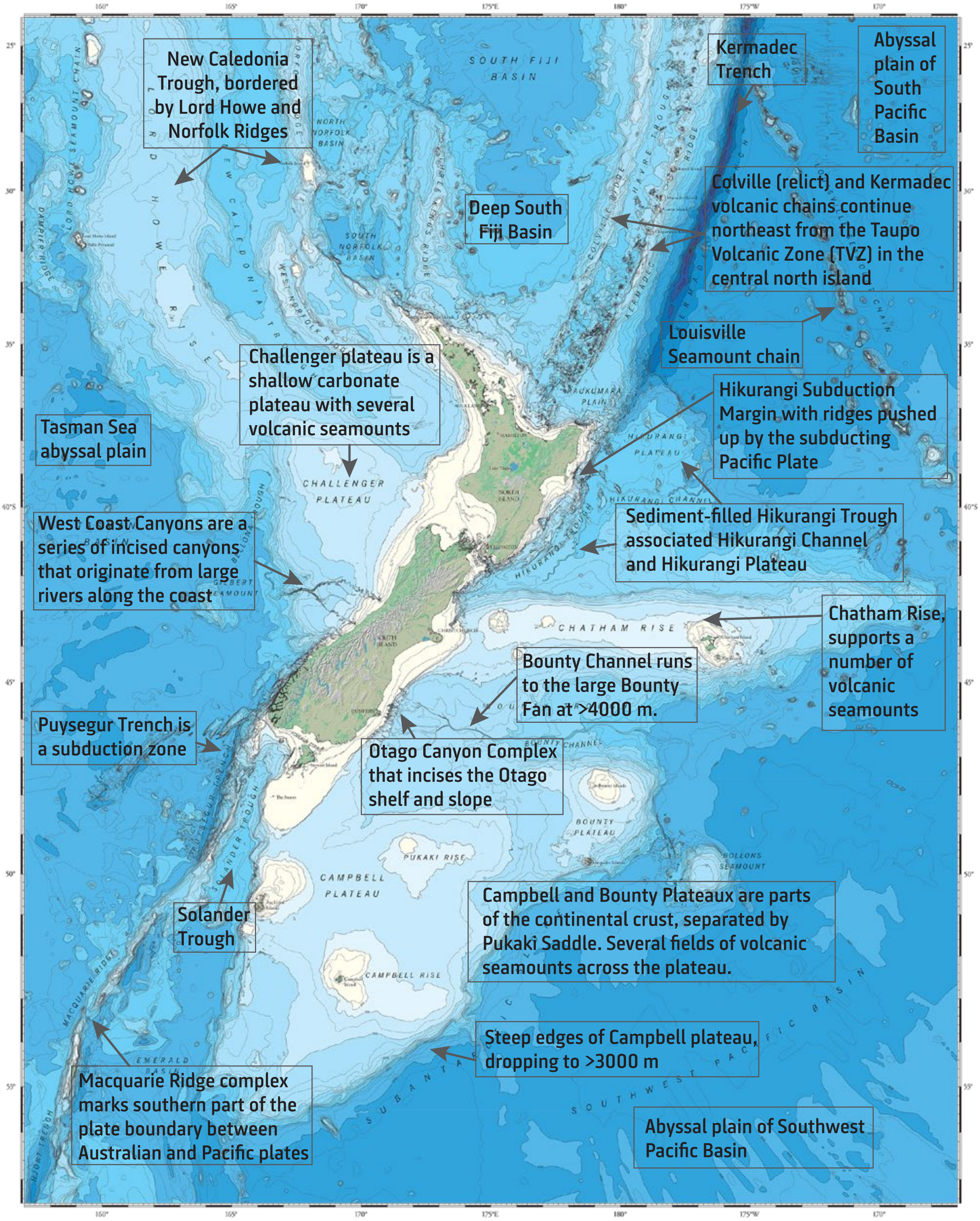


Figure 11: Submarine map of the New Zealand region showing shape of the seafloor and complexity of the sea-scape (Mitchell *et al*. 2012).



New Caledonia Trough, bordered by Lord Howe and Norfolk Ridges

Kermadec Trench

Abyssal plain of South Pacific Basin

Deep South Fiji Basin

Colville (relict) and Kermadec volcanic chains continue northeast from the Taupo Volcanic Zone (TVZ) in the central north island

Louisville Seamount chain

Challenger plateau is a shallow carbonate plateau with several volcanic seamounts

Tasman Sea abyssal plain

Hikurangi Subduction Margin with ridges pushed up by the subducting Pacific Plate

West Coast Canyons are a series of incised canyons that originate from large rivers along the coast

Sediment-filled Hikurangi Trough associated Hikurangi Channel and Hikurangi Plateau

Chatham Rise, supports a number of volcanic seamounts

Bounty Channel runs to the large Bounty Fan at >4000 m.

Puysegur Trench is a subduction zone

Otago Canyon Complex that incises the Otago shelf and slope

Solander Trough

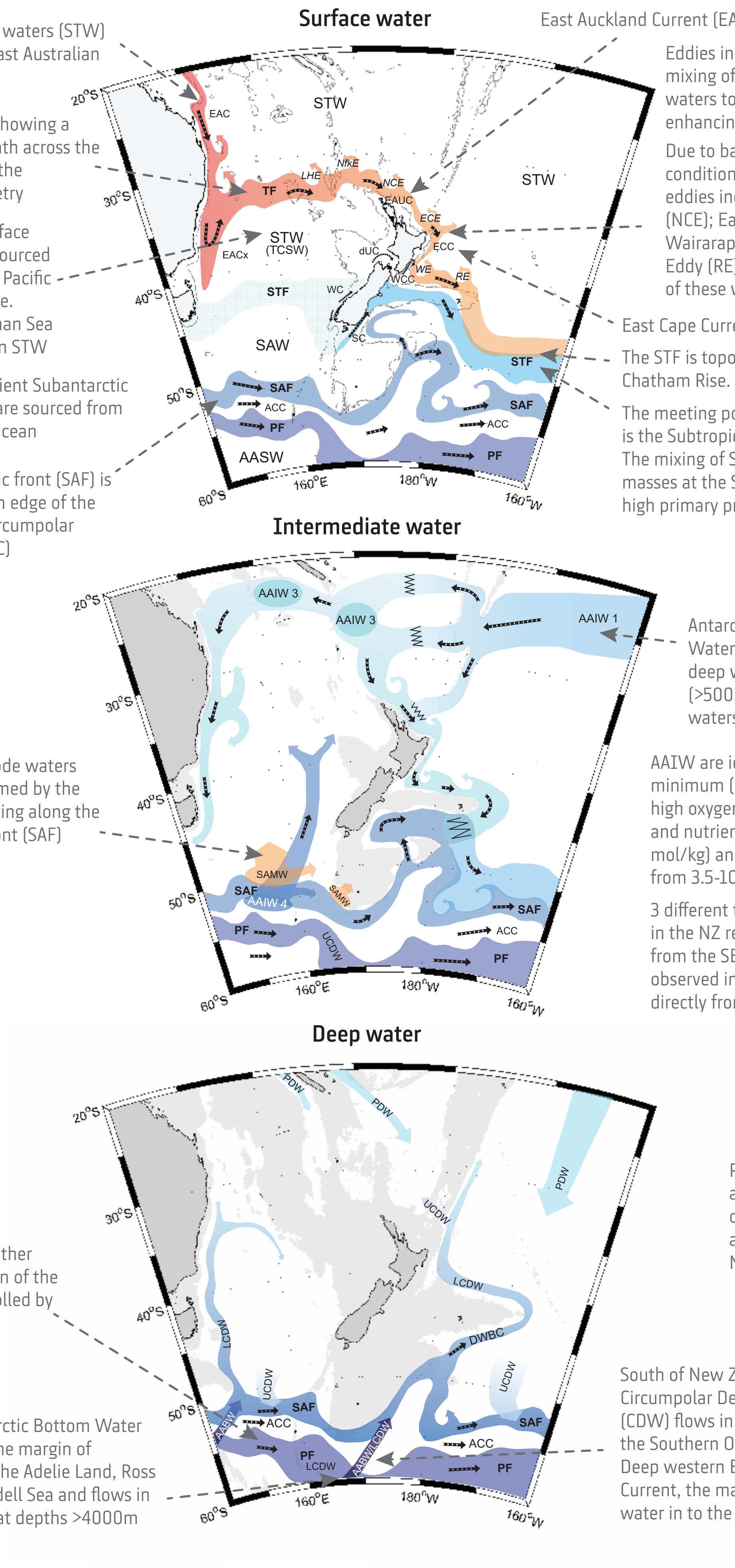
Campbell and Bounty Plateaux are parts of the continental crust, separated by Pukaki Saddle. Several fields of volcanic seamounts across the plateau.

Steep edges of Campbell plateau, dropping to >3000 m

Macquarie Ridge complex marks southern part of the plate boundary between Australian and Pacific plates

Abyssal plain of Southwest Pacific Basin

Figure 12: Key bathymetric features for the New Zealand region.



Subtropical surface waters (STW) sourced from the East Australian Current (EAC)

Tasman Front (TF) showing a meandering flow path across the Tasman Sea due to the underlying bathymetry

Subtropical surface waters (STW) sourced from the South Pacific Subtropical Gyre. The south Tasman Sea is also bathed in STW

Cool, high nutrient Subantarctic waters (SAW) are sourced from the Southern Ocean

Sub antarctic front (SAF) is the northern edge of the Antarctic Circumpolar Current (ACC)

East Auckland Current (EAUC)

Eddies increase the amount of mixing of deeper nutrient rich waters to the surface and enhancing productivity.

Due to bathymetry and oceanographic conditions a series of semi-permanent eddies including the North Cape Eddy (NCE); East Cape Eddy (ECE); Wairarapa Eddy (WE) and the Rekohu Eddy (RE) are present along the flow of these warm STW

East Cape Current (ECC)

The STF is topographically controlled by the Chatham Rise.

The meeting point of the STW and SAW is the Subtropical Front (STF). The mixing of STW and SAW water masses at the STF results in a region of high primary productivity zone

Antarctic Intermediate Waters (AAIW) is formed by a deep winter mixed layer (>500 m) in the surface waters of the Southern Ocean

Subantarctic mode waters (SAMW) are formed by the deep winter mixing along the Subantarctic Front (SAF)

AAIW are identified by their salinity minimum (34.4–34.6) and have high oxygen (200–250 µmol/kg) and nutrients (nitrate 15–36 µ mol/kg) and temperatures range from 3.5-10°C.

3 different types of AAIW are found in the NZ region. AAIW1 comes from the SE Pacific, AAIW 3 is observed in the Tasman and AAIW4 directly from the Southern Ocean.

Pacific deep water (PDW) are old waters with low oxygen and high nutrients and flow south from the North Pacific

Polar front (PF) is another ACC front. The position of the SAF and PF are controlled by the bathymetry.

AABW – Antarctic Bottom Water forms along the margin of Antarctica in the Adelie Land, Ross Sea and Weddell Sea and flows in to the region at depths >4000m

South of New Zealand Circumpolar Deep Water (CDW) flows in directly from the Southern Ocean in the Deep western Boundary Current, the main flow of water in to the South Pacific.

Figure 13: The ocean currents at the surface, intermediate and deep waters in the New Zealand region.

New Zealand region controls the oceanographic currents. Figure 13 shows the present understanding of the water masses and ocean currents in the region at the surface, in intermediate waters below the surface and thermocline waters, and deep waters, recently reviewed by Chiswell *et al*. (2015).

Of relevance to the deep-sea corals are the flow of the waters and their varying levels of temperature, oxygen, nutrients, salinity content, and carbonate content, specifically the aragonite saturation state (see Minerology section pg. 22).

Substrate

The complex bathymetry, climate, geology and oceanography result in discrete sediment regions around New Zealand. The majority of corals are seen attached to underwater topographical features such as seamount summits and flanks and or rocky hard bottom, and results from habitat suitability modelling (HSM) studies show that seamounts (and seafloor slope) are the preferred bottom type for most corals (Anderson *et al.* 2014). While fine sediment and/or resuspension of sediments thought to interfere with feeding, and as such is not an ideal environment for corals, some stony cup corals such as *Flabellum* spp. (Figure 14) and *Stephanocyathus platypus*, as well as most sea pen species, are located in soft sediment.

Figure 14: *Flabellum* cup corals collected at sea from a soft-sediment environment.

Maps of the sediment texture (mud percent, sand percent, gravel percent) and carbonate percent (as a proxy for biological productivity versus influx of sediment from the land e.g., terrigenous riverine sediments), display distinct patterns on the seafloor, which were mapped and reviewed in Bostock *et al*. (2019; (Figure 15). Carbonate comprises animals with carbonate material, and while these are many and varied and include material from mega-fauna - corals, molluscs, bryozoans, as well as from smaller planktonic organisms, the bulk of the carbonate comes from the crystalline calcite of the abundant Phylum Foraminifera (called Foraminiferida).

While maps, as well as layer data for HSM, have been compiled for the region's sediment areas, to date no 'hard bottom or rock' maps or layer data exist for offshore / deepwater habitats. Seamount layer data are used as a proxy for hard bottom substrate in the models. In Figure 15, the sediment texture and carbonate maps have been overlain with coral presence data in the New Zealand region. An inset shows the same data for the Chatham Rise. This is the first instance of plotting these coral presence data over mud, sand, gravel, and carbonate. Where the % of sand, mud, gravel, and carbonate is low, corals are found in abundance – by proxy on the hard, rocky substrate with which to attach.

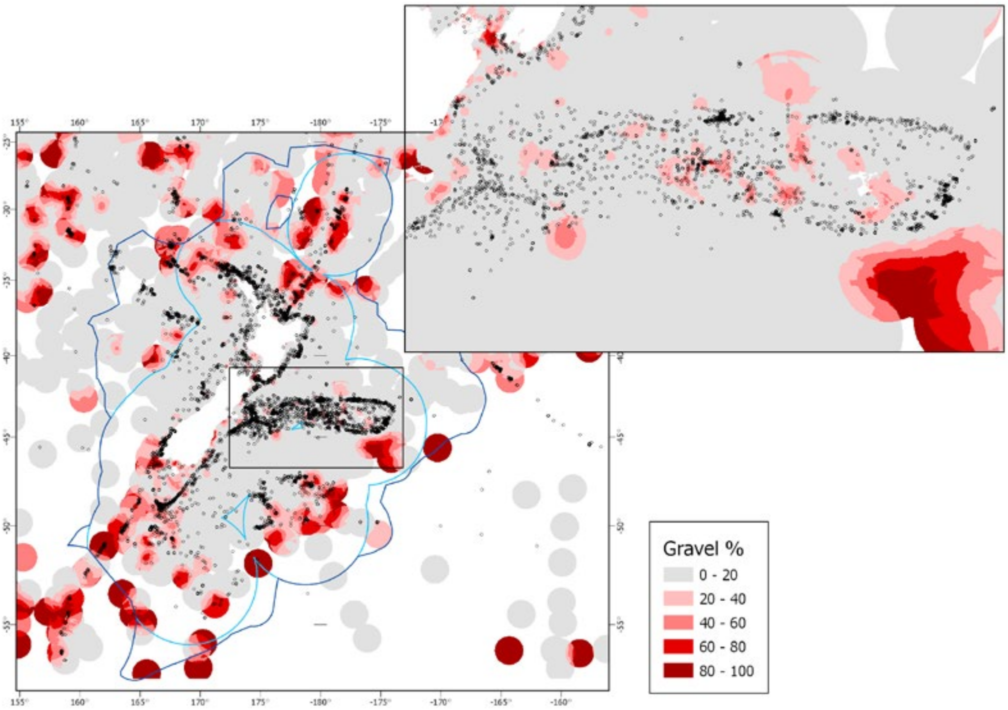
The sediment texture for different regions around New Zealand is briefly summarised below. Along with the maps in Figure 15, this information helps inform on areas of suitable substrate for coral.

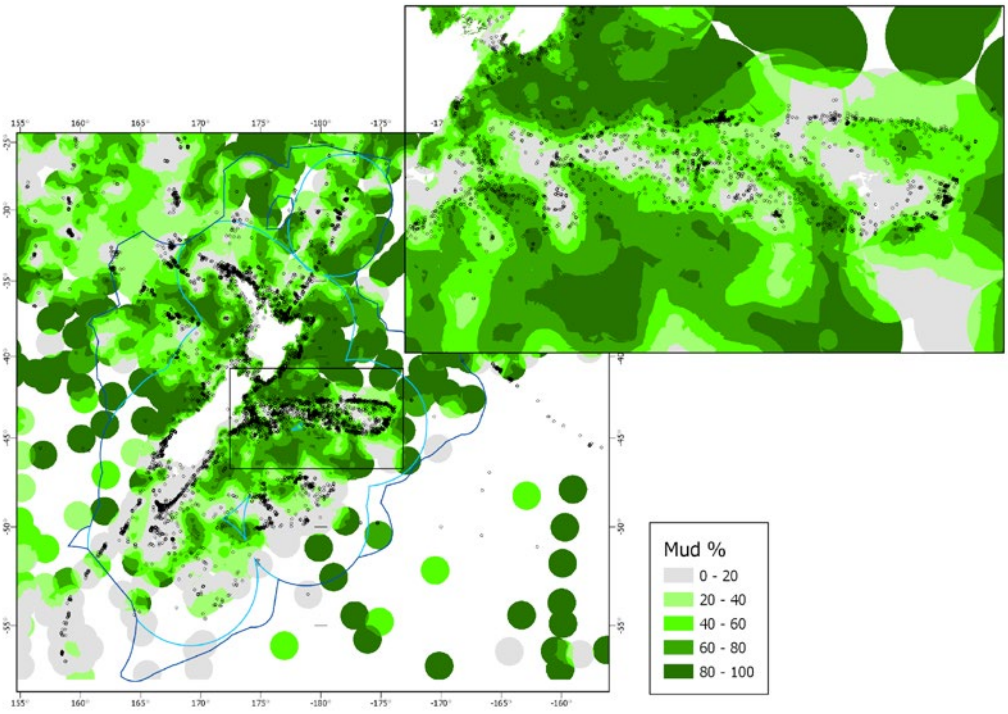
Substrate type by region

To the north of New Zealand carbonate sands and gravels dominate on the Norfolk and Three Kings Ridges (Nelson *et al*. 1982). The South Fiji Basin has high mud content and low carbonate below the Calcite Saturation Horizon (CSH; Bostock *et al*. 2011). While the Colville and Kermadec Ridges are a mix of volcanic rocks, gravel, sand and mud (Gamble & Wright, 1995), with some areas of higher carbonate. Polymetallic crusts were observed on the Colville, Kermadec, Three Kings and Norfolk Ridges (Glasby & Wright, 1990). These crusts are likely the result of low sedimentation rates and hydrothermal activity from volcanoes (De Ronde *et al*. 2007). Kermadec region coral fauna including those located on the deep-sea seamounts are described in Tracey *et al*. 2016.

East of the North Island, the region from the coast to the southwest Pacific basin (>3000 m) is dominated by terrigenous mud (Carter *et al*. 2002), flushed out of the rivers at the coast and then transported down canyons by gravity currents, but also submarine landslides (Lewis *et al*. 1998; Mountjoy *et al*. 2009; 2012). Some of these mass transport deposits are thought to be initiated by earthquakes along the margin (Mountjoy *et al*. 2018). The floors of several canyons (e.g., Kaikoura, Cook Strait) are gravel-boulder dominated in the lower reaches with a very thin mud drape (Lewis & Barnes 1999). The main Hikurangi Channel axis is sand dominated along much of its length (Lewis & Pantin 2002). The high mud content and the regular tectonic activity resulting in gravity driven sediment flows makes some of this region unsuitable for deep-sea corals. However, there are some gravel patches along the continental slope associated with rock exposures and uplifted ridges, some associated with active and extinct cold seeps (Lewis and Marshall, 1996), that will provide suitable substrate for coral attachment, as highlighted by the coral distribution in this area (Figure 15).

The Chatham Rise has complex sedimentation patterns (McDougall, 1982). The region is dominated by sand, with very little mud and a few areas of gravel. The patches of gravel (and larger) size sediment on the top (and occasionally on the flanks) of the Chatham Rise are large concentrations of glauconite and phosphate nodules (Glasby & Summerhayes, 1975; Cullen 1989). These nodules formed millions of years ago under different environmental conditions and they provide suitable hard substrate for corals. A large number of the stony branching coral *Goniocorella dumosa* have been found associated with the nodules (Rowden *et al.* 2014). Numerous studies refer to the corals located on seamount features in this region (e.g., see Clark & Rowden 2009).





The Bounty Trough is dominated by mud, with small amounts of sand. The Bounty Channel is currently inactive (Carter & Carter, 1986). The sediment within the Trough is a mix of terrigenous material and carbonate sediments (Carter *et al*. 2000) and there is little evidence for any hard substrates within this region to provide suitable habitat for deep-sea corals, other than those associated with mud substrates.

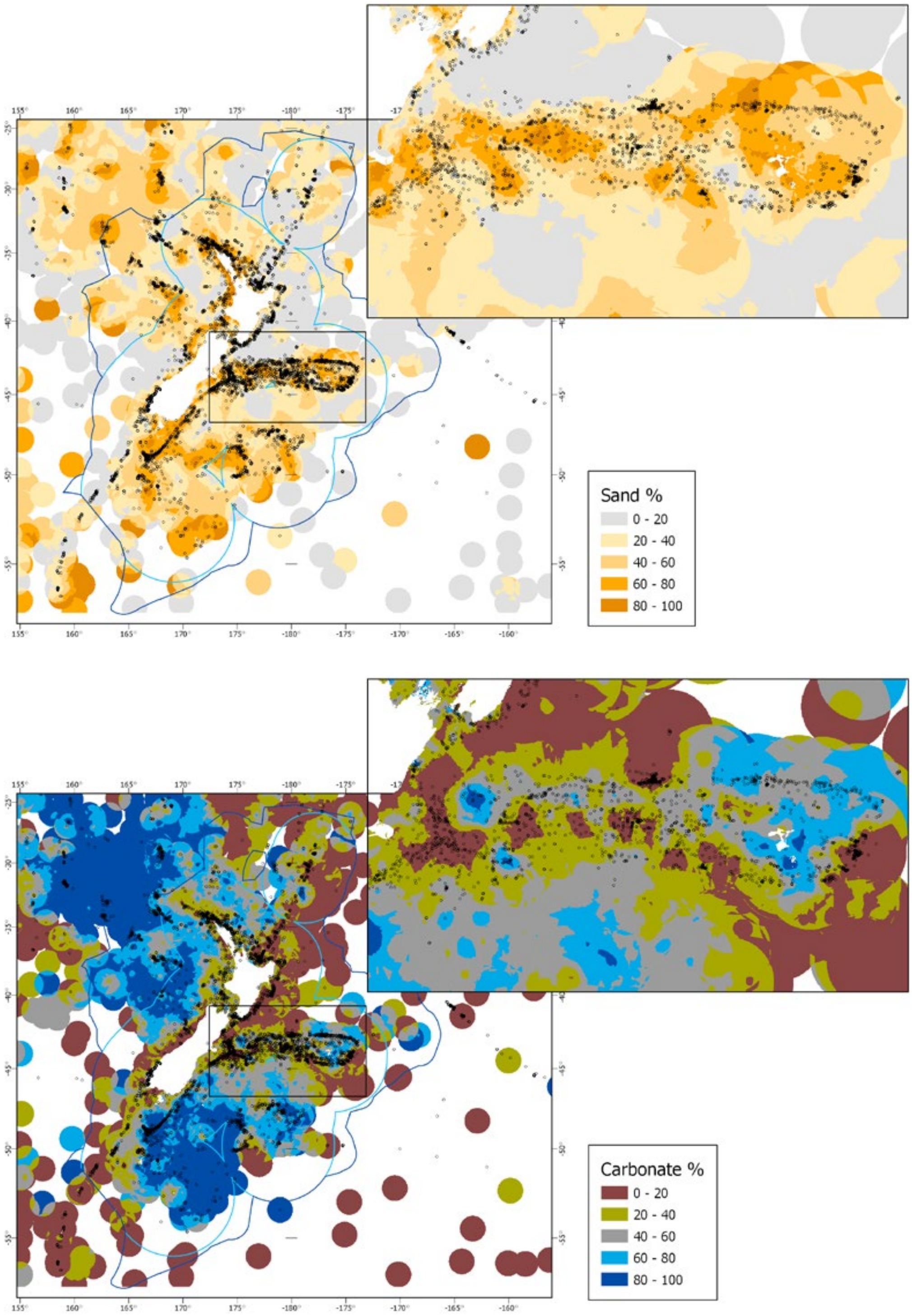


Figure 15: Sediment texture and carbonate maps overlain with coral presence, New Zealand region and inset Chatham Rise. This is the first instance of plotting these coral presence data and provides a general overview of their preferred bottom type. Where the % of sand, mud, gravel, and carbonate is low, is where corals are found as overall corals prefer hard rocky substrate with which to attach. Certain cup corals, soft corals, and most sea pens prefer softer sediment.

The Campbell Plateau is dominated by carbonate sands (and gravel for Bounty Plateau), with lower carbonate and higher gravel content immediately around the volcanic islands (Summerhayes 1969). There is increased mud content in the deeper parts. There is substantial gravel concentrations around the southeastern edge of the Plateau, in part due to high currents long this flank. These provide suitable substrates for deep sea corals and they have been found on and around the edge of the plateau (Figure 15).

The Macquarie Ridge is dominated by volcanic rocks, with the occasional polymetallic crust, especially at the southern end (Summerhayes 1967; Conway *et al*. 2012). Significant numbers of deep-sea corals have been found on the Macquarie Ridge seamounts (Rowden *et al. Unpubl*. Voyage Report, TAN0803). In contrast, the Solander Trough is a combination of terrigenous and carbonate sediments and dominated by sand and mud (Schuur *et al*. 1998). Although, there is the Christabel seamount that sits in the middle of the Solander Trough that is made up of granite rock and supports some deep-sea corals (Rowden *et al. Unpubl*. Voyage Report, TAN0803).

The results show that west of New Zealand the continental slope is a mixture of carbonate and terrgenous sediment that is sandy nearshore, with increasing mud content with water depth, especially in the deep Tasman Basin and the New Caledonia Trough. The Challenger Plateau is dominated by carbonate sands (Nelson *et al*. 1986), but also, as seen during the various orange roughy surveys in this region, has several volcanic seamounts and hard bottom substrate in the Westpac Bank region that provide ideal deep-sea coral habitat (e.g., see Clark & Tracey 1994).

Chapter 6. Seafloor Mapping

Kevin Mackay, Malcolm Clark (NIWA)

The seafloor affects species distribution through depth, rugosity, and substrate. While direct sampling methods, such as cores, dredges, grabs, and video/photography can give a localised understanding of the make-up of the bottom substrate including the sediment described in the previous Chapter, it is the multibeam sonar that provides an understanding of morphology and substrate at regional scales through its bathymetric and acoustic backscatter output. Here mapping of New Zealand's seafloor is described.

In the New Zealand region, tectonic and volcanic activity, particularly over the last 80–100 million years, has led to the development of complex seafloor bathymetry (Mitchell *et al*. 2012). The major physiographic features were known by the early 1970s (e.g., Brodie 1964; Wanoa & Lewis 1972; Thompson 1991), but with the advent of GPS satellite navigation, use of multibeam swath mapping, and declassification of satellite altimetry data (Sandwell & Smith 1997), the last 20 years have seen a significant increase in knowledge of the distribution of underwater features around New Zealand (Ramillien & Wright 2000).

Most of the swath bathymetry for the region (e.g., see Figure 11) has been acquired by RV *Tangaroa*. A hull-mounted EM302 high resolution 30-kHz multi-beam echosounder system maps the seafloor using a fan of 288 acoustic beams, producing up to 864 soundings per ping in dual swath mode, and thus providing 100% coverage of the seabed. The resulting surveys show far greater detail than the earlier method of multiple lines using a single-beam sounder, and produce bathymetry and imagery in depths to approximately 8000 meters

Such multi-beam echosounder (MBES) data have produced detailed bathymetry of habitats relevant to deep-sea corals, in particular seamount features (Figure 16) (seamounts, knolls, hills, pinnacles). These are well known as important topography for deep-sea corals (e.g., see review by Clark *et al*. 2010, Tracey *et al*. 2011, Rowden *et al*. 2010). Information on these features specifically have been compiled since 1999 when new research became focused on assessing the diversity and ecology of seamount benthic macroinvertebrate fauna (Clark *et al*. 1999a). The "seamount database" (Mackay 2006, Rowden *et al*. 2008) presents a synopsis of the physical characteristics of seamounts within the New Zealand region. (taken here as the area bounded by 24° S, 167° W, 57° S, and 157° E).

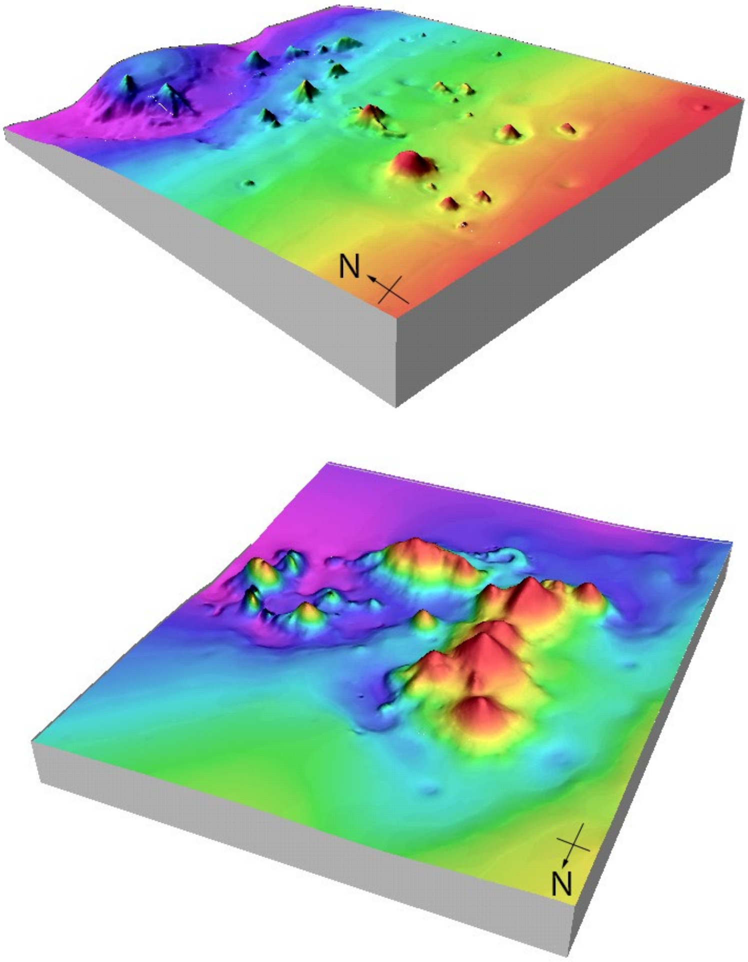
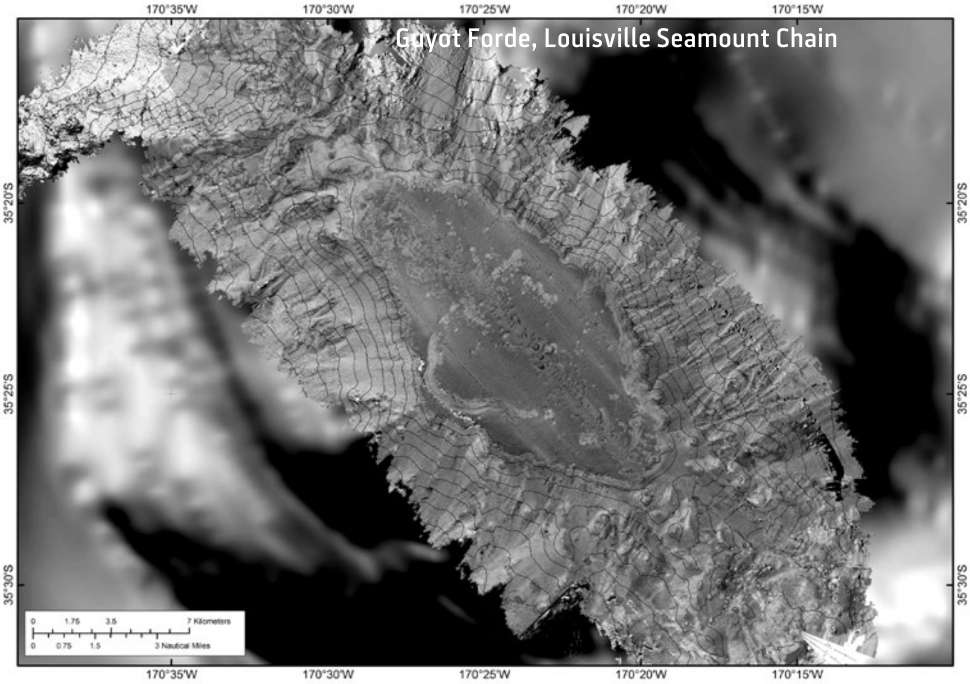


Figure 16: 3-D swath images of Graveyard (top) and Andes (bottom) Knolls, complexes of small seamount features on Chatham Rise, New Zealand.

While swath mapping has identified many new seamount features, determining the likely distribution of corals on them is not so easy. Corals often have a patchy distribution on a seamount feature which makes the predictions of their presence based on knowledge of fine-scale topography and substrate type difficult. Detailed and accurate information to support estimates of coral distribution are required (Anderson *et al*. 2016). A key element here is the combination from MBES surveys of both topographic data (bathymetry) and the backscatter component that is suggestive of hard substrate. These, considered together, can direct research to areas on a seamount likely to have high densities of corals (Clark *et al*. 2014).



More and more the mapping is revealing detail of features – here mapping of a Guyot in the Louisville Seamount Chain region shows bottom topography detail.

An application of using swath map and predicted distributions of corals to investigate the trawl footprint impacts was carried out by Clark *et al*. (2014a) and Roux *et al*. (2014). The aim was to evaluate the effects of target orange roughy and oreo fishing on Endangered, Threatened or Protected (ETP) species, and Habitats (underwater topographical features (UTF's). Swath map images of New Zealand seamount features were overlain with the trawl footprint and coral presence data. In Figure 17, examples of the study are shown for two seamount features from the study, one on the east coast North Island and the second in the Andes Knolls region, and where the trawl footprint and coral presence (P) or absence (A) data were overlain to inform results presented in Roux *et al*. (2014).

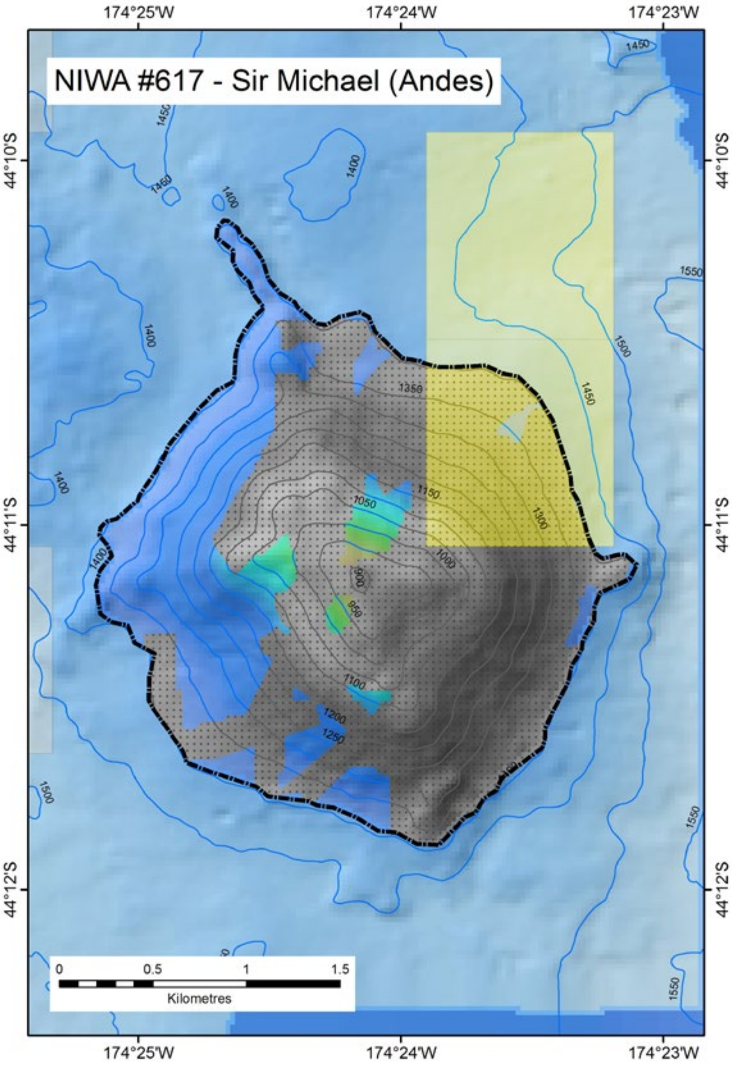


Figure 17: Trawl footprint and coral presence (P) or absence (A) data that contributed to the underwater topographical feature (UTF) study is illustrated in the bathymetric map for Sir Michael Hill in the Andes Knolls. The orange roughy/oreo target trawl fishery catch and effort information for the period 2008-09 to 2012-13, is plotted on the UTF with coral presence or otherwise (as determined in Clark *et al*. 2014), overlain as a shaded box. Other data used to evaluate the effect of fishing included elevation; basal polygon area; lateral surface; last year fished (or not fished); number of tows; and target species e.g., orange roughy.

