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PROTECTED DEEP-SEA CORAL  
SPECIES IN THE NEW ZEALAND  
REGION

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**NIWA Client Report: WLG2006-85**  
**November 2006**

**NIWA Project: DOC06307**

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# INFORMATION REVIEW FOR PROTECTED DEEP-SEA CORAL SPECIES IN THE NEW ZEALAND REGION

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## Department of Conservation

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## Executive Summary

There are growing concerns about the long term impacts of fishing activities on deep-sea corals, both within and outside New Zealand's Exclusive Economic Zone (EEZ). The Wildlife Act 1953 protects all "black corals" and "red corals"; the definition of the latter is currently being revised. However, the vulnerability of all coral groups to anthropomorphic threats is increasingly being recognized.

Corals can grow as (1) individual colonies (2) in beds and (3) in reefs; the latter two may be considered as structural assemblages and provide habitat for a wide range of other animals including other corals, sponges, echinoderms, and fish. There are no shallow-water corals which form reefs in New Zealand waters. The deep-sea species *Goniocorella dumosa* is the major New Zealand reef-former.

Deep-sea corals are fragile, sessile, slow growing, long-lived, have a low natural mortality rate, can have limited larval dispersal, and are restricted to certain habitats (e.g. seamounts) which are the focus of commercial fisheries. This makes deep-sea corals especially vulnerable to damage by fishing gear, and their low productivity means they have a long recovery period. Deep-sea corals are also at risk from other threats e.g. increased atmospheric CO<sub>2</sub> (drop in ocean alkalinity).

This review presents (1) a comprehensive summary of research information for the New Zealand region on "black corals" and all "red corals", as well as *Paragorgia* spp. (including the proposed protected species *Paragorgia arborea*), and other deep sea coral groups, (2) distributional information for the main protected taxa, and an examination of likely factors that determine their distribution, and (3) a list of all coral species in New Zealand waters.

Research in the New Zealand region has focused on the (a) black corals (Order: Antipatharia e.g. *Antipathes fiordensis*) (b) stony corals (Order: Scleractinia e.g. *Goniocorella dumosa*, *Madrepora oculata*, *Solenosmilia variabilis* and the New Zealand endemic *Oculina virgosa*) (c) Octocorals (Sub-Class: Octocorallia e.g. bamboo corals, gorgonians including the bubblegum corals *Paragorgia* spp.) and (d) "red corals" (Family: Stylasteridae e.g. *Errina* spp.).

The distributions of protected (including proposed protected) New Zealand corals have been mapped. Black corals had a wide distribution, by both depth and latitude. The occurrence of bubblegum corals increased northwards and east of New Zealand e.g. north Bounty Plateau, Chatham Rise, Bay of Plenty and the Kermadec arc. Records of the precious corals *Corallium* spp. (a sub-set of the gorgonians) largely occurred in the north - concentrated over the Kermadec arc, but were relatively infrequent. The "red corals" had a wide occurrence, with concentrations occurring in west coast South Island (WCSI) fiords, on the Chatham Rise and along the Kermadec arc. There are considerably fewer records of *Errina* spp. Concentrations are evident around the Chatham Islands, and off the coast of the WCSI. The "red corals" and *Errina* spp. have more frequently been found in shallower offshore areas (e.g., on the Chatham Rise). The distribution maps may be an artifact of sampling effort, as the distribution was noted to be similar to the recent distribution of commercial orange roughy trawl fisheries. Absence from the plots is not evidence of absence. The species included under the term "red coral" may be confused.

In New Zealand, deep-sea coral research has addressed some aspects of four core research themes (not exhaustive): (1) Biodiversity (including taxonomy) and biogeography (2) Reproduction and Recruitment (3) Growth and ageing and (4) Impacts of trawling. To understand (4) requires knowledge of (1), (2), and (3). However, our knowledge of deep-sea coral fauna in the New Zealand region remains poor. Without adequate research to determine the long term vulnerability and

biodiversity of deep-sea benthic communities, including deep-sea corals, and a better understanding of their ecology, good management practice will be hard to achieve.

## 1. Introduction

In the New Zealand region corals have been recorded from the intertidal to a depth of 4954m (Cairns *et al.* in prep). While the common view of corals remains that of shallow tropical reefs there are, in fact, no shallow reef formers in the New Zealand region, rather these are found in the deeper waters of New Zealand's Exclusive Economic Zone (EEZ). Patricia Ralph's 1948 statement "It is not generally recognised that the temperate waters surrounding New Zealand support quite an extensive coral population" remains as true now as it was then. Globally two thirds of all known coral species are deep-sea (Roberts and Hirshfield 2003). Deep-sea corals are often cited as an icon of deep-sea biodiversity and may serve as a rough indicator for community level biodiversity (e.g. Mortensen and Buhl-Mortensen 2005). However, the biodiversity of deep-sea corals around the world is poorly researched and New Zealand is no exception.

There are growing concerns about the long term impacts of fishing activities, both within and outside New Zealand's EEZ. It is widely recognised that deep-sea corals may be impacted by commercial trawling. Analogies have been drawn between forest felling and deep-sea trawling (Watling and Norse 1998). Many of the life history characters of corals (e.g. slow growing, long-lived, low natural mortality and short dispersal distance) could increase their susceptibility to anthropomorphic threats (Roberts and Hawkins 1999; Miller *et al.* 2004). However, to move beyond speculation requires a concerted research effort pertaining to the distribution and life history of these organisms. Only then will comprehensive risk assessments be possible.

This review presents (1) an overview of the current state of knowledge of deep-sea corals in New Zealand (2) a list of all New Zealand coral species (3) distribution plots of the protected and potential protected species and (4) suggestions for future research - with the aim of ultimately helping to inform management decisions to avoid, remedy or mitigate the adverse effects of fishing for protected (or to be protected) deep-sea coral species. New Zealand deep-sea coral literature is limited and therefore this review will also draw on research on the same, or similar species, from areas outwith New Zealand's EEZ.

## 2. Corals

Corals are found within the phylum Cnidaria (coming from the Greek word "Cnidos" which means stinging nettle). Four main classes of Cnidaria are known: the **Anthozoa** (which contains the true corals, anemones and sea pens); **Hydrozoa** (the most diverse class, comprising hydroids, siphonophores and many medusae); **Cubozoa** (the box jellies) and **Scyphozoa** (true jellyfish). Corals (found in the Anthozoa and Hydrozoa) can exist as individuals or in colonies, and may secrete calcium carbonate external skeletons which may act as habitat for other organisms.

Corals can be found in the photic zone of the ocean where sunlight penetrates (with symbiotic photosynthetic zooxanthellae, a type of alga) as well as in the deep-sea, the so called "cold-water corals" or "deep-sea corals" (azooxanthellate, meaning without zooxanthellae - note that azooxanthellate corals also occur in the shallow photic zone and therefore this trait cannot be taken as being indicative of deep-sea corals). Unlike zooxanthellate corals azooxanthellate can have a far wider distribution, not being limited by the ecological requirements of algal symbionts (Cairns and Stanley 1981). Most azooxanthellate corals are solitary (83% of known New Zealand species) (Cairns 1995) but several reef-formers are found in the New Zealand region e.g. *Solenosmilia variabilis*, *Madrepora oculata*, *Desmophyllum dianthus* and *Oculina virgosa*

The terms "cold-water corals" or "deep-sea corals" are often used interchangeably and within this report no attempt will be made to standardise usage, rather the terms will be used

consistently with the original literature source. Definitions of “deep” have been found to vary between authors and are generally arbitrary e.g. Etnoyer and Morgan (2005) defined deep-sea corals as those being deeper than 200m, the New Zealand Ministry of Fisheries (MFish) deep-sea fisheries working group includes species deeper than about 600m.

The existence of cold-water coral reefs has been known only since the 18<sup>th</sup> Century, but it is only recently, with technological advances (e.g. deepwater trawling, deep-towed imaging systems, submersibles, and advanced acoustics), that the extent of these organisms has been realised (Roberts *et al.* 2006). Cold-water corals are generally restricted to oceanic waters with temperatures between 4° and 12°C, which occur between ~50 – 1000 m (high latitudes) but up to 4000 m at lower latitudes (i.e. beneath warmer water masses) (Roberts *et al.* 2006). Research has indicated that cold water corals are fuelled by surface primary productivity (Duineveld *et al.* 2004).

Quoy and Gaimard (1833) published the first records of corals in New Zealand waters though corals received scant attention over the next century. Much of the collecting work was “adventitious” aboard expeditions of *New Golden Hind*, *Discovery II*, and *Terra Nova* (Squires and Keyes 1967). One of the first expeditions to focus on filling knowledge gaps was the Chatham Islands Expeditions (1954) (see Ralph and Squires 1962; Squires 1964).

The main corals that will be discussed in this report are: the scleractinians (stony corals), antipatharians (black corals), and octocorals (which include the gorgonians), all found within the Anthozoa, and the stylasterids (hydrocorals), which are found within the Hydrozoa. All “black corals” and “red corals” are protected under the Wildlife Act 1953 (under Schedule 7A). “Red corals” are currently legally classed as “coelenterates of the order Stylasterina” (Michael Gee pers comm.) but interests have largely focused on *Errina* spp. However, some confusion was evident in the literature and amongst the fishing industry as to what constitutes the “red corals” with opinion ranging from (1) this only including *Errina novaeseelandiae* (2) including all *Errina* spp. and (3) including other “red” species. The bubblegum coral *Paragorgia arborea* has also been proposed for protection. Other species of interest may include the precious coral *Corallium* spp. and the New Zealand endemic *Oculina virgosa*.



### 3. Habitat

Etnoyer and Morgan (2005) described deep-sea corals as being uniquely adapted to an extreme environment (and references therein) and Cairns and Stanley (1981) described 3 environmental requirements placed on deep-water coral banks: (1) hard substrata (2) association with vigorous current activity and nutrient supply and (3) cool water temperature. In the deep-sea exposed rock surfaces are limited. Seamounts represent a major source of exposed rock suitable for recruitment of sessile invertebrates (Gage and Tyler 1991). Additionally seamounts and other elevated topographical features can alter oceanic water flow and currents, thereby potentially increasing settlement rates and providing ideal habitat for suspension feeding animals. Seamounts can therefore sometimes support diverse and unique coral assemblages (Genin *et al.* 1986; Rogers 1994).

There are 800 known seamounts in the New Zealand region (almost certainly an under estimate) making them a common and widely distributed feature (Rowden *et al.* 2005). New Zealand has a complex seafloor relief and there is no “typical” seamount - they span a wide range of sizes, depths, elevations, geological associations and origins as well as occurring over the entire latitudinal range of the region both near and off-shore therefore offering a wide range of habitats. Of all the seamount complexes in the New Zealand region the Chatham Rise Graveyard complex is one of the most studied – and large sessile species including scleractinian and stylasterid corals are thought to be a major faunistic component (Probert *et al.* 1997; see early accounts from Ralph and Squires 1962; Squires 1965). Overall benthic species diversity and numbers (to the authors knowledge no coral specific study exists) can be similar as well as variable between seamounts (both within and between complexes) (Rowden *et al.* 2002, 2003, 2004). It is therefore not possible to make generalisations about seamount communities e.g. what type of seamount will support diverse benthic assemblages.

Until recently, research into New Zealand’s seamounts largely focussed on associated fish and fisheries (see Probert *et al.* 1997; Clark 1999; Clark and O’Driscoll 2003; Tracey *et al.* 2004) with Clark *et al.* (1999) being the first local paper to address seamount benthic invertebrates. Research has suggested a link between the physical characters of seamounts and the fish fauna, however information is lacking on any linkages between fish and the benthic invertebrate fauna e.g. corals (Clark and Field 1998; Tracey and Fenaughty 1997; Clark *et al.* 2001; Tracey *et al.* 2004).