Chapter 7. Spatial Distribution

Owen Anderson, Ashley Rowden (NIWA)

Collection of specimens for taxonomic identification has also enabled the mapping of spatial distributions of species, not only for the recorded localities but also for broad oceanic areas using inference from statistical models. These models predict the distribution of corals in unsampled space, based on presence records and environmental data, and were created for individual species and genera, as well as for broader taxonomic groups and morphological forms (Tracey *et al*. 2011a, b; Baird *et al*. 2013; Anderson *et al*. 2014, 2015, 2016a, 2016b; Rowden *et al*. 2017; Georgian *et al*. 2019). Maps of recorded localities of corals are provided for each modelled taxon as well as references for predicted distributions from habitat suitability modelling studies in Chapter 12. Model predictions highlight suitable habitat and records of coral species across a broad range of deep-sea and inshore regions. Corals are shown to be widely distributed in the New Zealand region, and occupy a broad depth range, from shallow-waters to well over 2000 m. Individual species and, to a lesser extent genera and broader taxonomic groupings, exhibit strongly preferred depth ranges, and most prefer a hardbottom substrate on which to settle and grow.

Maps prepared for the various predictive habitat modelling studies typically include plots of coral presence locations (e.g., see Figure 18 reproduced from Anderson *et al*. 2016). Research to map and

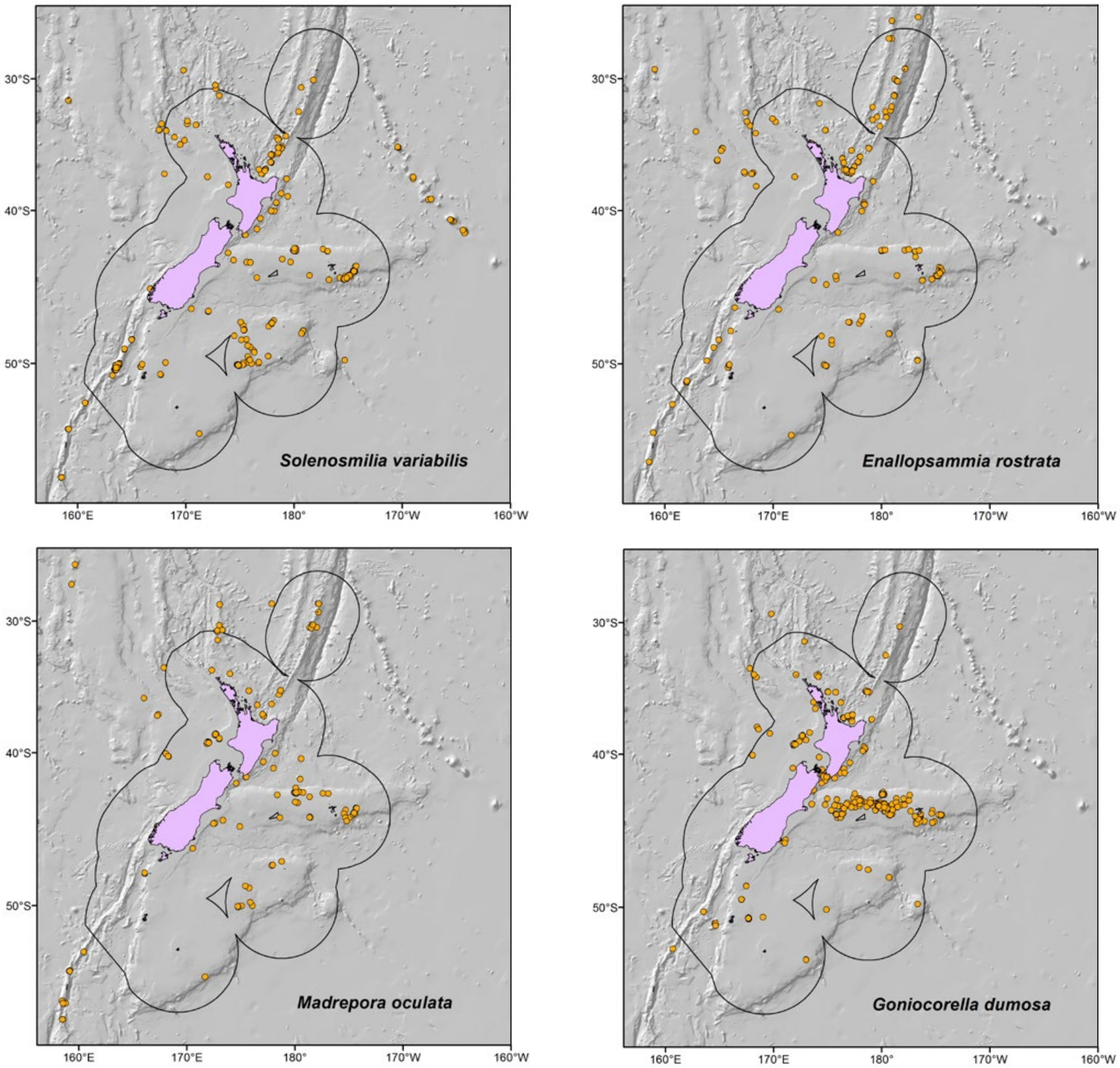


Figure 18: Distribution maps of four key habitat-forming branching stony corals (Scleractinia) found in New Zealand waters. Published as supplementary material in Anderson *et al*. (2016).

determine the biodiversity and significance of biogenic habitats in New Zealand was carried out by Jones *et al*. (2018). This work has focussed on shallower water continental shelf and coastal regions (5–150 m) and includes the minimum depth ranges of several of the region's deep-sea coral species. Several corals were described in the Jones *et al*. (2018) study as providing key biogenic habitat, e.g., black corals and gorgonian octocorals in the East Coast North Island Ranfurly Bank and North Cape Region, and black corals from North Taranaki Bight.

Habitat Suitability Modelling

A range of statistical modelling methods to predict habitat suitability and species distributions in unsampled regions have been developed in recent years, many of which take advantage of the processing power of modern computers and machine learning algorithms. In New Zealand such models have been used to predict the distribution of fish and benthic invertebrate taxa over broad regions of the Exclusive Economic Zone (EEZ) and beyond into the wider Pacific. Utilising predictions of future marine climatic conditions from Earth System Models, these modelling tools were also applied to help identify potential future refuges for deep-sea corals and to help identify areas of risk from ongoing interactions with commercial fishing gear (Anderson *et al*. 2015). Other models have focussed on smaller areas of interest, using camera surveys and fine-scale environmental data sets derived from multibeam echo-sounder surveys to predict species distributions across the variable terrain of individual seamounts (e.g., Rowden *et al*. 2017). The more recent studies combined predictions from two or three methods into ensemble models in order to provide averaged estimates from models using disparate methodologies. Precision of the outputs was often estimated, typically using bootstrap resampling techniques.

The predictive habitat modelling studies for marine benthic invertebrates were commissioned by several New Zealand government agencies and most have focussed on protected corals (Anderson *et al*. 2014, 2015; Rowden *et al*. 2014; Baird *et al*. 2013; Tracey *et al*. 2011) and vulnerable marine ecosystem (VME) indicator taxa (Anderson *et al*. 2016a, 2016b; Rowden *et al*. 2017; Georgian *et al*. 2019), with only one published study producing models for individual species/genera across a wide range of taxonomic groups (Compton *et al*. 2013). Examples of the methods applied include boosted regression trees (BRT); maximum entropy (MaxEnt); random forest (RF), and generalised additive models (GAM). Models used either presence-background data (i.e., using random background points from the study area to define the underlying environmental landscape), while others were based on presence-absence data (i.e, using real absence locations derived from a combination of research survey, fisheries observer, and collection/museum databases). Predictions from presence-background models provide a measure of relative suitability rather than actual probability of presence; presence-absence models give an indication of the probability of capture (notwithstanding variation in gear type and duration of deployment), with those based on camera surveys (where detection ability is greatest) providing the best estimates of probability of presence.

Predicted habitat distribution maps for various coral species, genera, and morphological forms were presented in Tracey *et al*. (2011a, b), Baird *et al*. (2013), Anderson *et al*. (2014; 2015; 2016b), as well as in several other studies that developed predictive models and spatial management options for the protection of vulnerable marine ecosystems in the South Pacific Ocean region (Rowden *et al*. 2013; 2015, 2017; Anderson *et al*. 2016a; Georgian *et al*. 2019).

Example habitat suitability predictions from these studies are presented by species in the following chapters. Figure 19 shows predicted habitat suitability for the stony coral *Solenosmilia variabilis*, from Anderson *et al*. 2014 alongside the historical "trawl footprint" made by New Zealand fishing vessels (Baird *et al*. 2011). The overlap between the two distributions was assessed as medium (25–50%) for the New Zealand region as a whole but high (>50%) for the Chatham Rise.

Data sources for models

Coral location data were sourced from various databases e.g., Fisheries New Zealand (FNZ) observer and research trawl databases (*COD* and *trawl* respectively), the NIWA Invertebrate Collection (NIC) Specify Database *niwainvert*, and databases of the Museum of New Zealand Te Papa Tongarewa, and Auckland Museum.

Environmental data used in the models that potentially influence coral settlement, survival, reproduction, and growth have typically comprised a combination of seafloor characteristics (e.g., depth, slope, curvature, roughness, on/off seamount), water chemistry (e.g., carbonate saturation state, dissolved oxygen, salinity, temperature), and productivity (particulate organic carbon, dissolved organic matter). To be useful for predictions, these

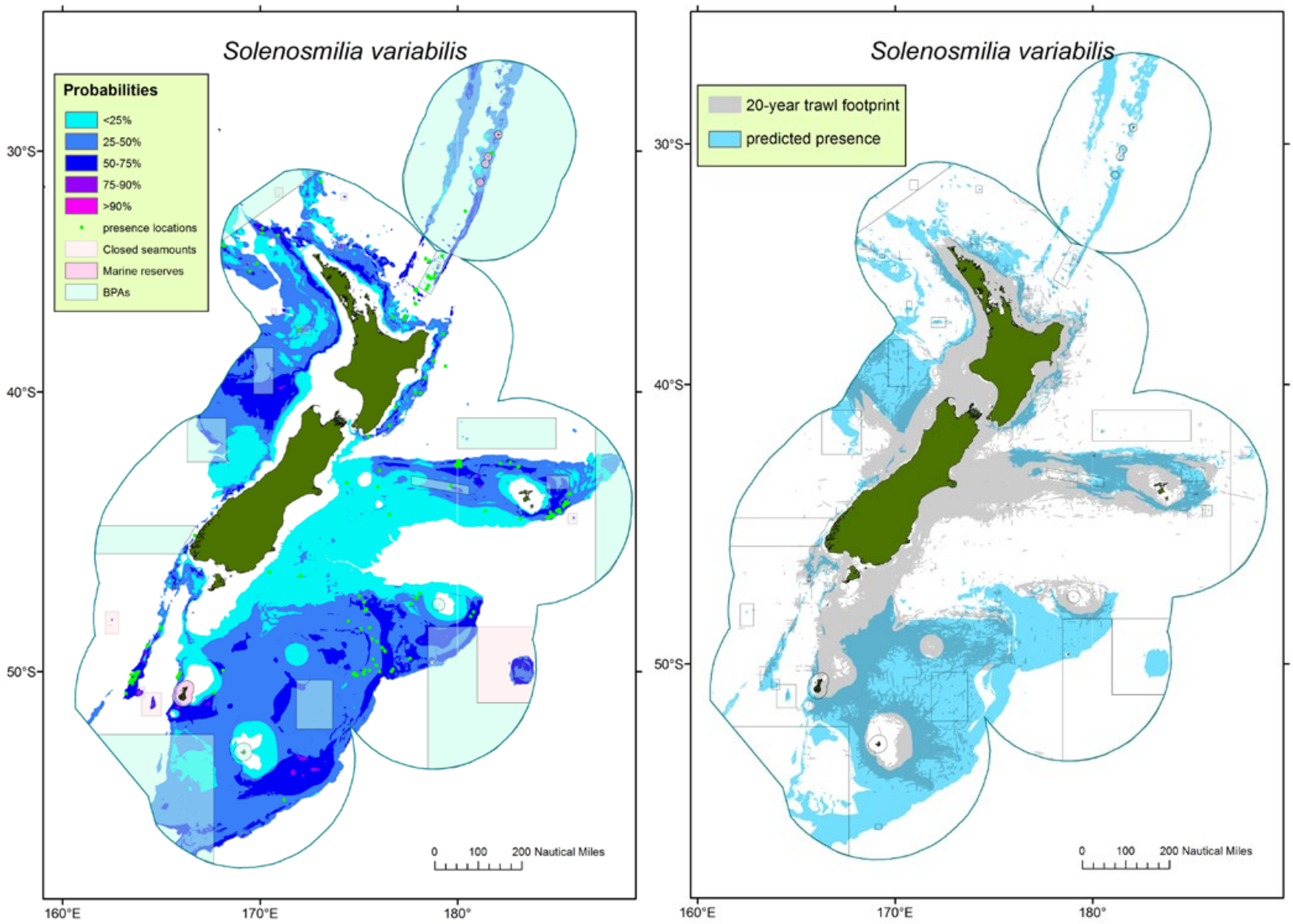


Figure 19: Probability of occurrence of suitable habitat for *Solenosmilia variabilis* from BRT models. Left panel: probabilities of occurrence (n = 311 presence records); closed seamounts (introduced in 2001); Benthic Protected Areas (introduced in 2007), and large Marine Reserves. Right panel: predicted occurrence of *S. variabilis* habitat based on probabilities greater than the model mean, relative to the 20-year trawl footprint (1989–90 to 2008–09) from Anderson *et al*. 2015.

data must be available as grids of the entire area of interest and are often based on models themselves. These grids are sourced from a combination of global and regional datasets and are often scaled to a finer resolution using NIWAs 250 m bathymetry raster (Mackay *et al*. 2015).

Earth system model data

Discussion often centres around how accurate the predictive models are, given the rapidly changing physical and biogeochemical status of the ocean. A recent study (Anderson *et al*. 2015) used earth system model (ESM) simulations of the future physical and chemical state of the oceans (Williams *et al*. 2016) to provide grids of predicted environmental conditions at the end of the 21st century, enabling estimation of the future distribution of protected coral species. This study used outputs from the best fitting ESM from a broad range of available models by assessing that which best represented the ocean biogeochemistry for the New Zealand Region (Rickard *et al*. 2015). This work enabled identification of potential areas of refuge for some protected corals. For example, the stony coral *Goniocorella dumosa* (Figure 21) occurs in shallower waters on the crest of the Chatham Rise. Changes in carbonate ion saturation levels in deeper water may provide a refuge for this and other coral species in this region.

A refined ESM, specifically tuned for the New Zealand region, is currently under development by NIWA climate scientists and will be used to revise these models.

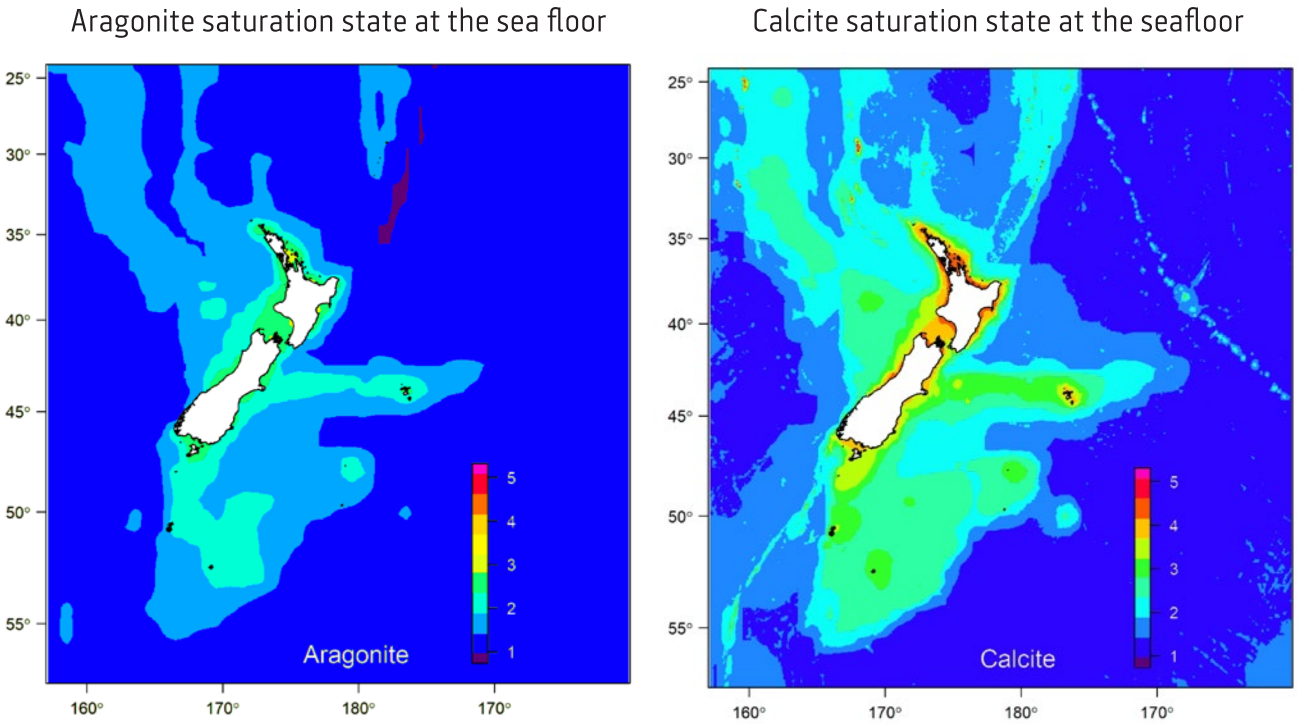


Figure 20: Left: Map of the aragonite saturation state at the sea floor. Dark blue colour represents under-saturated (Ω aragonite <1), light green (Ω aragonite=1–2) and green (Ω aragonite=2–3) are saturated. Right: Map of calcite saturation state at the seafloor. Dark blue colour represents under-saturated (Ω calcite <1), light blue (Ω calcite 1–2), dark green (Ω calcite 2–3), orange (Ω calcite 3–4) and red (Ω calcite 4–5). Everything >1 is saturated with respect to calcite (maps prepared by Owen Anderson, NIWA, using data from New Zealand's Earth System Model, Williams *et al*. 2016).

Figure 21: Small clumps of discrete communities of the stony branching coral species *Goniocorella dumosa* on the Chatham Rise in a depth of about 400 m. Two tam-o-shanter sea urchins can also be seen, along with a school of banded bellows fish.

Suitable environments for corals

As well as predicting habitat suitability, habitat suitability models also provide an indication of the importance of the environmental variables in the distribution of each coral taxon or group of taxa.

The relative influence of each explanatory variable in models for thirteen protected coral taxa, along with the number of presence records used in each model is shown in Figure 22. For example, the distribution of the scleractinian stony branching coral *Solenosmilia variabilis* is most strongly influenced by bottom temperature, with surface water masses and currents (dynoc), productivity levels (vgpm), sea surface temperature gradient (sstgrad), seafloor slope, and aragonite concentration also important.

While it is apparent that deep-sea coral distributions are dependent on hydrographic conditions and linked to the geomorphology of the seabed, combined with environmental parameters such as temperature, salinity, ocean chemistry and nutrient supply (Anderson *et al*. 2015), information on preferred habitat at species level is variable and poor for many coral groups. In some instances, however, data on the proportion of a species associated with seamount or slope habitats is available (Clark & Rowden 2009), along with accompanying data on the oceanographic environment within which they thrive.

Although habitat suitability models are often based on combined taxa e.g., morphological groups (reef-like, tree-like, corals) or higher taxonomic levels (e.g., Isididae, *Antipatharia*) model performance statistics show that they tend to be more reliable when individual species are used. When multiple species are aggregated the model becomes less reliable due to variability in the environmental requirements between individual species. A recent focus has been to test the models.

Testing the models

Anderson *et al*. (2018) summarise the various models applied to corals, their points of difference, and the key results as the models have been developed and improved on and as improved or augmented environmental and coral location data have become available.

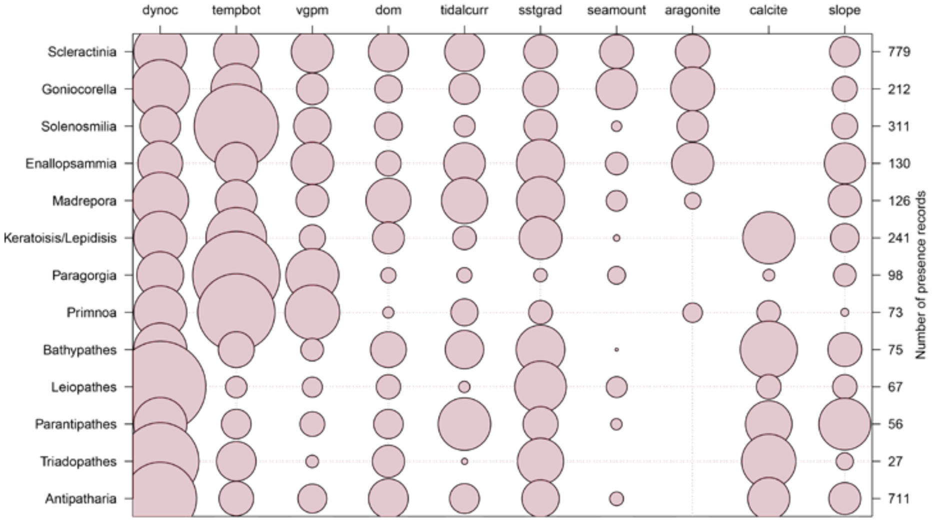


Figure 22. Bubble plot showing the relative influence of each explanatory variable in the BRT predictive models for each protected coral taxon and the number of presence records in each model (from Anderson *et al*. 2014). Dynoc, dynamic oceanography; tempbot, bottom temperature; vgpm, surface water primary productivity; dom, dissolved organic matter; tidalcurr, tidal current velocity; sstgrad, sea surface temperature gradient; seamount, on or off a seamount; aragonite, seafloor aragonite saturation state; calcite, seafloor calcite saturation state; slope, seafloor slope.

The recent use of towed video and camera systems at sea has enabled a significant amount of in situ data collection for coral taxa and their related sediment type as observed along transect lines (e.g., see Compton *et al*. 2012). This information is improving on the knowledge of the ecological status of the coral fauna to New Zealand in terms of abundance, habitat, and ecology. While there has been intensive camera survey sampling in some areas, e.g., the Chatham Rise, species-level data are not usually available due to the difficulty in fully identifying various fauna from image data. The in situ image data have also enabled scientists to assess the accuracy of predictions from existing habitat suitability models for benthic taxa on Chatham Rise.

Results also showed that there was evidence of improvement in the reliability of models over time, presumably as input data have improved and methods have developed throughout the nine separate studies conducted since 2011. The best performing models tended to be those developed for individual species rather than groups of species and for frequently-recorded species rather than rare species. Models with a more restricted spatial extent tuned specifically to the environmental conditions of the Chatham Rise also performed better than broader-scale models, and models based on real absence records performed better than models that relied on random background points.

Next steps

Ongoing research will expand on the work carried out to date on habitat suitability modelling for protected coral species. Improved and refined habitat modelling will be possible due to the availability of new data, including; in situ coral records collected by researchers and the FNZ Observer Programme during the past four years, regional environmental predictor layers for the current and future climate conditions based on NIWAs Earth System Model (ESM), and the most recent sediment texture and carbonate layer data (see Chapter 5 and Bostock *et al*. 2018).

Comparisons of predicted distributions with current fishing effort will be made, using published trawl footprint data for the most recent fishing years (see Rowden *et al*. 2019, Chapter 10). Updating the predicted distribution maps for protected corals will enable improved definition of suitable current and future habitat, help to assess risk from commercial fishing, and inform the management of these fragile and long-lived animals.

Chapter 8. Stressors on Coral Communities

Malcolm Clark, Di Tracey (NIWA), Malindi Gammon (previously Victoria University and FNZ now University of Western Australia), David Aguirre, Libby Liggins (Massey University, Auckland)

The deep-sea environment can be vulnerable to a range of natural and anthropogenic-induced disturbances. These include direct impacts from the exploitation of natural resources for commercial use and also from a changing regime of temperature and ocean acidification (OA) due to climate change, as well as deoxygenation and pollution (e.g., Ramirez-Llodra *et al*. 2010). These effects, individually or cumulatively, may be significant for numerous marine organisms including coral (Cordes *et al*. 2017).

Due to their fragile forms, skeletal composition, and location, corals are vulnerable to the various physical disturbances, such as trawling, mineral exploration, and mining (Clark *et al*. 2016). Several studies have investigated the effects of bottom trawling on deep-sea macro-invertebrate assemblages (including coral) around New Zealand and Australia (Clark & Rowden 2009, Althaus *et al*. 2009, Clark *et al*. 2010, Williams *et al*. 2010; Anderson *et al*. 2014; Clark *et al*. 2019). These have demonstrated appreciable impacts from trawling, with little or no evidence of recovery in the short-term, making commercial-scale bottom trawling a major risk to deep-sea coral communities.

Also of significance will be the effects from the impacts of OA where the changes in seawater pH and the predicted shoaling of the saturation levels of calcium carbonate ($CaCO_3$) minerals has led to concerns for calcifying organisms such as corals.

A summary of recent research that has explored impacts of these various stressors on corals are described.

Interaction with Fishing Gear

Bottom-contacting gears, (specifically bottom trawl, Danish seines, dredge and bottom longlines), all potentially impact coral fauna and habitats. Fishing activity has been heavy in some habitats, an example being that in some years up to 50% of orange roughy bottom trawl effort and catch has come off seamounts, knolls and hills, and 80% of these features where summit depths range between 800 to 1200 m have been fished (Clark & O'Driscoll 2003). The extent of the trawl footprint varies between seamount features, with some having few lines that can be trawled, whereas others can be fished and impacted over most of their area (O'Driscoll & Clark 2005) and see Figure 23.

Interaction with trawl gear will vary depending on the type of trawl used, and the different components of the trawl rig. This varies with fishery (see Baird & Wood 2015). Orange roughy trawls used in New Zealand fisheries have doors weighing 1000–1500 kg, a small net (about 25 m wingtip spread) with cut-away lower wings, and heavy bobbin or rock-hopper ground-gear that can weigh between two and four tonnes (Clark and Koslow 2007). Sweep length can vary from 50 to 200 m. The importance of gear type is that the degree of seabed penetration, or amount of continual contact with the seabed (and hence corals) can be different between fishery type and target species. Eigaard *et al*. (2016) reviewed global trawl data and on coarse substrate (mixed sediments) trawl doors could penetrate 5-10 cm, ground gear (bobbins etc) 1-8 cm, with variable sweep-bridge-chain penetration (and these wires can also tend to bounce above the seafloor).

A review of benthic impacts from trawl fisheries by Clark *et al*. (2016) summarised a number of studies that included effects of fishing on corals. However, around New Zealand most quantitative data are from seamount features subject to bottom trawling in the orange roughy and oreo fisheries. Trawled features have been shown to have lower average percent cover of stony corals (0.04–0.03%) than untrawled seamounts (12–25%) for two species of thicket-forming corals (*Solenosmilia* and *Madrepora*) (Clark & Rowden 2009). New Zealand seamounts in depths of 700-1000 m suggest that as few as 10 "deep-sea" trawls can eliminate corals from 15 to 20% cover to no visible cover (Clark *et al*. 2010). Some small and/or flexible coral species appear resilient to trawling damage (Clark & Tittensor 2010), some remnant thickets of corals can persist in areas that are too rough to trawl (Clark *et al*. 2010), but most coral species have attributes that make them highly sensitive to impact, with low recovery potential (see following section).

Tuck *et al*. (2017) assessed the effects of fishing on soft sediment habitat, fauna and processes in the New Zealand context, concluding that long-lived species, surface-living species, structurally fragile species, and biogenic habitat-forming species are all particularly vulnerable, and such species are frequently found in high energy environments. Some taxa have natural resilience due to their size, shape, and structure, and some can survive in natural refuges inaccessible to trawls. Many deep-sea corals however, are exceptionally long-lived and grow extremely slowly meaning they have low resilience and low recoverability (Clark *et al*. 2016).

The direct physical disturbance of corals by bottom trawl gear is the most obvious and dramatic source of impact. However, secondary effects on corals can come about through sediment plumes from fishing operations which can smother small corals, or clog polyps and affect feeding success. Trawl gear mobilises sediments creating plumes of particles in their wake (O'Neill *et al*. 2013) which are typically 2–4 m high (Durrieu de Madron *et al*. 2005; Palanques *et al*. 2001), and 120-150 m in width depending on the size of trawl gear (Bradshaw *et al*. 2012). In low-current, deep-sea environments, these can disperse very slowly over large distances (Rolinski *et al*. 2001; Bluhm 2001), and potentially affect areas well beyond, and deeper than the area of the fishery (Martin *et al*. 2014; Black & Parry 1999). O'Neill & Summerbell (2011) estimated that a typical Scottish demersal trawl would suspend up to 3 kg/m^2 of sediment between the trawl doors, and trawling-induced sediment gravity flows can remove large volumes of sediment from the shelf (Puig *et al*. 2012).

Small amounts of sediment settling on the bottom, of the order of only few mm, can smother small deep-sea corals such as *Lophelia pertusa*, and prevent expansion or recovery of the colony (Rogers 1999). Impacts on coral feeding and metabolic function are uncertain, although stony corals can actively shed sediment, both in shallow-water species (Riegl 1995), and on the slope. Larsson & Purser (2011) observed that *L. pertusa* in an aquarium setting was able to survive repeated light smothering by sediment, but when wholly covered by particles polyps died. Hence some taxa can potentially cope with a degree of sediment increase caused by trawling.

Static gears, such as longlines and traps are considered to have lower impacts than mobile gear types, by up to 300 times (Pham *et al*. 2014) However, in certain conditions, for example during retrieval, static gear may move laterally across the seafloor, resulting in impacts to the habitat and biota (Ewing & Kilpatrick 2014; Sampaio *et al*. 2012). Longline impacts on sessile fauna such as sponges and corals has been observed (Fossa *et al*. 2002; Mortensen *et al*. 2008) where the animals have been broken by longline weights or by the mainline cutting through them while moving laterally during fishing or hauling (Welsford & Kilpatrick 2008).

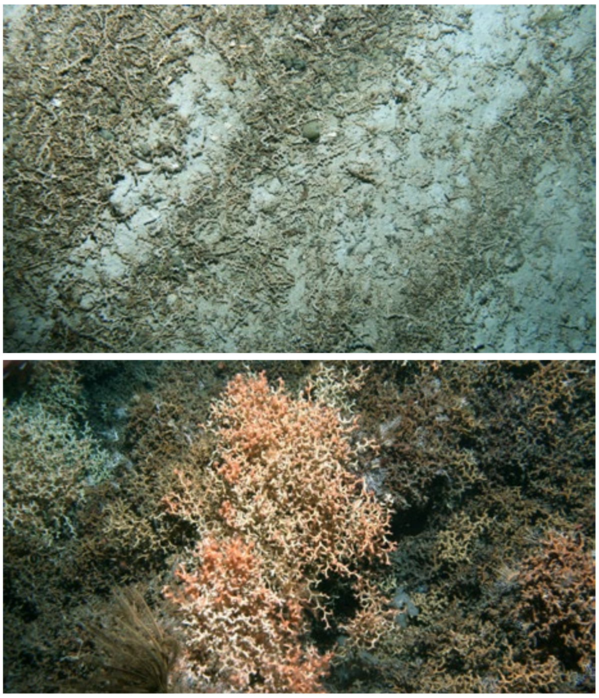


Figure 23: Image showing trawl tracks ('trawl "footprint') on a heavily fished underwater topographical feature (UTF), (top) and an unfished UTF (bottom), Southwest Chatham Rise.

Recovery studies

The importance of understanding the resilience of biotic communities to impacts from human activities, in the context of ecosystem approaches to resource and environmental management, has led to an increasing focus on recovery studies in both terrestrial and marine ecosystems in recent years (e.g., Lotze *et al*. 2011, Lambert *et al*. 2014). The speed and nature of recovery can vary greatly, depending upon the type and duration of impact, the physical and life-history characteristics of the species making up the communities, and conservation and management measures applied during the recovery period (Lotze *et al*. 2011). However, there have been relatively few studies of the recovery dynamics of impacted deep-sea habitats.

Experience from studies on changes in benthic communities at 200-300 m depth associated with iceberg disturbance in the Antarctic suggest a succession of faunal recolonization is likely, with first colonisers within 10 years consisting of bryozoans, sponges, polychaetes, gorgonians and ascidians, followed by longer-lived biogenic habitat-forming sponges and slow growing coral species (Teixido *et al*. 2004). Patterns of recolonization and recovery in a number of shelf environments also appear to show a strong correlation with life history characteristics of certain taxa, with bushy bryozoans being early dominants in successional stages within two years, and longer-lived and slower-growing species becoming more predominant over time (up to six years) (Asch & Collie 2008).

In the New Zealand context, there are two key time series of seamount habitat studies on the Chatham Rise and off Tasmania that are relevant to consideration of potential recovery of corals. Althaus *et al*. (2009) reported a recovery in some large fauna from previously trawled seamount features off Tasmania to 33% of pre-closure levels after 5-10 years, but corals to only 6%. Williams *et al*. (2010) compared benthic community structure on New Zealand and Australian seamounts after 5 and 10 years, respectively, following fisheries closures and concluded that benthic community structure may take decades or longer to return to a pre-disturbed state in the deep sea because of slow growth rates and high longevity of a number of major invertebrate taxa, including corals. Since these studies, further surveys have been done on the Graveyard Knolls on the northern slopes of the Chatham Rise. Clark *et al*. (2019) report on changes over 15 years from a fishing impact recovery comparison based on repeated towed camera surveys of six features in the Graveyard complex. These features cover conditions where trawling has ceased, where trawling is still active, or seamounts which have been lightly/untrawled (e.g., see Figure 23). Surveys were carried out in 2001, 2006, 2009, and 2015. Univariate community metrics of biodiversity (abundance, species richness) were almost always higher for untrawled Ghoul and Gothic than the other four. Multivariate community analyses of each seamount at each time-step showed a similar pattern, with the untrawled Gothic and Ghoul having similar levels and patterns of community structure at one end of the ordination space, the persistently heavily trawled Graveyard at the other end along with the previously heavily trawled and now closed Morgue, and intermittently trawled features lying in-between. This ordination matches the gradient in commercial fishing effort. Community structure on Graveyard was more consistent than on the other features, with persistently lower faunal richness, possibly due to a regular 're-setting' of the community by disturbance from trawling. The time series of surveys indicates low resilience of benthic communities on these seamount-like features to the effects of bottom trawling. There is no evidence that benthic communities on Morgue are recovering following its closure to fishing in 2001. Intact scleractinian coral 'reef' is or was a "climax habitat" on the Graveyard Knolls, and levels of this habitat on Morgue remain much lower than those on the untrawled features. Further surveys off Tasmania in 2018 (https://ecos.csiro.au/deep-sea-life/) show little sign of any recovery of stony coral habitats on two seamounts closed to fishing in the late 1990s.

Slow recovery after disturbance is also indicated by studies following the Deepwater Horizon oil spill in the Gulf of Mexico. For colonies (primarily the plexaurid octocoral *Paramuricea biscaya*) with over 50% coverage of the flocculent oil-bearing material created after the spill, there has been little recovery over several years, and their health and colony size has continued to decline (Girard & Fisher 2018). The time to complete recovery of the corals that have already exhibited some improvement in state was estimated at approximately 50 years (Girard *et al*. 2019). A recent US survey on seamounts of the northwestern Hawaiian Ridge and southern Emperor Seamount Chain indicates some potential recovery from effects of trawling in the 1970s (Baco *et al*. 2019), although these seamounts are shallower than those off New Zealand and Australia, coral groups have apparently recolonized several areas, supplementing patches of fauna assumed to be remnants from the period when the seamounts were fished.

Trawl footprint

Trawl footprint studies show where bottom contact fishing activity is carried out in the region and this provides an understanding of the percentage overlap between fishing and these habitats, including for protected corals. Various bottom-contacting trawl footprint studies are summarised in the Aquatic Environment and Biodiversity Annual Review 2018 (MPI 2019) and details presented in Baird *et al*. (2002; 2011; 2015); Baird & Wood (2018); Black *et al*. (2013; 2015); Black & Tilney (2017); Clark *et al*. (2014a); Roux *et al*. (2014). The area of the trawled footprint for the orange roughy fishery was overlain with coral presence data on knolls and hills and percentage overlap with deep-sea corals was calculated (Clark *et al*. 2014a; Roux *et al*. 2014). Data on coral presence and areas that could not be bottom trawled, were used in follow up analyses by Black *et al*. (2015) to estimate that on average for each fished knoll and hill about 51% has been trawled. (Also see Figures 17 and 23).

Several studies have investigated the extent of corals and other benthic invertebrate fauna taken as bycatch in trawl and bottom longline fisheries. Anderson & Clark (2003) examined records from government observers on vessels trawling for orange roughy on the South Tasman Rise off

Tasmania between 1997 and 2000. They noted high levels of coral bycatch (*Solenosmilia variabilis*) in the first year of the fishery (estimated 1750 t of coral bycatch associated with 4000 t of the target orange roughy catch) that declined over time to about 100 t per year. Anderson *et al*. (2017), examined by-catch from New Zealand target fisheries such as scampi, orange roughy, and oreo species. Protected coral species were a substantial part of the bycatch. Between 2001 and 2015 they accounted for around:

- 0.10% of the total catch in the observed fraction of both the oreo and orange roughy fisheries.
- 0.38% of the total catch in the observed fraction of the scampi fishery. Note the scampi data may include anemones in the dataset.

A changing environment of temperature

Shallow-water stony coral communities around the world have been repeatedly threatened by thermally induced coral bleaching, where increases in ocean temperature trigger a cascade of physiological responses that can cause coral hosts to evict their symbionts, giving corals a characteristic "bleached" appearance (Hoegh-Guldberg 1999; Warner *et al*. 1999). Bleaching signals a breakdown in the mutualism that allows corals to survive in nutrient-poor tropical waters. Currently no monitoring has been carried out of the Kermadec Islands Marine Reserve/ Rangitāhua, to assess if coral bleaching of the shallow stony coral fauna is occurring in the New Zealand region.

Ocean acidification

It is clear that CO^2 levels are rising and with the subsequent pH changes, many marine calcifiers are likely to be vulnerable due to dissolution. Corals are also potentially susceptible to a changing environment from climate change and the response of corals to temperature increase and OA may be significant.

OA will impact both shallow and deep-sea coral communities and while the world's coral reefs are considered to be at high risk of extinction in the near future – equally the deep-sea reefs and other deep-sea corals whose skeleton comprises calcium carbonate, are threatened. Increased temperature and CO^2-levels are considered key drivers of coral reef degradation, noting however that, individual assessments of ecological responses (calcification) to these stressors can vary.

Environmental impacts from climate change and OA are described internationally by Caldeira and Wickett (2003), Guinotte *et al*. (2006), Turley *et al*. (2007), and locally in publications such as Law *et al*. (2017); Tracey *et al*. (2016); Gammon (2016); Gammon *et al*. (2018). Most global OA studies have been carried out on shallow-water fauna. Fewer studies have taken place on OA impacts on deep-sea coral fauna, and only one in the New Zealand region (Gammon *et al*. 2018).

End of century predictions for some coral species show a very reduced habitat as a result of climate change (Anderson *et al*. 2015). This work showed that there is a possibility that some parts of New Zealand will act as a refuge for corals and what the implications of that occurring would need to be investigated. Deep-sea stony corals abundant in depths shallower than 300-400 m could act as a refuge for corals in the face of climate change as could the high latitude coral communities located in the Kermadecs. Shallow-water corals from the wider Pacific region settling in the New Zealand region, and deep-sea corals finding refuge on the top of the Chatham Rise are both factors.

The predicted shoaling of the aragonite saturation horizon (ASH) and calcite saturation horizon (CSH) into the present depth range of deep-sea corals is also perceived as a very serious threat; reef-like deep-sea scleractinians are likely sensitive to low carbonate ion concentrations and rarely occur far below the modern aragonite saturation horizon - the resultant spatial distribution maps show this (see above Mineralogy section and Figure 20 page 42).

One form of carbonate, aragonite, is particularly vulnerable to increasing acidity (declining pH). The aragonite saturation state (ASH), is predicted to shoal to depths as shallow as 500 m in the New Zealand region by 2100. This could result in the loss of >50% of the deep-sea habitat forming stony corals. It is likely that the high Mg calcite gorgonian corals will also be significantly affected by this reduction in carbonate saturation states. (also see Section 1.3.2.)

Experiment to investigate ocean acidification impacts

To investigate how calcifying scleractinian corals may respond to the future predicted environmental conditions of OA, colonies of *Solenosmilia variabilis* were maintained for a 12-month period in temperature controlled (3.5^{0}C) continuous flow-through tanks at a seawater pH that reflects the region's current conditions (7.88) and an end-of-century scenario (7.65). Impacts on coral growth and the intensity of colour saturation (as a proxy for the coenenchyme tissue) were measured bimonthly. Respiration rate was measured after a mid-term (six months) and long-term (12 months) exposure period. Growth rates were highly variable, ranging from 0.53 to 3.068 mm year-1 and showed no detectable difference between the treatment and control colonies. Respiration rates also varied independently of pH. A significant change in colour was observed in the treatment group over time, indicating a loss of coenenchyme (Figure 24). This loss was greatest after 10 months at 5.28% and could indicate a reallocation of energy with physiological processes (e.g., growth and respiration) being maintained at the expense of coenenchyme production. The research by Gammon *et al.* (2018) illustrates important first steps to assessing and understanding the sensitivity of deep-sea corals to ocean acidification. The study showed *S. variabilis* to be vulnerable to OA and other stony coral species are likely to have similar thresholds. It is important however, to investigate how other coral groups will respond to OA.

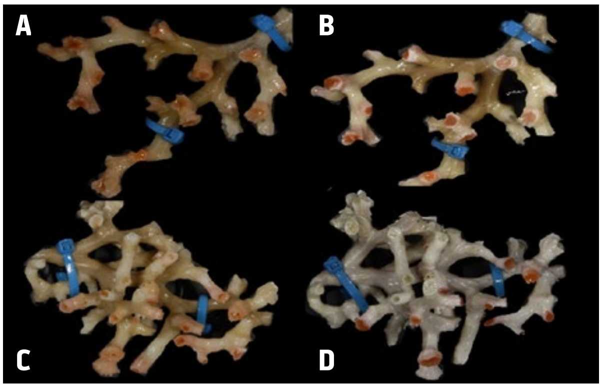


Figure 24 (From Gammon *et al* 2018): The effect of seawater pH on the loss of coenenchyme tissue of the coral *Solenosmilia variabilis*. Images A and B are of the same colony at control pH (pH 7.88). Images C and D are of the same colony at the treatment pH (pH 7.65). Images A and C were taken prior to the start of the experiment, and images B and D after three months into the experiment. Note the marked reduction in the intensity of the red/pink colouration to a pale colour once the coral had been exposed to low pH for several months (D).

Mineral, mining, plastics

Worldwide, there is increasing interest in the commercial potential of deep-sea minerals and the development of deep-sea mining operations (Sharma 2017). These minerals include polymetallic manganese nodules, generally occurring at abyssal depths (3,500 – 6,000 m); seafloor massive sulphides, associated with active or extinct hydrothermal vents; cobalt-rich ferromanganese crusts that form on the summits of seamounts at depths of 400 to 2000 m; and phosphorite nodules, typically found between 200-to 400 m depth. New Zealand has all of these mineral types in its offshore waters, which represents a considerable economic potential which could support increasing "green technology" (Ellis *et al*. 2017, Hein *et al*. 2013). However, the environmental effects of deep-sea mining could be severe, with direct physical damage over large areas, and a wider sediment plume generated by seafloor production tools as well as discharge waters post screening at the surface (Clark *et al*. 2017, Miller *et al*. 2018, Levin *et al*. 2016). Impacts may in general terms be similar to bottom trawling, but regulations under the EEZ Act as well as those developing for areas beyond national jurisdiction by the International Seabed Authority require detailed and rigorous environmental impact assessments (Clark *et al*. 2017). Deep-sea corals are an important component of such assessments, as revealed through concerns about effects on benthic communities associated with *Goniocorella dumosa* raised by the New Zealand Environmental Protection Agency (EPA) and in the EPA decision in the turning-down of a mining application for phosphorite nodules on the Chatham Rise (see https://www.epa.govt.nz/assets/Uploads/Documents/Marine-Activities-EEZ/Activities/990a6509eb/CRP-Decision-EEZ000006.pdf reference).

Oil and gas exploration and extraction (Gass & Roberts 2006), physical disturbance during the laying of cables and telecommunications links, and waste disposal (Kogan *et al*. 2003), are additional human activities that can all impact deep-sea coral habitats. Cumulative impacts from multiple industries or uses of the marine estate need to be considered in regional-scale impact assessments and management regimes (Ellis *et al*. 2017).

Plastic contamination is recognised as a serious environmental issue for oceans although the question of how harmful microplastics are to marine life are not clear (Lubofsky, 2018). Both macro– and microplastic debris are accumulating in surface and deep waters but little is known about their impact on deep marine ecosystems and especially on deep-sea corals. A recent paper by Chapron *et al*. (2018) investigated the effects of micro– and macroplastics on the growth, feeding and behaviour of a key scleractinian stony coral species, *Lophelia pertusa*. It was found that the plastics significantly reduced skeletal growth rates, and while this species is not found in New Zealand waters, clearly the plastics will provide a physical barrier to food supply for corals, thus affecting energy acquisition and allocation.

Impacts on shallow-water corals

Here we describe impacts on shallow-water stony corals in the Kermadec region also known as Rangitāhua. Actual or potential threats to shallow-water corals in coastal habitats throughout the New Zealand region, e.g., from anchoring or sedimentation, are outlined in Chapter 9. The coastal habitats encapsulated by the Kermadec Islands Marine Reserve which surrounds each of the four main island groups of the archipelago, are one of only four places globally that can be considered truly pristine (Edgar *et al*. 2014). Accordingly, while New Zealand's reef building coral communities in this area are protected from localised anthropogenic pressures such as fishing and pollution, these coral communities are not immune to all anthropogenic changes. Coral communities around the world have been repeatedly threatened by thermally induced coral bleaching, where increases in ocean temperature trigger a cascade of physiological responses that can cause coral hosts to evict their symbionts, giving corals a characteristic "bleached" appearance (Hoegh-Guldberg 1999; Warner *et al*. 1999). Bleaching signals a breakdown in the mutualism that allows corals to survive in nutrient-poor tropical waters.

At a local scale, the coral eating crown–of–thorns starfish *Acanthaster planci* is present in significant numbers at Rangitāhua (Richards & Liggins 2015) and is a self-sustaining population (Liggins *et al*. 2014). Corals throughout the Pacific have been decimated during periods of explosive population growth of *A. planci* and managing populations of *A. planci* is seen as one of the major future challenges to the preservation of the Great Barrier Reef.


Crown-of-thorns starfish
Acanthaster planci

The hermatypic coral fauna of Rangitāhua are a unique contribution to New Zealand's biodiversity. However, because of a lack of routine monitoring of the Kermadec Islands Marine Reserve, and therefore the coral communities within the reserve, very little is known of the stability, resilience or threats to these coral communities. It is not clear if the corals of Rangitāhua are affected by mass coral bleaching events and thereby how resilient these communities might be to this global challenge. We also do not know the extent of the impacts of *A. planci* on coral communities at Rangitāhua or the trajectories of populations of *A. planci* around the islands.

Chapter 9. Current Management Measures and Threats

Debbie Freeman (DOC), Martin Cryer (FNZ)

Brief overview of threats

The New Zealand corals are at risk from a range of stressors, depending at least in part on their location (e.g., depth), aspects of their life history and physiology, and the particular management or protection measures in place. Chapter 8 identifies fishing, climate change, mining and collection/harvest as some of the main stressors for corals; bottom trawling and ocean acidification were identified by MacDiarmid *et al*. (2012) as the top threats to New Zealand habitats that may support deep sea corals, including hard canyon habitats and seamounts shallower than 2000 metres depth. Similar findings have been reported from around the world (e.g., Lumsden *et al*. 2007, Turley *et al*. 2007).

For shallow-water corals, the key threats along with those associated with climate change or severe weather events include damage from anchoring, mooring and from diver activity (e.g., fin damage), but also illegal removal by divers. Sedimentation or deposition of material from land use activities and marine activities such as dredging or seabed mining may also pose a threat in some locations, in particular where the relief is low and/or where tidal flow is low and material can accumulate on the corals. For New Zealand's subtropical corals at the Kermadec Islands, potential threats include the coral predator *A. planci*, or the crown -of-thorns starfish, which has been present at the Kermadec Islands for at least 30 years (Richards & Liggins 2015). This species has had significant effects on coral reef communities in areas such as the Great Barrier Reef (e.g., Vercelloni *et al*. 2017).

New Zealand management in an international context

There are several key international drivers for the management of corals within New Zealand waters. New Zealand has international commitments to protect and manage its marine environment and associated resources, including under the United Nations Convention on the Law of the Sea (UNCLOS). Part XII of UNCLOS imposes on states a general obligation to protect and preserve the marine environment as well as more specific obligations relating to protection and preservation of rare or fragile ecosystems and the habitat of depleted, threatened or endangered species. Such species and habitats include corals.

United Nations General Assembly (UNGA) resolutions have addressed the impacts of fishing on vulnerable marine ecosystems in international waters, with specific reference to seamounts, hydrothermal vents, and cold-water corals. The 2006 UNGA Sustainable Fisheries Resolution (A/61/105) calls upon states and regional fisheries management organizations (RFMOs) to ensure the sustainable management of fish stocks and prevention of significant adverse impacts on vulnerable marine ecosystems (VMEs) – including seamounts, hydrothermal vents, and cold-water corals – from destructive fishing practices.

As a signatory of UNCLOS, New Zealand also engages with activities of the International Seabed Authority which is responsible for deep-sea minerals exploration and exploitation. Deep-sea mining is not yet taking place, but as the ISA develops rules and regulations around the environmental assessment and management of mining activities, New Zealand has an obligation to ensure that national management of the environment conforms to these international standards.

New Zealand is involved with several regional fisheries management organisations (RFMOs) including the South Pacific RFMO (SPRFMO) and is also a party to the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), which is part of the Antarctic Treaty System. Management and protection of vulnerable ecosystems is a component of these agreements, and New Zealand has played a role in the development of measures related to them. The Ross Sea region Marine Protected Area, Antarctica, was implemented in 2017, following the development of a proposal over many years by co-proponents New Zealand and the United States. The MPA has a specific objective relating to rare and vulnerable benthic habitats. Information on the presence of coral species such as black corals was used to identify benthic areas of particular importance for which 100% protection was sought in the design of the MPA (Sharp & Watters 2011, Sharp *et al*. 2011).

The Convention on International Trade in Endangered Species of Fauna and Flora (CITES) is an international agreement between governments aimed at ensuring that international trade in specimens of wild animals and plants does not threaten their long-term survival in the wild. CITES entered into force on 1 July 1975 and New Zealand became a Party in 1989. The species covered by CITES are listed in three Appendices, according to the degree of protection they need. Species in Appendix I can be traded only under exceptional circumstances. Trade in Appendix–II species must be regulated and is permitted only if export will not be detrimental to the long-term survival of the species in the wild. Species in Appendix III are regulated to prevent or restrict exploitation. CITES lists all black, hydrozoan and stony corals in Appendix II, so their international trade is allowed under permit.

Many coral species have been through the International Union for the Conservation of Nature's (IUCN) process for listing species on their "Red List" (IUCN 2014). This system classifies taxa according to their risk of extinction using specified criteria. To date, no deepwater coral taxa recorded in New Zealand waters have been assessed under this system but a large number of corals from around the world, in particular shallow-water corals, have been assessed and some of these occur in New Zealand waters.

As a signatory to the Convention on Biological Diversity, New Zealand has commitments to protect at least 10 percent of its coastal and marine environment in an ecologically representative network of MPAs and other conservation measures by 2020. Additionally, there are commitments to ensure that fisheries have no significant, adverse impacts on threatened species and vulnerable ecosystems and that the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits (Secretariat of the Convention on Biological Diversity 2011). There is also a commitment to develop a national biodiversity strategy to deliver on these international targets.

Particular bilateral and multilateral agreements among nations are also of relevance to New Zealand's coral fauna. For example, the Joint Committee Meeting (JCM) on Science and Technological Cooperation provides a high-level bilateral agreement between New Zealand and the United States. The inaugural meeting of the JCM was in 2007; the last JCM was held in the United States in September 2012, where delegates developed a Roadmap of Cooperative Activities for 2012–2014, which included topics related to Climate Change Monitoring, Research, and Services in the Pacific; and Marine and Ocean Research. A range of research on corals has been made possible through this agreement, in particular around deepwater coral taxonomy.

New Zealand framework for management of corals

New Zealand has a large marine environment of significant ecological, economic, cultural and social value. The agencies that have responsibilities within this realm are numerous and include:

- Ministry for the Environment
- Environmental Protection Authority
- Fisheries New Zealand, Ministry for Primary Industries
- Department of Conservation
- Ministry of Transport
- Maritime New Zealand
- Regional councils
- National Maritime Coordination Centre
- Ministry of Business, Innovation and Employment
- New Zealand Petroleum and Minerals

The framework describing the management of the marine environment, primarily by the Department of Conservation (DOC) and Fisheries New Zealand (FNZ), is described below. These organisations make the greatest contributions to the future of marine conservation, policy, and management of corals

National Framework

New Zealand Threat Classification System

The New Zealand Threat Classification System (Townsend *et al*. 2008) provides a framework for assigning a threat status, or risk of extinction, to any terrestrial, marine or freshwater taxon. It complements the global view of the IUCN Red List by assessing risk of extinction within the New Zealand context. Assessments of taxa can provide the basis for prioritising recovery programmes and research, monitoring management effectiveness, and assisting in decisions around species and habitat management and use. The system provides a range of categories (Figure 25) and taxa are assigned to these categories based on an expert process that considers information on population status and trends (including for sub-populations), area of occupancy, as well as taxonomic status. There is also provision for recording “qualifiers”, or additional information such as whether the taxon is data poor, restricted to one location, or is secure overseas.

Deepwater corals have been included in the assessment process for New Zealand marine invertebrates and during the most recent threat assessment process (Freeman *et al*. 2014) all known deepwater coral taxa were considered. Nineteen taxa were categorised as Data deficient (15 of these were taxonomically determinate and four were taxonomically indeterminate); two were categorised as Threatened – Nationally Vulnerable; five were At Risk – Declining; 24 were At Risk – Naturally Uncommon (six of these were taxonomically indeterminate).

Appendix 3 provides an overview of the conservation status of New Zealand deepwater corals (Freeman *et al*. 2014); a description of the New

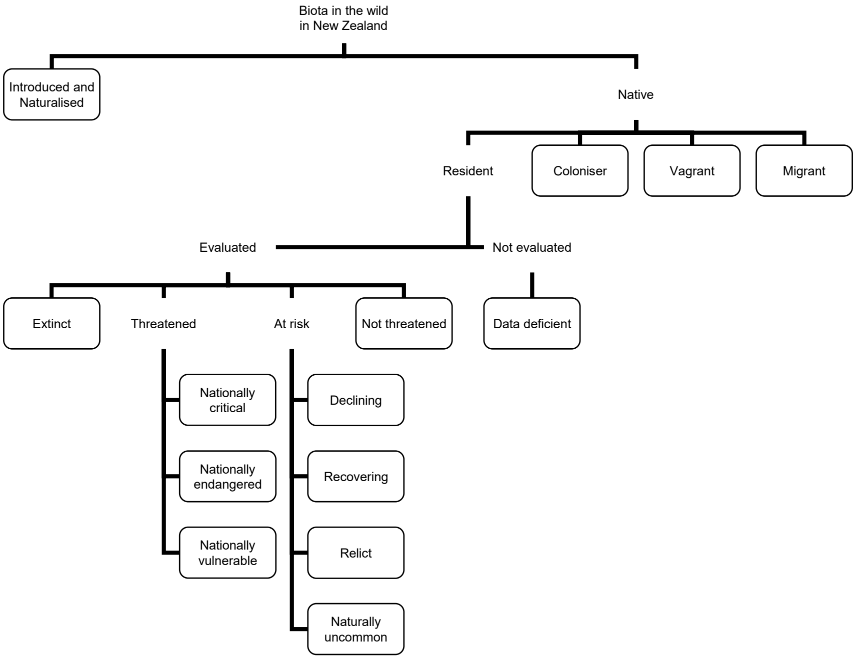


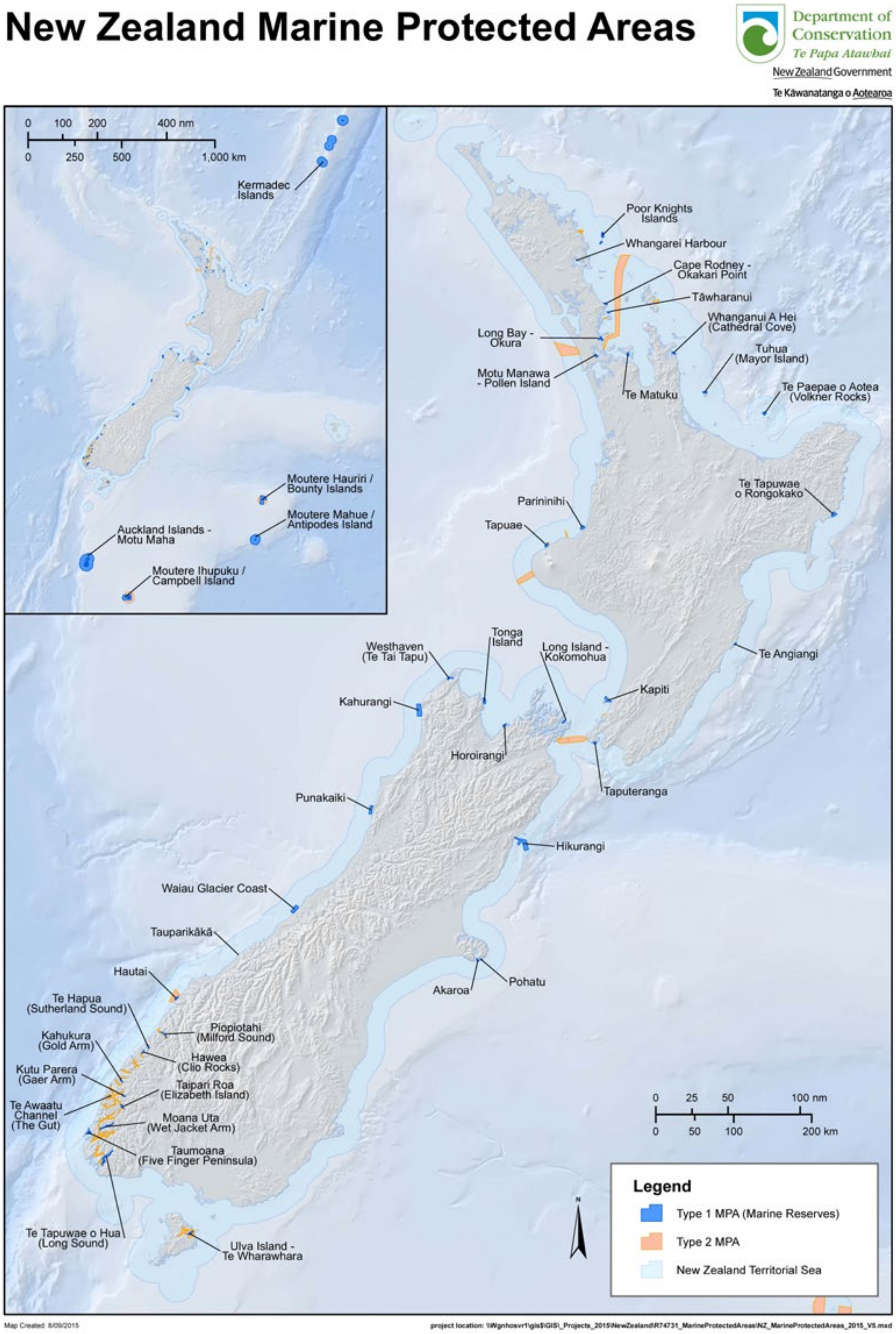
Figure 25: Structure of the New Zealand Threat Classification System (Townsend *et al*. 2008).

Zealand Threat Classification System is included, e.g.,

- whether the taxon is indigenous or naturalised in New Zealand.
- information on the distribution of the taxa in New Zealand waters and overseas.

Qualifiers are also provided under the New Zealand Threat Classification System for assessing the conservation status of species such as corals, (Appendix 3).

New Zealand's draft Threatened Species Strategy, released for consultation in 2017 (Department of Conservation 2017a) identified bubblegum octocoral (*Paragorgia* spp.) as one of the 150 priority threatened and at-risk species, for which protection was proposed to be enhanced under the draft strategy. Work is also underway to refresh New Zealand's Biodiversity Strategy.

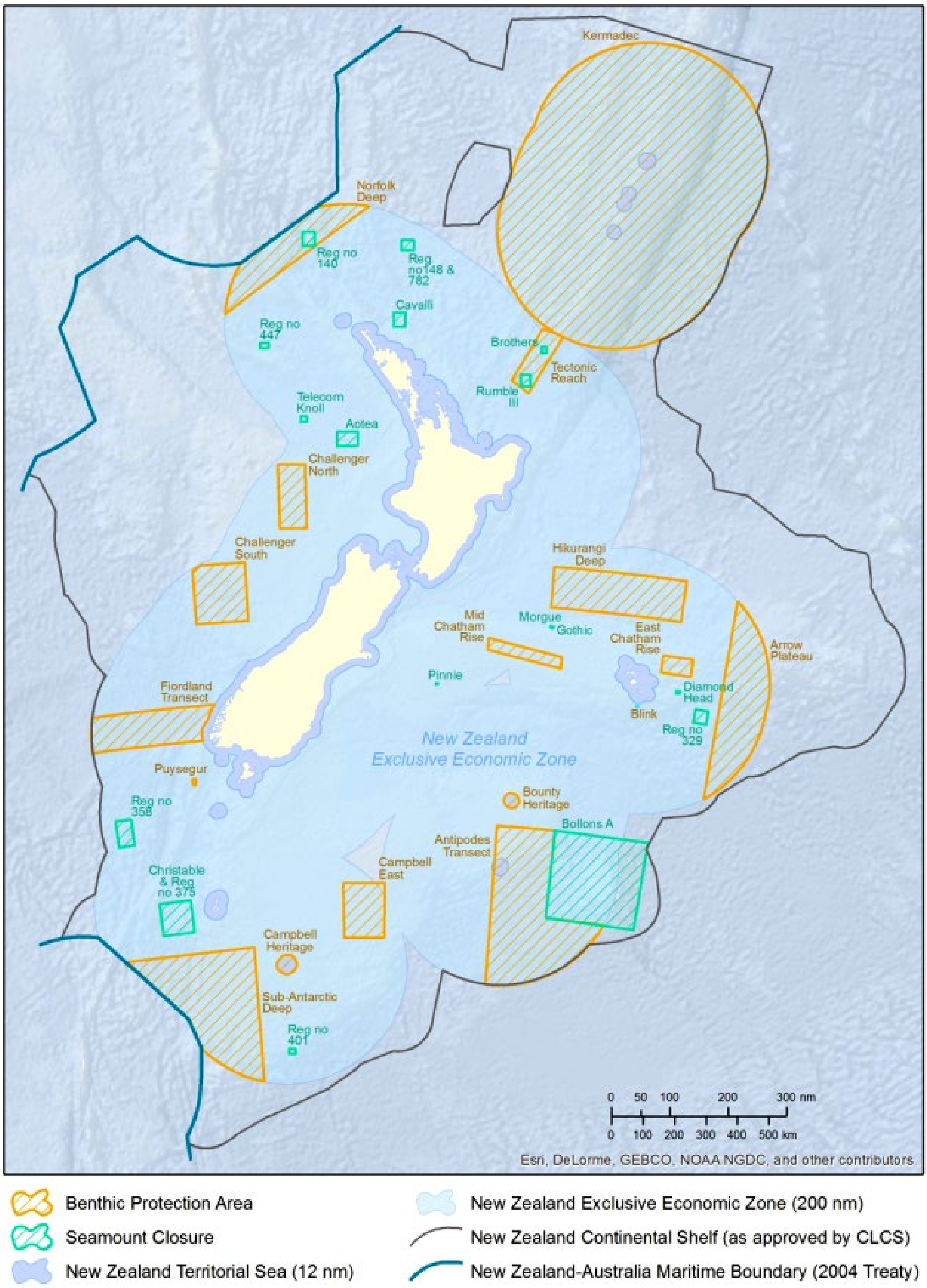


Statutory Management Mechanisms

Legislated spatial protection

Marine reserves and marine protected areas in the Territorial Sea

New Zealand has a range of marine protected areas in place within the Territorial Sea, some of which provide protection of coral species. Corals are identified as one potential component of biogenic habitats, to be represented within a network of marine protected areas (Department of Conservation and Ministry of Fisheries 2011). As at September 2019, there are 44 marine reserves implemented under the Marine Reserves Act 1971 and 19 “Type 2” marine protected areas implemented under other legislation (Figure 26). Marine reserves provide the highest level of protection by prohibiting activities that may involve the take or disturbance of marine life. Type 2 MPAs are managed areas that meet a defined protection standard under New Zealand’s MPA Policy (Department of Conservation and Ministry of Fisheries 2005; Ministry of Fisheries and Department of Conservation 2008). These protected areas range in latitudinal extent from



Figures 26 (left) and 27 (top): Locations of New Zealand Marine Protected Areas and Benthic Protection Areas and Seamount Closures.

the subtropical Kermadec Islands Marine Reserve in the north, to subantarctic Moutere Ihupuku/ Campbell Island Marine Reserve in the south. A wide range of other spatial restrictions apply that provide protection against some but not all of the disturbance agents specified in the marine protected areas protection standard. While some of these protected areas and other spatial closures are relatively small and confined to nearshore habitats, some are large and extend across habitats within the Territorial Sea and likely include at least some species of protected corals. For example, the spatial closure in Spirits Bay implemented under the Fisheries Act 1996 contains at least 29 species of corals and gorgonians (Cryer *et al*. 2000).

Spatial protection in the Exclusive Economic Zone

Marine reserves cannot be established outside the Territorial Sea under the Marine Reserves Act 1971. Current spatial measures to protect corals from the effects of fishing in New Zealand's Exclusive Economic Zone (EEZ, from 12 to 200 nautical miles from the coast) have been put in place using the Fisheries Act 1996. In 2001 the Government prohibited trawling in 17 seamounts distributed throughout the EEZ. Within these areas all trawling methods are prohibited; there is no provision for midwater trawling. In 2007, in response to a fishing industry proposal, the Government closed an additional 17 areas (Benthic Protection Areas, BPAs) within the EEZ to dredging and placed tight restrictions on trawling in those areas. The purpose of the BPAs and seamount closures (Figure 26) was to protect benthic (seafloor) biodiversity. The BPAs cover between 3 and 86% of oceanic environment classes (as defined by the 20-class New Zealand Marine Environment Classification; Snelder *et al*. 2005). While the BPAs were not focussed specifically on corals, the BPAs and Seamount Closures together cover 28% of known underwater topographic features in the EEZ, 52% of known seamounts with an elevation of >1000 m, and 88% of known active hydrothermal vents (Helson *et al*. 2010). Currently these are the only deepwater protected areas that have been established in the EEZ.

Legislation that protects coral taxa

Wildlife Act 1953

Most corals in New Zealand waters are absolutely protected under the provisions of the Wildlife Act 1953, that relate to the protection and control of wildlife. The Wildlife Act applies to New Zealand's lands and waters, including the Territorial Sea and Exclusive Economic Zone. Specifically, the following coral taxa are listed in schedule 7A which was inserted by way of a 2010 amendment to the Wildlife Act:

- black corals (all species in the order *Antipatharia*)
- gorgonian corals (all species in the order Gorgonacea) – gorgonian octocorals are now in order Alcyonacea, an order that also includes unprotected soft corals
- stony corals (all species in the order Scleractinia)
- hydrocorals (all species in the family Stylasteridae).

It is illegal to deliberately collect or damage these species and all protected corals accidentally brought to the surface (e.g., on or in fishing gear or fouled by anchors) must be immediately returned to the sea. Not all coral taxa listed in the Wildlife Act are classified as threatened under the New Zealand Threat Classification System.

CITES

As noted above, many corals are listed on Appendix II of the Convention on International Trade in Endangered Species (CITES). These species may not be imported or brought into New Zealand without an export permit from the country of origin. The Department of Conservation is the New Zealand CITES authority, via the Trade in Endangered Species Act 1989.

Legislation that requires the avoidance of adverse effects on threatened species and the habitats of threatened species.

Resource Management Act 1991

The Resource Management Act 1991 promotes the sustainable management of the natural and physical resources of the land and territorial sea of New Zealand. One of the listed matters of national importance is the protection of significant habitats of indigenous fauna.

The New Zealand Coastal Policy Statement 2010 (NZCPS) is a "second level" statutory instrument developed under the Resource Management Act to provide national level policies for the management of the coastal environment including the territorial sea. It is required to be given effect to in regional level documents such as regional policy statements, and regional coastal plans. Policy 11 of the NZCPS refers specifically to indigenous biological diversity. Adverse effects of activities on those New Zealand corals that are listed in the New Zealand Threat Classification System are to be avoided (i.e., not allowed) and adverse effects are also to be avoided on indigenous ecosystems that are threatened or are naturally rare.

Figure 27: Sea pen field, *Pennatula* spp.

Sensitive environment	Indicator of existence of sensitive environment
Stony coral thickets or reefs	A stony coral reef or thicket exists if— a colony of a structure-forming species (ie, *Madrepora oculata*, *Solenosmilia variabilis*, *Goniocorella dumosa*, *Enallopsammia rostrata*, *Oculina virgosa*) covers 15% or more of the seabed in a visual imaging survey of 100 m2 or more; or ▪ a specimen of a thicket-forming species is found in 2 successive point samples; or ▪ a specimen of a structure-forming species is found in a sample collected using towed gear.
Sea pen field	A sea pen (e.g. Figure 27) field exists if— ▪ a specimen of sea pen is found in successive point samples; or ▪ 2 or more specimens of sea pen per m2 are found in a visual imaging survey or a survey collected using towed gear.

Table 4: Sensitive environments identified in the Exclusive Economic Zone and Continental Shelf (Environmental Effects—Permitted Activities) Regulations 2013. Listed here are those relevant to this report, corals and sea pens.

Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012

Within the New Zealand Exclusive Economic Zone, the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 provides for the management of effects on species and habitats. Of particular relevance to corals is the requirement in this Act for an impact assessment to (among other things) identify the effects of a proposed activity on rare and vulnerable ecosystems and on the habitats of threatened species, and for the consent authority to take into account the importance of protecting rare and vulnerable ecosystems and the habitats of threatened species. This Act provides for the declaration of marine species to be threatened or at risk, as classified under the New Zealand Threat Classification System (see above). All the coral taxa identified as threatened or at risk in the 2013 assessment (Freeman *et al*. 2014) have been notified in a Gazette Notice as “threatened species” for the purposes of implementing this Act (see New Zealand Gazette, 11 July 2013 Notice 2013–go4245).

The Exclusive Economic Zone and Continental Shelf (Environmental Effects—Permitted Activities) Regulations 2013, provide for the management of the environmental effects of permitted activities in the EEZ if they occur in areas of sensitive marine benthic environments; Schedule 6 of these regulations includes a list of indicators of the existence of sensitive environments. Table 4 lists those sensitive environments relevant to this report – those for corals and sea pens, (Table 4).

A review by MacDiarmid *et al*. (2013) was used as the basis for developing this list and provides a description, distribution, and definition of 13 sensitive marine benthic habitats, including stony coral thickets or reefs. More recently, as part of MfE’s State of the Environment reporting, Anderson *et al*. (2019), provide a review of New Zealand’s key biogenic habitats (many of which are also defined as sensitive marine benthic habitats in MacDiarmid *et al*. (2013). The 15 key biogenic habitats examined in Anderson *et al*. (2019) includes ‘Stony-coral thickets, and other habitat-forming corals’. The review, which includes current knowledge on biogeographic distribution, ecosystem services, stressors and threats, and the current and likely future projected condition of these habitats, also identified the importance of non-thicket forming coral groups (black corals, octocorals and hydrocorals) as structural habitats for benthic communities as well as their vulnerability to disturbance and likely slow recovery times following disturbance.