Around 40 New Zealand seamounts have been biologically sampled to quantify benthic marine invertebrate diversity and examine spatial patterns (within and between seamounts) but the time and expense of such research restricts the sampling effort that is possible per locality. Furthermore, while data have been collected there can be considerable lag time between sampling and scientific publication, and data can remain in “grey” format for considerable periods (e.g. Clark and O’Shea 2001; Rowden *et al.* 2002, 2003, 2004). Regardless, the biological importance of seamount habitats has been recognised through legislative measures e.g. closing 19 seamounts to trawling.

### 4. Corals as a habitat

Cold-water corals can grow (1) as individual colonies (2) in beds, and (3) as reefs. The latter two may be considered as structural assemblages which can provide important habitat for organisms including other corals, fish (adult and juvenile), sharks, crustaceans, molluscs, echinoderms, anemones, bryozoans, foraminiferans and sponges. Furthermore coral frameworks can represent

a range of sub-habitats including (1) coral rubble (2) sediment clogged coral framework (3) dead coral frame (Rogers 1999; Rogers *et al.* submitted) increasing habitat availability, and therefore the biodiversity and faunal abundance/composition compared to background communities (Turner *et al.* 1999; Rogers *et al.* submitted). Freiwald *et al.* (2004) discussed, based on work on *Lophelia*, that dead coral framework may be the most speciose.

None of the warm-water coral species in New Zealand form reefs. It is in the deeper waters that New Zealand corals obtain large sizes and can create 3D habitats. The first Pacific deep-water coral structure (depth = 320m; structure = 40m high and 700m wide) was described from the Campbell Plateau (Squires 1965). *Goniocorella dumosa* was the major faunistic component, followed by *Desmophyllum cristagalli*. It was noted that other species were found within the coral structure including ophiuroids, sea star and molluscs. In the same publication Squires (1965) also recorded evidence of structures on the Chatham Rise. The dominant matrix forming and/or reef building scleractinians in the New Zealand regions are *Madrepora oculata*, *Madrepora vitiae* (apparently a symbiotic form of *Madrepora*), *Goniocorella dumosa*, *Enallopsammia rostrata*, and *Oculina virgosa* (endemic to New Zealand) which span depths from 70 to 2850m (Tracey *et al.* in prep). These are comparable to the well known *Lophelia pertusa* which is the subject of much research in the Atlantic.

The “constructional” diversity of deep-water reefs tends to be low, dominated by one or only a few species but can support high faunistic diversity (Cairns and Stanley 1981). Rogers (1999) compared deep-sea reef faunal diversity to shallow-water reefs (though noted that data were limited). Strong correlations have been reported between the presence of fish and a diverse benthic community (Squires 1963; Jones 1992; Koslow *et al.* 2000, 2001; Bett 2001) Deep-sea coral reefs may provide shelter and feeding grounds for fish, some of which may be commercially valuable (Husebø *et al.* 2002). Beu and Climo (1974) described the association of molluscs with *Goniocorella dumosa*, as well as crustaceans, echinoderms and some solitary corals. In Tasmania 24 – 43% of the species collected from *Solenosmilia variabilis* reefs were new to science (and 16 – 43% could be endemic) (Richer de Forges *et al.* 2000; Koslow *et al.* 2001).

However, corals do not have to be reef building to be important structural components with large erect fauna serving to increase the complexity of the habitat (Probert *et al.* 1997). Etnoyer and Morgan (2005) define habitat-forming deep-sea corals as those species which are of sufficient size to provide substrata or refugia to other organisms and typically have a complex branching morphology, coming from the octocorals (e.g. Coralliidae, Isididae, Paragorgiidae and Primnoidae), hexacorals (Antipathidae, Oculinidae, and Caryophyllidae), and stylasterids (Stylasteridae). Etnoyer and Morgan (2005) do not consider scleractinian solitary corals to be habitat forming.

Octocorals are ecologically important habitat forming corals that can be found on seamounts providing habitat for numerous other invertebrates and fish (Koslow *et al.* 2001; Heifetz 2002; Krieger and Wing 2002; Buhl-Mortensen and Mortensen 2004 and references therein). Gorgonian fans habitats do not overlap with scleractinian corals, instead occurring in more solitary habitats and therefore providing habitat for other invertebrates and fishes (Andrews *et al.* 2002; Auster *et al.* 1999). Cairns *et al.* (in prep) highlighted the ecological significance of large gorgonians on seamounts, knolls and hills in the New Zealand EEZ. Such deep-sea corals may become very old and robust, providing refuges for invertebrates and fish.

In 1948 Ralph recorded barnacles, marine worms and brittle stars to form associations with antipatharians. Polychaete worms can form galls in stylasterids (Cairns 1991) as well as inducing the formation of calcareous tubes on branches e.g. *Madrepora oculata*.

Large structure forming corals such as *Paragorgia* spp. (Paragordiidae) are common gorgonians on New Zealand seamounts (Cairns *et al.* in prep). *Paragorgia arborea* may be the largest seafloor invertebrate on the planet and lives in New Zealand waters. A specimen of *Paragorgia arborea* is held in the NIWA invertebrate collection. In the North Atlantic 7 colonies of *Paragorgia arborea* were found to harbour 1300 crustaceans, 16 species (Buhl-Mortensen and Mortensen 2004). The stylasterid *Conopora adeta* grows around the polychaete *Benhamipolynoe cairnsi* to encase it in a coiled tube (Pettibone 1989).

Cold-water corals act as ecosystem engineers and are “arguably the most three-dimensionally complex habitat in the deep-sea” (Roberts *et al.* 2006) but few quantitative studies have been made. The function of deep-sea corals as habitats for other organisms is often anecdotal or from photography/videography. Further investigation is required if we are to investigate this quantitatively, and research programmes in Europe and America are rapidly moving into this field (see Etnoyer and Morgan 2005).

## 5. Major taxonomic groups of deep-sea corals in New Zealand

The following sections of this report will examine the major taxonomic groups of deep-sea corals within New Zealand’s EEZ but it should be noted that the list is not exhaustive.

**Class: Anthozoa**

**Subclass: Hexacorallia**

**Order: Scleractinia**

**Stony corals**

**Research has focussed on:** *Desmophyllum dianthus*, *Enallopsammia rostrata*, *Goniocorella dumosa*, *Madrepora oculata*, *Madrepora vitiae* (apparently a symbiotic form of *Madrepora*), *Oculina virgosa* (endemic to New Zealand), *Solenosmilia variabilis*

Stony corals or scleractinians are exclusively sessile with an aragonitic calcium carbonate corallum, typically white but can range in colour from mottled/streaked blacks, browns and pinks. While most azooxanthellate scleractinians are solitary (83%) some do grow as colonies (Cairns *et al.* in prep). Scleractinian corals are the only reef forming corals (Morgan 2005). 51% of stony corals are azooxanthellate which increases the range of niches available as they can tolerate a wider range of temperatures and can extend beyond the photic zone (Cairns *et al.* in prep).

The scleractinians were once recorded as one of least known coral faunas of New Zealand (Ralph and Squires 1962) and in 1967 Squires and Keyes reported that stony corals were not a major faunal element of the New Zealand shelf, having limited diversity and abundance, though recognised that this could be indicative of limited sampling. However, the work of Stephen Cairns has reversed this situation (e.g. Cairns 1995). The rises and plateaux in the New Zealand region are now reported to contain a rich scleractinian assemblage – higher than those recorded in other ocean basins.

105 azooxanthellate scleractinians have been recorded in the New Zealand region (representing 15% of the known azooxanthellates) with 80% occurring on the upper slope (defined as 200 – 1000m) and 39% on the lower slope (defined as 1000 m to 3000 m), and only one species known from the abyssal region (Cairns 1995; note % exceeds 100 because some species occur in more than one zone). Azooxanthellate scleractinians occur from the Arctic Circle to off continental Antarctica and despite being referred to as “deep-water” can occur from the surface to 6328 m (Cairns 1995).

Of the 18 scleractinian species known in 1943, 10 were thought to be endemic (Vaughan and Wells 1943). In 1991 32% of New Zealand scleractinians were estimated to be endemic but care must be taken with the interpretation of this number as it is likely that these species could be found to be more cosmopolitan with an increased sampling effort (Cairns 1991).

In 2004 Tracey et al (in prep) recorded 422 records of scleractinians in New Zealand compared to 2 in 1962. *Goniocorella dumosa* is the most common species recorded (40%). *G. dumosa* has its main distribution in New Zealand waters (Freiwald et al. 2004). *Solenosmilia variabilis* has a cosmopolitan distribution but reefs have only been seen in the Tasman (Koslow et al. 2001; Freiwald et al. 2004). *Enallopsammia rostrata* has been recorded to form reefs along the edges of some Pacific banks e.g. Chatham Rise (Probert et al. 1997) but there has been no targeted survey of the occurrence of these reefs (Freiwald et al. 2004).

Burgess (2002) reported that greater than 60% of the scleractinian samples examined in New Zealand were dead. These findings are consistent with other locales (see also Wilson, 1979; Mortensen et al. 1995, 2001; Koslow and Gowlett-Holmes 1998). The microbored calices and manganese stains suggested that these dead corals have remained undisturbed in the relatively stable deep-sea environment. These dead reefs are most likely resultant from historical environmental changes e.g. in circulation than recent anthropogenic influences (Burgess 2002).

**Class: Anthozoa**

**Subclass: Hexacorallia**

**Order: Antipatharia**

**Black corals (all protected)**

**Research has focussed on:** *Antipathes fiordensis*; *Antipathes aperta*

Black corals, or antipatharians, are distinguished by their erect and often bushy growth forms and hard proteinaceous skeleton that bears tiny polyps. There are around 58 black coral species known in New Zealand waters (Tracey et al. 2005) and of the 58 species found, 8 appear to be new and undescribed adding to the number of endemic black coral species. Black corals are important structure forming corals (Morgan 2005) yet, in spite of their recognised ecological importance (Cairns et al. in prep) are under-studied because of the difficulties inherent in observing them alive.

Some black corals are harvested to make jewellery, but none of the New Zealand species are suitable, and are all protected. Most species live in the deep-sea on seamounts between 200 and 1000m depth, but the depth and geographic distributions have not yet been analysed in sufficient detail to be conclusive (Cairns et al. in prep).

Rare antipatharian species including only the second known specimen of *Saropathes scoparia* (Totton) which was originally collected from the Three Kings Islands in 1910 by the British

*Terra Nova* Expedition (Opresko 2003). These specimens are held in the exist in the NIWA collection.

**Class: Anthozoa**  
**Sub-class: Octocorallia**  
**Order: Alcyonacea**  
**Order: Gorgonacea**  
**Order: Pennatulacea**

**Octocorals**

**Research has focussed on:** Isididae (bamboo corals), *Paragorgia* species especially *P. arborea*

Octocorals are so named because their polyps have 8 fold symmetry and can range from being hardened to relatively soft, they also may be jointed. Some of the largest deep-water sessile benthic invertebrates come from the subclass Octocorallia, yet the octocorals have been described as the poorest known group of large animals in New Zealand's EEZ (Sánchez 2005).