Non– Statutory Management Mechanisms

Government research to underpin management

DOC supports protected coral and other conservation research projects and FNZ has a broader programme of aquatic environment and biodiversity research projects that are specific to corals or include corals alongside other taxa. These research programmes support a variety of spatial and other management responses under the Fisheries Act 1996, Marine Protected Areas Policy, or other legislation.

Research carried out by or administered under DOC has the aim of avoiding, remedying or mitigating the adverse effects of commercial fisheries on protected species. As protected species under the Wildlife Act 1953, coral species fall within the remit of The Conservation Services Programme (CSP). DOC develops an annual plan for "conservation services" to be delivered, subject to cost recovery from the commercial fishing industry. "Conservation services" are defined under the Fisheries Act 1996 to mean "outputs produced in relation to the adverse effects of commercial fishing on protected species, as agreed between the Minister responsible for the administration of the Conservation Act 1987 and the Director–General of the Department of Conservation, including—

(a) research relating to those effects on protected species:

(b) research on measures to mitigate the adverse effects of commercial fishing on protected species:

(c) the development of population management plans under the Wildlife Act 1953 and the Marine Mammals Protection Act 1978".

The objectives of the CSP are defined in the CSP Strategic Statement (Department of Conservation 2015) and are:

Objective A: Proven mitigation strategies are in place to avoid or minimise the adverse effects of commercial fishing on protected species across the range of fisheries with known interactions.

Objective B: The nature of direct adverse effects of commercial fishing on protected species is described.

Objective C: The extent of known direct adverse effects of commercial fishing on protected species is adequately understood.

Objective D: The nature and extent of indirect adverse effects of commercial fishing are identified and described for protected species that are at particular risk to such effects.

Objective E: Adequate information on population level and susceptibility to fisheries effects exists for protected species populations identified as at medium or higher risk from fisheries.

The CSP has delivered a range of reports related to New Zealand deepwater coral species, including an identification guide for Government observers on the identification of protected corals known to be caught incidental to fishing (Tracey *et al*. 2014), an assessment of the relative risk to protected coral species from deepwater bottom trawling (Clark *et al*. 2014), and predictive modelling of habitat suitability for corals (Anderson *et al*. 2014).

FNZ manages aquatic environment and biodiversity research programmes that cover protected species like corals, seabirds, and marine mammals, but also a much broader range of taxa and issues (summarised in MPI 2019). Under the Fisheries Act 1996, the Minister of Fisheries can take measures to avoid, remedy or mitigate the effect of fishing on any protected species, such as corals, but can also take measures to avoid, remedy or mitigate any adverse effect of fishing on the wider aquatic environment. Decision-making under the Fisheries Act is guided by three environmental principles:

- associated or dependent species should be maintained above a level that ensures their long-term viability;
- biological diversity of the aquatic environment should be maintained;
- habitat of particular significance for fisheries management should be protected.

There are particular requirements around reporting of bycatch of corals with all coral and benthic bycatch being required to be reported by commercial fishers. Observers are placed in key fisheries in order to independently quantify and sample coral bycatch.

New Zealand Biodiversity Strategy

The New Zealand Biodiversity Strategy (Department of Conservation and Ministry for the Environment 2000) and Action Plan (Department of Conservation 2016) identified a number of objectives and national targets that are relevant to corals and the habitats they occur in. Key actions identified under National Target 5 ("Biodiversity is integrated into New Zealand's fisheries management system") refers to enhanced recording of bycatch and managing the impacts of bottom trawling; National Target 6 ("Improved understanding of the impacts of climate change on biodiversity informs better management of vulnerable ecosystems and indigenous species") identified key actions relating to consideration of the impacts of climate change in the management of vulnerable ecosystems and species, and better understanding of climate change effects. Key actions around the management of threatened marine species (under Target 12) and the implementation of a representative network of marine protected areas (Target 13) are also identified. New Zealand's Biodiversity Strategy is currently being revised.

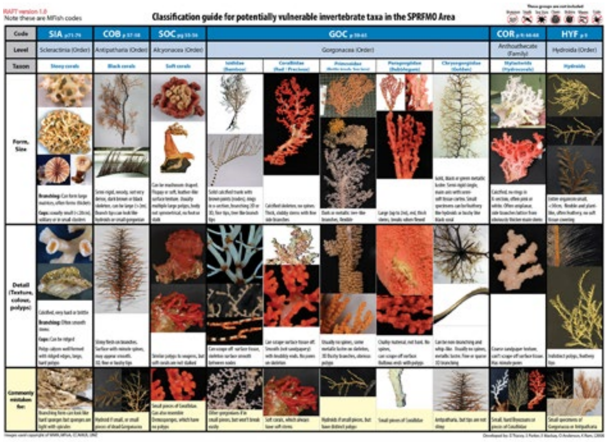


Figure 28: Coral fauna illustrated in the Classification guide for potentially vulnerable invertebrate taxa in the SPRFMO Area. (Developed by Tracey *et al*. 2008)

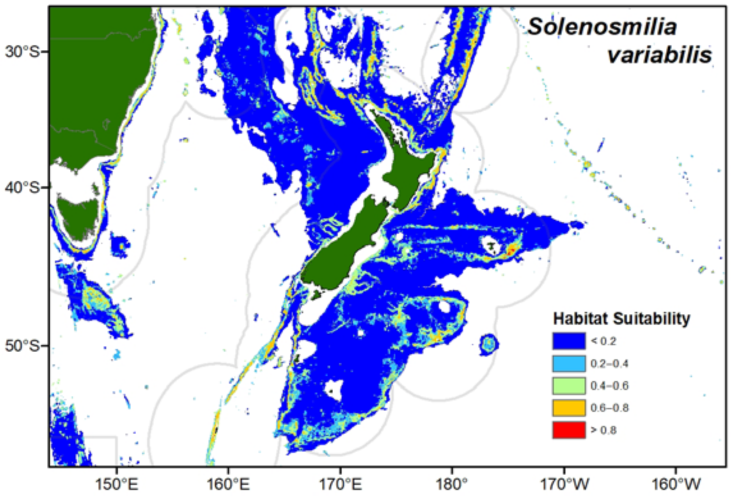


Figure 29: Ensemble model habitat suitability map for the stony coral *Solenosmilia variabilis* in the south west Pacific Ocean (modified from Georgian et al. 2019, see this study for more detail).

Regional management actions

While there are international and national frameworks for the management of corals in New Zealand, there are also examples of the implementation of regional-scale management actions.

Not all protected coral populations occur outside the Territorial Sea. Black corals, red hydrocorals, and the stony coral *Oculina virgosa*, are found in shallow coastal regions off Kapiti Island, in Fiordland, in Port Pegasus (Stewart Island), in diving depths in the Bay of Plenty, and in the Spirits Bay - Three Kings Islands regions. Coral taxa recorded in Spirits Bay in 1999 included gorgonian octocorals, the black coral *Antipathes*, and several stony cup corals including species of *Monomyces*, *Culicea*, and *Balanophyllia*, (authors pers. comm). Some of the marine reserves and areas with fragile species termed ‘china shops’ in Fiordland, southwest New Zealand, were specifically established to provide protection to species of corals (black corals and red hydrocorals) that inhabit shallow-water below the dark, tannin-stained surface waters of the fiords (Fiordland Marine Guardians 2017). The policies provided in the NZCPS may also have particular relevance in some regions. For example, the Regional Coastal Plan for the Southland Region of New Zealand (Southland Regional Council 2013) has specific policies related to the preservation of the habitat of distinctive communities such as the black coral habitats in Fiordland, and restrictions on mooring and anchoring within the “china shops” referred to above were implemented under this Regional Coastal Plan; the value of black coral habitats in Fiordland for divers was also identified as a key issue under this plan.

The subtropical Kermadec Islands region is the only place in New Zealand where hermatypic (reef-building) corals are found in subtidal areas; 17 species of coral have been recorded there and one species of coral is considered to be endemic to the islands (Department of Conservation 2017b). The Territorial Sea around these islands in fully protected within a no-take marine reserve and the value of corals was also recognised in the Regional Coastal Plan for the islands (Department of Conservation 2017b), which puts in place specific restrictions on vessel activity to address the potential threats to marine biodiversity from invasive species and oil spills. The Kermadec Islands and the surrounding marine reserve were placed by New Zealand on the tentative list for World Heritage Area status in 2007.

Chapter 10: South Pacific Regional Fisheries Management Organisation

Ashley Rowden, Malcolm Clark (NIWA), Martin Cryer (FNZ)

In areas outside national EEZs, the South Pacific Regional Fisheries Management Organisation (SPRFMO), regulates deep-sea fishing activities in the southern Pacific Ocean. As referred to in section 1.9.2, UNGA resolutions require actions are taken to both ensure the sustainability of fisheries, and that significant adverse impacts on vulnerable marine ecosystems (VMEs) are prevented. The characteristics of VMEs are defined by FAO (2009) and, in the SPRFMO Convention Area, a number of VME indicator taxa are specified (Parker *et al*. 2009). These include stony corals, soft corals, black corals, gorgonian octocorals and hydrocorals (Figure 28). Since interim management measures were established in 2007, catching above a threshold weight of any of these taxa in a trawl required the vessel to move away from the area to reduce the risk of further damage to VMEs.

The interim management measures introduced by the New Zealand and Australian governments to protect VMEs also restricted bottom trawling to within their respective historical footprints. New Zealand (but not Australia) also closed about one-third of that footprint to fishing, being mostly areas that had been fished only lightly (Penney *et al*. 2009). The effectiveness of the New Zealand closed areas was assessed by Penney & Guinotte (2013) using a habitat suitability model for stony corals (a subset of the global model of Davies & Guinotte 2011) and a cost-benefit analysis. This analysis indicated that it was possible to improve the distribution of the closed areas to better protect coral VME indicator taxa, as well as allow for more catch to be retained by the fishery. Following the review by Penney and Guinotte (2013), work began on assembling the scientific information needed to improve and integrate the spatial management of bottom fishing in the SPRFMO Convention Area to provide for a sustainable fishery and prevent significant adverse impacts on VMEs (e.g., Rowden *et al*. 2015, Clark *et al*. 2015, Cryer *et al*. 2018a and b).

Among the outputs from these projects were habitat suitability models and predictive maps for VME indicator taxa, including corals. These maps were produced at three geographic scales and different spatial resolutions; SPRFMO–scale (1km resolution; Anderson *et al*. 2016a), New Zealand region-scale (1 km resolution; Anderson *et al*. 2016b), and individual seamount-scale for 5 seamounts on the Louisville Seamount Chain (25 m resolution, Rowden *et al*. 2017).

Building on these models (see Georgian *et al*. 2018) and using the spatial decision support tool Zonation (Di Minin *et al*. 2014), New Zealand and Australia together conducted a formal spatial management planning process to devise new spatial measures to provide for a fishery while preventing significant adverse impacts on VMEs in the south-western part of the SPRFMO area (Government of New Zealand 2019, see Figure 29). This work included habitat suitability maps for VME indicator taxa, and uncertainties associated with these model predictions; naturalness condition, represented by two proxy variables using New Zealand trawl effort data; and value to the New Zealand fishery using trawl catch data for two gear types and three time-periods. Running scenario analyses with these data demonstrated the practical utility of using the data and a planning software, to inform an understanding of the effect of varying the input data on the spatial prioritisation of areas for VME conservation, as well as allowing for the cost to fishing to be determined if high priority areas for VME indicator taxa are protected (Rowden *et al*. 2019). The spatial management recommendations (and other conservation measures) presented in early 2019 to the SPRFMO Commission based on the results of this process were implemented by SPRFMO starting in March 2019.

Chapter 11. Coral information needs/ gaps, and research priorities

Freya Hjorvarsdottir (previously DOC now MPI), Di Tracey, Malcolm Clark (NIWA)

Workshop on research needs for protected corals in New Zealand waters

A workshop was held on the 12 October 2017 with the purpose of providing a forum where personnel (i.e., government agencies, stakeholders, industries, researchers) with interest in corals in New Zealand waters had the opportunity to come together to discuss the current status of research, identify knowledge gaps and their importance to the conservation and management of New Zealand protected corals, as well as highlighting possible synergies for different end-user needs (Hjorsvarsdottir & Tracey 2017).

The workshop comprised sessions featuring presentations covering a range of aspects of deep-sea coral ecology, impacts, and management (Appendix 4). These presentations formed the basis of a questionnaire and subsequent discussion on knowledge gaps. In total, 58 gaps were identified, and assigned to six categories: ‘Biological Gaps’, ‘Environmental Gaps’, ‘Spatial Gaps’, ‘Modelling Gaps’, ‘Threat and Pressure Gaps’, and ‘Data, Management & Communication Gaps’ (Appendix 4). This list incorporates a smaller assessment of research needs by Anderson *et al*. (2018).

Knowledge gaps

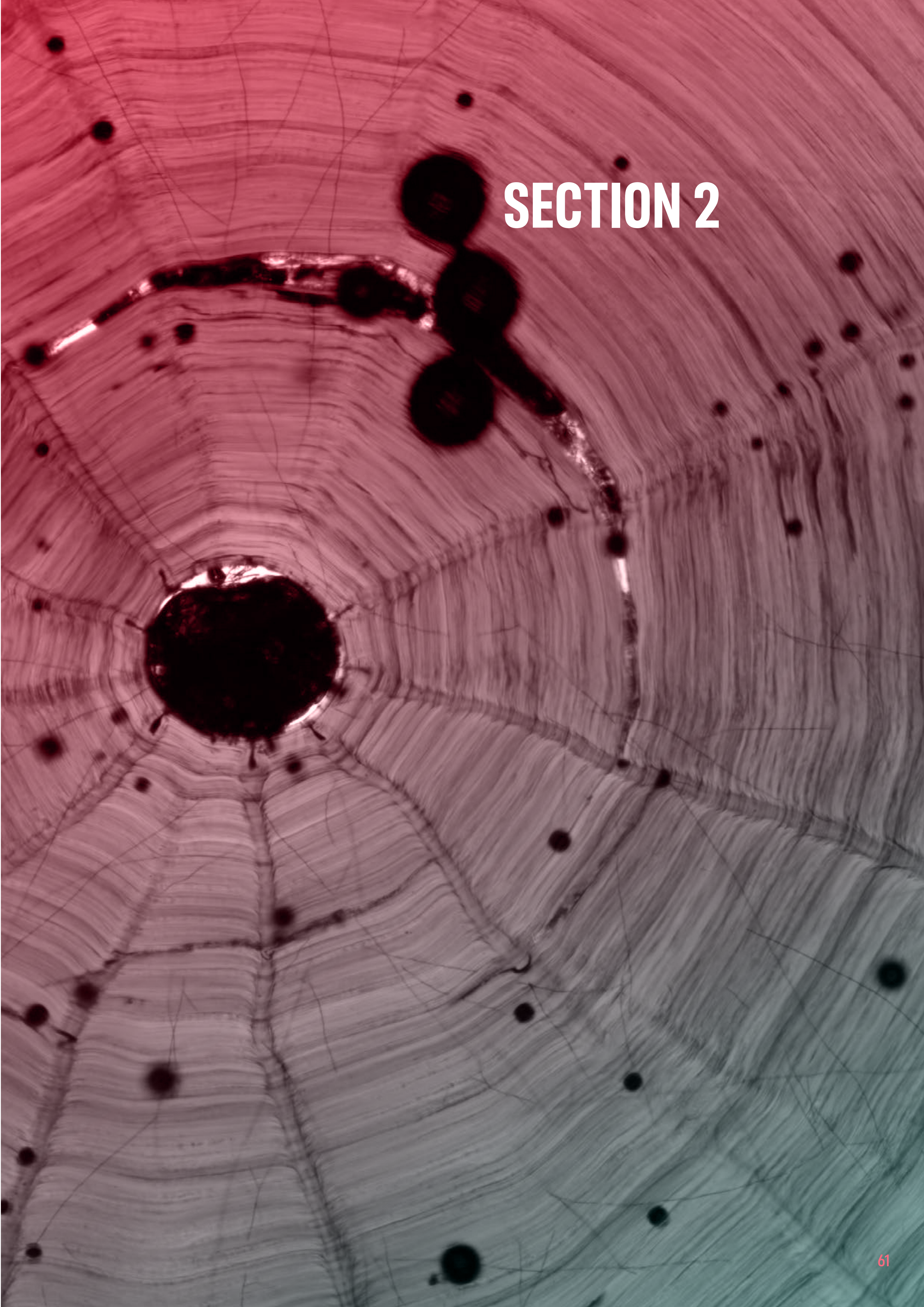
The workshop output is a long and somewhat daunting list. However, research and data priorities need to be driven primarily by management objectives and linking the list to the objectives outlined in section 1.9 is a key step. That can then help drive and construct a 5-year research and management plan as already developed for other threatened or protected groups within New Zealand (e.g., seabirds, marine mammals). This can then allow the linkages and synergies in the list of 58 research and data gaps (see Appendix 4), to be mapped into an integrated plan that will slowly address the key gaps in a structured way to support improved management. Most deep-sea corals species are fully protected, but the key for effective management is to ensure that species, communities and populations are maintained above a level that ensures adverse effects (from human impacts but also natural factors) do not risk sustainability. The status of protected species is likely to be insufficient by itself to guarantee that goal is met. Outside the BPAs and SCAs there is no network of protected areas in the EEZ, and no monitoring programme to track the stability or otherwise of coral populations.

From the outset, management objectives need to be made operational, in the context of what is needed to evaluate whether they are being met, and controls are adequate.

Although knowledge of the composition, distribution and ecology of deep-sea corals in the New Zealand region has developed in recent years, there are still some critical gaps that need to be filled as priority actions in a research plan to underpin the management objective.

- **Distributional gaps** in sampling and hence knowledge of the species composition in some areas is poor, and especially so for depths greater than 2000 m. Such data are a priority to better understand the spatial scale of community and population levels, improve knowledge of species and population connectivity, ensure species modelling is reliable, and from a climate change perspective, help inform how corals will respond to carbonate saturation horizon changes.
- Improved distributional data needs to be coupled with **improved data on abundance/density/biomass** to support analyses and models that better reflect the relative importance of certain species or areas. This will require a shift towards more image-based sampling and analyses to support quantitative analyses (although direct sampling is still required for specific identification and genetic specimens to infer source-sink dynamics).
- A preliminary ecological risk assessment was conducted in 2014 (Clark *et al*. 2014a). This identified that most deep-sea protected species were at risk from existing trawl fisheries. However, although vulnerability criteria could be assessed reasonably well, a limitation of this analysis was **data paucity on coral productivity**. This relates directly to the overall resilience of coral species, and their recoverability from disturbance. This analysis highlighted a pressing need for research to determine the age and growth characteristics (especially growth rates) of deep-sea corals. Information for some species is available (see summary in Tracey *et al*. 2018), but there are few data for many other species. Further linked to understanding productivity and recovery dynamics is improved understanding of connectivity between areas, and specific knowledge on reproduction, while often challenging to ascertain for deep-sea corals, is a research field that is growing internationally (e.g., see Feehan & Waller 2015) and necessary for determining spawning patterns, and hence how coral communities may grow, or recolonise impacted areas.
- The improved knowledge of coral biology and ecology that would be prioritised in the above points, can then support measurements of changes in deep-sea coral populations/habitats over space and time. There needs to be **long-term monitoring** of several offshore sites to establish temporal and spatial trends, and hence assess whether population levels of deep-sea corals are being maintained and are sustainable, or whether they are being affected by human activities. Results from four surveys over 15 years on the Graveyard Knolls highlight that trawling has a severe impact on stony coral communities, and recovery is very slow (Clark *et al*. 2019). This type of study emphasises the value of time series data. It would be appropriate to establish a survey plan for a variety of locations or habitat types across the EEZ to measure and monitor the status of deep-sea corals. Fishery–independent surveys are likely to be required for this (Bowden *et al*. 2015). Sites could be informed by work currently being undertaken for DOC compiling and collating data sources to identify “Key Ecological Areas” in the New Zealand marine environment (Stephensen *et al*. 2018).
- These priority gaps reflect a way forward to collect data focussed on improving understanding of deep-sea coral distribution and population structure, focus analysis on quantifiable abundance data to identify important

areas, and progress information on productivity (age, growth, reproduction) that supports risk assessments of vulnerability and recoverability. In turn, the interpretation of spatial and temporal trends in coral populations that would come from a new monitoring programme of “key” sites in the EEZ would inform protected area design if appropriate. Many of the “list of 58” would nest inside the above, and ultimately improve confidence in the adequacy and effectiveness of management.



SECTION 2

Chapter 12. Key Coral Groups

Di Tracey, Rob Stewart, Jaret Bilewitch, Diana Macpherson, Caroline Chin, Sadie Mills, Kate Neill (NIWA), Gustav Kessel (PhD Student NIWA/Victoria University of Wellington), David Aguirre, Libby Liggins (Massey University, Auckland)

Appendix 1 summarises the key species for each taxonomic group described below.

Scleractinia stony corals (Order: Scleractinia)

Scleractinian corals are calcified hexacorals, i.e., having body parts in multiples of 6, and in the New Zealand region there are around 110 azooxanthellate stony corals, (i.e., lacking symbiotic algae) (Cairns 1995). These azooxanthellates are sometimes called ‘deepwater’, ‘cold-water’, or ‘deep-sea’ corals. Some stony coral growth forms, such as cup corals, occur as solitary individuals or in small clumps, while reef-like or thicket forms provide extensive biogenic habitats. Several species of shallow-water hermatypic corals are found in New Zealand and it is the accretion of their calcium carbonate skeleton that builds coral reefs. However, these are restricted to the northern-most subtropical regions of New Zealand (e.g., in the Kermadec/Rangitāhua archipelago). Early work on this group was carried out by Ralph & Squires (1962), Squires (1965), Squires & Keyes (1967), McKnight & Estcourt (1978), and Cairns (1982; 1995).

Reef formers

Colonies of branching scleractinian corals produce large (but fragile) three-dimensional matrices that form ‘reef’, ‘mound’ or ‘thicket’ structures. They are comprised of the aragonite form of calcium carbonate and have existed for hundreds or thousands of years (see review by Tracey *et al.* 2018). The upper zone of the reef matrix contains live coral, whereas the lower region matrix zone comprises dead coral framework. Both live and dead coral matrix provides biogenic reef habitat (an ecosystem complex) on continental slope margins, ridges and seamounts. The reef structures produced by some of the stony coral species act as a refuge for some fish and invertebrates, and there is an association between commercial fish species and these reef matrices (see chapter 4).

Six key species form reefs or thickets in New Zealand waters are described as structure-forming scleractinian species:

- *Solenosmilia variabilis* (Family: Caryophylliidae)
- *Goniocorella dumosa* (Family: Caryophylliidae)
- *Madrepora oculata* (Family: Oculinidae)
- *Enallopsammia rostrata* and *E. pusilla* (*E. marenzelleri*) (Family: Dendrophylliidae)
- *Oculina virgosa* (Family: Oculinidae)

Photo. © Crispin Middleton

Detailed descriptions of the key reef-formers and their branching forms are provided in Tracey *at al*. (2011). When live, these corals are pink, bright red to orange, yellow, brown, and purple. Examples of the branching scleractinian stony corals that form reef-like structures or thickets on hard substrata within the New Zealand region are shown in Figure 30. *Solenosmilia variabilis* is a globally distributed species. *S. variabilis* form large colonies with equal, three-dimensional branching. The intratentacular budding for this species always results in dichotomous and angled branching with no axial corallite. Similar to *S. variabilis* is *G. dumosa,* but the latter is thicker with branches developing from the calyces and has branches that are reinforced by slender and smooth tubular bridges and most of the branches bud at right angles. *E. rostrata* forms large uniplanar colonies with occasional branch anastomosis (i.e., branch fusion). Polyp calyces are confined to only one plane of the coral. The branching coral *Madrepora oculata* has many forms. There are three different morphs or shapes in New Zealand waters. One morph has calyces that alternate sympodially on each side of thick branches in a flute-like regular orientation. The vibrant *Oculina virgosa* (Figure 32) are sparsely branched colonies with regularly arranged circular calyces. (Cairns 1995; Stephen D. Cairns Smithsonian Institution, Washington, USA, pers. comm.).

These corals occur in densities >15% cover (at the scale of m^2) and cover over areas 100s m^2 to a few km^2. Thickets can be identified by using direct sampling or, ideally, by imaging the seabed (MacDiarmid *et al*. 2013). Branching scleractinians are found across the whole region, although very few are seen on the Challenger Plateau. They are predominantly found at 800–1200 m depth (see Figure 31: where the depth range for the four most abundant reef-formers is shown), except for *G. dumosa* (200–600 m peak) and *O. virgosa* (0–200 m). While previously thought to be rare below 1600 m, several (particularly the commonly occurring *S. variabilis*) have been found in depths of 2000 m, below the ASH, on the Louisville Seamount Chain. The condition of coral thickets is variable based on past fishing impacts (Clark *et al*. 2018). Untrawled reef corals have complex habitat structure and provide good ecosystem services (e.g., Ghoul and Gothic Seamounts), in contrast to heavily trawled habitats which have lower complexity with poor ecosystem services (e.g., Morgue Seamount). Although no longer fished, the Morgue Seamount shows no signs of recovery, demonstrating a lack of recoverability on scales of decades.

Small patch reefs or thickets of scleractinian coral species (up to 600 m long, 20 m wide, and 3 m high) have been directly observed on many seamounts around New Zealand. *G. dumosa* forms more clump-like structures and is also abundant in shallower waters (e.g., on the top of the Chatham Rise at 400 m). This species is an important component of large localised reefs which reach up to 40 m in height and 700 m width, in water depths of 334 m, on the Campbell Plateau, (Mackay *et al*. 2014).

Specimens of stony coral have been collected from a wide range of locations within New Zealand waters and spatial distribution plots of the key scleractinian stony branching corals are shown in Figure 32 for *Oculina virgosa* and also see Chapter 7.

Modelled distribution likelihoods based on environmental relationships for the stony coral *S. variabilis*

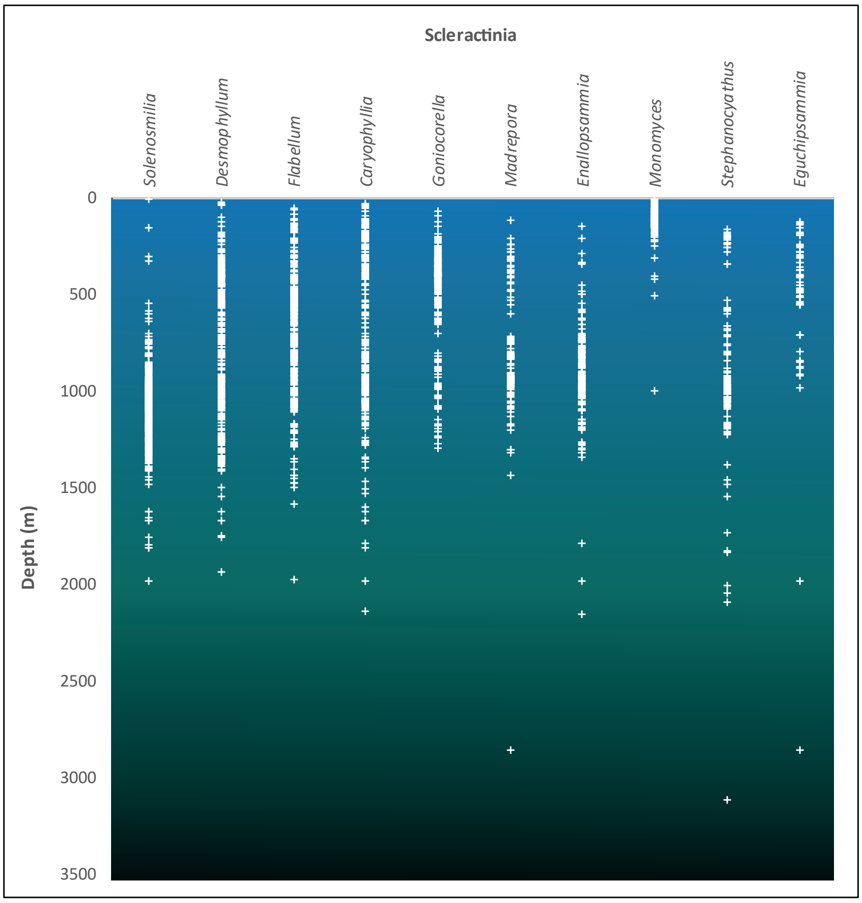


Figure 30: Depth distribution plot of the most abundant reef-forming and cup-like scleractinian stony corals.

are presented in (Chapters 7 and 10) of the report. These plots show where these corals occur and are predicted to occur throughout the region.

Biology

Endemism

No branching stony corals (Figure 31) found in the New Zealand region are endemic. From his recent work for the French National Museum of Natural History, Dr Marcelo Kitahara (Universidade de São Paulo) was able to confirm that the branching stony coral *Oculina virgosa* (Figure 32) that was previously thought as endemic to the region, is in fact found in other nearby parts of the Pacific.

Age and growth (see Section 1)

Reproduction

Burgess (2002) examined *Solenosmilia variabilis*, *Enallopsammia rostrata*, *Goniocorella dumosa*, and *Madrepora oculata* and determined them to be gonochoristic with broadcast spawning indicated by the synchronous presence of both male and female gametes, and fertilisation occurring in April/May which coincides with the end of summer biomass accumulation. Although only oocytes were observed in the samples of *G. dumosa* and *E. rostrata*, and male gonads in *M. oculata*, these species are also considered to be gonochoric.

There appeared to be a high degree of spawning synchrony between seamounts. In contrast, and highlighting the variability of deepsea coral fecundity and timing, *E. rostrata* found off Brazil and *M. oculata* in the North East Atlantic appear to have continuous reproduction (Pires *et al*. 2014, Waller *et al*. 2005) and the large size of oocytes suggests it produces lecithotrophic (yolk feeding) larvae (Rogers *et al*. 2007 and references therein). Burgess (2002) estimated high fecundities for *S. variabilis*, *E. rostrata*, and *G. dumosa* (but see Burgess & Babcock 2005 for a low fecundity estimate for *E. rostrata*).

Recent genetic studies of populations of *S. variabilis* on several seamounts off southern Tasmania, shows that their populations are genetically isolated, which suggests there are only low levels of larval dispersal among them, and that the corals are largely self-recruiting (Miller & Gunasekera 2017).

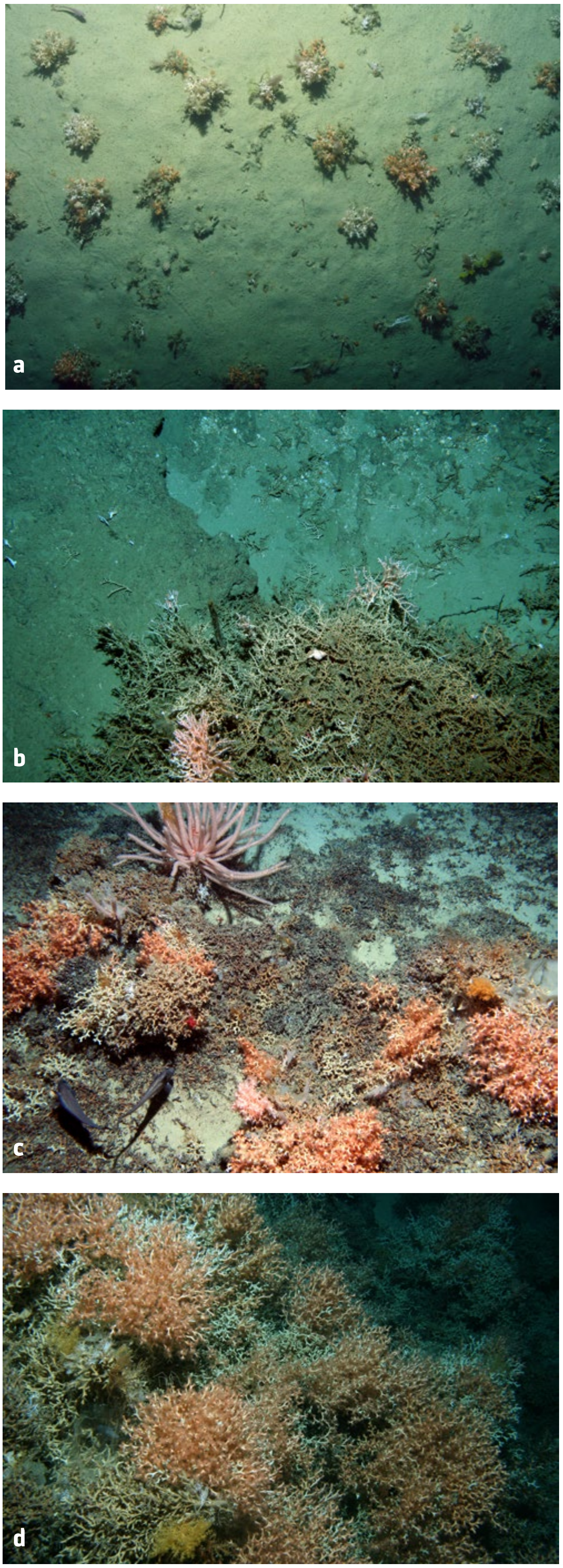


Figure 31: Examples of the branching scleractinian stony corals that form reef-like structures or thickets on hard substrata within the New Zealand region: (a) *Goniocorella dumosa* occurring in small clumps on hard substrate, Chatham Rise; (b) *Madrepora oculata* Chatham Rise; (c) and (d) *Solenosmilia variabilis* found on seamount summits and flanks, primarily on the Chatham Rise. (Images from NIWA DTIS towed-camera)

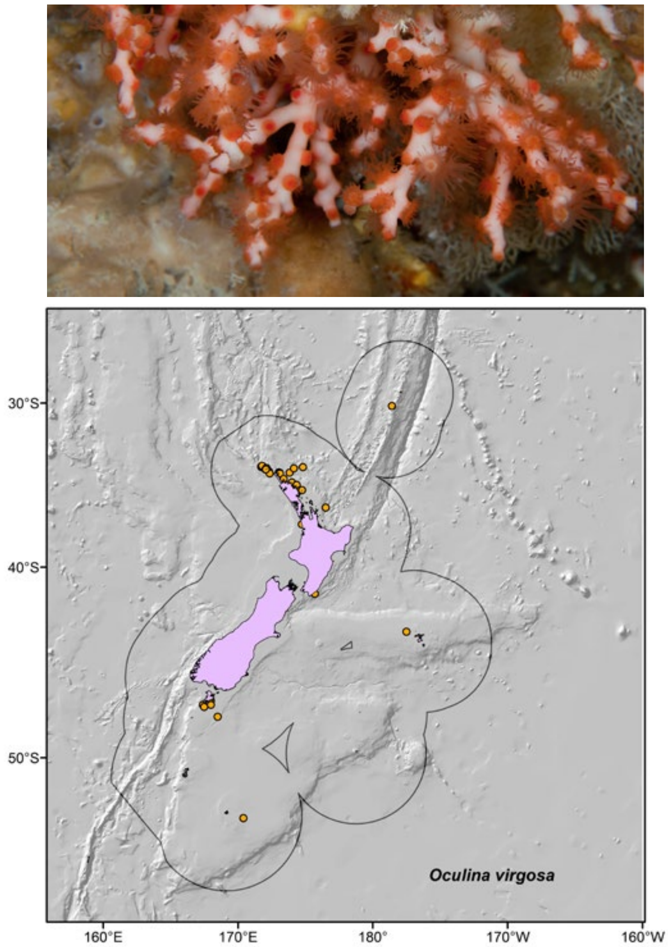


Figure 32: *Oculina virgosa* specimen (top) and known distribution (bottom). Published as supplementary material in Anderson *et al*. (2016).

Stony cup corals

Deep-sea scleractinian cup corals (Figure 33) occur as solitary individuals or in small clumps attached to hard substrate or living in areas of soft sediment. Those in regions of soft sediment are the *Flabellum* cup coral (Family Flabellidae), whose distribution covers regions of flat slope (Figure 34), as well as *Stephanocyathus platypus*. Other cup corals prefer hard substrate, such as *Desmophyllum dianthus* and members of the Family Caryophillidae.

Depth distribution data for the six most abundant cup coral genera *Desmophyllum*, *Flabellum*, *Caryophyllidae*, *Monomyces* (a shallow-water species), and *Eugichipsammia*, are shown in Figure 31.

Biology

Endemism (see Section 1)

Endemic species include various cup corals belonging to the genus *Flabellum*.

Age and growth

No age and growth data are available for New Zealand stony cup corals.

Reproduction

No New Zealand data available. There is some evidence for gonochorism in shallow *Desmophyllum dianthus* colonies in the Patagonian Fjords (Feehan 2016), although to date, this has not been confirmed for the New Zealand species. Congeneric

Figure 33: Common cup corals that occur in the New Zealand region include genera *Caryophyllia*, *Flabellum*, *Stepanocyathus*, and *Desmophlyllum*.

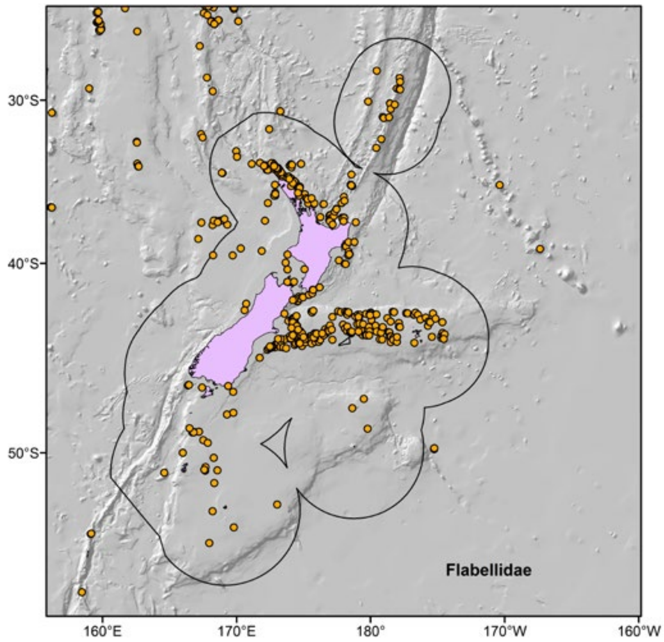


Figure 34: Distribution map of cup coral Family Flabellidae. Published as supplementary material in Anderson *et al*. (2016).

species can vary their strategy from spawning to brooding depending upon their habitat; e.g., North East Atlantic *Flabellum* spp. are spawners, whereas Antarctic representatives are brooders (Waller *et al*. 2008).

Shallow-water hermatypic corals

Shallow-water coral groups belonging to genera such as *Turbinaria* and *Pocillopora*, in the Kermadec Islands area are listed in Appendix 1. The genus *Monomyces* (Figure 35), along with other cup corals have been collected at diving depths (Figure 31).

The hermatypic coral fauna of New Zealand are largely restricted to the Kermadec/Rangitāhua archipelago. Unlike the azooxanthellate deep-sea corals, hermatypic shallow-water corals form a symbiotic relationship with a group of single-celled dinoflagellates called zooxanthellae. Zooxanthellae live within the tissues of the cnidarian host and contribute nutrients to the symbiosis as a product of photosynthesis.

Although there is evidence for historical and contemporary reef-building by shallow-water hermatypic corals at Rangitāhua, the coral communities typically consist of individual colonies and have inconsistent reef formation (Brooks 1999; J.D. Aguirre pers. obs.). Nevertheless, in some parts of the archipelago, and in particular locations around Raoul Island, live coral can cover 90–100% of the available substrate (at a scale of 10's of m^2). More generally however, coral cover on hard substrates at the Raoul Island group is 10–15%, with species diversity and cover declining rapidly from north to south along the archipelago, resulting in <1% cover and only one species present (*Montipora spongodes*) at L'Esperance rock (Brook 1999, Aguirre & Liggins *unpub*. data). Furthermore, preliminary analyses suggest that coral cover has remained stable over the past 30 years around Raoul Island (Brooks 1999, Wicks *et al*. 2010a, Aguirre & Liggins *unpub*. data).

New Zealand's shallow-water reef-building coral fauna is comprised of at least 11 species (Richards & Liggins 2015) and perhaps as many as 24 species with ongoing morphological and molecular work aiming to refine a clearer understanding of this group. The coral community at Rangitāhua is strongly depth stratified with species such as *Pocillopora damnicornis* dominating shallow habitats (0–10m) around Raoul, Macaulay and Cheeseman Islands, whereas species such as *Turbinaria frondens* are most common in habitats deeper than 15m around Raoul and Macaulay Islands (Brook 1999, Schiel *et al*. 1999, Aguirre & Liggins *unpub*. data). Ongoing research suggests that in addition to zonation at the species-level, there is evidence for coordinated morphological changes within species that allow individuals to cope with decreasing amounts of light in deeper habitats (Aguirre & Liggins *unpub*. data). At a regional scale, the species composition of New Zealand's reef-building coral communities most closely resembles those of coastal southeast Australia rather than other high-latitude islands such as Lord Howe Island (Wicks *et al*. 2010a). Moreover, the diversity of zooxanthellae present in corals inhabiting Rangitāhua display high diversity and endemism compared with coral communities on the Great Barrier Reef (Wicks *et al*. 2010b).

Figure 35: Shallow-water colonial stony coral *Tubinaria* (Family Dendrophylliidae), Kermadec Region. (Malcolm Francis NIWA). Members of this genus of hermatypic (reef-building) corals can form massive structures.

Antipatharia (black corals)

Black corals (Cnidaria: Anthozoa: Hexacorallia: Antipatharia)

Black corals (Order Antipatharia) are a predominantly deep-water group with (~75% of the 247 currently recognized species occurring at depths >50 m (Opresko *et al*. 2014). They are an abundant and diverse, widely distributed group (Figures 36 and 39), found in the region's cold-water fjords as well as throughout the EEZ from shallow-waters down to over 2000 m depth (Figure 37). The group is CITES listed and during the last DOC threat classification round only three genera/species of black coral were listed as naturally uncommon, or data deficient (Freeman *et al*. 2014). There are 78 species in the region, of which seven have recently been described as new to science (Opresko *et al*. 2014; Opresko 2016). Several species are endemic to the region, additional new species are yet to be described.

Black corals are generally found in deeper waters between 200 and 1000 m (see plot page 66) and mostly attached to rock substrates, but there are exceptions where divers can observe them at 40 m on reefs in northern New Zealand. Or as shallow as 10 m at Fiordland and even shallower in Port Pegasus (Stewart Island / Rakiura). They generate relevant 3-D structure in deep waters, which is useful for several species of snake star that can be found living in association, entwined on the branches of black corals (Grange 1990).

Black corals have various forms (Figures 38). Several are distinguished by their erect, often bushy, "tree-like" habit of growth. These colonies can vary in size, some with heights exceeding 1–2 metres (e.g., *Bathypathes* black coral, respectively). Black coral groups can occur closely spaced or clustered in densities of >10% cover (at the scale of m^2) over areas of 100s m^2; other times the colonies are more dispersed and solitary-like in their distribution, e.g., Bathypathes.

There are concerns about increasing sea temperatures affecting the black corals, some habitats may be too warm for them to thrive in. However, black corals have a proteinaceous skeleton (chitin) so they may not be at such threat from increasing ocean acidification. Areas where deep-sea coral species are at highest risk of interactions with commercial fishing gear have been identified and mapped, and the most likely coral distributions determined via predictive models are presented.

There are several seamount features amongst the Graveyard Hills on the North Chatham Rise that have now been closed to future bottom trawling. In shallower regions, there are 10 marine reserves within waters adjacent to Fiordland National Park where fishing and the anchoring of vessels is prohibited. Nevertheless, we are still lacking basic knowledge of their biology (diet, growth and reproduction), and how these factors affect and recover from human impacts.

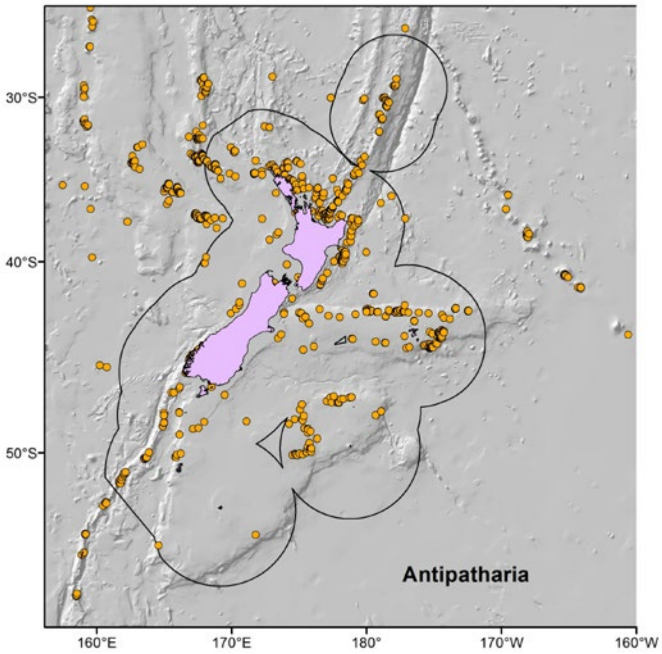


Figure 36: Distribution map of black coral group *Antipatharia*. Published as supplementary material in Anderson *et al*. (2016).

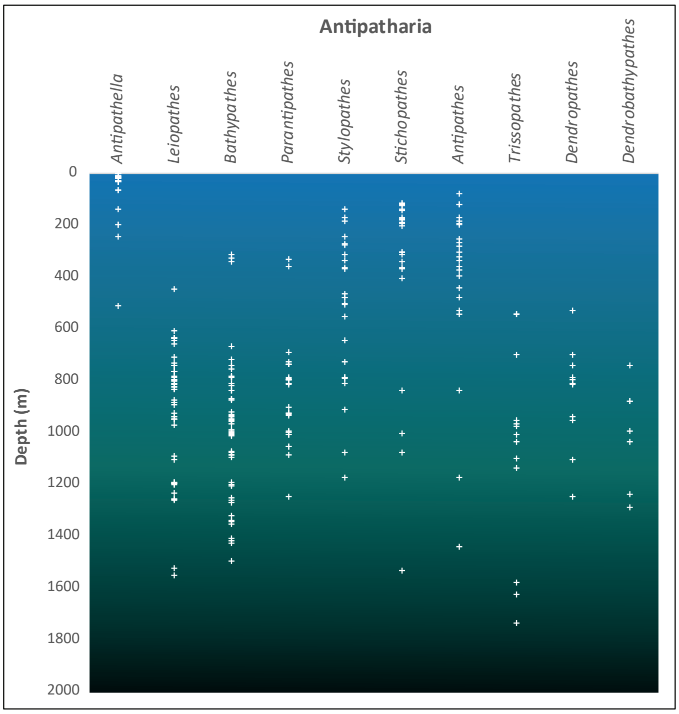


Figure 37: Depth distribution of the ten most abundant black coral genera.

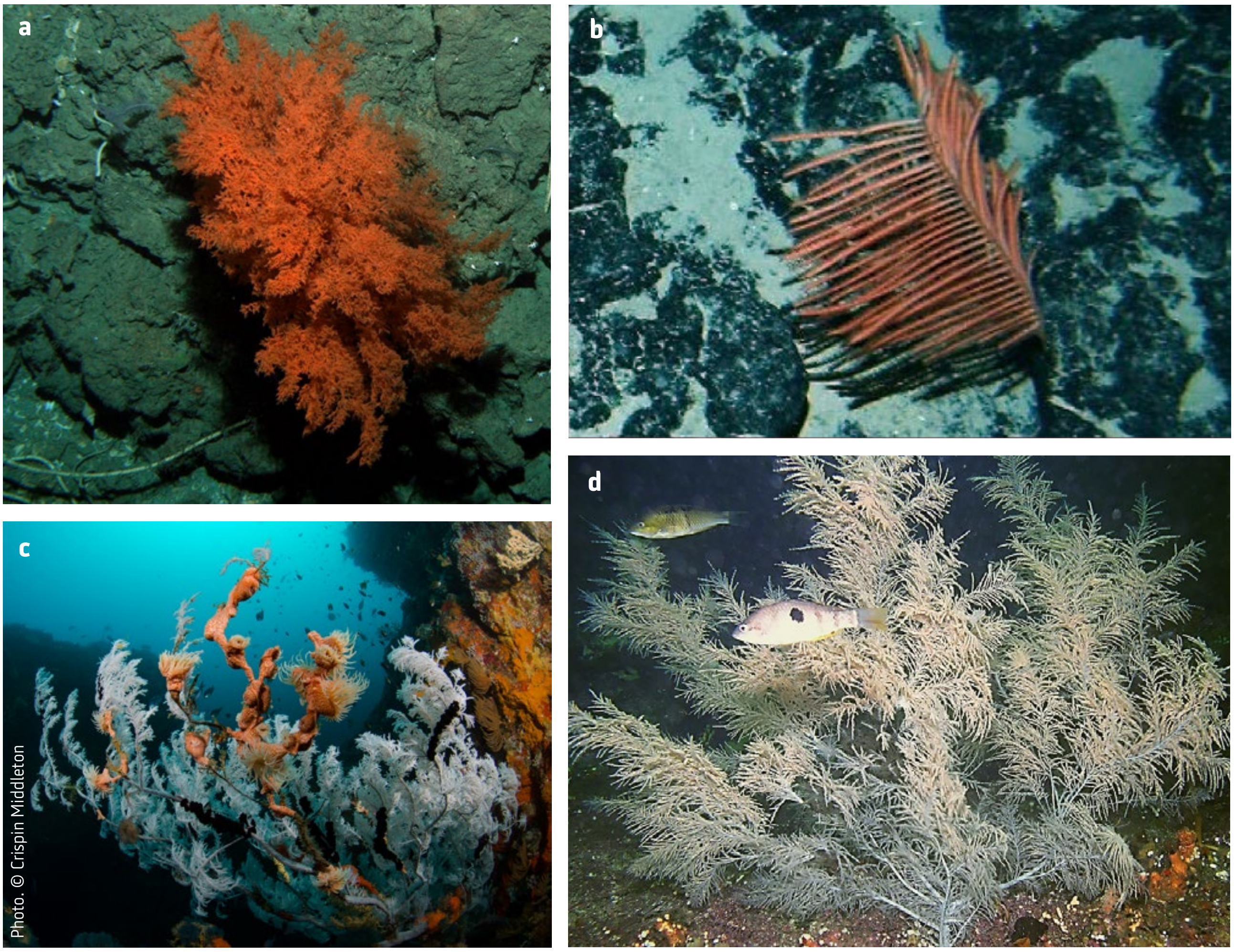


Figure 38: (a) Bushy tree-like *Dendrobathypathes* sp. black coral with a deep-sea scorpion fish in 880m depth off the Wairarapa coast. (b) Uni-planar tree-like black coral *Bathypathes* spp. (c) Black coral colony with invertebrate associates; Poor Knights Islands, Northland, NZ; Photo credit – Crispin Middleton. (d) Tree-like black coral *Antipathella* spp., Fiordland, with Spotties (*Notolabrus celidotus*). (Images NIWA DTIS towed-camera; bottom left image provided by Crispin Middleton: bottom right image provided by Sean Handley, both of NIWA).

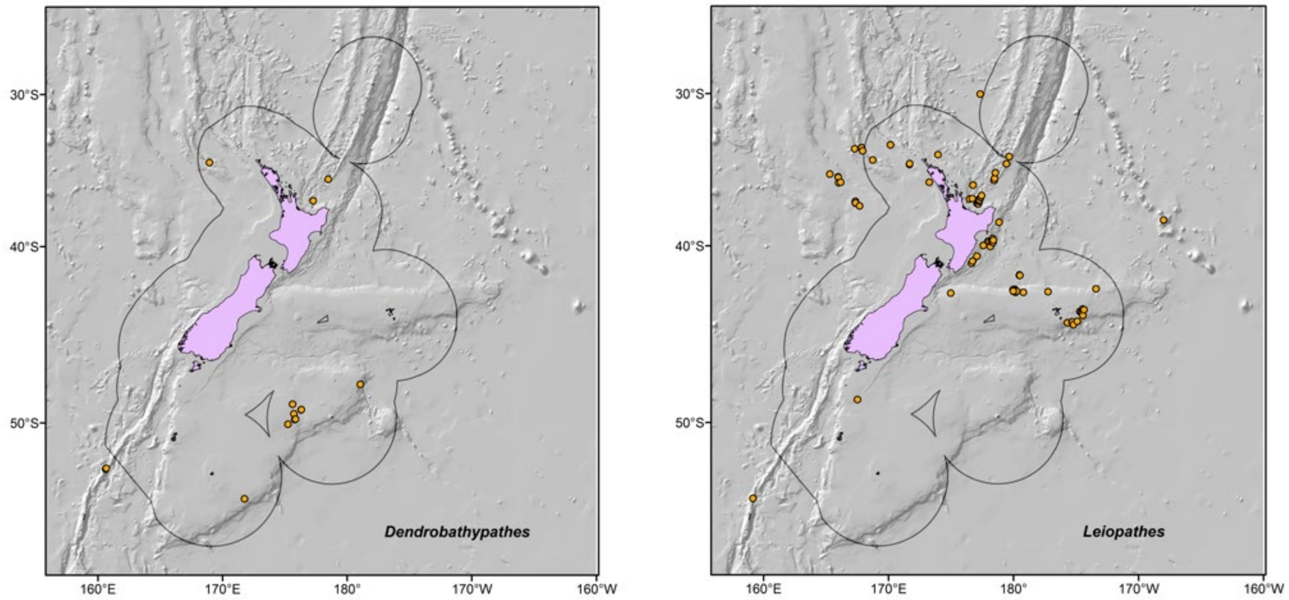


Figure 39: Distribution map of key black coral genera *Dendrobathypathes* (L); *Leiopathes* (R). Published as supplementary material in Anderson *et al*. (2016).

Biology

Endemism (see Section 1)

It is difficult to identify true New Zealand endemics at this stage because so few adjacent regions have been surveyed as extensively. If we consider, however, most of the new species currently being described in Opresko (submitted) and Opresko *et al*. (submitted) as endemics then there are about 20 "endemic" species and one "endemic" genus in the New Zealand region, with the total number of black coral species being around 80 (Dennis Opresko pers. comm).

Age and growth (Section 1 presents age and growth data for some key black coral species)

In summary, radiocarbon dating of large deep-sea black coral species found in New Zealand waters indicates ages of well over 1000 years. Growth rates vary depending on the species from around 8 to 40.0 µm/yr (see Hitt *et al*. in press). Long life-spans have also been determined for shallow (fiord) cold water black coral *Antipathella fiordensis* (Grange & Singleton 1988; Grange & Goldberg 1993; Hitt *et al*. in press). As coral structures are often fragile and long-lived, with recovery time appearing to be very slow, they are vulnerable to physical disturbances such as from fishing, mineral exploration but also natural oceanographic process and geological activity from storms and undersea mudslides. In shallower water, black corals are vulnerable to damage by anchors, droplines, scuba divers and rock lobster pots.

Reproduction

Very little is understood about reproduction in deep-sea black corals, especially reproductive seasonality. Miller's (1996) study of the shallow Fiordland black coral *Antipathes fiordensis* found it to be gonochoristic and reproduce once a year (most likely simultaneously spawning towards the end of summer).

Observations on black coral larvae have demonstrated that they can be lecithotrophic (yolk feeding), are negatively buoyant, phototactic (i.e., they sink and move away from light), and are poor swimmers. However, these observations relate to shallow-water species or areas beyond New Zealand and potentially do not reflect behaviour of deeper black corals. It is thought that *Bathypathes patula*, like most black corals, is gonochoristic, which explains philopatric settlement (i.e., back to their natal area) and limited dispersal (Brugler *et al*. 2013 and references therein, Wagner *et al*. 2011). Miller (1997; 1998) reported *A. fiordensis* to have a restricted larval dispersal with larvae being negatively buoyant, weak swimming and short-lived (Parker *et al*. 1997).

A NIWA Biodiversity memoir and papers describing the region's black corals are being prepared (Opresko *et al*. (submitted); Opresko (in prep.)). The Memoir will consider recent systematic results (e.g., by Brugler in prep.) and include a revision of the genera *Stichopathes* and *Cirrhipathes* (Bo in prep.) and a revision of the genus *Bathypathes* (Molodtsova in prep.). There are also possible future nomenclatural changes to all but one of the species of the genus *Antipathes*.

Figure 40: Growth zones on black coral *Bathypathes patula* (left). Large Antipatharian black coral in situ (right).

Octocorallia (Octocorals/ Gorgonian sea fans)

Octocorals (Order Alcyonacea) are a common group found in the New Zealand region, with over 250 species (~ 200 are undescribed) divided among 103 genera in 28 families (Daly *et al*. 2007). The families Acanthogorgiidae, Plexauridae, Primnoidae, Isididae, Chrysogorgiidae and Paragorgiidae are well represented in the region's deepsea. Where they are most common at depths of 1500 m or more (see depth figure to the right Figure 41). The diversity of three families of deep-sea calcified gorgonians (Isididae and Keratoisidinae. – bamboo corals, Primnoidae – bottle-brush and tree-like corals, and Chrysogorgiidae – golden corals) is probably the highest in the world for a single country (Sanchez & Rowden 2006).

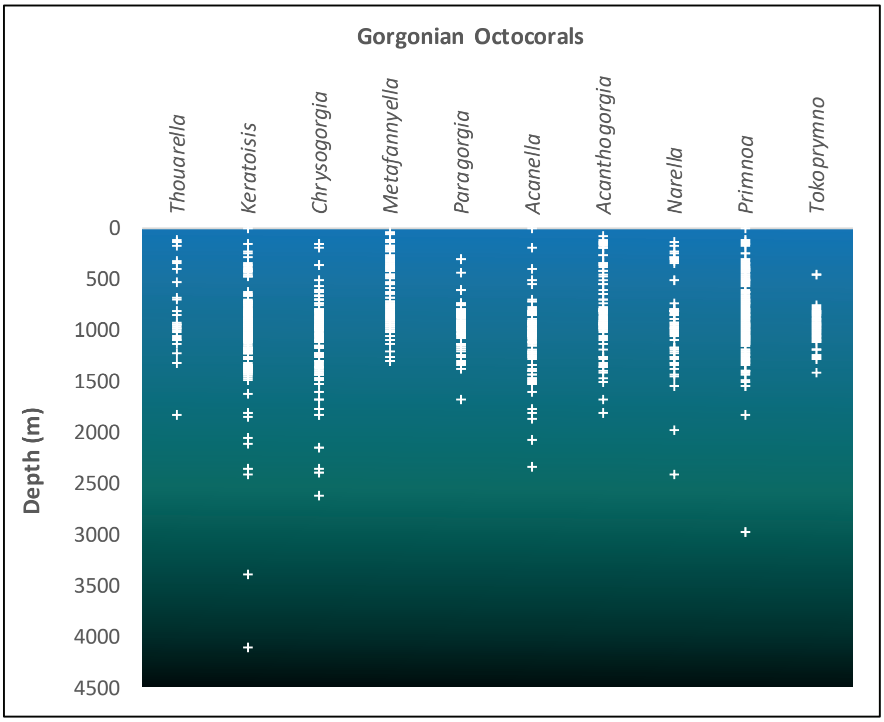


Figure 41: Depth distribution of commonly occurring gorgonian octocorals.

Habitat-forming gorgonian octocorals are distinguished by their erect, often bushy, "tree-like" habit of growth (Figures 43). These colonies can vary in size, some with heights exceeding 1–2 metres (e.g., *Paragorgia* spp.–the charismatic bubblegum corals) (Figure 43). Other common arborescent groups are species in the Primnoidae and Plexauridae (Figure 43), and Isididae, the bamboo corals, however some of these corals can also have an unbranched, whip-like form (Figure 42). Several octocorals form low bushy structures (e.g., some primnoid *Thouarella* spp. and the rasta coral *Narella* spp. (Figure 31c).

Gorgonian corals are also commonly observed as mono-specific or mixed assemblages of deep-sea habitat-forming coral colonies that are clustered in densities of >10% cover (at the scale of m^2) over areas of 100s m^2; other times the colonies are more dispersed and solitary-like in their distribution.

Biology

Endemism (see Section 1)

The endemic octocoral *Taiaroa tauhou,* is the only octocoral that lives as a single, solitary polyp (Bayer & Muzik, 1976). Several species of the bubblegum corals *Paragorgia* spp. (Figure 43), are endemic. Sánchez (2005) identified eight endemic bubblegum corals (*Paragorgia alisonae, P. aotearoa, P. kaupeka, P. maunga, P. wahine, P. whero, Sibogagorgia dennisgordoni*, and *S. tautahi*). Several of these bubblegum coral species are familiar as observed bycatch fauna.

Figure 42: Whip like unbranched octocoral form Primnoidae *Primnoella*

Age and growth (see Section 1)

Age and growth data are available for one New Zealand gorgonian octocoral the bubblegum coral *P. arborea* and for bamboo coral species *Keratoisis* and *Lepidisis*.

Reproduction

Some gorgonian octocorals such as primnoids are gonochoric brooders, possibly with an asynchronous reproductive cycle. Brooding, in which larval maturation occurs within a coral polyp, has been observed in samples of the New Zealand primnoid octocoral *Tokoprymno* (Susana Soto de Matos-Pita, pers. comm and Cairns (submitted) describes many members of the Primnoidae *Thouarella*, *Metafannyella*, *Dasystenella*, as gonochoric brooders). Although no reproductive study has been conducted on other New Zealand gorgonians, research on congeners from elsewhere in the Pacific indicate that seasonal gonochorism is likely to be prevalent (e.g., Feehan & Waller 2015). Recent work by Fountain *et al*. (2019), also described a West Atlantic species of the plexaurid *Paramuricea* as gonochoristic.

Little is known of the reproductive biology of the deep-sea gorgonian octocoral bamboo coral group Isididae: Keratoisidinae. There may be fewer physiochemical barriers to dispersal for this group in the deep sea (Grigg & Bayer 1976; Marsh *et al*. 2001) and the larvae may remain viable for extended periods e.g., 100 days is calculated for dispersal from the central to eastern Pacific (Richmond 1987). However, these discussions are based on the genetic analyses of Smith *et al*. (2004), who also discuss that the mitochondrial gene regions used to reach this conclusion may have been insensitive to recent speciation events.

In this Chapter we describe Families Primnoidae and Plexauridae. Regional distribution maps for the key gorgonian octocoral species *Primnoa*, *Keratoisis*, and *Paragorgia*, and Family Plexauridae are shown (Figure 44).

Primnoidae

Within the New Zealand region the primnoid fauna is diverse and widespread (Cairns *et al*. 2009; Cairns 2012; 2016; Anderson *et al*. 2014, 2015). It is difficult to draw conclusions about the general biology, growth rates, age, reproduction, colonisation and dispersal strategies of New Zealand primnoids from overseas studies because biological data are poor globally. However, studies on species of *Primnoa* indicate considerable longevity (Andrews *et al*. 2002; Risk *et al*. 2002; Mortensen & Buhl-Mortensen 2004), and it can be assumed that the New Zealand taxa would also be long-lived and follow the general reproductive and dispersal trends known for the group. Some primnoids are gonochoric brooders, possibly with an asynchronous reproductive cycle. We also know that brittle star colonies and polychaetes are found in commensal relationships with some primnoid genera.

Water chemistry and carbonate mineralogy of corals have a strong influence on the distribution of these organisms. Thresher *et al*. (2015) showed that Primnoidae in the South Pacific region may be bimineralic with different carbonate levels and solubility. Some Primnoidae have predominantly high magnesium (Mg) calcite (HMC) and others are predominantly aragonitic. Aragonite is 50% more soluble than low Mg calcite (LMC), while HMC has equal or greater solubility than aragonite. The mineralogy of *Primnoa notialis* (Cairns & Bayer, 2005), has been studied in detail in New Zealand; it too is a bimineralic species but with a skeleton made up of a number of different layers of both aragonite and Mg calcite (Bostock *et al*. 2015).

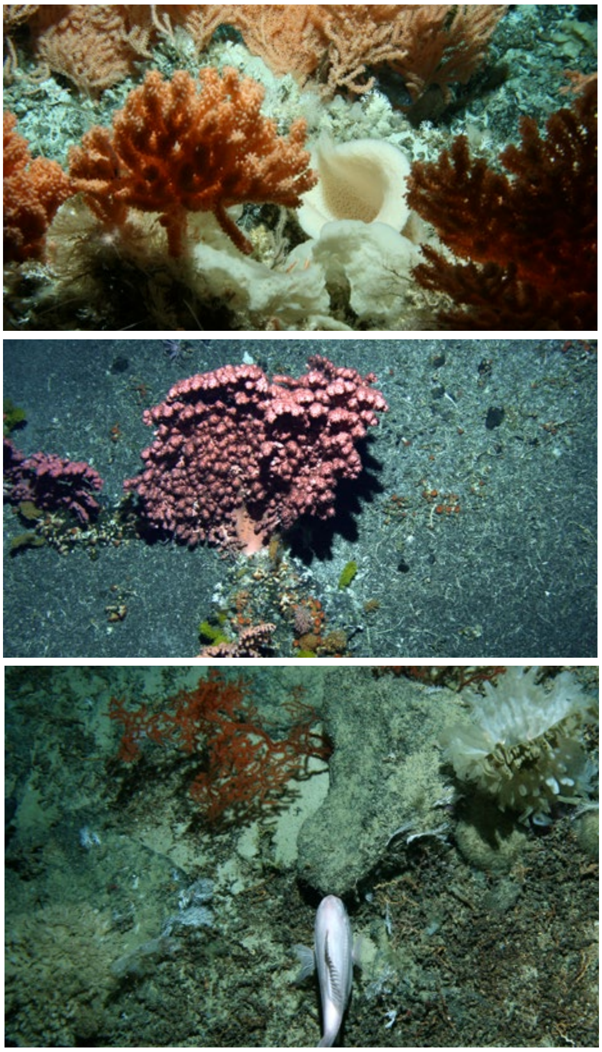


Figure 43: Dense community of the bright orange sea fan *Primnoa notialis* (top); A large tree-like colony of *Paragorgia* bubblegum coral, nested at the base are small bushy forms of the octocoral *Thouarella* spp., (middle); Red form of plexaurid coral (bottom). (Images, NIWA DTIS towed-camera).

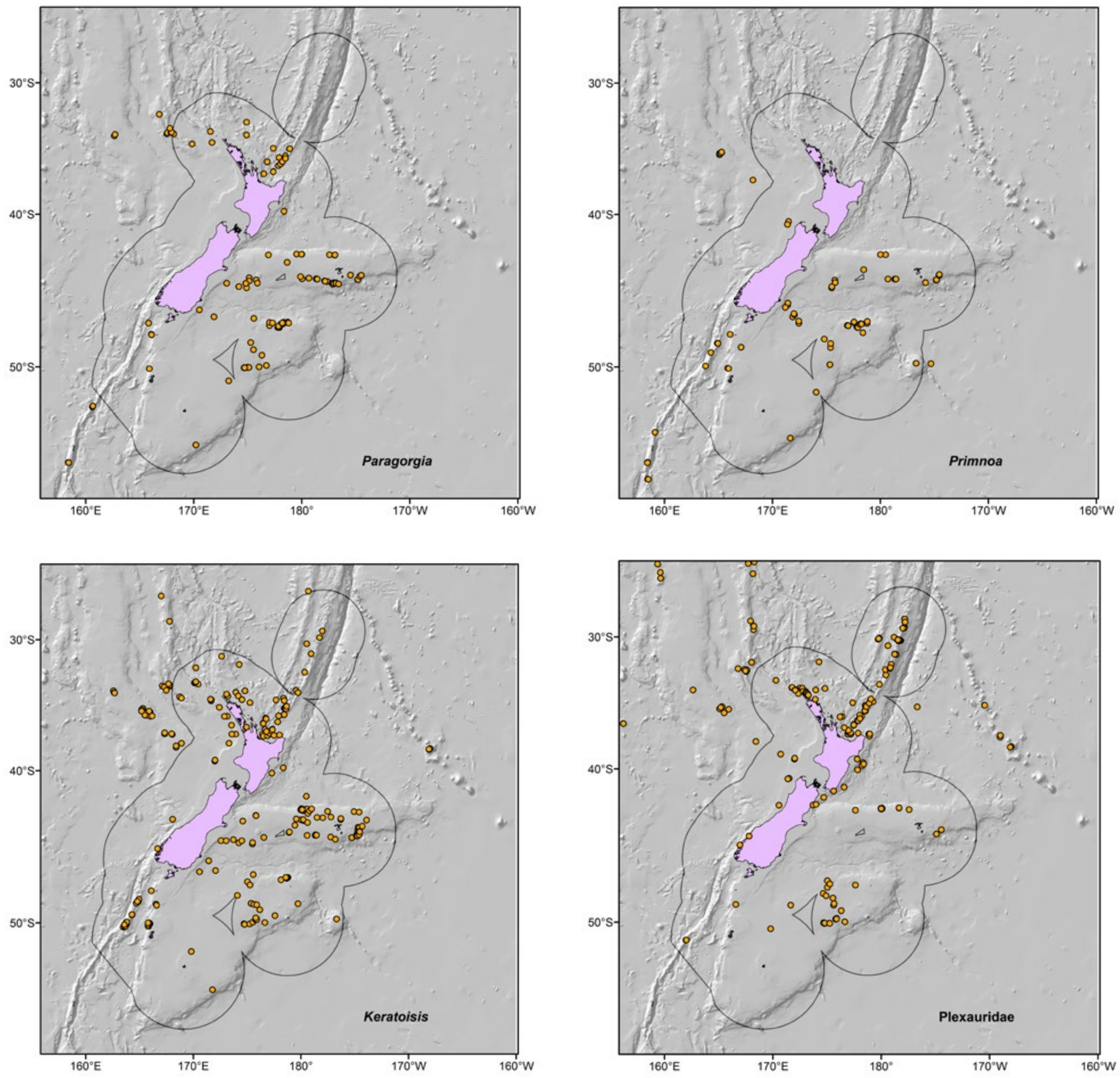


Figure 44: Distribution maps for key gorgonian octocorals located in the New Zealand region. Top L to R: Bubblegum coral *Paragorgia* and sea fan *Primnoa*. Bottom L to R: Bamboo coral *Keratoisis* and Family Plexauridae. Published as supplementary material in Anderson *et al*. (2016).

Plexauridae

The Plexauridae are a diverse and cosmopolitan family of gorgonian octocorals, with 365 species in 38 genera that are distributed from shallow tropical reefs to deepseas and polar oceans (Daly *et al*. 2007). Compared to the tropical shallow-water contingent, deep-sea plexaurids have received lesser attention worldwide – presumably due to discrepancies in their systematics and taxonomy, a lack of breadth and representation in regional specimen collections, high levels of intraspecific variation and their often conservative appearance – all of which combine to make their identification difficult and subjective.

The New Zealand Plexauridae have been recorded from near-shore to the deep-sea. They are recognisable as highly branched, fan-shaped colonies with a beige, red, (Figure 43), brown or brown or black woody axis underneath variously coloured outer tissue layers. However, their outward appearance is easily confused with members of the Acanthogorgiidae, Isididae and Primnoidae, which also include seafan forms. Thus, reliable identification to genus-level requires close examination of specimens and can rarely be accomplished based on video or photographic records alone. These challenges have resulted in a poorly described plexaurid fauna for New Zealand. There has been only one published account of plexaurid genera known from the region (Cairns *et al*. 2004; repeated in Sanchez & Rowden 2006 and Consalvey *et al*. 2006), which lists a single species (*Paracis squamata* (Nutting, 1910)). The number of reported genera has changed over time, and numbers 14 in a recent review of material in the NIWA invertebrate collection (J. Bilewitch, *unpubl.* data). With further consideration it is likely that a number of endemic plexaurid species will be identified in New Zealand. However, a revision of the genera is needed to establish at which taxonomic level the New Zealand fauna share similarites with other Pacific plexaurids.

Biology

Endemism Unknown

Age and growth

No age and growth data are available for New Zealand. Given the dearth of basic understanding of their diversity at genus and species levels, it is not surprising that few studies of basic biological parameters have been attempted on the deep-sea plexaurids, and none have been done in New Zealand (see Watling *et al*. 2011).

Reproduction

No data are available for New Zealand. The reproductive biology of seven *Swiftia* spp. have been studied in the Eastern Pacific by Feehan & Waller (2015), who found all to be gonochoric with seasonal broadcast spawning as the most likely mode of reproduction. However, their study examined no more than five specimens for any species of *Swiftia* – in some cases only a single individual was available from museum collections. Two species of Mediterranean *Paramuricea* have been documented for reproductive characteristics and both (Mokhtar-Jamai *et al*. 2013; Grinyo *et al*. 2018); were found to be surface brooders with limited dispersal abilities.