Sánchez and Rowden (2006) carried out the first assessment of octocoral diversity in New Zealand, examining collections from 27 seamounts. They determined a high level of potential species endemism, particularly in the Isididae, Paragorgiidae and Primnoidae; with many of these taxa new to science (see also Smith *et al.* 2004). A total of 104 species (see Table 1 in Sánchez and Rowden, 2006) were recorded from 13 families (the most well represented families were the Primnoidae: 27 species; Isididae: 21 species; Plexauridae: 19 species). The overall number of octocoral families found in the New Zealand region is comparable to other Pacific regions e.g. Hawaii (for example Grigg and Bayer 1976) but the lack of detailed studies prevented Sánchez and Rowden (2006) from carrying out more robust comparisons. However, this is thought to be the largest number of octocoral species from a single Exclusive Economic Zone, though the worldwide lack of published data prevents any strict comparisons (Sánchez and Rowden 2006).

The "Bubblegum" corals (species of *Paragorgia* and *Sibogorgia*), including the proposed protected species *Paragorgia arborea*, are unusual octocorals – whilst they form tree-like structures they are not corneous (horny) and calcareous, rather they are formed of sclerites (microscopic calcium carbonate bits) (Sánchez 2005). In 2005 Sánchez described 11 new species of Paragorgiidae in the New Zealand region (taking the total to 17) as well as determining 2 areas of endemism for bubblegum corals corresponding to New Zealand and the Eastern Pacific. New Zealand is thought to have 6 species of endemic *Paragorgia* (*P. alisonae*, *P. kaupeka*, *P. maunga*, *P. aotearoa*, *P. where* and *P. wahine*) as well as 2 of *Sibogorgia* (*S. tautahi* and *S. dennisgordoni*) (Sánchez 2005)

Sánchez (2005; see also Sánchez and Rowden, 2006) found the New Zealand Paragorgiidae to be the most diverse in the world, but noted that this should not be surprising as New Zealand has already been noted as a deep-water biodiversity hotspot for other sessile colonials e.g. stylasterids, bryozoans (Gordon 1989; Cairns 1991). However, Sánchez (2005) suggested that this could be the tip of the iceberg as samples were based on few specimens.

There are very rare groups of other gorgonian corals e.g. *Anthomastus robustus* and members of the Ifalukelidae family have been found in New Zealand.

Australasia has also been shown to be a diversity hotspot for bamboo corals (Alderslade 1998). With less than 30 seamounts sampled, and limited sample units per seamount these numbers are most likely an underestimate.

Sánchez and Rowden (2006) predict that further analysis of the octocorals - including the Chrysogorgiidae (golden corals), Plexauridae (gorgonian), and Primnoidae (scaled)- will yield further new/endemic species. Many of the largest octocorals are thought to be undescribed and a concerted effort is needed to identify these organisms and their likely habitat, especially regards protection (e.g. from bottom trawling) and conservation of these species.

**Class: Hydrozoa**

**Order: Anthoathecata**

**Sub-order: Filifera**

**Family: Stylasteridae**

**Stylasterids**

**Research has focussed on:** *Errina dendyi*; *Errina novaezelandiae* (protected)

Hydrocorals all belong to the hydroid family Stylasteridae. Hydroids are non-calcified and generally have tiny polyps (some of these function like stomachs whilst the non-feeding polyps are used for food capture and reproduction). New Zealand hydrocorals are erect and branching, and may be white or red. New Zealand has one of the most rich stylasterine faunas in the world (80% of described species are endemic to New Zealand) (Cairns 1991; Miller *et al.* 2004).

The higher classification of Hydrozoa has been in a state of flux as phylogenetic studies try to elucidate monophyletic groups. The Stylasterina (since revised to Stylasteridae) are now understood to be calcified anthoathecates (Order Anthoathecata). The suborder Filifera includes the coral-like Stylasteridae (formerly order Stylasterina) one of five families of the super family Hydractinoidea. The New Zealand stylasterid fauna of 55 species is one of the most diverse in the world (Cairns 1991).

The largest and most “striking” stylasterid is the protected “red coral” *Errina novaezelandiae* which can branch up to 21cm across. Historically, another stylasterid, *Errina dendyi* (Hickson 1912), was synonymized with *E. novaezelandiae* but was reinstated as a species by Cairns (1991). *E. dendyi* can vary in colour from red through orange to white (Cairns 1991) and while mature colonies can be morphologically distinguished from *E. novaezelandiae* small (< 5cm) colonies can be difficult to tell apart and genetic sampling may be required (Miller *et al.* 2004). Miller *et al.* (2004) reported, on average 19 % (varying from 0 to 59%) of the “*E. novaezelandiae*” they collected were in fact *E. dendyi* rather than *E. novaezelandiae*.

The biology and ecology of the stylasterids are largely unknown (Miller *et al.* 2004) however, *E. novaezelandiae* possesses numerous life history traits that mark it as vulnerable to extinction e.g. skewed population structure with small colonies being most abundant (in shallow fiords), slow growth, and genetically subdivided populations (Terborgh and Winter 1980; Ångermeier 1995; Roberts and Hawkins 1999; Miller *et al.* 2004).

Hydrocorals may be more vulnerable to breakages than scleractinians (Tilmant and Schmahl 1981).

## 6. Distribution of deep-sea corals in the New Zealand region

### 6.1 Primary literature

Early New Zealand research on the distribution of deep-sea corals came from raising cables (by William Foster; Ralph and Squires 1962). While the majority of the early major oceanographic expeditions visited New Zealand, reports on the corals collected are rare (Ralph and Squires 1962). To date there is still limited information pertaining to the distribution of deep-sea corals in the New Zealand region (Smith *et al.* 2004) however, to thoroughly assess the vulnerability of deep sea corals to anthropogenic activities such as fishing, an understanding of this distribution is essential.

In 1955 the New Zealand Oceanographic Institute developed a programme of benthic research which increased knowledge of coral distribution. Initial publications (e.g. Squires and Keys 1967) recognised that sampling effort biased maps of distribution, but demonstrated that corals extend around the New Zealand coastline and along the north and south Chatham Rise.

In New Zealand the cold-water branching stony coral taxa *Madrepora oculata*, *Madrepora vitiae*, *Solenosmilia variabilis*, *Goniocorella dumosa*, *Enallopsammia rostrata*, and *Oculina virgosa* have been observed on seamounts and on flattops (Squire 1965; Clark 1999). Cairns (1995) assessed the distribution of the 105 azooxanthellate scleractinian corals (15% of known azooxanthellate scleractinian worldwide) in New Zealand - both geographically and by depth. He determined 4 general patterns of distribution (1) Cosmopolitan (2) Endemic (3) Wide spread temperate and (4) Antarctic; defining up to 5 divisions within each of these. 80% of New Zealand scleractinians were found to occur deeper than 200m (down to 1000m. However, the deepest occurred at 4954m). Note that species can bridge depth zones. Cairns (1995) also reported that 57% of New Zealand's azooxanthellate scleractinian corals represent the southern limit of these species worldwide.

The depth and distribution of black corals has not been analysed in detail (Cairns *et al.* in prep).

Despite the apparent diversity of octocorals, sampling has been limited and hence a accurate characterisation of their range is not possible. Many are thought to be endemic to the New Zealand region, such as 6 species of *Paragorgia*. *Paragorgia arborea* (proposed for protection) has an apparently cosmopolitan but highly discontinuous distribution (sub-polar and equatorial, with no records in between) (Sánchez 2005).

The abundance of stylasterids in the deep water from off the North Cape to the Southern Fiords as well as eastwards towards the Chatham Islands was recorded in 1948 (Ralph 1948) and the growth forms in excess of a foot (30 cm) were recorded as early as 1947 (Powell 1947).

At the ocean scale factors such as large scale patterns of hydrography will also influence distribution e.g. through different levels of surface productivity. However, within the New Zealand region more localised factors such as topography will influence the distribution patterns of cold-water corals. Rogers *et al.* (submitted) compared the global depth distributions on different coral groups (scleractinian, octocoral, antipatharian, and stylasterid) determining that the depth distributions were significantly different between groups, with octocorals occurring the deepest. This has clear implications for predicting potential coral diversity on unsampled seamounts (Rowden *et al.* 2005; Rogers *et al.* submitted) though depth was not shown to be the

major driver of distribution (Rogers *et al.* submitted). Genin *et al.* (1986) determined that antipatharian and gorgonian corals are most abundant near the peaks of seamount, which may be linked to the enhanced water flow.

A key issue when examining any distribution data is that they can be inherently biased by sampling locations (both scientific and commercial fishing), absence from a distribution plot cannot be taken as evidence of absence. An additional consideration must be data quality. Etnoyer and Morgan (2005) outlined a selection/ranking system based upon skill of identification and availability of specimen as well as the accuracy of geographic information.

Modelling is increasingly being utilised to predict coral distribution using existing presence records and environmental data (e.g. Leverette and Metaxas 2005; Data Analysis Working Group (CenSeam: global census of marine life on seamounts) in press). Leverette and Metaxas (2005) were the first to model deep-sea coral habitat; determining *Paragorgia arborea* (on the Canadian Atlantic shelf and slope) to have high niche specialization – characterised by steep slopes and rocky substrates. This was in contrast to another species *Primnoa resedaeformis* which was more cosmopolitan in its distribution.

## 6.2 Species distribution maps

In compiling this review, current databases (see Appendix) were used to map the distributions of the following groups, chosen for their relevance to the Department of Conservation Conservation Services Programme Strategic Plan: (a) all black corals (b) all gorgonians (c) All *Paragorgia* spp. / *Sibogorgia* spp, which included the proposed protected *Paragorgia arborea* (d) all precious corals *Corallium* spp. (e) all corals classified as red (for further discussion see Appendix) (f) the protected red hydrocoral *Errina* spp.

Although we can't be certain about species absences, the maps allow some general distribution trends to be described for corals in the New Zealand region. Most of the mapped species were recorded from the deep-sea regions, and in particular from the cold waters of the west coast South Island (WCSI) fiords.

The protected black corals had a wide distribution, by both depth and latitude (Figure 1). They were clustered around WCSI fiords, over commercially fished seamount features, and in regions on the flat. The depth range recorded was surface to 4954m. Excluding the fiords, records increased towards the north and in eastern waters (e.g. Chatham Rise) – although this may be an artefact of sampling effort, as the distribution is similar to the recent distribution of commercial orange roughy trawl fisheries on seamounts (See Anderson and Dunn 2006).