More recent work by Fountain *et al*. (2019), looked at the reproduction of the *Paramuricea* in the Atlantic, and identified them as gonochoristic. Their reproductive potential was described based on the relationship between colony morphology and reproductive output and using height as a predictive proxy. Although *Paramuricea* also occurs in the deep sea, extrapolations from these studies to New Zealand species should be avoided since other studies have demonstrated that gorgonian congeners in the Mediterranean and Pacific regions are actually distantly related and often need reclassification into separate genera (see Bilewitch *et al*. 2014 for an example from the Ellisellidae). The only deep-sea plexaurid genus for which reproductive biology has been examined was a species of *Spinimuricea*, but the study was conducted on an unusual shallow-water population—again in the Mediterranean.

Class Hydrozoa – hydroids and hydromedusae Order Anthoathecata – (Stylasteridae: stylasterids, lace corals)

Stylasteridae (Hydrocorals)

Stylasterid hydrocorals are the hard-coral form of hydrozoans. Their skeletons are distinguished from those of stony corals by being generally much smaller and less robust, minutely porous and pitted with small holes for the polyps. Several species are found throughout the region, the common pink endemic hydrocoral species, the red *Errina novaezelandiae* (Figure 45), occurs in the west coast cold-water fiords as well as throughout the region in deeper waters, and in the Ross Sea (Figure 46). White hydrocoral colonies include *Stylaster* and *Lepidotheca* (Figure 45).

Spatial distribution maps are also shown in Figure 46 for all Stylasterid hydrocorals and the common hydrocoral *Stylaster euguchii*.

Depth range plot for the ten most abundant stylasterid hydrocoral genera is shown in Figure 46.

Biology

Endemism (see Section 1)

Errina novaezelandiae a common hydrocoral species is endemic to the region.

Age and growth

No age and growth data are available for New Zealand hydrocorals.

Reproduction

Stylasterid hydrocorals: The red coral *Errina novaezelandiae* has been determined to be dioecious with male and female gametes developing in the skeletal cavities and internal fertilisation.

Brooded planulae are hypothesised to crawl on the surface of adults before settling on the substrate below (P. Stratford, pers. comm. to Miller *et al*.

Figure 45: Stylasterid hydrocoral *Errina* colonised by zoanthid anemones (left); White hydrocoral (right).

2004). *E. novaezelandiae* recruitment may be variable in space and time (Underwood & Fairweather, 1989; Miller *et al*. 2004).

Miller *et al*. (2004) speculated that the limited connectivity between fiords has implications for population subdivisions and this argument may also hold true in certain deep-sea habitats, such as seamounts where there may be limited opportunities for long-distance dispersal. New Zealand may represent an adaptive radiation centre of *Errina* species (Cairns 1991). The Fiordic red corals may be satellite populations, and their degree connectivity with the deep sea is unknown.

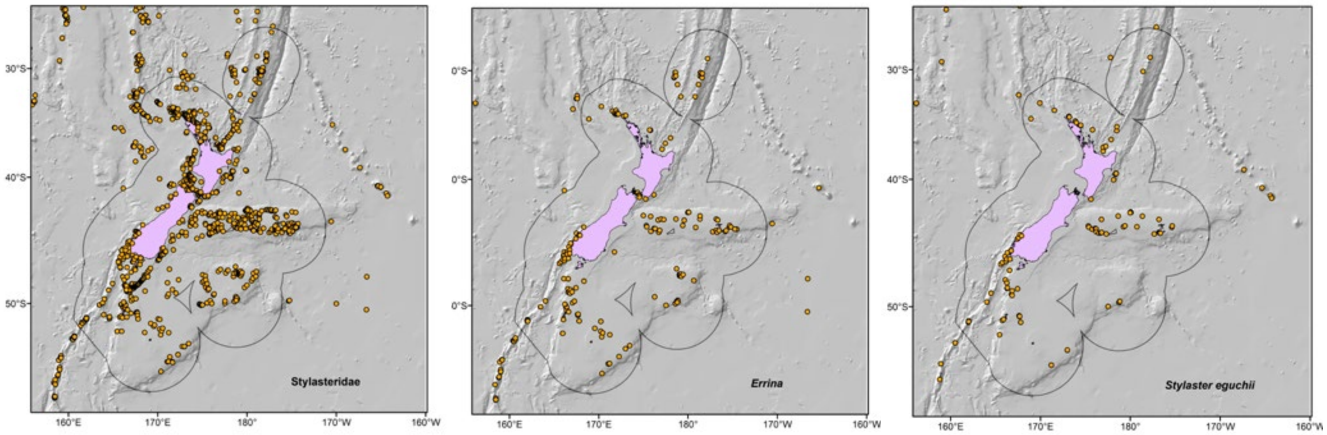


Figure 46: Distribution map of all Stylasteridae hydrocorals (left), and most common species *Errina novaezelandiae* (middle), and *Stylaster eguchii* (right). Published as supplementary material in Anderson *et al*. (2016).

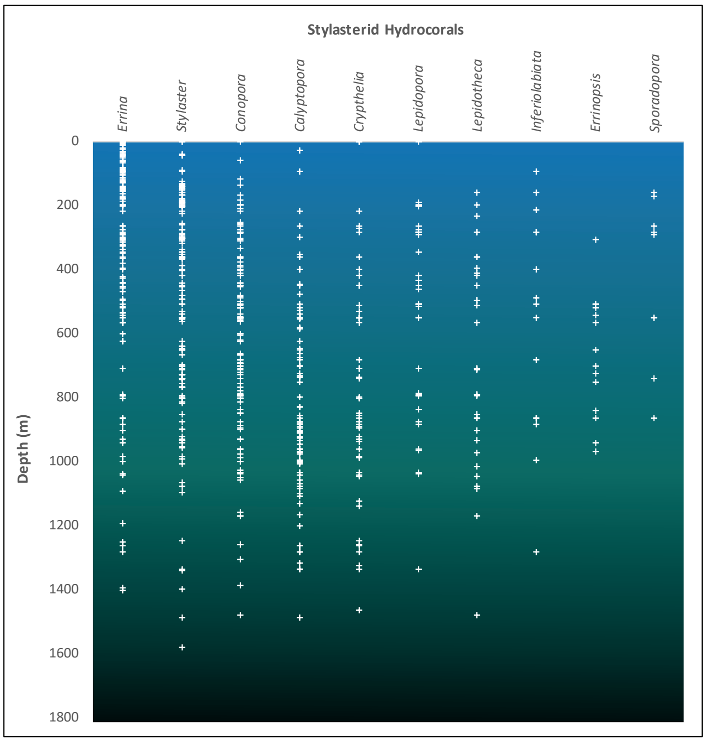


Figure 47: Depth range plot for the ten most abundant stylasterid hydrocoral genera.

Although they are not protected groups of corals, descriptions of soft coral and sea pens are provided in the following two sections, for completeness.

Soft corals

True soft corals form part of the diverse Order Alcyonacea, to which gorgonian octocorals also belong. Unlike most gorgonian octocorals, soft corals lack a skeletal axis. While soft corals, along with sea pens, are not protected fauna in New Zealand waters, they are an ecologically significant component of benthic marine communities since they often occupy a high proportion of the available substratum or are attached to other invertebrates including corals (see Figure 48).

Knowledge of the distribution or ecology of New Zealand's shallow-water soft corals and species-level taxonomy is particularly poor. However, they are an abundant and widespread group of Cnidarians, found from shallow-waters down to the deep sea (to max depths of over 1300 m) (Figure 49). The key soft coral fauna comprise three forms: the monospecific Protoalcyonaria where the polyps are solitary; Stolonifera where the polyps

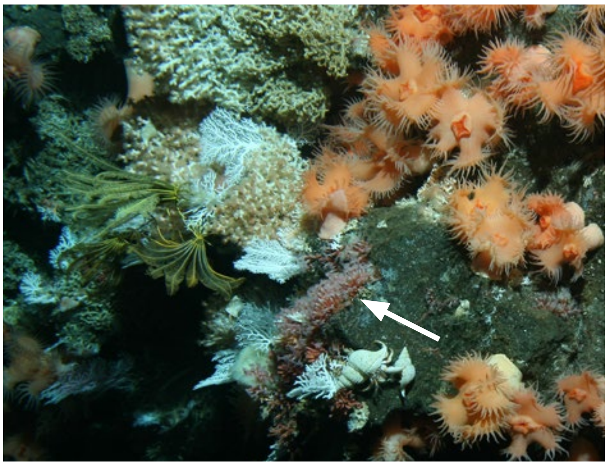


Figure 48: Red soft coral, *Rhodelinda* spp. attached to rock. (NIWA DTIS Image).

are basally connected by stolons or membranes, and Alcyoniina where the polyps are embedded in coenenchymal tissue that forms a fleshy mass. Appendix 1 highlights the diversity of the region's soft corals. Growth data are only available for tropical settings and soft corals are extremely diverse in terms of their reproductive methods with five completely different strategies observed for the genus *Alcyonium* alone.

Shallow-water soft corals

Eight genera have been identified at depths of <50 m: *Clavularia*, *Telesto*; *Alcyonium*, *Cladiella*, *Dendronephthya*, *Sarcophyton*, *Capnella* and *Efflatounaria*, with the latter 5 genera confined to the subtropical Kermadec region (Duffy & Ahyong 2015). Only two species have so far been described for New Zealand (Cairns, 2009).

Biology

Endemism

The most common shallow-living soft coral in New Zealand is the endemic and highly variable *Alcyonium aurantiacum*. Also known as "deadman's fingers", (Figure 50) these corals are currently the subject of taxonomic revision. Morphological and genetic data indicate that they comprise a complex of at least four endemic species that may warrant the erection of a new, endemic genus (Kessel *et al*. in prep.).

Age and growth

No data available for the region

Reproduction

No data available for the region

Figure 50: *Alcyonium aurantiacum,* also known as "deadman's fingers" (Image G Kessel, NIWA, VUW).

Deep-sea soft corals

In deeper waters, soft corals such as *Bathyalcyon robustum* (previously referred to as *Anthomastus robustus*), and members of the family Ifalukelidae commonly occur. The deep-sea fauna also comprise three key forms: Protoalcyonaria that displays solitary (i.e., not colonial) polyps. This particular form is represented in the New Zealand region by the endemic *Taiaroa tauhou*, found widespread on soft sediment on the Chatham Rise (Compton et al. 2013), and the only extant Octocoral to grow as a solitary polyp; the Stolonifera which has individual tubular polyps arising separately from, but connected by, ribbon-like stolons e.g., *Rhodelinda* spp.; and the fleshy or branched colony form of Alcyoniina that comprise many polyps e.g., *Heteropolypus* spp. (see Figure 51 from Tracey et al. 2014).

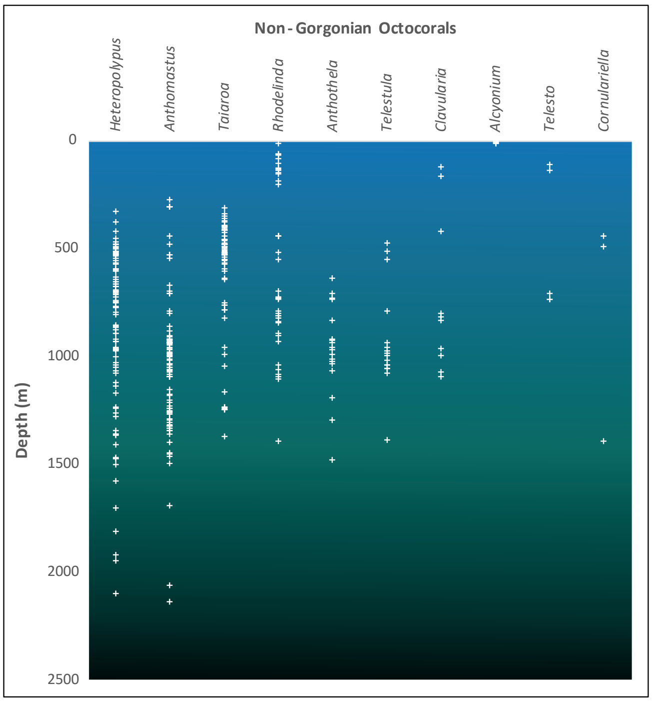


Figure 49: Depth distribution of the most commonly occurring soft corals.

Biology

Endemism

No data available for the region

Age and growth

No data available for the region. Cordes *et al*. (2001) determined the *Anthomastus ritteri* corals from the Pacific to reach asymptote size after 25 – 30 years, agreeing with the theory that deep-sea species are slower growing and longer lived than shallow-water species.

Reproduction

The deep-sea Pacific coral *Anthomastus ritteri* has been determined to be gonochoristic, larval brooders that can continuously reproduce. Once larvae are released, they are determined to be capable of settlement after two days (Cordes *et al*. 2001).

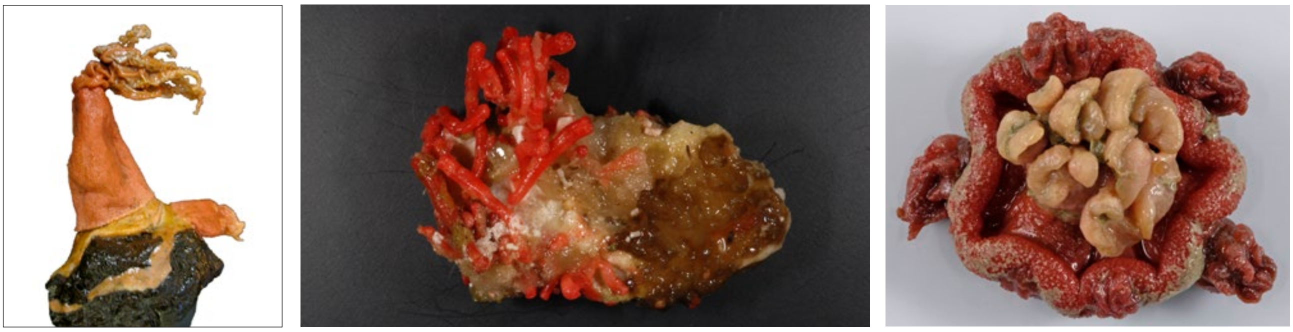


Figure 51: L to R: *Bathyalcyon robustum*, *Rhodelinda* spp., *Heteropolypus* spp. (NIWA images from Tracey *et al*. 2014). Top image is *Anthomastus* in situ.

Sea pens

Sea pens are colonial marine cnidarians belonging to the octocoral group Octocorallia Order Pennatulacea. They are classified as Vulnerable Marine Ecosystem (VME) species but unlike hard corals, sea pens are not protected under the Wildlife Act. There are currently 31 species of sea pens known from New Zealand waters (about 15% of the global fauna). Williams *et al*. (2014) prepared a field guide for the commonly sampled sea pens (15 species), described their morphology, and mapped their distribution.

Sea pens are found around New Zealand from shallow inshore regions to the abyssal plain (Figure 52) but are uncommon at depths of less than 50 m except where there is protection from strong waves and currents as they are vulnerable to being uprooted from the soft sediment where they typically occur (Figure 53). Sea pens are also an important species in soft-sediment and sill communities in Fiordland.

Because they form an emergent three-dimensional structure with a buried bulb, it is likely that in areas where they are common sea pens help to stabilise the sediment and contribute to a distinct sea floor

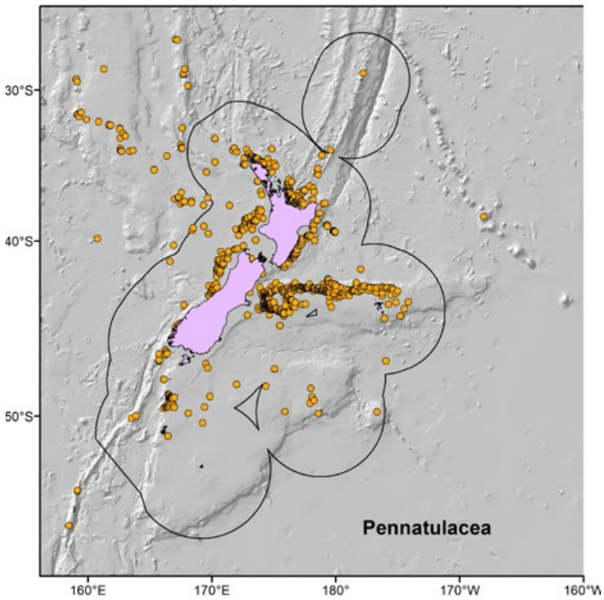


Figure 52: Distribution map of all sea pens (Order Pennatulacea) (Published as supplementary material in Anderson *et al*. (2016).

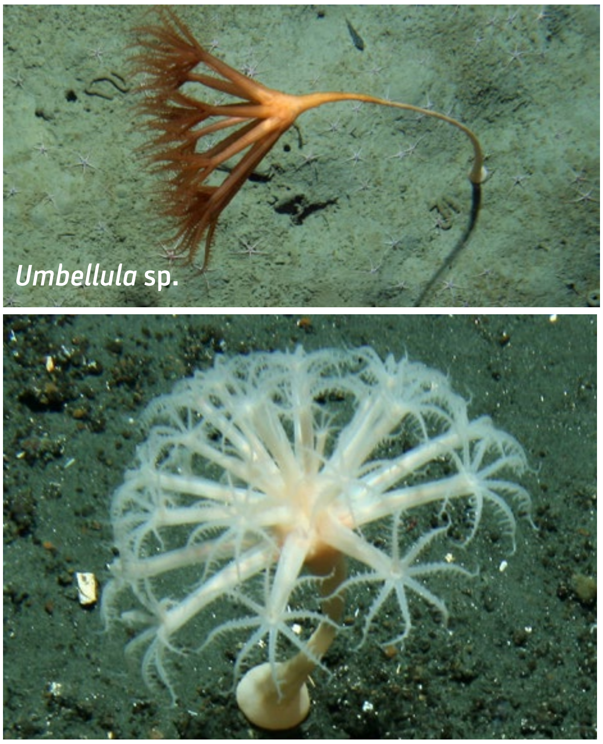


Figure 53: Examples of umbrella sea pens on soft sediment. *Umbellula* sp. (top) is perhaps the deepest octocoral.

boundary layer of slower currents. (Williams *et al*. 2014). One species in the region, the rock pen *Anthoptilum gowlettholmesae,* attaches to rocky substrate (Figure 54). The erect structures may also provide refuge to small fish and invertebrates. Baillon *et al*. (2012) found fish larvae were consistently associated with five species of sea pen on the Grand Banks off eastern Canada – including *A. grandiflorum* which is also found in New Zealand. It is also likely that some species are an important food source to specialised nudibranch and ophiuroid predators.

Biology

Endemism and Age and growth

No data available for the region

Reproduction

No data available for the region. Reproduction in the sea pen *Pennatula phosphorea* (a species also found in New Zealand waters; Figure 55) was investigated by Edwards & Moore (2008). The authors found the group broadcast-spawned during the northern hemisphere summer months of July and/or August. Although spawning occurs annually, the duration of oogenesis exceeds 12 months for this species. The timing and periodicity of oogenesis and spawning may be related to seasonal environmental cues and it was proposed that annual spawning constitutes a brief and synchronous event.

Figure 54. Unlike other sea pens the rock pen *Anthoptilum gowlettholmesae* attaches to rocky substrate.

Figure 55: Sea pen, *Pennatula phosphorea.*

Appendices:

Appendix 1. List of described and undescribed species for the New Zealand region (Table 1), Ross Sea (Table 2); and High Seas (Table 3), as selected from the NIWA Invertebrate Collection (NIC) Specify Database *niwainvert*. Australian records from Macquarie Ridge region are not included, nor are 'undetermined' records of which there are significant numbers held in the NIC. Shallow-water specimens are under-represented.

Appendix 2. Coral connectivity review.

Appendix 3. Overview of the conservation status of New Zealand deepwater corals (Freeman *et al*. 2014).

Appendix 4. Workshop on research needs for protected corals in New Zealand waters.

Appendix 5. Example images collected at sea by observers on commercial fishing vessels.

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Appendix 1. List of described and undescribed species for the New Zealand region (Table 1), Ross Sea (Table 2); and High Seas (Table 3), as selected from the NIWA Invertebrate Collection (NIC) Specify Database *niwainvert*. Australian records from Macquarie Ridge region are not included, nor are 'undetermined' records of which there are significant numbers held in the NIC. Shallow-water specimens are under-represented. (see chapter on shallows)

New Zealand EEZ, depth range for the NZ EEZ region only from NIWA Invertebrate Collection records - may not reflect the complete range for the species, especially for shallow-water taxa

Higher Taxon	Taxon	Species Authority	Depth Range (m)	Reference or Source
Anthozoa				
Alcyonacea				
Acanthogorgiidae	*Acanthogorgia* spp.		88–1805	At least four undescribed species, prelim. ID by Sanchez, Rowley & Alderslade in 2006-2012 from NIC specimens
	Anthogorgia sp.		786–810	Undescribed species, prelim. ID by Rowley in 2014
Alcyoniidae	cf. *Alcyonium spp.*		3–174	Three undescribed spp., possible new genus, prelim ID by Alderslade in 2013 and Kessel *et al.* in preparation 2018
	Bathyalcyon robustum	(Versluys, 1906)	275–1430	
	Anthomastus spp.		275–2312	Four undescribed species, prelim. ID by Sanchez in 2005 and Alderslade in 2012 from NIC specimens
	cf. *Bellonella undet*. sp.		519–882	Preliminary ID by Alderslade in 2013 from NIC specimens
	Cladiella sp.		0–18	Undescribed species, prelim ID by Williams in 1995 from NZOI collection
	Eleutherobia cf. *splendens*	(Thomson & Dean, 1931)	140–203	Preliminary ID by Alderslade in 2012 from NIC specimens
	Eleutherobia sp.		1150–1500	Undescribed species, prelim ID by Alderslade & Mills in 2014 from NIC specimens
	Heteropolypus sp.		327–2102	Undescribed species, prelim ID by Alderslade in 2014 from NIC specimens
	Paraminabea sp.		260–280	Undescribed species, prelim ID by Molodtsova in 2007 from Bay of Plenty (TAN0413 voyage)
	Pseudoanthomastus sp.		613–1460	Undescribed species, prelim ID by Mills in 2014 from Chatham Rise and Kermadec Ridge seamounts (TAN0905 & TAN1104 voyages)
	Sarcophyton sp.		8–14	Undescribed species from Raoul Island, Kermadec Islands, NZOI collection
Anthothelidae	*Anthopodium australe*	Verrill, 1876	0–1	
	Anthothela vickersi	(Benham, 1928)	843–1486	
	Anthothela spp.		635–1190	Four undescribed spp., prelim. ID by Alderslade in 2012 from NIC specimens
	Iciligorgia koellikeri	Studer, 1878	143–173	
	Iciligorgia spp.		200–1210	Two undescribed spp., prelim. ID by Alderslade in 2013 & Sanchez in 2006 from NIC specimens
	Solenocaulon sp.		373–753	Undescribed species, prelim ID by Alderslade & Moore in 2013 from NIC specimens
	cf. *Stereogorgia claviformis*	Kukenthal, 1916	165	

	Victorgorgia eminens	Moore, Alderslade & Miller, 2017	880–972	
	Victorgorgia n. sp.		609–1030	Preliminary ID by Moore in 2013 from NIC
Chrysogorgiidae	*Chrysogorgia chryseis*	Bayer & Stefani, 1988	837–1107	
	Chrysogorgia comans	Kinoshita, 1913	140–203	
	Chrysogorgia elegans	(Verrill, 1883)	504–990	
	Chrysogorgia expansa	(Wright & Studer, 1889)	1199–1221	
	Chrysogorgia geniculata	(Wright & Studer, 1889)	573–1826	Probably a species complex (Untiedt work in progress, 2018)
	Chrysogorgia orientalis	Versluys, 1902	1395	
	Chrysogorgia pinnata	Cairns, 2007	872–1086	
	Chrysogorgia rigida	Versluys, 1902	912–997	
	Chrysogorgia spiculosa	(Verrill, 1883)	1357–1540	
	Chrysogorgia squamata	(Verrill, 1883)	701–1086	
	Chrysogorgia stellata	Nutting, 1908	650–1187	
	Chrysogorgia cf. *scintillans*	Bayer & Stefani, 1988	1571–1619	Preliminary ID by Untiedt in 2018 from NZOI collection
	Chrysogorgia spp.		362–2400	12 undescribed species, work in progress by Untiedt in 2018 from NIC specimens
	Iridogorgia sp.		850–1830	Undescribed species, prelim ID by Sanchez, Alderslade, Cairns, Watling & Matsumoto 2005-2017 from NIC specimens
	Isidoides sp.		363–961	Undescribed species, prelim ID by Alderslade in 2012 from NIC specimens
	Metallogorgia melanotrichos	(Wright & Studer, 1889)	1000–1496	
	Metallogorgia spp.		617–2120	Two undescribed spp., prelim. ID by Sanchez in 2005 from NIC specimens
	Pseudochrysogorgia bellona	Pante & France, 2010	1323–1462	
	Pseudochrysogorgia n. sp.		918–1077	Preliminary ID by Alderslade in 2017 from Scientific Observer collection
	Radicipes sp.		305–2361	Undescribed species, prelim IDs by Sanchez, Cairns, Alderslade, Rowley, Tracey, Mills, Untiedt 2005-2014 from NIC specimens
	Stephanogorgia sp.		1124–1127	Undescribed species, prelim ID by Alderslade in 2013 from Tangaroa Seamount (TAN1206 voyage)
Clavulariidae	*Clavularia* sp.		121–1123	Undescribed spp., prelim. ID by Sanchez in 2008–2010 from NIC specimens
	Cornulariella spp.		398–1697	Two undescribed spp., prelim. ID by Alderslade in 2012 from Macquarie Ridge (TAN0803 voyage)
	Rhodelinda gardineri	Gohar, 1940	60–1113	
	Rhodelinda n. spp.		385–498	Two undescribed species, prelim. ID by Alderslade in 2012 from Macquarie Ridge (TAN0803 voyage)
	Telesto spp.		108–746	Five undescribed spp., prelim. ID by Alderslade in 2012 from Hikurangi Margin & Bay of Islands (TAN1004, & TAN0906 voyages)
	Telestula sp.		470–1402	Undescribed species

	Trachythela rudis	Verrill, 1922	900–993	
Coralliidae	*Corallium borneanse*	Bayer, 1950	398	
	Corallium nix	Bayer, 1996	280–460	
	Corallium thrinax	Bayer & Stefani in Bayer, 1996	165–180	
	Corallium cf. *kishinouyei*	Bayer, 1996	1282–1378	Preliminary ID by Ardila in 2012 from Kermadec Ridge (TAN1007 voyage)
	Corallium cf. *konojoi*	Kishinouye, 1903	1150–1400	Preliminary ID by Dueñas in 2013 from Kermadec Ridge (TAN1104 voyage)
	Corallium cf. *niveum*	Bayer, 1956	120–124	Preliminary ID by Ardila in 2012 from Bay of Islands (TAN0906 voyage)
	Corallium spp.		110–2147	3 undescribed spp., prelim. ID by Ardila, Cairns, Marriott and Sanchez in 2007–2014 from NIC specimens
	Hemicorallium imperiale	(Bayer, 1955)	297–2550	
	Hemicorallium laauense	Bayer, 1956	510–1800	
Ellisellidae	*Ellisella* sp.		145	Undescribed species, prelim ID by Bilewitch in 2018.
	Nicella carinata	Nutting, 1910	160–210	
	Viminella sp.		142–225	Undescribed species, prelim ID by Williams & Alderslade in 2005-2013 from NIC specimens
Isididae	*Acanella eburnea*	(Pourtalès, 1868)	903–1050	
	Acanella japonica	Kukenthal, 1915	850–1518	
	Acanella sibogae	Nutting, 1910	796–1395	
	Acanella sp.		193–2320	Undescribed species, prelim. ID by Sanchez, Alderslade & Dueñas in 2005–2012 from NIC specimens
	Chathamisis bayeri	Grant, 1976	291–1254	
	Chathamisis n. spp.		849–1583	Three new species, prelim. ID by Alderslade in 2012 & Moore in 2015 from Kermadec Ridge, Bay of Plenty and Chatham Rise Seamounts (TAN1104, TAN1206 & TAN1503 voyages)
	Circinisis circinata	Grant, 1976	165	
	Echinisis spicata	(Hickson 1907)	33	
	Echinisis spp.		796–1408	Two undescribed spp., prelim. ID by Alderslade in 2012 from Macquarie Ridge (TAN0803 voyage), Christable Seamount (TAN0306 voyage) and Aloha Seamount (TAN0905 voyage)
	Isidella sp.		670–1887	Preliminary ID by Dueñas, Sanchez & Alderslade in 2007–2017 from NIC specimens
	Jasonisis sp.		1180–1284	Undescribed species, prelim ID by Watling in 2014
	Karakaisis waipounamu	Unpublished genus" "K" undescribed species "w" species name, (Juan Sanchez, 2004). Potential holotype held at NIWA.	998–1053	
	Keratoisis flexibilis	Pourtales, 1868	1033	
	Keratoisis glaesa	Grant, 1976	406–2340	
	Keratoisis hikurangiensis	Grant, 1976	951–1327	

	Keratoisis magnifica	Dueñas, Alderslade & Sanchez, 2014	650–1080	
	Keratoisis peara	Dueñas, Alderslade & Sanchez, 2014	1919–2275	
	Keratoisis projecta	Grant, 1976	645–768	
	Keratoisis tangentis	Grant, 1976	406	
	Keratoisis wrighti	Nutting, 1910	800	
	Keratoisis zelandica	Grant, 1976	611–1680	
	Keratoisis spp.		104–4500	12 undescribed spp., prelim. ID by Dueñas, Sanchez, Alderslade & Tracey in 2003–2017 from NIC specimens
	Lepidisis solitaria	Grant, 1976	805–1077	
	Lepidisis spp.		385–2870	10 undescribed spp., prelim. ID by Dueñas, Sanchez, Alderslade & Tracey in 2003–2012 from NIC specimens
	Lissopholidisis nuttingi	Grant, 1976	978	
	Minuisis granti	Alderslade, 1998	88	
	Minuisis spp.		495–1440	2 undescribed spp., prelim. ID by Dueñas, Sanchez & Alderslade in 2005–2012 from NIC specimens
	Muricellisis echinata	Kükenthal, 1915	790	
	Notisis sp.		899–1254	Undescribed species, prelim. ID by Moore in 2015 from Graveyard Seamounts, Chatham Rise (TAN1503 voyage)
	Orstomisis crosnieri	Bayer, 1990	536–720	
	Peltastisis sp.		809–1044	Undescribed species, prelim. ID by Sanchez in 2005 from NIC specimens
	Primnoisis ambigua	Wright & Studer, 1889	880	
	Primnoisis chatham	Moore, Alderslade & Miller, 2016	880–1129	
	Primnoisis erymna	Moore, Alderslade & Miller, 2016	757–1123	
	Primnoisis fragilis	Kükenthal, 1919	18	
	Primnoisis niwa	Moore, Alderslade & Miller, 2016	1007–1024	
	Sclerisis macquariana	Bayer & Stefani, 1987	740–1254	
Keroeididae	*Keroeides* sp.		64–288	Undescribed species, prelim. ID by Rowley, Moore and Mills in 2011–2014 from NIC specimens
Melithaeidae	*Melithaea* sp.		15	Undescribed species from Three Kings Islands
Nephtheidae	*Daniela* sp.		327	Undescribed species from NZOI Collection
	Dendronephthya sp.		23–117	Undescribed species, prelim ID by Williams & Alderslade from Poor Knights Island (NZOI) and Ranfurly Bank (TAN1108 Biogenic Habitats voyage)
	Drifa sp.		636–751	Preliminary ID by Sanchez in 2005 from Kermadec Ridge (TAN0205 voyage)
Nidaliidae	cf. *Nidalia* sp.		401–395	Preliminary ID by Alderslade in 2012 from Chatham Rise (TAN1116 voyage)

	Chironephthya spp.		88–328	Undescribed species, prelim. ID by Sanchez & Alderslade in 2005–2013 from Kermadec Ridge (NZOI & TAN0205 voyage)
	Siphonogorgia sp.		390–490	Undescribed species, prelim. ID by Williams in 1995 from NZOI collection
Paragorgiidae	*Paragorgia alisonae*	Sanchez, 2005	730–1248	
	Paragorgia aotearoa	Sanchez, 2005	682–1004	
	Paragorgia arborea	(Linnaeus, 1758)	427–1798	
	Paragorgia coralloides	Bayer, 1993	836–955	
	Paragorgia kaupeka	Sanchez, 2005	787–949	
	Paragorgia maunga	Sanchez, 2005	653–1121	
	Paragorgia splendens	Thomson & Henderson, 1906	935	
	Paragorgia wahine	Sanchez, 2005	900–1000	
	Paragorgia whero	Sanchez, 2005	772–951	
	Sibogagorgia dennisgordoni	Sanchez, 2005	820–976	
	Sibogagorgia tautahi	Sanchez, 2005	872–1086	
Plexauridae	*Anthomuricea* spp.		168–1771	Four undescribed spp., prelim ID by Alderslade in 2012 from Northern NZ NIC specimens
	Astrogorgia sp.		820	Undescribed species, preliminary ID by Alderslade in 2013 from NIC specimens
	Bebryce spp.		341–1258	Two undescribed spp., prelim ID by Alderslade, Bilewitch & Rowley in 2011–2018 from Kermadec Ridge (NZOI, TAN0205 & TAN1213 voyages)
	Clematissa sp.		145–155	Undescribed species, prelim. ID by Bilewitch in 2018 from Ranfurly Bank (TAN1108 Biogenic Habitats voyage)
	Discogorgia spp.		780–1328	Three undescribed spp., prelim ID by Alderslade & Bilewitch in 2012–2018 from Cavalli Seamounts, Kermadec Ridge and Bay of Plenty (KAH0204, TAN1104 & TAN1206 voyages)
	Echinogorgia sp.		142–160	Undescribed species, preliminary ID by Bilewitch in 2014 from Kermadec NZOI collection
	Euplexaura sp.		115–440	Preliminary ID by Alderslade & Bilewitch in 2012–2018 from Kermadec Ridge & Ranfurly Bank (TAN1213 & TAN1108 Biogenic Habitats voyage)
	Muriceides kuekenthali	(Broch, 1912)	385–498	
	Muriceides sp.		321–1600	Preliminary ID by Sanchez, Alderslade & Bilewitch in 2006-2018 from NIC specimens
	Paracis squamata	(Nutting, 1910)	128–720	
	Paracis spp.		106–797	Preliminary ID by Ardila & Sanchez, Alderslade in 2007–2012 from NIC specimens
	Paramuricea spp.		78–1600	Two undescribed spp., prelim ID by Alderslade, Sanchez, Bilewitch, Tracey & Rowley in 2005–2018 from Kermadec Ridge & Bay of Plenty regions (various voyages)
	Paraplexaura sp.		55–155	Undescribed species, prelim. ID by Bilewitch in 2018 from NZOI specimens
	Placogorgia spp.		83–1644	Four undescribed spp., prelim ID by Sanchez, Alderslade, Rowley, Moore & Bilewitch in 2005–2018 from Kermadec Ridge & Bay of Plenty Seamounts (various voyages)
	Pseudothesea sp.		270	Undewcribed species, prelim. ID by Moore in 2013 from NIC specimen
	Swiftia sp.		145–1675	Preliminary ID by Sanchez, France, Rowley & Bilewitch in 2005–2018 from NIC specimens

	Villogorgia spp.		145–2120	Four undescribed spp., prelim ID by Sanchez, Alderslade & Bilewitch in 2005–2018 from NIC specimens
Primnoidae	*Callogorgia dichotoma*	Cairns, 2016	92–940	
	Callogorgia formosa	(Kükenthal, 1907)	341	
	Callogorgia gilberti	(Nutting, 1908)	875–1431	
	Callogorgia sertosa	(Wright & Studer, 1889)	349–471	
	Callogorgia tessellata	Cairns, 2016	340–388	
	Callogorgia spp.		79–1190	Four undescribed spp., prelim ID by Cairns in 2015 from NIC specimens
	Callozostron acanthodes	Bayer, 1996	744–2385	
	Callozostron mirabile	Wright, 1885	1280	
	Callozostron pinnatum	Cairns, 2016	878–1160	
	Calyptrophora clinata	Cairns, 2007	670–1086	
	Calyptrophora cristata	Cairns, 2012	350	
	Calyptrophora cucullata	Cairns, 2012	490–1680	
	Calyptrophora diaphana	Cairns, 2012	677–1680	
	Calyptrophora inornata	Cairns, 2012	471–1297	
	Calyptrophora niwa	Cairns, 2012	1180–1440	
	Calyptrophora wyvillei	Wright & Studer, 1889	643–1650	
	Candidella helminthophora	(Nutting, 1908)	617–1700	
	Dasystenella acanthina	(Wright & Studer, 1889)	800–1119	
	Fanellia cf. *granulosa*		976	Preliminary ID by Cairns in 2015 from Waioeka Knoll
	Fanellia histoclados	Cairns, 2016	122–600	
	Fanellia korema	Bayer & Stefani, 1989	510	
	Fanellia tuberculata	(Versluys, 1906)	122–1143	
	Fanellia n. sp. B		398–489	Preliminary ID by Alderslade in 2012 from Macquarie Ridge (TAN0803 voyage)
	Loboprimnoa exotica	Cairns, 2016	1313–1420	
	Metafannyella chathamensis	Cairns, 2016	60–1302	
	Metafannyella eos	(Bayer, 1998)	250–107	
	Metafannyella polita	Cairns, 2016	167	
	Metafannyella ventilabrum	(Studer, 1878)	39–277	
	Metafannyella sp. B		100–1288	Preliminary ID by Cairns in 2018 from NIC specimens
	Mirostenella cf. *articulata*	Bayer, 1988	801–823	Preliminary ID by Cairns in 2016 from Chatham Rise Graveyard Seamount Complex (TAN0905 voyage)
	Narella clavata	(Versluys, 1906)	122–1982	

	Narella hypsocalyx	Cairns, 2012	275–1436	
	Narella mesolepis	Cairns, 2012	157–1165	
	Narella mosaica	Cairns, 2012	247–312	
	Narella parva	(Versluys, 1906)	768–2407	
	Narella studeri	(Versluys, 1906)	800–1670	
	Narella vulgaris	Cairns, 2012	275–1320	
	Narella sp.		800–1380	Preliminary ID by Cairns in 2013 from Kermadec Ridge (TAN0205 & TAN1007 voyages)
	Narelloides crinitus	Cairns, 2012	157–970	
	Narelloides traceyae	Cairns, 2016	1165–1280	
	Ophidiogorgia cf. *kuekenthali*		30	Preliminary ID by Cairns in 2015 from Kermadec Islands (NZOI collection)
	Paracalyptrophora hawaiiensis	Cairns, 2009	158–185	
	Paracalyptrophora mariae	(Versluys, 1906)	990–1105	
	Paranarella sp.		1192–1300	Undescribed species, prelim. ID by Alderslade in 2017 from Scientific Observer collected specimen
	Parastenella pacifica	Cairns, 2007	1240–1290	
	Parastenella spinosa	(Wright & Studer, 1889)	720–1132	
	Perissogorgia vitrea	Bayer & Stefani, 1989	50–270	
	Plumarella cordilla	Cairns, 2016	55–172	
	Plumarella delicatula	Thomson & Rennet, 1931	520–1431	
	Plumarella n. sp. B		1070–1408	Preliminary ID by Alderslade in 2012 from Macquarie Ridge (TAN0803 voyage)
	Primnoa notialis	Cairns & Bayer, 2005	86–1824	
	cf. *Primnoeides* sp.		740–1254	Preliminary ID by Moore in 2015 from Chatham Rise Graveyard Seamounts (TAN1503 voyage)
	Primnoella distans	Studer, 1879	796–2312	
	Primnoella insularis	Cairns, 2016	64–2650	
	Primnoella n. sp. A		1130–1201	Preliminary ID by Alderslade in 2012 from Macquarie Ridge (TAN0803 voyage)
	Thouarella hilgendorfi	(Studer, 1879)	444–2974	
	Thouarella spp.		108–1826	15 undescribed spp., prelim. IDs by Sanchez, Alderslade, Tracey & Cairns in 2005–2018 from NIC specimens
	Tokoprymno maia	Bayer 1996	398–1416	
	Tokoprymno sp.		775–1365	Undescribed species, prelim. ID by Alderslade, Matsumoto, Sanchez & Cairns in 2008–2018 from NIC specimens
Subergorgiidae	*Rosgorgia* sp.		996–1011	Undescribed species, prelim. ID by Alderslade in 2017 from Scientific Observer collected specimen
Taiaroiidae	*Taiaroa tauhou*	Bayer & Muzik, 1976	309–1373	
Antipatharia				

Antipathidae	*Antipathes* cf. *plana*	Cooper, 1909	154–240	Preliminary ID by Opresko in 2006 from Kermadec Ridge (TAN0205 voyage)
	Antipathes chamaemorus	Pax et Tischb. in Pax, 1932	123	
	Antipathes densa	Silberfeld, 1909	310–534	
	Antipathes flabellum	Pallas, 1766	521–539	
	Antipathes gracilis	Gray, 1860	79–1174	
	Antipathes leptocrada	Opresko, 2015	175–1143	
	Antipathes pauroclema	(Pax & Tischierek, 1932)	168–270	
	Antipathes valdiviae	Pax,1915	420–471	
	Antipathes n. sp.		735–942	Preliminary ID by Opresko in 2006 from Kermadec Ridge (TAN0205 voyage)
	Cirrhipathes propinqua	Brook, 1889	320–415	
	Stichopathes spiessi	Opresko & Genin, 1990	365–1534	
	Stichopathes variabilis	(Pesch, 1914)	88–1081	
	Stichopathes cf. *filiformis*	Gray, 1868	358–380	Preliminary ID by Opreko in 2012 from Bay of Plenty Seamounts (TAN0413 voyage)
	Stichopathes cf. *solorensis*	van Pesch, 1914	140–141	Preliminary ID by Opreko in 2012 from Bay of Islands (TAN0906 voyage)
Aphanipathidae	*Acanthopathes* cf. *undulata*	(van Pesch, 1914)	154–440	Preliminary ID by Molodtsova (2008) & Opresko (2010) from the Kermadec and Colville Ridges
	Asteriopathes cf. *arachniformis*	Opresko, 2004	88–157	Preliminary ID by Opresko in 2012 from Kermadec Ridge (TAN0205 voyage)
	Asteriopathes n. sp.		122–307	Preliminary ID by Opresko in 2012 from NIC material
	Phanopathes zealandica	Opresko, 2015	154–240	
	Rhipidipathes sp.		180	Undescribed species, prelim. ID by Opresko in 2007 from NZOI collection
Cladopathidae	*Cladopathes plumosa*	Brook, 1889	935–1067	
	Sibopathes cf. n. sp. *gephura*		787	Preliminary ID by Opresko in 2005 from NIC
	Trissopathes pseudotristicha	Opresko, 2003	956	
	Trissopathes tristicha	(van Pesch, 1914)	525–1880	
Leiopathidae	*Leiopathes acanthophora*	Opresko, 1998	449–1608	
	Leiopathes bullosa	Opresko, 1998	609–1300	
	Leiopathes secunda	Opresko, 1998	610–1280	
	Leiopathes aff. n. sp.		1494–1556	Preliminary ID by Molodtsova in 2007 from Chatham Rise (TAN0709 fisheries research voyage)
Myriopathidae	*Antipathella fiordensis*	Grange, 1990	1–514	
	Cupressopathes n. sp.		88–157	Preliminary ID by Opresko in 2012 from Kermadec Ridge (TAN0205 voyage)
	Myriopathes cf. *ulex*	(Ellis and Solander, 1786)	88–157	Preliminary ID by Opresko in 2006 from Kermadec Ridge (TAN0205 voyage)
	Myriopathes myriophylla	Pallas, 1766	70–157	

	Plumapathes fernandezi	(Pourtalès, 1874)	122–307	
Schizopathidae	*Bathypathes alternata*	Brook, 1889	316–1506	
	Bathypathes patula	Brook, 1889	628–1490	
	Dendrobathypathes grandis	Opresko, 2002	865–1300	
	Dendrobathypathes isocrada	Obresko, 2002	690–800	
	Dendropathes intermedia	(Brook, 1889)	506–1250	
	Lillipathes lilliei	(Totton, 1923)	155–365	
	Parantipathes dodecasticha	Opresko, 2015	787–1108	
	Parantipathes helicosticha	Opresko, 1999	335–1250	
	Parantipathes robusta	Opresko, 2015	693	
	Parantipathes wolffi	Pasternak, 1977	986–1010	
	Parantipathes n. spp.		362–1090	Two undescribed spp., prelim. ID by Molodtsova in 2007 and Opresko in 2006 from NIC specimens
	Saropathes sp.		154–850	Undescribed species, prelim. ID by Opresko in 2006 from NIC specimens
	Stauropathes n. sp.		617–935	Preliminary ID by Opresko in 2005/2006 from NIC specimens
	Telopathes cf. *confecta*		250–310	Preliminary ID by Brugler in 2015 from Bay of Plenty (KAH9907 voyage)
	cf. *Telopathes* sp. undet.		200–295	Preliminary ID by Opresko in 2015 from Bay of Plenty (TAN0413 voyage)
	Umbellapathes n. sp.		405–845	ID by Opresko (n. sp. in prep 2014)
Stylopathidae	*Stylopathes columnaris*	(Duchassaing, 1870)	510–1174	
	Stylopathes tenuispina	(Silberfeld, 1909)	140–1081	
	Triadopathes glutinata	Totton, 1923	745	
	Triadopathes sp.		115–1191	Undescribed species, preliminary ID by Opresko in 2006-2012 from NIC specimens
	Tylopathes sp.		419–1460	Undescribed species, preliminary ID by Opresko in 2006-2012 from NIC specimens
Pennatulacea				
Anthoptilidae	*Anthoptilum gowlettholmesae*	Williams & Alderslade, 2011	865–1132	
	Anthoptilum grandiflorum	(Verrill, 1879)	44–1704	
	Anthoptilum lithophilum	Williams & Alderslade, 2011	2620–2660	
Echinoptilidae	*Echinoptilum* sp.		307	Unidentified species, prelim. ID by Kate Neill from Bay of Plenty
Funiculinidae	*Funiculina quadriangularis*	(Pallas, 1766)	41–1502	
Halipteridae	*Halipteris finmarchica*	(Sars, 1851)	518–528	
	Halipteris willemoesi	Kölliker, 1870	75–558	
Kophobelemnidae	*Kophobelemnon stelliferum*	(Müller, 1776)	21–2278	
	Kophobelemnon cf. *biflora*		3034–3036	Preliminary ID by Williams in 2014 from the Kermadec Ridge (TAN1007 voyage)

	Kophobelemnon cf. *pauciflorum*	Hickson, 1916	999–1030	Preliminary ID by Williams in 2011 from the Hikurangi Margin (TAN1004 voyage)
	Kophobelemnon sp.		1812–1813	Preliminary ID by Dolan in 2008 from Chatham Rise (TAN0705 voyage)
	*Malacobelemnon*sp.		155–157	Unidentified species, prelim. ID by Alderslade from Bay of Islands
Pennatulidae	*Gyrophyllum sibogae*	Hickson, 1916	394–1124	
	Pennatula aculeata	Danielssen, 1860	1193–1215	
	Pennatula phosphorea	Linnaeus, 1758	614–1328	
	Pennatula cf. *moseleyi*	Kölliker, 1880	451–472	Preliminary ID by Williams in 2011 from Rumble III Seamount (TAN1104 voyage)
	Pteroeides cf. *doefleini*		40	Preliminary ID by Williams in 1995 from NZOI collection
	Pteroeides sp. 1		1515–1530	Preliminary ID by Sanchez in 2005 from Bay of Plenty Seamounts (TAN0413 voyage)
Protoptilidae	*Distichoptilum gracile*	Verrill, 1882	627–1931	
	Distichoptilum sp. 1		1164–1193	Preliminary ID from Alderslade in 2012 from Bay of Plenty Seamounts (TAN1206 voyage)
	Protoptilum sp.		451–503	Unidentified species, prelim. ID by Williams from Kermadec Ridge
Scleroptilidae	*Calibelemnon* sp.		328	Unidentified species, prelim. ID by Williams in 2011
Stachyptilidae	*Stachyptilum* sp.		1050–1140	Unidentified species, prelim. ID by Sanchez in 2006 from Graveyard Seamounts, Chatham Rise (TAN0604 voyage)
Umbellulidae	*Umbellula* cf. *lindahli*	Kölliker, 1875	315–330	Preliminary ID by Williams in 1995 from NZOI collection
	Umbellula spp.		256–2794	Two undescribed spp., prelim. ID by Sanchez in 2005 from Bay of Plenty Seamounts (TAN0413 voyage)
Virgulariidae	*Acanthoptilum longifolium*	Williams, 2007	9–1020	
	cf. *Virgularia* undet. sp.		19–476	Preliminary ID by Williams in 2014 from NZOI collection
	Stylatula austropacifica	Williams, 2007	201–1167	
Scleractinia				
Acroporidae	*Montipora capricornis*	Veron, 1985	1–32	
	Montipora spongodes	Bernard, 1897	1–32	
Agariciidae	*Dactylotrochus cervicornis*	(Moseley, 1881)	88–287	
	Leptoseris papyracea	(Dana, 1846)	142–260	
Anthemiphyllidae	*Anthemiphyllia dentata*	(Alcock, 1902)	265–506	
Caryophylliidae	*Anomocora fecunda*	(De Pourtalès, 1871)	325–388	
	Aulocyathus recidivus	(Dennant,1906)	471–1042	
	Bourneotrochus stellulatus	(Carins, 1984)	465	
	Caryophyllia ambrosia	Alcock, 1898	665–1600	
	Caryophyllia atlantica	(Duncan, 1873)	317–1402	

	Caryophyllia diomedeae	Marenzeller, 1904	33–1982	
	Caryophyllia elongata	Cairns & Keller, 1993	243–641	
	Caryophyllia hawaiiensis	Vaughan, 1907	125–287	
	Caryophyllia japonica	Marenzeller	44–1669	
	Caryophyllia lamellifera	Moseley, 1881	144–615	
	Caryophyllia profunda	Moseley, 1881	15–1464	
	Caryophyllia quadragenaria	Alcock, 1902	60–210	
	Caryophyllia rugosa	Moseley, 1881	125–328	
	Caryophyllia scobinosa	Alcock	397–2312	
	Caryophyllia versicolorata	Kitahara, Cairns & Miller, 2010	358–380	
	Caryophyllia n. spp.		128–335	Three undescribed spp., prelim. ID by Kitahara in 2018 from NIC specimens
	Coenocyathus brooki	Cairns, 1995	88–157	
	Conotrochus brunneus	(Moseley, 1881)	365–800	
	Crispatotrochus curvatus	Cairns, 1995	1373–2505	
	Crispatotrochus rugosus	Cairns, 1995	142–398	
	Crispatotrochus septumdentatus	Kitahara & Cairns, 2008	125–136	
	Crispatotrochus n. spp.		968–1366	Two undescribed spp., prelim. ID by Kitahara in 2018 from NIC specimens
	Dasmosmilia lymani	(De Pourtalès, 1871)	230–999	
	Deltocyathus cameratus	Cairns, 1999	850–1930	
	Deltocyathus formosus	Cairns, 1995	142–565	
	Deltocyathus inusitiatus	Kitahara & Cairns, 2009	698–1140	
	Deltocyathus ornatus	Gardiner, 1899	340–390	
	Desmophyllum dianthus	(Esper, 1794)	10–1928	
	Goniocorella dumosa	(Alcock, 1902)	63–1366	
	Hoplangia durotrix	Gosse, 1860	161–404	
	Labyrinthocyathus langae	Cairns, 1979	150–1300	
	Labyrinthocyathus limatulus	(Squires, 1964)	508	
	Labyrinthocyathus sp. A		741–1000	Preliminary ID by Cairns in 1995 (NZOI collection)
	Paraconotrochus antarcticus	Gardiner, 1929	1082–1473	
	Paracyathus durhami	sensu Kitahara	340–390	
	Polycyathus sp.		440	Unidentified species from the Kermadec Region
	Rhizosmilia maculata	(Pourtalès, 1874)	90–109	
	Rhizosmilia n. sp.		220–320	Preliminary ID by Kitahara in 2018 from Bay of Plenty Seamounts (KAH9907 voyage)

	Solenosmilia variabilis	Duncan, 1873	150–1982	
	Stephanocyathus coronatus	(Pourtalès, 1867)	1197–2040	
	Stephanocyathus platypus	(Moseley, 1876)	450–1627	
	Stephanocyathus regius	Cairns & Zibrowius, 1997	981–3112	
	Stephanocyathus spiniger	(Marenzeller, 1888)	154–710	
	Stephanocyathus weberianus	(Alcock, 1902)	1422–1826	
	Tethocyathus cylindraceus	(Pourtales)	117–320	
	Tethocyathus virgatus	(Alcock, 1902)	424–486	
	Thalamophyllia tenuescens	(Gardiner, 1899)	195–287	
	Trochocyathus cepulla	Cairns, 1995	398–630	
	Trochocyathus efateensis	Cairns, 1999	287–328	
	Trochocyathus gordoni	Cairns, 1995	398–950	
	Trochocyathus hastatus	Bourne, 1903	405–710	
	Trochocyathus maculatus	Cairns, 1995	72–160	
	Trochocyathus rhombocolumna	Alcock,1902	471	
	Vaughanella concinna	Gravier, 1915	918–1440	
	Vaughanella multipalifera	Cairns, 1995	968–1500	
Dendrophylliidae	*Balanophyllia chnous*	Squires, 1962	132–388	
	Balanophyllia crassitheca	Cairns, 1995	190–508	
	Balanophyllia gigas	Moseley, 1881	177–502	
	Dendrophyllia alcocki	(Wells, 1954)	118–1160	
	Dendrophyllia arbuscula	Van der Horst, 1922	202	
	Eguchipsammia fistula	(Alcock,1902)	260–554	
	Eguchipsammia gaditana	(Duncan,1873)	88–1982	
	Eguchipsammia japonica	(Rehberg,1892)	113–2850	
	Eguchipsammia n. spp.		796–882	Preliminary ID by Kitahara in 2018 from Kermadec Ridge (TAN1007 voyage) & Chatham Rise Graveyard Seamount complex (TAN0905 voyage)
	Enallopsammia profunda	(De Pourtalès, 1867)	462–524	
	Enallopsammia pusilla	(Alcock, 1902)	918–944	
	Enallopsammia rostrata	(Pourtalès, 1878)	117–2147	
	Enallopsammia sp. A		462–524	Preliminary ID by Cairns in 2010 from Macquarie Ridge (TAN0803 voyage)
	Endopachys grayi	Milne Edwards & Haime, 1848	95–974	
	Turbinaria frondens	(Dana, 1846)	0–32	

Flabellidae	*Flabellum aotearoa*	Squires, 1964	125–565	
	Flabellum apertum	Moseley, 1876	322–2000	
	Flabellum cinctutum	Cairns & Polonio, 2013	1052–1080	
	Flabellum flexuosum	Cairns, 1982	815–1506	
	Flabellum hoffmeisteri	Cairns & Parker, 1992	442–1252	
	Flabellum impensum	Squires, 1962	55–1165	
	Flabellum knoxi	Ralph & Squires, 1962	80–1167	
	Flabellum lowekeyesi	Squires & Ralph	376–1064	
	Flabellum messum	Alcock, 1902	44–1471	
	Javania fusca	(Vaughan, 1907)	430–670	
	Javania lamprotichum	(Moseley, 1880)	321–1079	
	Javania pachytheca	Cairns, 1995	505–800	
	Javania sp.		1050–1053	Unidentified species, prelim. ID by Kitahara in 2018 from Wairarapa (TAN0616 voyage)
	Monomyces rubrum	(Quoy & Gaimard, 1833)	1–990	
	Placotrochides sp. (cf. *P. prolata*)		730–880	Preliminary ID by Kitahara in 2018 from TAN0616 & KAH0204 voyages
	Polymyces wellsi	Cairns, 1991	414–1545	
	Rhizotrochus flabelliformis	Cairns, 1989	212–290	
	Truncatoflabellum angiostomum	(Folkeson, 1919)	94–364	
	Truncatoflabellum arcuatum	Cairns, 1995	350–364	
	Truncatoflabellum dens	(Alcock, 1902)	470–530	
	Truncatoflabellum paripavoninum	(Alcock, 1894)	698–2327	
	Truncatoflabellum phoenix	Cairns, 1995	145–179	
Fungiidae	*Fungiacyathus fragilis*	Sars, 1872	920–1505	
	Fungiacyathus margaretae	Cairns, 1995	673–1100	
	Fungiacyathus pusillus pacificus	Cairns, 1995	265–673	
	Fungiacyathus stephanus	(Alcock, 1893)	1142–1690	
	Fungiacyathus turbinolioides	Cairns, 1989	600	
Gardineriidae	*Gardineria* sp.		142–710	Unidentified species, prelim. ID by Cairns and Kitahara from Bay of Plenty, Kermadec Islands and Kermadec Ridge (NZOI specimens)
Guyniidae	*Pedicellocyathus* keyesi	Cairns, 1995	70–209	
	Stenocyathus vermiformis	(Pourtalès,1868)	161–1140	
	Truncatoguynia irregularis	Cairns, 1989	145	
Merulinidae	*Astrea curta*	Dana, 1846	1–32	

	Goniastrea favulus	(Dana, 1846)	1–32	
	Hydnophora pilosa	Veron, 1985	1–32	
Micrabaciidae	*Letepsammia fissilis*	Cairns, 1995	157–172	
	Letepsammia formosissima	(Moseley, 1876)	290–1140	
	Letepsammia superstes	(Ortmann, 1888)	440–710	
	Stephanophyllia complicata	Moseley, 1876	865–867	
Oculinidae	*Madrepora oculata*	Linnaeus, 1758	109–2850	
	Oculina virgosa	Squires, 1958	6–1053	
Pocilloporidae	*Madracis kauaiensis*	Vaughan, 1907	90–109	
	Pocillopora damicornis	(Linnaeus, 1758)	1–32	
Rhizangiidae	*Culicia rubeola*	(Quoy & Gaimard, 1833)	10–95	
Turbinoliidae	*Kionotrochus suteri*	Dennant, 1906	59–318	
	Peponocyathus dawsoni	Cairns, 1995	141–790	
	Pleotrochus venustus	(Alcock, 1902)	1137–1570	
	Pleotrochus zibrowii	Cairns, 1997	1137	
	Sphenotrochus ralphae	Squires, 1964	55–104	
	Sphenotrochus squiresi	Cairns, 1995	66–318	
	Thrypticotrochus petterdi	(Dennant, 1906)	95	
Zoantharia				
Parazoanthidae	*Kulamanamana haumeaae*	Sinniger, Ocana & Baco, 2013	381–1824	
	Savalia		10–895	Preliminary ID by Sinniger in 2008–2018 from NIC specimens
Hydrozoa				
Anthoathecata				
Stylasteridae	*Adelopora crassilabrum*	Cairns, 1991	282–417	
	Adelopora fragilis	Cairns, 1991	520–560	
	Calyptopora reticulata	Boschma, 1968	28–1485	
	Conopora anthohelia	Cairns, 1991	780–1170	
	Conopora candelabrum	Cairns, 1991	486–1480	
	Conopora laevis	(Studer, 1878)	114–1380	
	Conopora tetrastichopora	Cairns, 1991	282–710	
	Conopora verrucosa	(Studer, 1878)	59–1408	
	Crypthelia curvata	Cairns, 1991	282–1484	
	Crypthelia cymas	Cairns, 1986	263–932	

	Crypthelia fragilis	Cairns, 1983	670–1335	
	Crypthelia polypoma	Cairns, 1991	710	
	Crypthelia robusta	Cairns, 1991	265–1363	
	Crypthelia studeri	Cairns, 1991	216–1276	
	Crypthelia spp.		845–1140	Two undescribed species, prelim. ID by Sanchez in 2010 from Christable Seamount (TAN0306 Sub-antarctic region seamounts) & Cairns in 2013 from Chatham Rise (TAN0905 Graveyard Seamounts)
	Distichopora dispar	Cairns, 1991	520–741	
	Errina bicolor	Cairns, 1991	95–944	
	Errina carnea	Boschma, 1965	20	
	Errina chathamensis	Cairns, 1991	65–623	
	Errina cheilopora	Cairns, 1983	86–1400	
	Errina cooki	Hickson, 1912	143–1268	
	Errina cruenta	Boschma, 1968	81	
	Errina dendyi	Hickson, 1912	9–282	
	Errina fissurata	Gray, 1872	11	
	Errina gracilis	Marenzeller, 1903	68–1697	
	Errina hicksoni	Cairns, 1991	40–363	
	Errina laevigata	Cairns, 1991	202–382	
	Errina laterorifa	Eguchi, 1964	11–900	
	Errina novaezelandiae	Hickson, 1912	6–350	
	Errina reticulata	Cairns, 1991	126–900	
	Errina sinuosa	Cairns, 1991	287–710	
	Errina n. sp.		47–54	Preliminary ID by Bax in 2012 from the Three Kings Islands (TAN1105 Biogenic Habitats voyage)
	Errinopsis n. sp.		265–1040	Preliminary ID by Cairns in 2013 from Chatham Rise (TAN0905 Graveyard Seamounts)
	Inferiolabiata labiata	(Moseley, 1879)	399–1280	
	Inferiolabiata lowei	(Cairns, 1983)	160–526	
	Inferiolabiata spinosa	Cairns, 1991	215–900	
	Inferiolabiata n. spp.		92–932	Three undescribed species, prelim. ID by Marriot & Bax in 2013-2015 from North Maria Ridge (TAN1312), Chatham Rise (TAN0905 Graveyard Seamounts) & Middlesex Bank (TAN1105 Biogenic Habitats voyage)
	Lepidopora cryptocymas	Cairns, 1985	197–970	
	Lepidopora dendrostylus	Cairns, 1991	190–810	
	Lepidopora microstylus	Cairns, 1991	780–1035	
	Lepidopora polystichopora	Cairns, 1985	197–875	
	Lepidopora sarmentosa	Boschma, 1968	460–1335	

	Lepidopora symmetrica	Cairns, 1991	282	
	Lepidopora n. sp.		837–1055	Preliminary ID from Marriott in 2015 from NZ region (TAN1312 & TAN0604 voyages)
	Lepidotheca altispina	Cairns, 1991	198–790	
	Lepidotheca cervicornis	(Broch, 1942)	161–1100	
	Lepidotheca chauliostylus	Cairns, 1991	417–1480	
	Lepidotheca fascicularis	(Cairns, 1983)	282–1076	
	Lepidotheca inconsuta	Cairns, 1991	645–1165	
	Lepidotheca robusta	Cairns, 1991	830–900	
	Sporadopora micropora	Cairns, 1991	549–741	
	Sporadopora mortenseni	Broch, 1942	161–900	
	Stellapora echinata	(Moseley, 1879)	454–741	
	Stenohelia conferta	Boschma, 1968	1335	
	Stephanohelia praecipua	Cairns, 1991	613–1080	
	Stylaster brunneus	Boschma, 1970	188	
	Stylaster eguchii	(Boschma, 1966)	40–1583	
	Stylaster horologium	Cairns, 1991	277–417	
	Stylaster imbricatus	Cairns, 1991	157–961	
	Stylaster sinuosus	(Cairns, 1991)	260–758	
	Stylaster n. sp. A		387–866	Preliminary ID by Cairns in 2014 from NIC specimens
	Systemapora ornata	Cairns, 1991	378–1114	

Appendix 2. Coral connectivity review table.

Reference	Protected Species Group	Species	Number of individuals	Number of Sites	Region	Markers	Connectivity?	Gene flow	spatial scale	Isolation by distance (IBD)	Genetic Diversity	Effective population size (Ne)?
Miller, KJ 1997	Black coral	*Antipathes fiordensis*	734	28	Fiordland	allozymes	structure within, rather than between, fiords		10s-100s km	No	low overall, consistent with asexual reproduction	n/a
Miller *et al.* 2010	Black coral	*Antipathes robillardi*	28	3	Australia / New Zealand	16S, ITS	regionally structured		100s kms		low overall given the genetic markers, slightly higher for black corals than stony corals	
Miller *et al.* 2010	Stony coral	*Desmophyllum dianthus*	60	7	Auckland Islands, Chatham Rise, Macquarie Ridge, Tasmania	ITS, MtC	regionally structured, with some structuring between adjacent areas (Auckland Islands and Macquarie Ridge distinct)		100s-1000s km	n/a*		n/a
Miller *et al.* 2010	Stony coral	*Enallopsammia rostrata*	28	5	Macquarie Ridge, Tasmania	ITS, MtC	no structure		100s-1000s km	n/a		n/a
Miller *et al.* 2010	Stony coral	*Madrepora oculata*	36	2	Chatham Rise, Western Australia	16S, ITS	no structure		1000s km	n/a		n/a
Miller *et al.* 2010	Stony coral	*Solenosmilia variabilis*	152	6	Tasmania, Kermadec Ridge, Western Australia, Chatham Rise, Macquarie Ridge	16S, ITS, MtC	no structure		100s-1000s km	n/a		n/a
Miller *et al.* 2010	Stony coral	*Stephanocyathus (A) spiniger*	21	5	western Australia	16S, ITS	no structure		10s-100s km	n/a		n/a
Miller *et al.* 2010	Stony coral	*Stephanocyathus platypus*	8	4	NSW, Chatham Rise, NZ Challenger	16S	no structure		100s-1000s km	n/a		n/a
Miller *et al.* 2010		*Stichopathes filiformis*	16	1	Bay of Plenty	ITS	inconclusive		10s-100s km	n/a		n/a
Miller *et al.* 2010		*Stichopathes variabilis*	19	8	Kermadec Ridge, Norfolk Ridge, NSW, Coral Sea)	ITS, ITS1, 16S	regionally structured		100s-1000s km	n/a		n/a

Miller *et al.* 2011	Stony coral	*Desmophyllum dianthus*	162	48	SE Australia, New Zealand, Chile	16S, ITS, MtC	depth and regionally structured		10s-1000s km	n/a	similar levels across study area	low and similar for all populations (0.0001 - 0.0009)
Bax. 2014	Hydrocoral	*Errina laterorifa*	8		Ross Sea	ITS						* ie relative to each other
Bax. 2014	Hydrocoral	*Errina fissurata*	21, 11			ITS, COI						
Duenas *et al.* 2016	Octocoral	*Tokoprymno*	80		South Pacific and Southern Ocean (Tasmania, Macquarie Ridge, New Zealand, Antarctica)	ITS2, 28S						
Duenas *et al.* 2016	Octocoral	*Thouarella*										
Miller & Gunasekara 2017	Stony coral	*Desmophyllum dianthus*	326		Southern Ocean (Tasmania, Macquarie Ridge)	8 microsatellites	depth structured	high, between seamounts 1000-1400m	100s kms	no evidence	high	much larger*
Miller & Gunasekara 2017	Stony coral	*Solenosmilia variabilis*	589			9 microsatellites	low connectivity at all spatial scales; locally structured (between tasmanian seamounts at 1000-1400m) and regionally structured (Macquarie Ridge vs. Tasmanian sites) populations		100s metres to 100s kms	no evidence	lower than D. dianthus	smaller*
Zeng *et al.* 2017	Stony coral	*Goniocorella dumosa*	134		New Zealand	D-loop, ITS, microsatellites	structured by region and geomorphic feature, Kermadec Ridge different to Chatham Rise		100s-1000s km	yes, by depth, both markers		very low
Zeng *et al.* 2017	Stony coral	*Madrepora oculata*	78		New Zealand	ITS, microsatellites	regionally structured		100s-1000s km	yes, by depth, ITS		very low
Zeng *et al.* 2017	Stony coral	*Solenosmilia variabilis*	208		New Zealand, and beyond NZ EEZ	D-loop, ITS, microsatellites	structured by region and geomorphic feature, Louisville Seamount Chain distinct		100s-1000s km	yes, by distance (microsatellites)		very low

Holland *et al.* 2019	Stony coral	*Desmophyllum dianthus*			New Zealand, and beyond NZ EEZ (Louisville Seamounts)	9 microsatellites	regionally structured		100s-1000s km			
Holland *et al.* 2019	Stony coral	*Enallopsammia rostrata*	*79*		*New Zealand*	*ITS*	*limited structure*		*100s-1000s km*			
Holland *et al.* 2019	Black coral	*Bathypathes patula*	*55-58*		*New Zealand, and beyond NZ EEZ (southern Ocean)*	*TRP, ND5,16S*	*regionally structured (Southern Ocean vs. New Zealand)*		*100s-1000s km*			
Holland *et al.* 2019	Black coral	*Leiopathes spp.*	*28-46*		*New Zealand*	*8 microsatellites*	*no structure*		*100s km*			
n/a =not tested or described explicitly												

Appendix 3 Overview of the conservation status of New Zealand deepwater corals (Freeman *et al*. 2014).

Conservation Status	**Family**	**Taxa**	**Common name**
Taxonomically determinate			
Data deficient	Antipathidae	*Antipathes fruticosa* Gray, 1857	Black coral
	Caryophylliidae	*Coenocyathus brooki* Cairns, 1995	Stony coral
	Isididae	*Circinisis circinata* Grant, 1976	Bamboo coral
		Primnoisis antarctica (Studer, 1878)	Bamboo coral
		Primnoisis ambigua Wright & Studer, 1889	Bamboo coral
	Paragorgiidae	*Paragorgia aotearoa* Sanchez, 2005	Bubblegum coral
		Paragorgia kaupeka Sanchez, 2005	Bubblegum coral
		Paragorgia maunga Sanchez, 2005	Bubblegum coral
		Paragorgia wahine Sanchez, 2005	Bubblegum coral
		Paragorgia whero Sanchez, 2005	Bubblegum coral
		Sibogagorgia dennisgordoni Sanchez, 2005	Bubblegum coral
		Sibogagorgia tautahi Sanchez, 2005	Bubblegum coral
	Stylasteridae	*Errina cooki* Hickson, 1912	Red coral
		Errina dendyi Hickson, 1912	Red coral
		Errina hicksoni Cairns, 1991	Red coral
Threatened – Nationally vulnerable	Isididae	*Chathamisis bayeri* Grant, 1976	Bamboo coral
	Paragorgiidae	*Paragorgia alisonae* Sanchez, 2005	Bubblegum coral
At risk – declining	Caryophylliidae	*Goniocorella dumosa* (Alcock, 1902)	Stony coral
		Solenosmilia variabilis Duncan 1873	Stony coral
	Dendrophylliidae	*Enallopsammia rostrata* (Pourtalès, 1878)	Stony coral
	Paragorgiidae	*Paragorgia arborea* (Linnaeus, 1758)	Bubblegum coral
	Oculinidae	*Madrepora oculata* Linnaeus, 1758	Stony coral
At risk – naturally uncommon	Dendrophylliidae	*Balanophyllia chnous* Squires, 1962	Stony coral
		Crateritheca novaezelandiae (Thompson, 1879)	Stony coral
	Flabellidae	*Falcatoflabellum raoulensis* Cairns, 1995	Stony coral
	Isididae	*Keratoisis glaesa* Grant, 1976	Bamboo coral
		Keratoisis hikurangiensis Grant, 1976	Bamboo coral
		Keratoisis projecta Grant, 1976	Bamboo coral
		Keratoisis tangentis Grant, 1976	Bamboo coral
		Keratoisis zelanica Grant, 1976	Bamboo coral
	Myriopathidae	*Antipathella fiordensis* (Grange, 1990)	Black coral
	Oculinidae	*Oculina virgosa* Squires, 1958	Stony coral
	Stylasteridae	*Errina bicolor* Cairns, 1991	Red coral
		Errina chathamensis Cairns, 1991	Red coral
		Errina cheilopora Cairns, 1983	Red coral
		Errina laevigata Cairns, 1991	Red coral
		Errina reticulata Cairns, 1991	Red coral
		Errina sinuosa Cairns, 1991	Red coral
	Schizopathidae	*Lillipathes lillei* (Totton, 1923)	Black coral
	Turbinoliidae	*Sphenotrochus squiresi* Cairns, 1995	Stony coral

Taxonomically indeterminate			
Data deficient	Isididae	*Mopsea* sp.	Bamboo coral
		Peltastisis sp.	Bamboo coral
		Primnoisis sp. C	Bamboo coral
		Sclerisis sp. NIWA J. Sanchez	Bamboo coral
At risk – naturally uncommon	Isididae	*Acanella* spp.	Bamboo coral
		Chathamisis spp. Kermadec Ridge	Bamboo coral
		Echinisis spicata (Hickson, 1907)	Bamboo coral
		Echinisis spp.	Bamboo coral
		Keratoisis n. sp.	Bamboo coral
		Minuisis	Bamboo coral

Note: The primary information needed to allow an assessment of species under the New Zealand Threat Classification System are:

- whether the taxon is indigenous or naturalised in New Zealand
- information on the distribution of the taxa in New Zealand waters and overseas
- information on population status – number of populations, population sizes, area of occupancy
- information on population trends (predicted and ongoing), including whether there are existing threats driving these trends
- information on generation time (under the NZTCS population trends are considered over 10 years or three generations, whichever is longer)
- information on taxonomic status – has the taxon name been legitimately and effectively published and accepted
- information to support addition of qualifiers to the listing (see below)

Qualifiers available under the New Zealand Threat Classification System for assessing the conservation status of species such as corals. An additional qualifier, “Designated”, is also available where the Expert Panel has designated the most appropriate listing without application of the criteria.