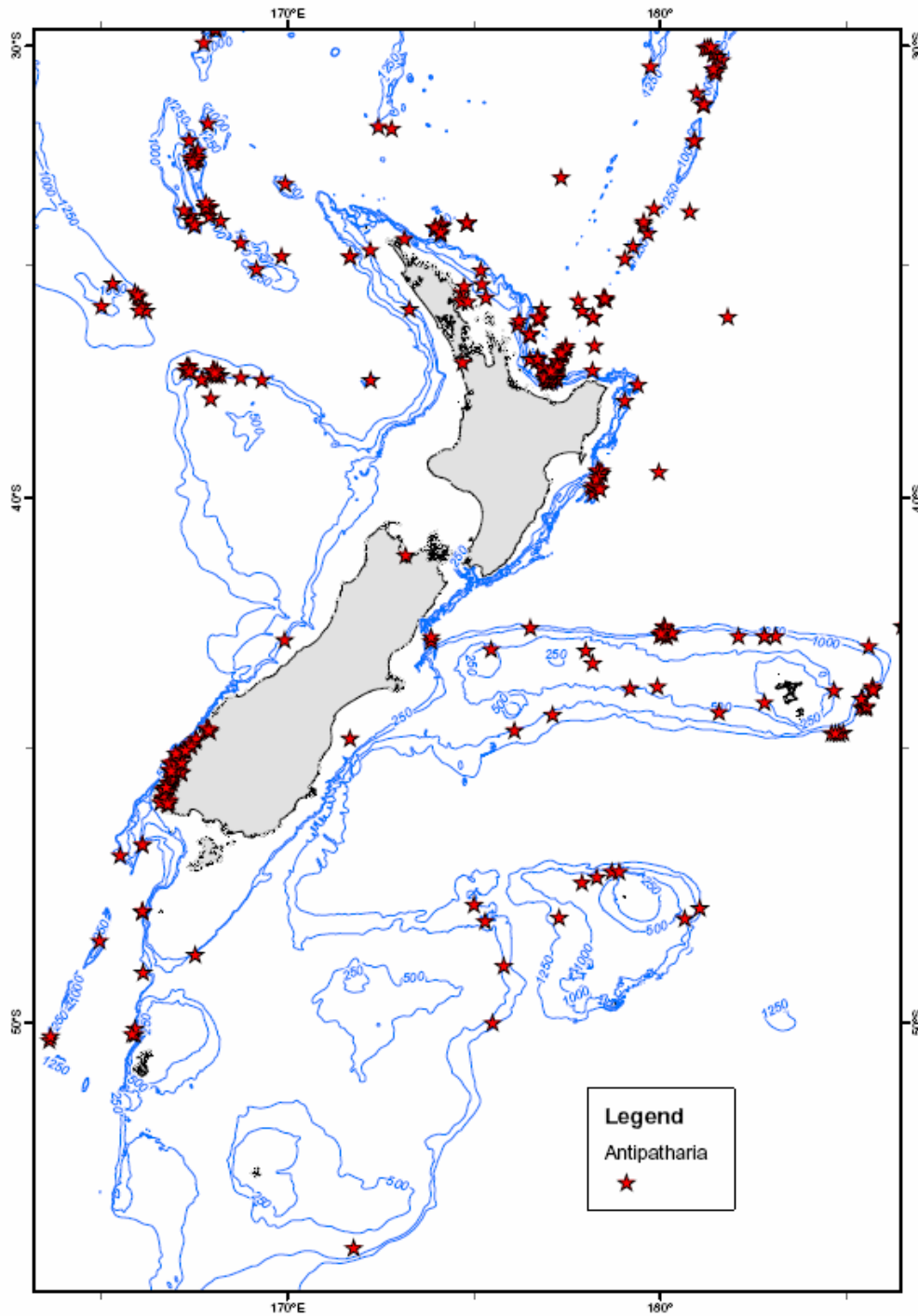
For corals recorded as “gorgonian” occurrence increased northwards and east of New Zealand (Figure 2) (e.g. Chatham Rise, Kermadec arc, Bay of Plenty, and north Bounty Plateau). As mentioned above, this may be artefactual because it may be related to patchy fishing effort. A subset of the gorgonian group, the bubblegum corals were concentrated around seamount features, similar to the gorgonians (Figure 3). The precious corals *Corallium* spp. (also a sub-set of the gorgonians) occur from the surface to 2147m, with records largely in the north and concentrated over the Kermadec arc, but relatively infrequent (Figure 4).

“Red coral” has previously been used as a generic term. The “red corals” may have included any coral with pink to red or red to orange colouration and could include, as well as *Errina* spp.,

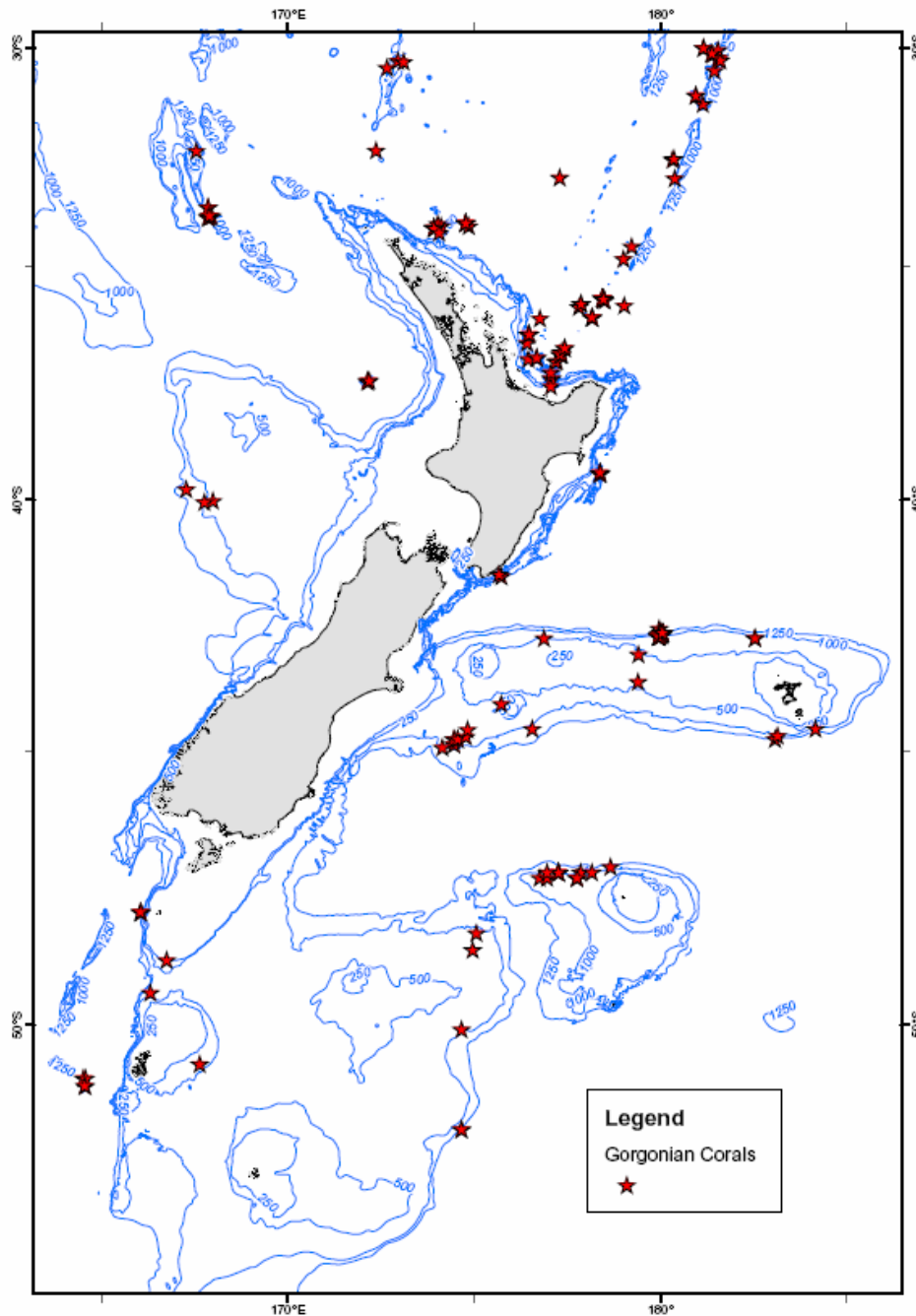


gorgonian corals such as *Corallium* spp. *Paragorgia* spp., and *Sibogorgia* spp, and possibly some Scleractinian stony corals such as *Solenosmilia variabilis*, *Goniocorella dumosa*, and *Oculina virgosa*. The Ministry of Fisheries species code used to record “red corals” (COR) may have also mistakenly been used as a generic code to record any corals. The “red corals” have a wide occurrence with concentrations occurring in WCSI fiords, on the Chatham Rise and along the Kermadec arc (Figure 5). There are considerably fewer records of *Errina* spp – concentrations are evident around the Chatham Islands and off the coast of the WCSI (Figure 6). The “red corals” and *Errina* spp. have more frequently been found in shallower offshore areas (e.g., on the Chatham Rise) than the other corals plotted.

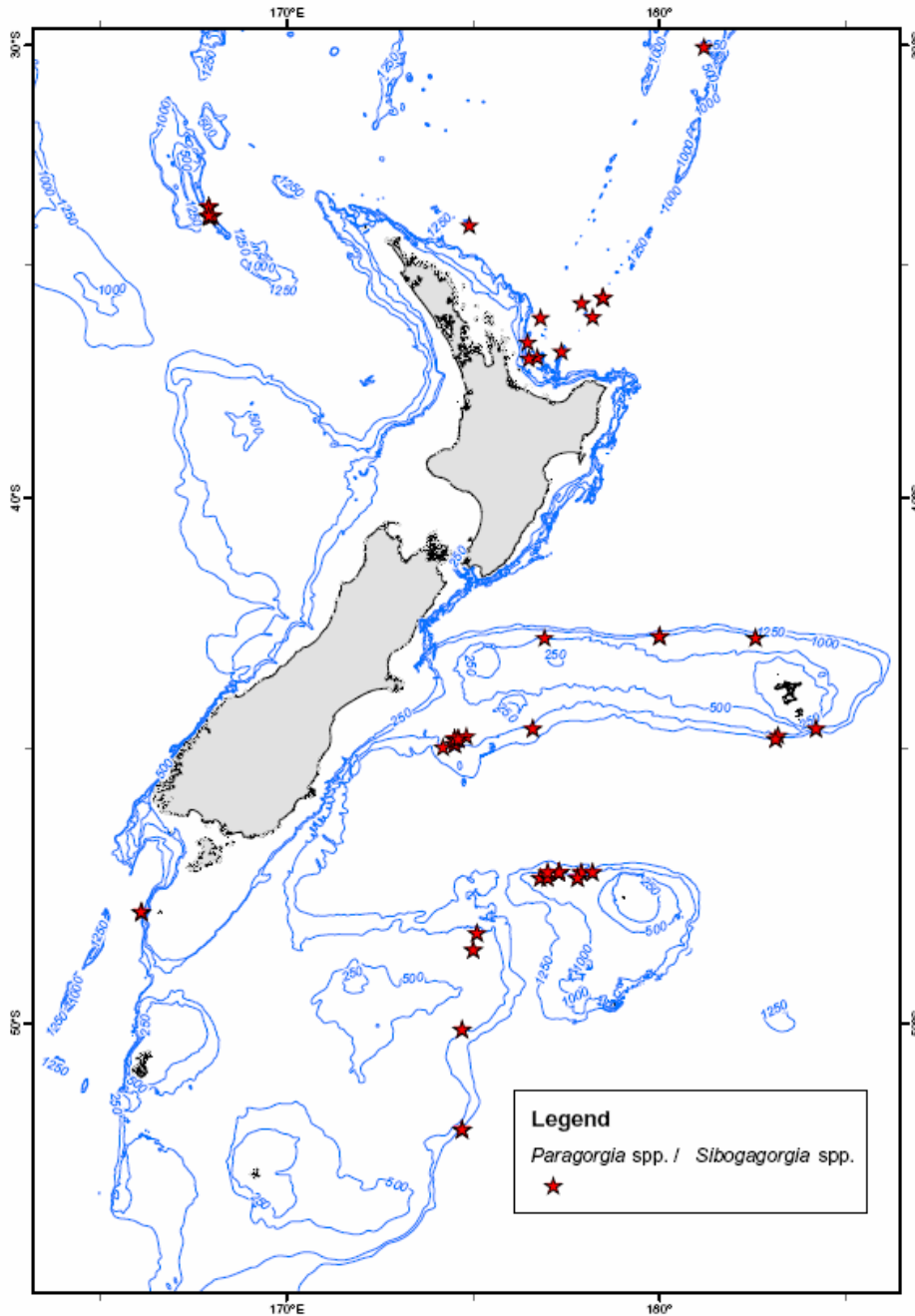
Some of the areas where corals are “absent” correspond with areas that are closed to commercial fishing e.g. Challenger Plateau - closed to fishing in 2000 or where there has been little recent commercial fishing activity e.g. Campbell Plateau. In addition, areas that have historically been commercially fished may no longer have corals as a result of extensive trawling. This may introduce a bias if corals were not recorded when they were present during the early years of the fishery.