Acronym	**Qualifier**
CD	Conservation Dependent
DP	Data Poor
EF	Extreme Fluctuations
EW	Extinct in the Wild
OL	One Location
RF	Recruitment Failure
SO	Secure Overseas
TO	Threatened Overseas
St	Stable
IE	Island Endemic
Inc	Increasing
PD	Partial Decline
RR	Range Restricted
Sp	Sparse

Appendix 4. Workshop on research needs for protected corals in New Zealand waters. Workshop minutes and Gaps identification.
https://www.doc.govt.nz/contentassets/1b230eee4e214f0da8ed6298d0c95add/doc-coral-workshop-minutes-and-gaps-nov-2017-final.pdf and https://www.doc.govt.nz/contentassets/1b230eee4e214f0da8ed6298d0c95add/doc-coral-workshop-gaps-final.pdf.

Department of Conservation
Te Papa Atawhai

NIWA
Taihoro Nukurangi

Workshop on research needs for protected corals in New Zealand waters

Date: 12 October 2017

Time: 9:30 – 15:00

Place: Level 4 Conference Room, Conservation House, Department of Conservation, 18-32 Manners Street, Wellington

Workshop leaders: Freya Hjorvarsdottir (fhjorvarsdot@doc.govt.nz) and Di Tracey (di.tracey@niwa.co.nz)

Workshop facilitator: Kris Ramm (kramm@doc.govt.nz)

Rapporteur: Julia Gibson (jgibson@doc.govt.nz)

Attendance: Ian Angus, Freya Hjorvarsdottir, Julia Gibson, Kris Ramm, Shane Geange, Debbie Freeman (DOC), Di Tracey, Helen Bostock, Jaret Bilewitch, Owen Anderson, Ashley Rowden, Mark Morrison, Andrew Tait (NIWA), Simon Davy, Jonathan Gardner (VUW), Rich Ford, Lyndsey Holland, Malindi Gammon, Mary Livingston, Jen Matthews, Tiffany Bock (MPI), Geoff Tingley (GFL/DWG), Rob Tilney (C&A Ltd), Ray Wood (CRP), Mike Patrick (MERMAN Ltd), Pierre Tellier (MFE), Oliver Wilson (FINZ), David Aguirre, Libby Liggins (Massey Uni)

By-catch, identification & data sourced – Di Tracey, Sadie Mills, Kevin Mackay

Presentation on the work carried out by NIWA to identify protected deep-sea corals returned from commercial vessels by Government Observers. Originally the project was funded through CSP, then MPI, but now sits with CSP (three-year programme). Outlined was the work that has been undertaken to improve the accuracy of the samples collected and returned to NIWA, the methods used to identify the samples, where and how the data is stored, and application of the results e.g., data used for spatial distribution maps, pooled with other datasets for predictive modelling, contributes to describing BPA fauna.

Discussions:

It was highlighted that new species are still being identified by the visiting global taxonomic experts. A significant driver for this was that the vessels are still going to new areas and therefore encountering species that we haven't come across before.

Further discussion occurred around the method of sample collection. Observer coverage is a key source of samples as well as biodiversity research voyages, in different areas.

Discussion on the frequency of areas being re-visited, and samples collected again from these same areas, it was noted that this is difficult as reliable time series do not exist for most areas, but historic data from some areas can be used to determine this.

Protected coral distribution modelling – Owen Anderson, Sara Mikaloff-Fletcher, Helen Bostock, Dianne Tracey

An overview on recent research conducted in relation to the modelled distribution of protected corals in NZ and the methods used. Suitability and use of models and model variables was described, as well as model development along the way.

Earth System Models - Sara Mikaloff-Fletcher, Helen Bostock, Owen Anderson, Dianne Tracey

Presented on the development of an algorithm that was used to estimate carbonate parameters from hydrographic data for the NZ region. The algorithm produced maps estimating the depth of the Aragonite and Calcite Saturation Horizons (ASH & CSH respectively). The depth of the saturation horizons were then used to predict the location of corals. Recent work has looked at how the saturation levels have changed in the last 20 years and how these types of models can be used to predict future distribution of coral species with respect to climate change.

In 2018 the next generation of IPCC models will be available, which will bring more opportunities for improved modelling.

Discussions:

Discussion centred around how accurate the models are at reproducing the current physical and biogeochemical status of the ocean. The model reliability was checked by comparing the outcomes with actual and historic data. This allows us to assess how reliable the models are at predicting the future biogeochemistry of the oceans.

The benthic habitat models can be run with combined data e.g., by the morphological groups (reef-like, tree-like, etc). The models are however more accurate when individual species are used. When multiple species are aggregated the model becomes less reliable due to variability in the environmental requirements between individual species. Additional layers such as for sediment will improve the models.

Discussion around the possibility to assess how many species we have good enough data to make predictions for and which species we are lacking data e.g., we only have data at the genus level for black corals and bubblegum corals, species level would be more ideal.

Will the location of refugia area for certain corals differ with changes in depths of saturations horizons? E.g., for the stony coral *Goniocorella dumosa* that occurs in shallower waters on the crest of the Chatham Rise.

Biology, age, and reproduction of corals – Di Tracey

Presentation on the biology - growth, growth rates and reproduction of deep-sea corals and the different methods used to age and assess growth rates for different species. The risk assessment highlighted how data poor our knowledge is on coral productivity, which related directly to recoverability of corals from disturbance, i.e., how long will it take certain species to recover from trawling impacts.

Discussions:

Under reproduction there was some discussion about what factors affect the dispersal of coral larvae including how long larvae are viable, whether the corals are brooders, or broadcast spawners, or does asexual budding exist. If they can disperse for many kilometres, they require suitable hard substrate to settle on. There are quite a few unknowns, particularly about larval settlement.

Molecular studies: Population genetic structure and connectivity – Jonathan Gardner, Malcolm Clark, Lyndsey Holland, Joanna Hamilton, Ashley Rowden, Di Tracey, Cong Zeng.

Part of a multi-year Vulnerable Marine Ecosystem (VME) project funded by Ministry of Business, Innovation and Employment (MBIE) and Ministry for Primary Industries (MPI) with the aim to identify population genetic structure, genetic hotspots, source and sink populations, and connectivity of VME (associated) taxa. Genetic stock and connectivity data to could be used to inform placement of new offshore Marine Protected Areas (MPAs).

Discussions:

Discussion around what role the life-history has in dispersal, and about the importance of filling that gap.

A query as to whether the effective population size is sensitive to sample size was addressed. Even though the method is susceptible to small sample sizes, a reasonable estimate can be obtained from 10-12 individuals. Different markers / analytical methods however are not comparable as results depend upon user-specified molecular evolutionary and reproductive (e.g. discrete generations) assumptions.

Ecology and connectivity of shallow reef building corals of the Rangitahua Kermadec Islands – Libby Liggins & David Aguirre

Presented on the shallow water corals in the Kermadec Islands area. Temporal changes in community composition, morphological divergence and genetic connectivity. Ongoing taxonomic and biodiversity work supported by New Zealand and Australian researchers.

Discussion

At the moment the work is limited because of limited samples from the region.

There is a need to compare species to look at overlap across factors such as depth.

Discussion around if the location of shallow water corals is all protected within reserves. In New Zealand all of the known locations are protected, but there is no formal study into distribution of shallow water corals, meaning that the gaps are still uncertain.

Ocean acidification & Mineralogy – Di Tracey, Malindi Gammon, Simon Davy, Helen Bostock

Ocean Acidification (OA) will impact both shallow and deep-sea coral communities, while those deep-sea stony corals abundant in depths shallower than 300-400 m could act as a refuge for corals in the face of climate change.

High latitude coral communities in the Kermadecs could act as a refuge for reef corals elsewhere in the face of climate change.

Assessed the potential impacts of OA on *Solenosmilia variabilis* (deep-sea stony coral). After a preliminary study on Chatham Rise samples, the research focussed on samples collected from theLouisville Ridge. These were kept alive for ~ 2 years. Growth rate and physiological processes were measured during the study. There was no detectable difference between the treatment and control colonies for growth & metabolic rates. However, there was more tissue loss in the treatment samples, which warrants further investigation to assess its long-term implications –i.e., tissue loss weakens skeleton, the reef matrix

OA also impacts capacity of shallow water corals to form a skeleton but at a cellular level impact mat be moderated.
Discussions:
There is a need to investigate the threshold of other coral groups to OA, as there will likely be a species difference. Discussion around the possibility that some parts of NZ will act as a refuge for corals and what the implications of that occurring would be. Shallow water corals from wider Pacific region settling in the New Zealand region, and deep-sea corals finding refuge on the top of the Chatham Rise.
The impact of trawl fisheries on deep-sea corals – Ashley Rowden, Malcolm Clark et al
Presented on the nature and extent of trawling impacts of corals, and if coral habitats and communities can recover. Some small and/or flexible coral species appear resilient to trawling damage, but most coral species have attributes that make them highly sensitive to impact, with low recovery ability.
The management of impacts on deep-sea corals – Ashley Rowden et al.
Presented on spatial management and its concepts, with examples of decision support tools. These tools provide a means to analyse data in an objective and transparent way that can benefit all stakeholders, necessary due to the competing spatial interests.
Discussions:
Although there are patterns of abundance, it's not clear what areas would be best to protect, which affect ecosystem function, or have an important role in connectivity between areas. General discussion around the need to set management objectives through which the various trade-offs can be assessed.
Inshore corals (biogenic habitats on New Zealand's continental shelf) – Mark Morrison, Emma Jones
Presented information on corals with a shallower distribution (less than 200 m). Surveys designed based on local knowledge on different habitats and associated unusual catches, and how the environment has changed over time. Fifty, mainly retired, trawl fishers were interviewed and the marking up of nautical charts were later digitised into GIS coverage. Many management issues apparent, including lost fishing gear and sedimentation from land.
Discussions:
Discussion around the sedimentation work and how there is more accurate data available on the dispersal of sedimentation around those areas. It was noted that more accurate sedimentation work is coming out soon. More knowledge and monitoring of our corals in shallower waters was discussed.

Ecological risk assessment for deep-sea protected corals – Malcolm Clark, Di Tracey, Owen Anderson, Steve Parker

Presented on a preliminary Ecological Risk Assessment (ERA), which was carried out in order to: inform managers of the type of outputs such a risk assessment may produce identify major knowledge gaps that limit the ERA, and provides an indication of relative vulnerability of different corals relevant for developing management options to reduce impacts from trawling.

The work was not intended to be a definitive ERA, but rather to investigate whether such approach could be carried out given the data available and whether it produced sensible results in terms of relative risk. Corals at high risk were identified.

Discussions:

The ERA looks at change in distribution patterns, not fishing impacts, as there is available information on fishing but not on the recoverability.

Discussion about the possibility of using data such as growth rates from same or similar species from studies in other countries to feed into the NZ risk assessment. However, it was identified that that due to unique oceanographic conditions data aren't always comparable, species can be different.
Note: Overseas biological data was considered in the RA and used as a guide to the general magnitude of age & growth.

Conservation status of corals – Debbie Freeman

Presented on the conservation status of corals and some of the major gaps. Threatened species described. Majority of marine invertebrates are data deficient, and many of them have not yet been assessed.

Discussions:

Discussion around how this could be best linked in with other coral work

Discussion around the process of categorising corals, as the percentage of decline in three generations, will in many cases be over 70%, which puts a species in the Nationally Critical category.

Conversation about the possibility of automating some of the assessment for the invertebrates, by linking it up to a database.

Biological Gaps

Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***	***Group discussion during workshop***	***Comments sent in during review of document***
Improved understanding of adaptability.	*Identification of species that could potentially adapt to changes in the environment, which might support the identification of important areas for spatial management.*	- Models lack the basic understanding of the biology of species, need to include more complex information. -	- Need to include cumulative or multiple stressors and impacts.
Improved understanding of small effective population sizes.	*Identifies the constraints on the resilience of populations to impacts.*		
Improved understanding of taxonomy.	*To provide basic understanding about the components of coral biodiversity, which is necessary for effective decision-making about conservation and sustainable use.*		
Improved understanding of the barriers of gene flow.	*Could allow us to identify species that may better cope with environmental changes, and to recover from disturbances, and those that can’t and are more vulnerable to extinction.*		
Improved understanding of contemporary vs historical structure.	*To identify trends over longer time series. To increase our knowledge on dispersal, connectivity, and genetic hotspots.* *Could benefit the identification of areas of high protection value.*	- We need to increase our understanding of change, evolution, adaptability, and plasticity of species.	- We need to consider the relative resolutions of different genetic markers, and assumptions and limitations of genetic analyses (and sample sized) when distinguishing contemporary and historical gene flow.
Improved understanding of productivity.	*To understand the potential resilience of corals to impacts.*		

	Main limiting factor identified in the ERA in relation to recovery ability.		
Improved understanding of age and growth, there is a lack of New Zealand specific parameters.	*Increased knowledge on the recoverability of species after disturbance.* *Could support prioritisation of areas/species to protect.*		
Improved understanding of the reproductive and dispersal capabilities.	*To understand if asexual budding is more or less common than sexual broadcast release, and determine how capable species are of long-distance dispersal. Increased understanding of dispersal will increase our knowledge of connectivity.* *Improved knowledge of coral fecundity could identify vulnerable/less resilient species.* *Could help to prioritise areas/habitats with low reproduction and dispersal for protection.*		*- Pelagic larval duration is used as a theoretical proxy for dispersal potential and longer PLD is assumed to correlate positively with dispersal distance, although this is not always the case. Such data are best coupled with genetic and/or hydrodynamic models if available.*
Work on larval biology & duration.	*To increase our knowledge of larval duration for broadcast spawners, how capable species are of long-distance dispersal, and at what depth the larvae move in the current. Increased understanding of dispersal will increase our knowledge of connectivity.* *Could help to prioritise areas/habitats with low reproduction and dispersal for protection.*		

Improved understanding and definition of what a coral 'population' is.	*Could help us understand the spatial extent of interbreeding units and define sources and sinks.* *Could help define management units.* *Could help us to consider and assess the effects of impacts both spatially and temporally.*		*- Management actions may consider the effects of impacts on population scale.* *- We need to consider impacts and management strategies for both small (i.e., geographically limited) and large (i.e., widespread) populations.* *- Emerging connectivity data indicate that metapopulation dynamics play a role in population sub-division (or homogenisation).*
Determine the coral mineralogy of more species and evidence for carbonate dissolution using tools like Scanning Electron Microscope.	*This will allow the identification of species that may be more resilient to changes in the environment such as decreasing pH, which might support the identification of important areas for spatial management.*		

Environmental Gaps

Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***	***Group discussion during workshop***	***Comments sent in during review of document***
Improved understanding of physical oceanography.	*Essential for understanding distribution and abundance patterns, resilience, adaptability, dispersal etc. to better inform the importance of certain environmental drivers of coral distribution and abundance for use in future models.*	- Needed to understand responses to environment and environmental stressors.	

Improved understanding of biogeochemical variation in explaining connectivity.	*To optimize management by incorporating landscape sensitivity and hydrological connectivity.*		
Improved understanding of the drivers of environment and ocean stressors (temperatures and chemistry).	*Necessary to understand past and current changes to help inform on policy relevant to future projections.*		
What habitat values/function does it support.	*To identify functional linkages and incorporate this information into sustainable management of resources supported by corals.*		

Spatial Gaps

Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***	***Group discussion during workshop***	***Comments sent in during review of document***
Improved sampling effort in areas of New Zealand interest in the High Seas (SPRFMO) and Ross Sea (CCAMLR) coral identification and distribution.	*Important to know what species are in these regions. Being able to understand total species distribution and population structure rather than just what is in our EEZ will increase our knowledge on connectivity between habitats/populations.* *Will help to inform management plans.*		
Further understanding on distribution and abundance. Still a lot of 'holes' in the map. Limited sampling in some areas (>2000m and some BPAs).	*Difficult to manage the EEZ if there are still large gaps in the map because the information isn't available.* *Filling in these gaps will support spatial management of the New Zealand EEZ.*	- We need to know what's there, if we are going to try to manage it	

Identification of sources and sinks, and biodiversity/functional hotspots.	*To identify high value areas to support decision making in spatial management.*	- Monitoring takes a long time, we need to find a way to identify these areas and act now.	
Are patterns of structure and gene flow "universal".	*Ensuring that research and management assumptions are appropriate and well informed.* *Ecosystem-based management would benefit from assessment of multiple species.*		*- To date, there are some inconsistencies in sample sizes, in molecular markers used and in how genetic analyses are conducted, making direct species-by-species comparisons difficult – yet based upon best available information, we already know that patterns of structure are not uniform across deep-sea corals in New Zealand* *- Understanding and translating gene flow patterns, especially if contrasting among species, into a management framework is challenging and needs addressing.*
Comparison of coral VME to other VME data such as that for sponges to identify overall vulnerable ecosystems.	*To be able to learn from and apply successful international regulation to protect vulnerable populations, communities, and habitats.*	- There are some biological givens, and we already know a lot about species tolerances. For example, certain fauna can only survive within certain oxygen levels, in particular temperature range, ocean chemistry, etc. By using basic biological principles, we can specify vulnerable ecosystems. - Interface between science, assumptions, management etc.	

Further genetic collections from sources not already explored.	*To provide basic understanding about the components of coral biodiversity, which is necessary for effective decision-making about conservation and sustainable use.*		
How effective are current seamount closures and BPAs for protecting deep water corals.	*Better understanding if these spatial management measures have been useful, and provide evidence that they may or may not require modifications (e.g., moving, expanding, additions).*	- Protected areas have less data as a lot of the data that we have comes from fisheries observers etc. How do we know that the protected areas are the most useful areas?	
Identification of the areas of highest protection value for deep water corals, given competing interests of fishing, future seabed mining, and effects of climate change/OA.	*Better understanding if these spatial management measures have been useful, and provide evidence that they may or may not require modifications (e.g., moving, expanding, additions).*	- How does the area of protected corals fit into other work, such as ecosystem based management.	
Improved understanding of colonisation and settlement patterns of larvae.	*To better understand nature and potential for recovery of populations in areas*		- Critical, more so than knowing about reproduction, but also more difficult. It requires time series in situ to see what is happening in the field.
Further connectivity work, including work on different species than has previously been done.	*This information is needed to be able to predict recovery.*		- What species are lacking that should be examined and why. Are there certain areas that need to be samples (so we don't assume the Challenger Plateau has the same patterns as the Chatham Rise). Spatial scale becomes important for most of these ecological and environmental elements.

Improved understanding on the role of life-history variation, physical oceanography, ABNJ and biogeochemical variation in explaining connectivity.	To be able to determine appropriate spatial and temporal scales for management and recovery of impacted areas.		- Needs to be a lot more specific to guide research to produce something useful for management. The obvious thing is a five-year plan.
Further information about the link between shallow and deep-water corals. For example, regarding shelf break areas etc.	*To be able to differentiate management measures between areas that require different protection.*	- Inshore corals need more samples.	

Modelling Gaps

Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***	***Group discussion during workshop***	***Comments sent in during review of document***
Improved prediction of future refugia for both deep water and shallow water species.	*Identification of priority areas for spatial management.*	- Suitable future habitat does not necessarily indicate that corals will be coming back to those areas. Are there any settlement cues that we can use? Absence/presence of physical disturbance in the areas, dispersal distances, presence of con-specifics etc. ○ Connectivity will be an important variable here, as well as a huge mathematical challenge.	
Better estimates of model uncertainty.	*Allows us to make more accurate decisions and trade-offs in spatial management.*		

Models that estimate abundance in addition to presence absence.	*To allow the estimation of biomass as well as distribution. This could support work in identifying high value areas, or species that have a greater need for protection.*	- Models are based on presence-absence and not more quantitative abundance or biomass.	
The use of models to work out what biological variables are the key drivers of coral community composition, density, and "health".	*In order to prioritise research projects so that the key environmental data are collected.*	- There is a need to refine models so they can include this more complex information.	
Incorporation of refined and updated predictions of future ocean climate from new Earth System Models.	*Updated model will enable spatial planning software's to utilise predicted future distributions and aid in re-prioritizing areas for protection.*	- We need to use more relevant timelines than 2100, perhaps a gradient of change expected over time.	
Identification of the linkages of gene flow to physical flow.	*To improve understanding of connectivity the therefore resilience of populations to disruption.*		*- We need to understand and incorporate physical (and gene) flow variation between sites to reflect coral distribution and connectivity by depth.*
Updated risk assessment with updated information, perhaps including parameters from the same coral species from other countries.	*To give us more accurate estimates to assess risk to coral species.*	- Do we first need to focus on our lack of biology knowledge in order to draw an assessment of risk? Is there anything in the science that would help to narrow the focus to certain species?	
More accurate models, that also include shallow water corals.	*Improve predictive power and priorities management strategies.*		
Models with more accurate inclusion of data	*Improve prediction power and priorities management strategies.*		

on biology of corals, and adaptive capacity.			

Threat & Pressure Gaps

Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***	***Group discussion during workshop***	***Comments sent in during review of document***
Investigation of ocean acidification impacts for deep and shallow water corals in the region, their dissolution and resilience.	*To identify possible refugia areas and identify species that are more likely to withstand the changes in the environment.*	- Oxygen levels and their impact on corals are not currently well known, future levels and their impact poorly understood.	
Further experiments to understand the sensitivity of deep-sea corals to climate change, and if there is potential for acclimation.	*To provide more policy relevant projections, not just end-of-century to help management – e.g. we could protect any areas of potential refugia.*		
Further investigation into the impacts of trawling on ecosystem function/services (e.g. carbon cycling, habitat provision for juveniles, fish etc.) provided by deep water coral/reefs.	*Better understand the wider impact on corals and associated communities, and be able to consider these impacts when designing management measures.*		-This is the type of broad gap that can then start to be better filled by smaller projects that all contribute to a better feel for what goods and services are provided (e.g. fish association with corals based on seafloor imagery as a discrete study).
Further investigation into the impacts of seabed mining on ecosystem function/services provided by deep water coral/reefs.	*Better understand the wider impact on corals and associated communities, and be able to consider these impacts when designing management measures.*		
Improved understanding on how long recovery from	*Better understanding on how long spatial closures may need to be in*		

trawling impacts and seabed mining take, and if communities recover to previous state.	*place, and if recovered areas will provide similar ecosystem function/services.*		
Improved understanding on what facilitates the recovery of corals/habitat after trawling and seabed mining.	*Better understanding if there are any management measures that can be taken to improve recovery rate.*		
What stressors and threats do these habitats and areas face (both repeated single stressors, and cumulative and multiple stressors).	*To identify all threats that these habitats and areas face for further assessment of risk.*		
What management approaches can we adopt to reduce/mitigate these stressors, and perhaps even enhance productivity.	*To inform a diverse and effective suite of management approaches.*		
Further information on affected and 'unaffected' areas from anthropogenic pressures	*To increase our understanding on these risks.*		
In which regions/areas are we seeing the most rapid change, or which ecosystems.	*To help us identify possible refugia areas and aid in spatial management of these areas.*	- Where are the hotspots of rapid change, which ecosystems etc. would we expect to see? Could use predictive models, but we don't' necessarily have enough temporal data. - We could use multiple models, but each model can giver different results so we must be careful with the conclusions drawn.	

		- Biggest gradient changes in the fronts, places with slow change could be looked at as refugia.	
Monitoring for changes in different areas, both in relation to larvae settlement and climate change.	*Improve the understanding of resilience and recoverability to better inform management approaches.*	- National monitoring strategy, could be very useful in the future. - Where would we look to sample/focus on. - We need to take action now, by directing the research we have already towards management decisions, some immediate protection and long-term objectives to build upon.	

Data, management & communicating science

Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***	***Group discussion during workshop***	***Comments sent in during review of document***
Incorporate new variables, records and methods.	*Ensure that the data architecture is adequate to facilitate relevant analysis.*		
More robust image database storage system used for the observer collected digital images.	*For efficiencies and consistency of the image identification, which will help inform management decisions.*		
Important to refine what is accepted as "robust" science when sample sizes are often small and spatial coverage may be poor.	*To ensure that management is informed by appropriate science.*		
Improved understanding of *Areas Beyond National Jurisdiction* (ABNJ).	*Ensures that and research and management decisions take into account whole populations rather than being made at an EEZ or regional level.*		

	This also ensures a degree of consistency on coral management within and adjacent to the EEZ.		
Selection (e.g. SNPs – seascape genomics).	*To better understand the processes shaping the genetic structure of corals and the appropriate spatial management scales of coral taxa.*		
How to best link in with other coral work, including approaches to assessing risk to corals.	*To minimize duplication in research and maximize the outcomes of research projects.*		
Identifying and accessing relevant information sources; data consolidation.	*To have an easy and accessible way of reviewing existing information.*		
Management discussion on what these gaps, or this information, means to us and to the management of the activities/species etc.	*To help us make more informed management decisions that both benefit the protection of these areas as well as the sustainable use of resources that are linked to them.*		
Identification of new ways to communicate this science and knowledge to the public, and/or other platforms – data platform?	*To get the public more involved and interested in the protection of coral species.*	- There is a potential to incorporate this into the Sustainable Seas project – which looks at how people value things etc. - We need to be able to inform the society about the consequences of the management decisions. - We also need to meet international obligation with communicating our science. - We need to filter both up data and information for management purposes and for education, turn data into something more tangible.	

More coordination of existing coral research/projects.	*Minimize duplication and create synergies.*	- There is a lot of small projects and we need to find a way to share this information to be able to coordinate. One place to look for what data exists is a workshop like this.	
We need to identify the difference of legislative. balance between inshore and offshore areas.	*To be able to better manage both shallow and deep-sea corals.*	- Creates problems for management. - Some species that exist over these barriers which have to be considered.	
We need to define specific management goals for deep-sea corals in New Zealand. Specific management objectives are ill-defined and poorly outlined, so it remains unclear what we're trying to achieve in terms of management with the data that we have (e.g, 10% spatial coverage? consider the CBD etc.).	*To use data available so far to, for example, derive management actions in line with NZs national and with international agreements to which NZ is a signatory.*		- Requires explicit management objectives, against which protective efforts can be measured, i.e. we need to define management targets. - May include development of a data portal /repository so that relevant managers could access useful data. - Requires cross-agency collaboration (DoC, MPI, MfE, MFAT).

12 October 2017

Workshop on research needs for protected corals in New Zealand waters

Gaps Identified during workshop, and the initial characterisation of the value of filling them.

Biological Gaps	
Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management?***
Improved understanding of adaptability.	*Identification of species that could potentially adapt to changes in the environment, which might support the identification of important areas for spatial management.*
Improved understanding of small effective population sizes.	*Identifies the constraints on the resilience of populations to impacts.*
Improved understanding of taxonomy.	*To provide basic understanding about the components of coral biodiversity, which is necessary for effective decision-making about conservation and sustainable use.*
Improved understanding of the barriers of gene flow.	*Could allow us to identify species that may better cope with environmental changes, and to recover from disturbances, and those that can't and are more vulnerable to extinction.*
Improved understanding of contemporary vs historical structure.	*To identify trends over longer time series.* *To increase our knowledge on dispersal, connectivity, and genetic hotspots.* *Could benefit the identification of areas of high protection value.*
Improved understanding of productivity.	*To understand the potential resilience of corals to impacts.* *Main limiting factor identified in the ERA in relation to recovery ability.*
Improved understanding of age and growth, there is a lack of New Zealand specific parameters.	*Increased knowledge on the recoverability of species after disturbance.* *Could support prioritisation of areas/species to protect.*
Improved understanding of the reproductive and dispersal capabilities.	*To understand if asexual budding is more or less common than sexual broadcast release, and determine how capable species are of long-distance dispersal. Increased understanding of dispersal will increase our knowledge of connectivity.* *Improved knowledge of coral fecundity could identify vulnerable/less resilient species.* *Could help to prioritise areas/habitats with low reproduction and dispersal for protection.*
Work on larval biology & duration.	*To increase our knowledge of larval duration for broadcast spawners, how capable species are of long-distance dispersal, and at what depth the larvae move in the current. Increased understanding of dispersal will increase our knowledge of connectivity.*

	Could help to prioritise areas/habitats with low reproduction and dispersal for protection.
Improved understanding and definition of what a coral 'population' is.	*Could help us understand the spatial extent of interbreeding units and define sources and sinks.* *Could help define management units.* *Could help us to consider and assess the effects of impacts both spatially and temporally.*
Determine the coral mineralogy of more species and evidence for carbonate dissolution using tools like Scanning Electron Microscope.	*This will allow the identification of species that may be more resilient to changes in the environment such as decreasing pH, which might support the identification of important areas for spatial management.*

Environmental Gaps	
Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***
Improved understanding of physical oceanography.	*Essential for understanding distribution and abundance patterns, resilience, adaptability, dispersal etc. to better inform the importance of certain environmental drivers of coral distribution and abundance for use in future models.*
Improved understanding of biogeochemical variation in explaining connectivity.	*To optimize management by incorporating landscape sensitivity and hydrological connectivity.*
Improved understanding of the drivers of environment and ocean stressors (temperatures and chemistry).	*Necessary to understand past and current changes to help inform on policy relevant to future projections.*
What habitat values/function does it support.	*To identify functional linkages and incorporate this information into sustainable management of resources supported by corals.*

Spatial Gaps	
Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***
Improved sampling effort in areas of New Zealand interest in the High Seas (SPRFMO) and Ross Sea (CCAMLR) coral identification and distribution.	*Important to know what species are in these regions. Being able to understand total species distribution and population structure rather than just what is in our EEZ will increase our knowledge on connectivity between habitats/populations.* *Will help to inform management plans.*
Further understanding on distribution and abundance. Still a lot of 'holes' in the map. Limited sampling in some areas (>2000m and some BPAs).	*Difficult to manage the EEZ if there are still large gaps in the map because the information isn't available.* *Filling in these gaps will support spatial management of the New Zealand EEZ.*
Identification of sources and sinks, and biodiversity/functional hotspots.	*To identify high value areas to support decision making in spatial management.*
Are patterns of structure and gene flow "universal".	*Ensuring that research and management assumptions are appropriate and well informed.*

	Ecosystem-based management would benefit from assessment of multiple species.
Comparison of coral VME to other VME data such as that for sponges to identify overall vulnerable ecosystems.	*To be able to learn from and apply successful international regulation to protect vulnerable populations, communities, and habitats.*
Further genetic collections from sources not already explored.	*To provide basic understanding about the components of coral biodiversity, which is necessary for effective decision-making about conservation and sustainable use.*
How effective are current seamount closures and BPAs for protecting deep water corals.	*Better understanding if these spatial management measures have been useful, and provide evidence that they may or may not require modifications (e.g., moving, expanding, additions).*
Identification of the areas of highest protection value for deep water corals, given competing interests of fishing, future seabed mining, and effects of climate change/OA.	*Better understanding if these spatial management measures have been useful, and provide evidence that they may or may not require modifications (e.g., moving, expanding, additions).*
Improved understanding of colonisation and settlement patterns of larvae.	*To better understand nature and potential for recovery of populations in areas*
Further connectivity work, including work on different species than has previously been done.	*This information is needed to be able to predict recovery.*
Improved understanding on the role of life-history variation, physical oceanography, ABNJ and biogeochemical variation in explaining connectivity.	To be able to determine appropriate spatial and temporal scales for management and recovery of impacted areas.
Further information about the link between shallow and deep-water corals. For example, regarding shelf break areas etc.	*To be able to differentiate management measures between areas that require different protection.*

Modelling Gaps

Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***
Improved prediction of future refugia for both deep water and shallow water species.	*Identification of priority areas for spatial management.*
Better estimates of model uncertainty.	*Allows us to make more accurate decisions and trade-offs in spatial management.*
Models that estimate abundance in addition to presence absence.	*To allow the estimation of biomass as well as distribution. This could support work in identifying high value areas, or species that have a greater need for protection.*
The use of models to work out what biological variables are the key drivers	*In order to prioritise research projects so that the key environmental data are collected.*

of coral community composition, density, and “health”.	
Incorporation of refined and updated predictions of future ocean climate from new Earth System Models.	*Updated model will enable spatial planning software’s to utilise predicted future distributions and aid in re-prioritizing areas for protection.*
Identification of the linkages of gene flow to physical flow.	*To improve understanding of connectivity the therefore resilience of populations to disruption.*
Updated risk assessment with updated information, perhaps including parameters from the same coral species from other countries.	*To give us more accurate estimates to assess risk to coral species.*
More accurate models, that also include shallow water corals.	*Improve predictive power and priorities management strategies.*
Models with more accurate inclusion of data on biology of corals, and adaptive capacity.	*Improve prediction power and priorities management strategies.*

Threat & Pressure Gaps	
Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***
Investigation of ocean acidification impacts for deep and shallow water corals in the region, their dissolution and resilience.	*To identify possible refugia areas and identify species that are more likely to withstand the changes in the environment.*
Further experiments to understand the sensitivity of deep-sea corals to climate change, and if there is potential for acclimation.	*To provide more policy relevant projections, not just end-of-century to help management – e.g. we could protect any areas of potential refugia.*
Further investigation into the impacts of trawling on ecosystem function/services (e.g. carbon cycling, habitat provision for juveniles, fish etc.) provided by deep water coral/reefs.	*Better understand the wider impact on corals and associated communities, and be able to consider these impacts when designing management measures.*
Further investigation into the impacts of seabed mining on ecosystem function/services provided by deep water coral/reefs.	*Better understand the wider impact on corals and associated communities, and be able to consider these impacts when designing management measures.*
Improved understanding on how long recovery from trawling impacts and seabed mining take, and if communities recover to previous state.	*Better understanding on how long spatial closures may need to be in place, and if recovered areas will provide similar ecosystem function/services.*
Improved understanding on what facilitates the recovery of corals/habitat after trawling and seabed mining.	*Better understanding if there are any management measures that can be taken to improve recovery rate.*
What stressors and threats do these habitats and areas face (both	*To identify all threats that these habitats and areas face for further assessment of risk.*

repeated single stressors, and cumulative and multiple stressors).	
What management approaches can we adopt to reduce/mitigate these stressors, and perhaps even enhance productivity.	*To inform a diverse and effective suite of management approaches.*
Further information on affected and 'unaffected' areas from anthropogenic pressures	*To increase our understanding on these risks.*
In which regions/areas are we seeing the most rapid change, or which ecosystems.	*To help us identify possible refugia areas and aid in spatial management of these areas.*
Monitoring for changes in different areas, both in relation to larvae settlement and climate change.	*Improve the understanding of resilience and recoverability to better inform management approaches.*

Data, management & communicating science	
Please identify as many research/knowledge gaps as you can	***What use would we have for this information, how would it benefit management***
Incorporate new variables, records and methods.	*Ensure that the data architecture is adequate to facilitate relevant analysis.*
More robust image database storage system used for the observer collected digital images.	*For efficiencies and consistency of the image identification, which will help inform management decisions.*
Important to refine what is accepted as "robust" science when sample sizes are often small and spatial coverage may be poor.	*To ensure that management is informed by appropriate science.*
Improved understanding of *Areas Beyond National Jurisdiction* (ABNJ).	*Ensures that and research and management decisions take into account whole populations rather than being made at an EEZ or regional level.* *This also ensures a degree of consistency on coral management within and adjacent to the EEZ.*
Selection (e.g. SNPs – seascape genomics).	*To better understand the processes shaping the genetic structure of corals and the appropriate spatial management scales of coral taxa.*
How to best link in with other coral work, including approaches to assessing risk to corals.	*To minimize duplication in research and maximize the outcomes of research projects.*
Identifying and accessing relevant information sources; data consolidation.	*To have an easy and accessible way of reviewing existing information.*
Management discussion on what these gaps, or this information, means to us and to the management of the activities/species etc.	*To help us make more informed management decisions that both benefit the protection of these areas as well as the sustainable use of resources that are linked to them.*
Identification of new ways to communicate this science and knowledge to the public, and/or other platforms – data platform?	*To get the public more involved and interested in the protection of coral species.*

More coordination of existing coral research/projects.	*Minimize duplication and create synergies.*
We need to identify the difference of legislative. balance between inshore and offshore areas.	*To be able to better manage both shallow and deep-sea corals.*
We need to define specific management goals for deep-sea corals in New Zealand. Specific management objectives are ill-defined and poorly outlined, so it remains unclear what we're trying to achieve in terms of management with the data that we have (e.g, 10% spatial coverage? consider the CBD etc.).	*To use data available so far to, for example, derive management actions in line with NZs national and with international agreements to which NZ is a signatory.*

Appendix 5. Example images collected at sea by observers on commercial fishing vessels.