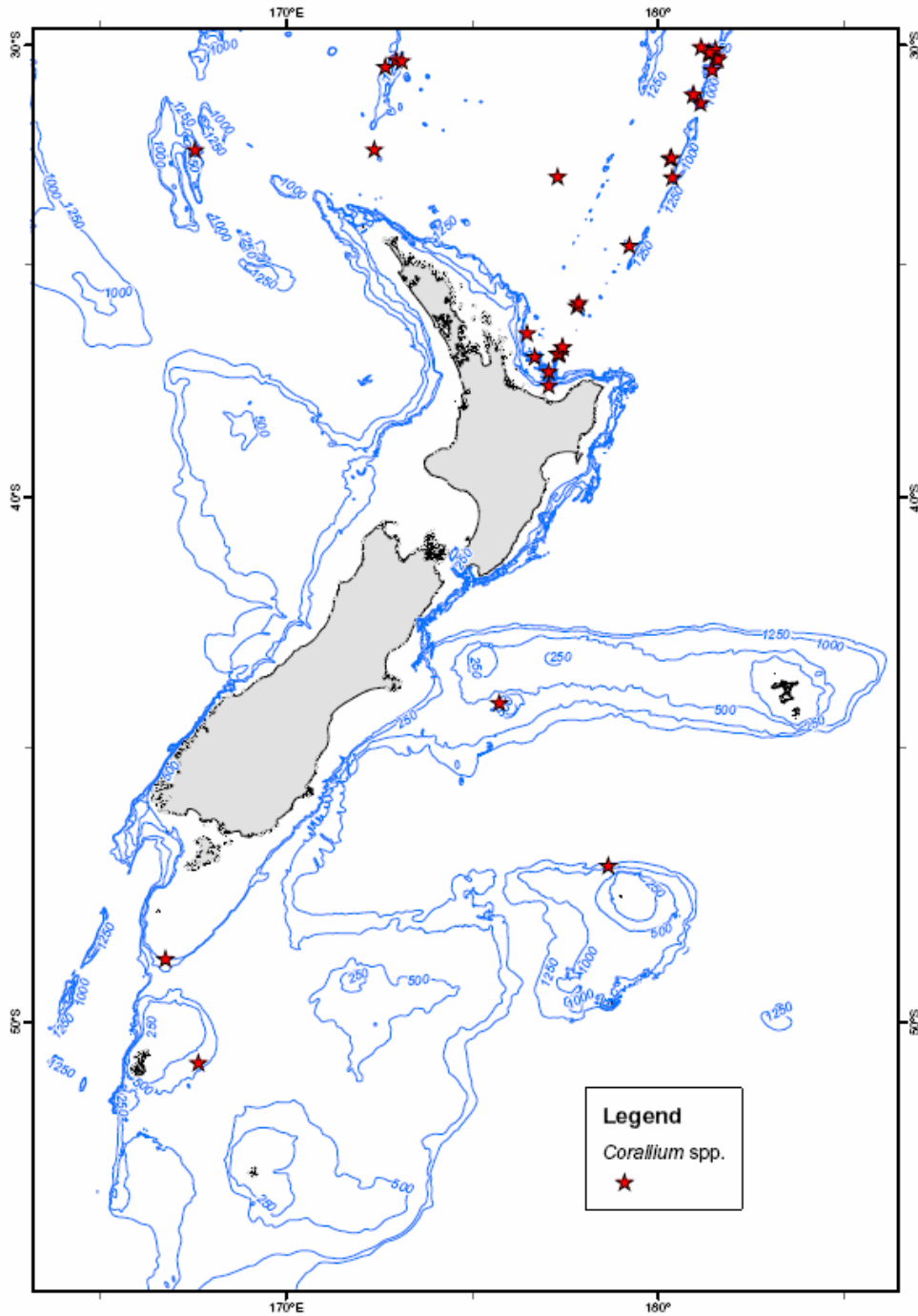
**Figure 1:**  
Known localities of all black corals (Order Antipatharia) records within the New Zealand region. Depth isobaths are 250, 500, 1000, and 1250 m.



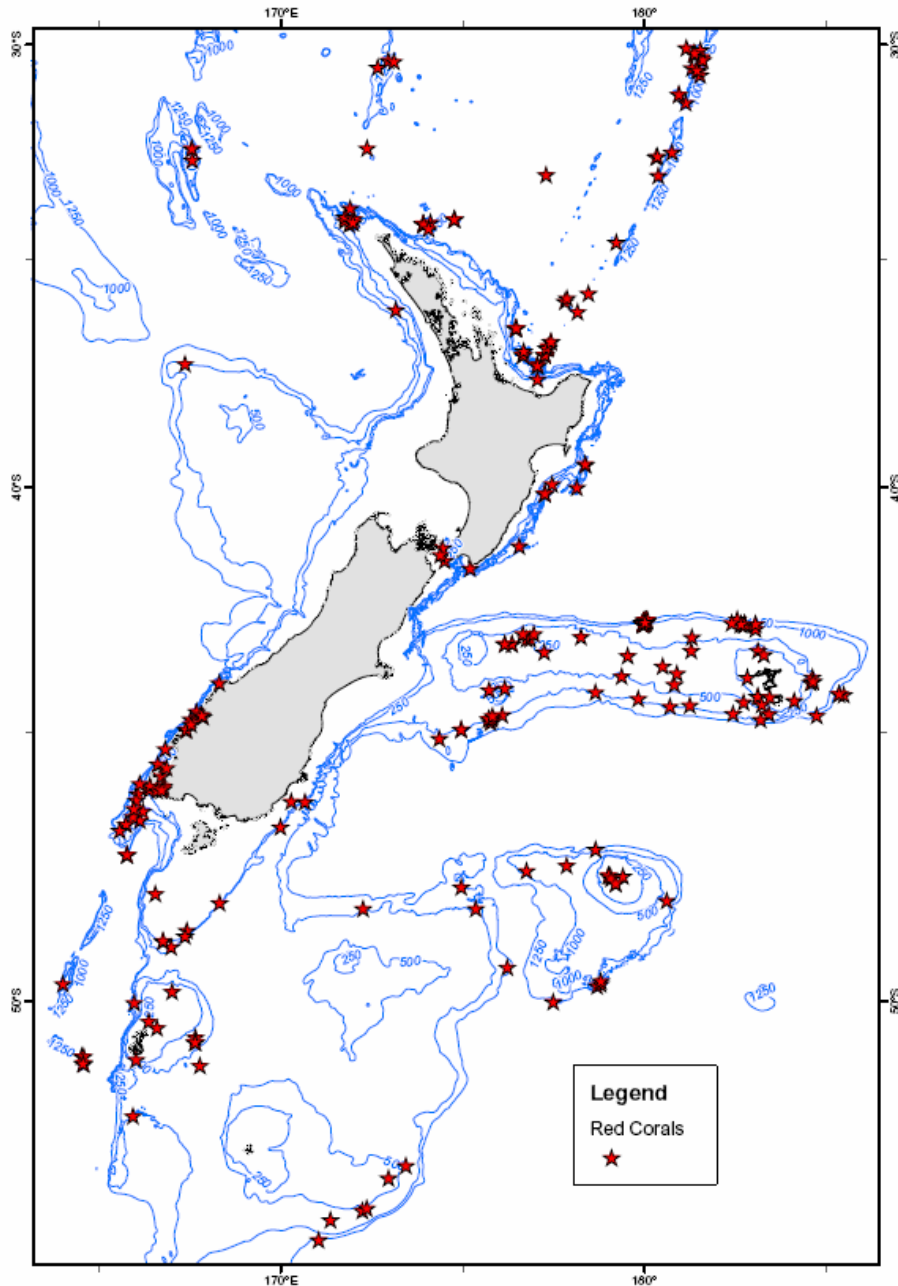
**Figure 2:**  
 Known localities of all gorgonian corals (code GOC) records within the New Zealand region. Depth isobaths shown are 250, 500, 1000, and 1250 m. Data for this plot were extracted from the Ministry of Fisheries observer and research trawl databases where the code GOU was used. Code GOU is likely to include coral records for any gorgonian species such as *Corallium* spp., *Paragorgia* spp., *Thourella*, or bamboo corals from the family Isididae (see complete list for Order Gorgonacea in Appendix 2).



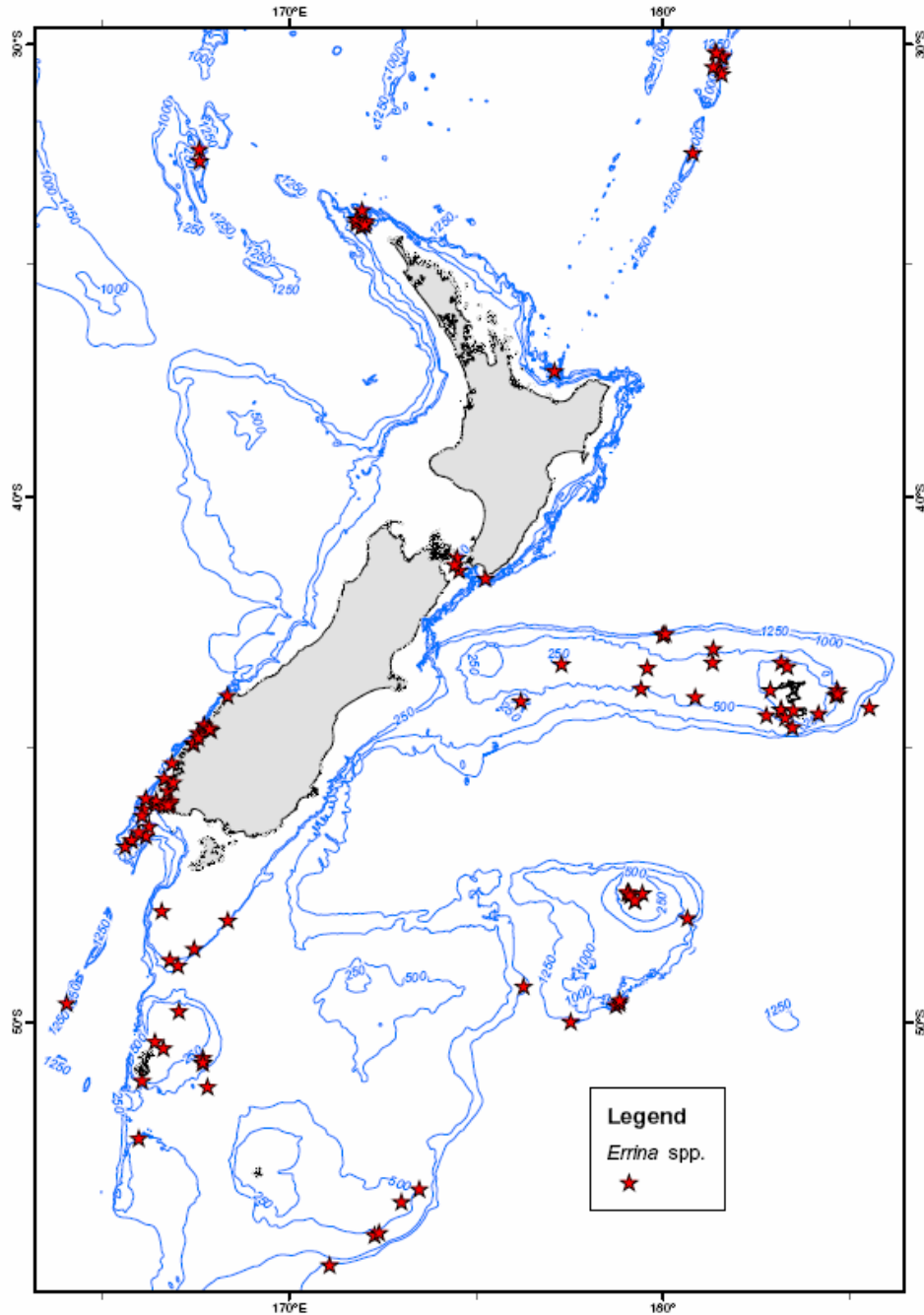
**Figure 3:**  
 Known localities of all bubblegum corals *Paragorgia* spp. / *Sibogorgia* spp. (Order Gorgonacea; Family Paragorgiidae) records within the New Zealand region. Depth isobaths are 250, 500, 1000, and 1250 m



**Figure 4:**  
Known localities of all precious coral *Corallium* spp. (Order Gorgonacea; Family Corallidae) records within the New Zealand region. Depth isobaths are 250, 500, 1000, and 1250 m



**Figure 5:**  
**Known localities of all red coral (code COR) records within the New Zealand region. Depth isobaths are 250, 500, 1000, and 1250 m. Data were extracted from Ministry of Fisheries observer and research trawl databases where the code COR was used. Code COR is likely to include any coral with pink to red or red to orange colouration and could represent Stylasterid hydrocorals such as *Errina* spp., gorgonian corals such as *Corallium* spp. *Paragorgia* spp., and *Sibogorgia* spp, and possibly some Scleractinian stony corals such as *Solenosmilia*, *Goniocorella*, and *Oculina*. Note: Code the code COR may have also mistakenly been used as a generic code to record any corals.**



**Figure 6:**  
Known localities of all red hydrocoral *Errina* spp. (Order Hydroida; Family Stylasteridae) records within the New Zealand region. Depth isobaths are 250, 500, 1000, and 1250 m.

## 7. Systematics of deep-sea corals in New Zealand

Systematics describes classification of organisms, with the aim of reconstructing their evolutionary histories and phylogenetic relationships. The taxonomy of cold-water corals is recognised as a neglected area of research. Squires and Keyes (1967) recognised that certain species were of doubtful status and noted that further research and review was required to enable a full classification and inventory of species in the New Zealand region. Genetic studies are increasingly important in this field but there are few genetic data on deep-sea corals (Smith *et al.* 2004). New Zealand's coral fauna, despite the apparent high levels of endemism, is not an old fauna, rather a new one (Neogene, corresponding to the Miocene and Pliocene epochs) (Squires and Keyes 1967) however, New Zealand's history of geological isolation may have provided opportunities for speciation which may lead to endemism (Cairns *et al.* in prep).

Until recently the number of black coral species known in NZ waters was 10. An ongoing study since 1999 of New Zealand material has increased the black coral fauna to 58 species, representing c. 35% of the approximately 160 species now known from the entire Indo-Pacific. These new records were "discovered" in the existing NIWA invertebrate collection (Cairns *et al.* in prep).

Octocorals are often called "trees" by fishers but recent molecular phylogenies have demonstrated that branching can in fact evolve independently (convergent evolution) and therefore care must be taken in using morphology for taxonomy (Sánchez *et al.* 2003). Shallow water corals show considerable phenotype plasticity and this may also be the case in the deep sea.

Octocorals in the New Zealand region are phylogenetically diverse (Sánchez *et al.* 2003; Sánchez and Rowden 2006). This may be attributed to the geological history as different clusters of seamounts were semi-isolated in different ocean basins (e.g. Pacific, Indian and Australasian plates). However, owing to the inadequate state of knowledge of species-level taxonomy it is not yet possible to evaluate the degree of endemism in the New Zealand octocoral fauna.

Biodiversity analysis by Sánchez and Rowden (2006) on octocorals in the New Zealand region revealed that the Average Taxonomic Distinctness (AvTD) of octocoral assemblages from most of the sampled seamounts did not significantly differ from the AvTD of the octocoral assemblage from the entire New Zealand region, the regional species pool. Furthermore the AvTD of some proximate seamounts was the same as for some distant ones. However, Sánchez and Rowden (2006) did note some exceptions with some of the more northern seamounts Havre, Rumble III and Cavalli having lower AvTD scores i.e. the taxa were distributed among very few genera/families and orders that were not well represented in other seamounts in the New Zealand region (though it should be noted that these octocoral assemblages were still speciose). This result indicates that local e.g. environmental conditions on these seamounts differ from others in the region. Whilst both Havre and Rumble III are volcanic it is unlikely that they significantly differ from other volcanic seamounts in the Kermadec arc in their physical and biological characters (Wright 1994) and further investigation is required to address questions about why these seamounts were different., Cavalli was the most taxonomically distinct seamount sampled in the New Zealand region and also differs from other seamounts in the region in both its geological origin (hence its physical/chemical substrata presenting a different benthic habitat see Mortimer *et al.* 2003) and biological situation (Cavalli is also located near the substantial Three Kings upwelling where there is associated high levels of primary productivity (Murphy *et al.*



2001)). Both are likely to drive at least some of the taxonomic distinctness associated with Cavalli.

Another biodiversity index VarTD revealed Gothic (from the Chatham Rise Graveyard complex) to have octocoral species that are both over and under represented compared to the regional geographical species pool. Possible reasons for a higher VarTD include (1) change in biogeographic region and (2) subjection to some anthropogenic disturbance (see Warwick and Clarke 2001 for further information on this). However, the location of Gothic in a complex (Graveyard) negates the first and the main source of regional disturbance would be trawling activities – Gothic had only been lightly fished and other lightly fished seamounts do not differ from the VarTD of the region therefore at this time the reasons for Gothic being apparently different remains unknown and warrants further attention (Sánchez and Rowden 2006)

The diversity of bubblegum coral (Paragorgiidae) species in the New Zealand EEZ is the highest in the world. Paragorgiids have a centre of endemism in New Zealand waters with eight endemic species (Sánchez 2005).

Sánchez (2005) described the distribution of *Paragorgia arborea* as cosmopolitan (unlike the other species in this family) but discontinuous e.g. widely distributed at subpolar oceans but not at equatorial latitudes (Broch 1957; Grasshoff 1979). Sánchez (2005) went on to compare the morphologies of an Alaskan specimen with a New Zealand one but found no major difference and it remains unknown if these species are genetically different or if there are connecting populations across equatorial latitudes. Further research is clearly required to address this question.

Sánchez (2005) concluded that most speciation within the Paragorgiidae took place within the Pacific Ocean and that most species collected from the depth range 800-1000m seemingly have similar habitat requirements. Most species were found to come from north New Zealand waters (though 2 species were found north and south *P. alisonae* and *P. whero*) but clearly more sampling is required to ascertain if this is a genuine pattern, and to further comment on the habitat and distribution of this family.

An example of the complications that can exist in deep-sea coral taxonomy occurs in the Keratoisidinae (bamboo coral). Prior to Smith *et al.* (2004) the most recent study was that of Grant (1976). In the intervening years there were several contradictory morphological studies (see Grant 1976; Muzik 1978; Bayer 1990). The deep-water trawling industry has increased the supply of specimens and these can be used to advance systematics. Utilising this source of specimens Smith *et al.* (2004) determined the distribution of deep-sea bamboo corals to be widespread across the Pacific, or mitochondrial markers used in this study are insensitive to speciation events and therefore ineffective for separating species. If the former is true then these corals have a far wider dispersal capacity than first thought. Furthermore Smith *et al.* (2004) contradicted earlier research that had suggested bamboo corals were endemic to seamounts, instead finding that bamboo corals can also grow on flat bottom areas – this has implications for conservation. While seamount closures may protect bamboo corals from extinction trawling on flat bottomed areas will result in an overall depletion of bamboo corals.

The protected red coral *Errina novaezelandiae* shows evidence of inbreeding and high genetic subdivision (in shallow fiords; Miller *et al.* 2004). This is attributed to limited larval dispersal (in contrast to the bamboo corals; Smith *et al.* 2004) however, very little is known about the life cycles of deep-sea corals.

## 8. Reproduction and recruitment of deep-sea corals

To develop conservation strategies for deep-sea corals it is essential to understand reproduction/recruitment and be able to answer the key questions (1) How often are new colonies established? (2) Where are new colonies established? and (3) Where do new colonists come from? (Mullineaux and Mills 2004) - the answers to which are central to how resilient coral communities are to disturbance.

Unsurprisingly most studies on coral reproduction and recruitment have been carried out on tropical reefs and little is known about the reproduction/recruitment of cold-water corals. It is generally thought that, like shallow water species, deep-sea corals may reproduce sexually, asexually or both (Mullineaux and Mills 2004). Vegetative reproduction can be common in some benthic invertebrates e.g. gorgonian corals in shallow water use clonal propagation to form dense colonies which can lead to low genetic diversity (Hughes *et al.* 1992).

The majority of cold-water corals studied to date have separate sexes (gonochoristic) (Roberts *et al.* 2006) including some of the reef formers in New Zealand waters e.g. *Solenosmilia variabilis*, *Goniocorella dumosa* (Burgess and Babcock 2005; Waller *et al.* 2002; Waller and Tyler 2005) the latter of which is restricted to the Southern Hemisphere and thus far has mostly been found in New Zealand (Freiwald *et al.* 2004). Corals that are sexually reproducing have 2 modes of larval development (1) brooding (2) broadcast spawning. Fecundity of deep-sea seamount corals ranges from low to high (Waller 2005).

Endemism is closely related to dispersal mechanism. The complex current topography around seamounts may serve to limit species dispersal, trapping larvae (see Genin *et al.* 1986) and thereby enhancing speciation. Seamounts and similar features can act as “islands” for many invertebrates, their geographic isolation driving species diversification (De Forges *et al.* 2000). Endemism is typically quoted as being high on seamounts (see De Forges *et al.* 2000) but this is increasingly being contested with calls for a greater sampling effort. With regards to investigations on reproduction and endemism is imperative that New Zealand is not considered as a single entity. Investigations must be conducted at an ocean basin/global scale e.g. Cairns (1999) determined that deep-water scleractinians from Vanuatu have strong affinity with corals from the ridges and islands north of New Zealand and also Hawaiian fauna.

Sexual reproduction of scleractinian corals has been poorly studied and despite receiving increasing attention in the last two decades the information available is conflicting (Burgess 2002). Seasonality and periodicity have been used to attempt to categorise scleractinian reproductive strategies but no clear relationships are apparent (Shlesinger *et al.* 1998). Whilst sexual reproduction has been linked to factors such as sea temperature and food availability there is scant information available in the wider literature (Rogers 1999). Scleractinians have a wide distribution which may be indicative of planktonic larvae, but this is not proven (Rogers *et al.* submitted).

Burgess (2002) examined *Solenosmilia variabilis*, *Enallopsammia rostrata*, *Goniocorella dumosa*, and *Madrepora oculata* and determined them to be gonochoristic with broadcast spawning and fertilization occurring in April/May which coincides with the end of summer biomass accumulation. There appeared to be a high degree of synchrony between seamounts. Burgess (2002) estimated high fecundities for *Solenosmilia variabilis*, *Enallopsammia rostrata*, *Goniocorella dumosa*. However, this research was based on only one sampling trip. Timing of reproduction is highly variable and one example, *Madrepora oculata* (in the northeastern Atlantic) (Waller and Tyler 2005) shows non seasonal periodic reproduction.

Miller (1996) worked on the shallow fiordic black coral *Antipathes fiordensis* and determined it to be gonochoristic and reproduce once a year (most likely simultaneously towards the end of summer). Miller (1997; 1998) went to report *A. fiordensis* to have a restricted larval dispersal with larvae being negatively buoyant, weak swimming and short-lived (Parker *et al.* 1997). Miller (1996) reported that the closer these corals were to each other (within 5m) the more related they were. Shallow-water corals such as *A. fiordensis* are easier to work on, but their applicability to deep-sea corals may be limited. Overall, more work is clearly required to investigate the reproductive of deep-sea black corals.

Detailed information on the reproduction and life histories of deep-sea octocorals is sparse (Cordes *et al.* 2001). The deep-water Pacific corals *Anthomastus ritteri* were determined to be gonochoristic, larval brooders that can continuously reproduce. Once larvae were released they were determined to be capable of settlement after 2 days. Cordes *et al.* (2001) determined the corals 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.

The Pacific wide distribution of some species such as Keratoisidinae is indicative of a wide dispersal capability. Little is known of the reproductive biology of the deep water Keratoisidinae but it could be that there are fewer physiochemical barriers to dispersal in the deep sea (Grigg and Bayer 1976; Marsh *et al.* 2001) and that the larvae 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.

Information on the biology of most hydrocorals is scarce (Stratford 2000), though male and female gonopores have been recorded in shallow species (Fritchman 1974). The protected red coral *Errina novaezelandiae* is found at shallow depths in New Zealand's fiords, enabling easier access for research. This coral has been determined to be dioecious with male and female gametes developing in the skeletal cavities and internal fertilisation. In laboratory studies, light stimulation triggered the release of gametes, but obviously would not be the case in the deep-sea. Miller *et al.* (2004) found significant genetic sub-division among populations of *E. novaezelandiae* in the shallow waters of New Zealand's fiords, which is consistent with limited gene flow and philopatric larval dispersal. 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) which was supported by the genetic findings of Miller *et al.* (2004). As with other marine invertebrates *E. novaezelandiae* recruitment may be variable in space and time (Underwood and Fairweather, 1989; Miller *et al.* 2004). Furthermore Miller *et al.* (2004) speculated that the limited connectivity between fiords will have implications for population sub-divisions 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 the degree of connectivity with the deep-sea is unknown.

Population genetics is particularly useful area of research in situations where detailing the movement of larvae or adults is problematic. However, many of the mitochondrial markers commonly used in invertebrates show little/no variation in hexacorals and octocorals (Baco-Taylor 2006. See also Shearer and Coffroth 2004). Microsatellites have recently shown promise in deep-sea coral studies but research is expensive and time consuming as microsatellite loci must be acquired for each species (loci are rarely able to be used within a genus).

## 9. Growth rates and deep-sea coral ageing

Information on growth rates and overall longevity is lacking for deep-sea corals in the New Zealand region (Probert *et al.* 1997). Deep-sea corals are slow growing and long lived, therefore may hold information about historic environmental changes (including sediment input, water temperatures, nutrient supplies, and heavy metal loadings) and may provide information that surpasses all methods currently available (Risk 2000). However, their life history also increases their potential vulnerability to anthropogenic damage (e.g. trawling, climate change).

The diverse growth forms of deep-sea corals prevents one single method to age all species or to assess their growth rates. Furthermore we do not fully understand how these organisms grow to know how best to sample them. As early as 1948 the use of man-made structures to estimate the growth rates of solitary corals was discussed e.g. submarine cables (Ralph 1948) but problems in determining how soon after the structure is laid the coral settles makes this an unreliable technique. The slow growing nature of deep-sea corals generally prevents monitoring growth through photography.

It is possible to obtain good estimates of the ages of deep-sea corals but the techniques present numerous hurdles (Tracey *et al.* 2003). The deposition of a calcium carbonate skeleton (calcium carbonate comes from adjacent water and the corals diet) enables the use of radiocarbon dating to estimate coral age. This method is based on the decay rate of  $^{14}\text{C}$  and has been used widely to estimate the ages of corals and other organisms, as well as to validate previous age estimates based on growth increment counts. However, further research is required before we can fully accept age estimates, with a greater understanding required of the waters around New Zealand, the rates of  $^{14}\text{C}$  mixing (marine reservoir effect) as well as the feeding of deep-sea corals. Radioisotopes can also be used to estimate age e.g. ratio of  $^{210}\text{Pb} / ^{226}\text{Ra}$ .

The rate at which individual corals grow depends on many factors e.g. food supply, prevailing environmental conditions (Tsao 2005) and a regional difference in growth rates would be expected from the complex dynamic oceanic region around New Zealand (Chiswell 2002). Tracey *et al.* (submitted) found the growth rates of bamboo corals around New Zealand to vary with depth and latitude.

Grigg (1974) first noted annual growth zones in gorgonians. Some coral species (e.g. bamboo corals) may be aged by counting concentric growth zones (as seen in trees, or fish ear bones) however, this technique is not applicable for colonial, tree-like corals. Additionally coral zones (see gorgonians, sea pens) may not be as discrete as those seen in trees because the skeleton of some corals has a high organic content which can interact with fixatives, as well as change size with dehydration and denaturation (Sánchez *et al.* 2004). Additionally growth rates within individual skeletons have been shown to vary in fossil specimens (Noé *et al.* submitted).

Bamboo corals may represent a good target species for coral age studies in the deep sea and are widely distributed in New Zealand's EEZ, occurring on seamounts and on flatter topography (Grant 1976; Smith *et al.* 2004). Whilst scleractinians and bubblegum coral sections can have complicated growth structures and high organic contents bamboo corals have low organic content and therefore growth rings have been used more successfully but still require specialist treatment and expertise (Sánchez *et al.* 2004). However, overall knowledge of bamboo coral morphology and growth remains poor (Noé and Dullo 2006).

Tracey *et al.* (submitted) report *Lepidisis* spp. to have up to 90 nominal growth zones and *Keratoisis* sp. to have around 160. However, Lead-210 dating aged *Lepidisis* sp. to between 40 and 50 years suggesting bi-annual growth zones (with a growth rate of 27 mm y<sup>-1</sup>). Scanning Electron Microscopy (SEM) analysis suggested some monthly bands, i.e. lunar periodicity, which Roark *et al.* (2004) previously hypothesised could be linked to zooplankton changes and particulate organic carbon flux. Noé and Dullo (2006) recorded a linear extension rate of 0.4mm year<sup>-1</sup> which was 2 orders of magnitude slower than that recorded by Tracey *et al.* (submitted), and highlighting that further work is required.

Black corals (antipatharians) generally have low mortality, growth rates, fecundity and recruitment. Colonies of the shallow water (<100m depth) *Antipathes fiordensis* greater than 4m are estimated to be over 300 years old, and estimated to grow at 1.62cm year<sup>-1</sup> (Grange and Goldberg 1993). In fiords colonies of the black coral *Antipathes aperta* have been estimated to grow at 3.9cm/year (Grange and Singleton 1988). Black corals can grow to 8 feet (2.4m) (e.g. *Aphanipathes* dredged in Milford Sound) implying an age of 50 years or more.

Growth rates may be slower in deeper water. 10m colonies of *Paragorgia arborea* as well as 4-5m tall *Bathypathes platycaulus* have been reported within New Zealand's EEZ. New Zealand specimens of *Paragorgia arborea* have been aged at over 300 years using radiocarbon dating (Tracey *et al.* 2003; Sánchez *et al.* 2004). Samples from the tip of *Paragorgia arborea* have been aged at between 100 and 200 years old, with the base aged at at least 300 – 500 years old (Tracey *et al.* 2003). Specimens of the New Zealand species *Keratoisis* sp. (bamboo coral) have been aged at between 300 and 500 years old; *Madrepora oculata* and *Enallopsammia rostrata* have been aged between 200 and 6000 years. This means that deep-sea corals are amongst the longest lived organisms.

Darwin recognised that environmental conditions can alter the growth form of corals (Ralph 1948). *Errina novae-zealandiae* (collected from 50 – 80 fathoms, equivalent to 91 to 146m) was recorded to show 3 growth forms, including a more erect vertical form and a larger horizontal form (Ralph 1948), the latter believed to come from rougher waters.

Miller *et al.* (2004) reported highly variable annual growth rates (in fiords) of the protected coral *Errina novaezealandiae*. Colonies were seen to increase and decrease in size (e.g. from partial mortality), and also to remain unchanged from year to year with no evidence of any geographical variation. However, despite colonies suffering from partial mortality, net growth was positive when averaged over a 3 year time frame. *Errina novaezealandiae* can have high growth rates (e.g. 7cm per year, though net growth is lower, 0.7cm per year) therefore large corals (taken as those > 20cm) will be more than 30 years old. This may certainly be an under estimate as partial mortality will mask some growth. Larger colonies were reported to have reduced growth rates compared to smaller, younger, colonies but will contribute disproportionately to reproduction (Babcock 1991; Hughes *et al.* 1992; Grange 1997; Miller *et al.* 2004). While shallow-water examples are not directly comparable to the deep-sea e.g. different growth conditions they are indicative of the slow growth rates.

*Solenosmilia variabilis* grows by intratentacular budding, whereas *Madrepora oculata* and *Goniocorella dumosa* grow by extratentacular budding (Cairns 1995). While we know something of individual coral growth the rate of reef growth is completely unknown and cannot be extrapolated from non-reef forming coral growth rate (Freiwald *et al.* 2004). The growth rate of *Goniocorella dumosa* is not known, but if comparisons are made with studies in the North Atlantic e.g. *Lophelia pertusa* we could expect a metre-high colony to be in the region of 200 – 360 years (Wilson 1979, Cairns and Stanley 1981).

Increasing our understanding of coral ageing studies will also yield critical information about coral demographics e.g. a continuous age range in a community indicates that recruitment is ongoing whereas modes indicate more intermittent recruitment (Mullineaux and Mills 2004). Recruitment patterns of deep-sea corals are currently unknown.

As ageing methods improve, it may become increasingly commonplace to use corals as indicators of climate change in the deep oceans e.g. stable isotopes from coral skeletons can be used to indicate (1) climatic changes e.g. from stable isotope ratios of oxygen (2) metabolic processes e.g. from carbon stable isotopes. As markers for the incorporation of anthropogenic substances into the oceans deep-sea corals have the advantage, over sediments, in that they are not subject to processes such as bioturbation.

## 10. Fishing effects on deep-sea corals

Epibenthic invertebrates, such as corals have a valuable ecosystem function but are fragile, and the limited information available on deep-sea biodiversity serves to heighten concern about perceived threats from human activities.

The impacts of fisheries on non-target species such as corals has been of increasing concern, with particular regard to the potential habitat altering activity of bottom trawling (see Probert *et al.* 1997; De Groot 1984; Hutchings 1990; Messieh *et al.* 1991; Jones 1992). ICES (1994) recognised the potential impact of bottom-trawling, and assessed species vulnerability on a variety of criteria which included life history; physical fragility/robustness; habitat; behavioural characteristics (Probert *et al.* 1997). The ICES report concluded that the most vulnerable species were fragile and long-lived, with infrequent recruitment, can be exterminated with one trawl passage and have a long recovery period – deep-sea corals fall within this definition. Example coral species include *Paragorgia arborea*, deep-water coral banks (see Atlantic example of *Lophelia pertusa*). Suggestions have been made that trawling could increase colonisation (e.g. *Lophelia pertusa* was cited by Wilson 1979) however, repeated trawling would be expected to ultimately eradicate coral patches (Jones 1992; Probert *et al.* 1997).

Fishing activities can have considerable physical effect on the seafloor (for a general review see Clark and Koslow submitted). However, taxonomic composition and substrate type vary spatially and therefore the effects of fishing cannot be considered uniform. Trawl gear affects the environment directly (scraping, ploughing, destruction of benthos, sediment resuspension, and waste dumping) and indirectly (post-fishing mortality, long terms changes to assemblage) (e.g. Jones 1992; Dayton *et al.* 1995). Research has established that type of trawl gear, as well as trawling frequency, depth, weight of the bottom gear, towing speed, substratum, and tide/current strength all influence the degree of environmental perturbation (Jones 1992; Dorsey and Pederson 1998; Kaiser and de Groot 2000; Thrush and Dayton 2002). Using a shallow example Pitcher *et al.* (2000) reported that a single tow can remove 5 – 20% of the sessile epibenthos in its path (on the Great Barrier Reef) therefore as few as 5 tows (in the same place) could remove most of the fauna. The sessile erect fauna that characterise harder-substrates are viewed as being more susceptible to fishing e.g. seamounts with coral communities. Trawling may also increase sedimentation which may also have considerable impact on corals directly encountered by the trawl (Churchill 1989; Riemann and Hoffman 1991; Thiel 1992) however, further research is clearly needed to assess this and also the natural rates of sediment resuspension.

Key (2002) recognised the potential impacts of climate change, pollution, dumping, and mining on deepwater benthic communities but identified bottom trawling as being the most pervasive human activity to affect New Zealand's benthic communities. Key (2002) went on to identify the Kaikoura Canyon and northern Macquarie Ridge, as having significant fishing activity without any existing knowledge of their biodiversity, and thereby potential areas for directed research under New Zealand's Biodiversity Strategy.

Many organisations have expressed concern about the need to implement management strategies to conserve deep-sea habitats and associated biodiversity. In response to such concerns about threats to New Zealand's seamounts, in May 2001 the New Zealand government closed 19 seamounts to all kinds of trawling. In the same year, New Zealand was one of 11 countries responsible for 95% of the high seas bottom trawl catch (Gianni 2004) but at present relatively little consideration is given to the impacts of New Zealand fishers outside of the EEZ (Clark 2006).

Research interests into the impacts of trawling initially focussed on shallower environments, but increasingly sophisticated fishing technologies have enabled fishers to operate in deeper waters, and research has followed suit. Jones (1992) announced an "*urgent need to carry out trawling impact studies in deeper water (> 500m) since this is where studies indicate that effects could be severe and that any recovery may be measured in decades*". Both the life histories of deep-sea benthic invertebrates, in tandem with the environmental conditions, suggest that the rates of recovery from disturbances such as trawling may not be comparable to those on the continental shelf (Probert *et al.* 1997).

Anecdotal observations from fishers in New Zealand suggest that there may have been a decline in trawl caught invertebrate benthic bycatch (Jones 1992). The deep water areas of the Chatham Rise have been commercially fished to depths of at least 1200m since 1978. Initially, flat areas were targeted but with the advent of increasingly sophisticated fishing technology seamounts (including hills/pinnacles) were also targeted (Probert *et al.* 1997), and are now the focus of most deepwater trawl fisheries in New Zealand (Anderson and Dunn 2006). Given the intense fishing history in the New Zealand region (e.g. 80% of known seamounts in the appropriate depth range have been fished; Clark and O'Driscoll 2003) establishing baseline data for unfished seamounts is now a significant challenge.

Seamounts are productive fish habitats, and major New Zealand seamount fisheries include those for orange roughy (*Hoplostethus atlanticus*), oreos (black – *Allocyttus niger* and smooth – *Pseudocyttus maculates*), black cardinalfish (*Epigonus telescopus*), alfonsino (*Beryx splendens*), blue nose (*Hyperoglyphe antarctica*) and rubyfish (*Plagiogeneion rubiginosum*). Fish have continued to aggregate on historically fished features, but longer terms effects this disturbance may have on younger fish, or other community species, is unknown (Francis and Clark 2005). Koslow and Gowlett-Holmes (1998) determined that within a few years a new orange roughy fishery had a major impact on biodiversity, with fished seamounts having 83% less biomass and 59% less species.

Koslow *et al.* (2001) compared fished and unfished seamounts in Tasmania and concluded that, despite depth differences, trawling had been responsible for stripping the coral cover. The Graveyard complex (Chatham Rise) allows a natural experiment, in that seamounts in close proximity have been fished to varying degrees, and some are now closed, enabling some comparisons to be made, and the potential opportunity to monitor "recovery" (see [censeam.niwa.co.nz/censeam\\_news/censeam\\_graveyard](http://censeam.niwa.co.nz/censeam_news/censeam_graveyard)). Probert *et al.* (1997) reported 82% of tows (from seamounts (63%) and flats (88%)) to contain invertebrate by-catch. In total, Probert

*et al.* (1997) recorded 96 species (notably many have not yet been scientifically described) of invertebrate by-catch, including gorgonian corals. Jones (1992) also reported that a loss in sponges, alcyonarians and gorgonians was associated with a change in the catch composition of the pair-trawl fishery between 1967-73 and 1979.

It is thought that damage to habitat forming corals can affect local hydrodynamic and sedimentary conditions (Rogers 1999) and can have profound implications to the entire ecosystem e.g. a shift from a diverse reef community to a reduced species/biomass “disturbance” community (Koslow and Gowlett-Holmes 1998).

Clark and O’Driscoll (2003) used a photographic survey to examine coral distribution in relation to varying levels of fishing intensity in the Graveyard Seamount Complex; seamounts with a higher FEI (Fishing Effects Index) had lower abundances and occurrence of live coral. Rowden *et al.* (2002; 2004) further examined the impacts of trawling on Graveyard seamounts, and reported that despite the seabed habitat on seamounts generally being heterogeneous, differences can clearly be seen on “fished” vs. “unfished” seamounts. Habitat forming corals e.g. *Solenosmilia variabilis* and *Madrepora oculata* were evident on 33% of images taken of the seabed on unfished seamounts (overall mean cover 17%) compared to 1.6% on “fished” seamounts (overall mean cover 0.04%) with evidence of trawling on 25% of images. Overall the non-coral assemblage composition of “fished” vs “unfished” seamounts was significantly different and this was related by Rowden *et al.* (2004) to the presence of live coral. The coral species that best discriminated between “fished” vs “unfished” were *Calyptopora reticulata*, and *Lepidotheca fascicularis* as well as a bryozoan *Lagenipora* sp. These are all small species with fast growth rates, characters making them relatively opportunistic species. Photographs (Rowden *et al.* 2002) also revealed physical evidence of trawling (e.g. old wires, netting, gouges from trawl doors and bobbins) on fished seamounts e.g. 29% of all photographs from Graveyard seamount and 17% from Morgue showed some impact compared to 5% and 1% on Diabolical and Gothic respectively. Research trawls on these seamounts demonstrated that the invertebrate by-catch on the unfished seamounts was high compared to the fished, supporting anecdotal descriptions of by-catch declining with increased fishing activity.

The by-catch composition can vary between geographical areas, and between seamounts and flats, with gorgonian and scleractinian corals being the most commonly recorded taxa from seamounts whereas non-coral fauna (e.g. holothurians, asteroids and natantia) were most commonly recorded from flats (Probert *et al.* 1997).

To better define the nature and extent of population changes, further research into the impacts of trawling on deep-sea corals is required, and across a wider geographic area, taking into account depth and any patterns in zonation (McKnight and Probert 1997). Additionally not all trawling can be considered equal and any management appraisal must consider the type of bottom trawl gear (Probert *et al.* 1997; Koslow *et al.* 2001), the spatial extent and intensity of tows (Thrush *et al.* 1998), as well as substrate type and community composition (van Dolah *et al.* 1987; Freese *et al.* 1999). The same overall trawling intensity may have a smaller impact on softer sediments than on corals (Clark and O’Driscoll 2003). Large bobbins may crush larger coral fauna but leave smaller organisms untouched. Fauna most likely to be by-catch include large upright species such as antipatharians as well as “spiny” species which can become entangled in the nets e.g. stylasterids (Probert *et al.* 1997).

Even sub-lethal damage can have profound impacts on modular marine organisms such as corals e.g. reproductive output may decline owing to (1) a reduction in colony size (2) an increase in energy resources channelled to repair rather than growth/reproduction (3) immature colonies



being delayed to reach maturity. Furthermore, the loss of larger individuals may be of greater impact than smaller ones as they may make a disproportionately large contribution to the reproductive output of the entire population (for concept see Miller *et al.* 2004 and references therein).

Heavily fished seamounts may still contain diverse assemblages e.g. the base of the heavily fished seamount Sister 1 (Koslow *et al.* 2001). Koslow *et al.* (2001) also reported no difference in species number or community structure in coral-dominated seamounts within or outside of a protected area (coral dominance indicated no or only light fishing). It is possible that coral diversity may be maintained on fished seamounts, as many are fished only on established tow lines, leaving some areas of the seamount, often where the seabed is particularly rough, unfished. Two, potentially endemic, new species from the family Paragorgiidae were collected from the Chatham Islands, traditionally areas of intense fishing (*P.aotearoa* and *P. wahine*) (Sánchez 2005).

The ability of coral assemblages to recover from trawling is not well known but Koslow *et al.* (2001) reported gorgonian assemblages on shallow heavily fished Tasmanian seamounts, which was either attributed to depth or their ability to colonise disturbed grounds or resist trawl disturbance e.g. through greater pliability (with evidence supporting the latter). Koslow *et al.* (2001) reported that the coral loss had no impact on Tasmanian deepwater fisheries but clearly had implications on other faunal groups and the overall biodiversity of the system.

Trawling can impact on the environment both directly (physical damage) and indirectly (e.g. attracting predators and scavengers) (Smith 2001). Disturbance is a natural process in the biological world (see Connell 1978) and can promote biodiversity, as frequent disturbance will favour opportunistic recolonisers (Eleftheriou and Robertson 1992; Kaiser and Spencer 1994; Probert *et al.* 1997). Deep-sea coral death/damage is a natural process e.g., as seen from historical environmental changes and predation (Koslow and Gowlett-Holmes 1998), and care must be taken when assessing dead coral material, as in the absence of definitive evidence e.g. trawl gouges, determining the cause of death can be difficult (Clark and O'Driscoll 2003).

Despite their potential impact, trawl fisheries have yielded much of the knowledge that we have to date on benthic fauna (Table 1). Observers, on a fraction of the deepwater fishing fleet, recorded 1642 records of cnidarians from subsamples of deepwater fisheries between 1995 and 2006, with a total weight of 497 t. Unspecified corals contribute 94% of the total coral weight. Black corals comprise 0.2 % of all coral groups (803 kg from 115 records), bubblegum corals 0.3% (1307 kg from 37 records), and red corals 1.4% (6876 kg from 60 records).

**Table 1: Summary of *observer* coral records (1996 to 2006).**

<b>Cnidaria – coral data</b>	<b>Species code</b>	<b>Weight (kg)</b>
Total (all,Cnidaria) [of these corals = 497 t ]		556215
Coral unspecified	COU	464986
Coral rubble	CBB	22342
Coral rubble - dead	CBD	506
Deepwater branching corals – <i>Solenosmilia variabilis</i>	SVA	72
Bushy hard coral <i>Goniocorella dumosa</i>	GDU	158
Deepwater branching coral – <i>Oculina sp.</i>	OVI	1
Crested cup coral	DDI	18
Flabellum cup corals	COF	33
Black coral	COB	803
Gorgonian coral	GOC	1
Bubblegum coral	PAB	1307
Golden corals	CHR	22
Precious corals	CLL	1
Bamboo coral	ISI	96
Red coral (Stylasterid or ? Paragorgia)	COR	6876
Hydrozoa - hydroids - incl hydrocorals Stylasteridae	HDR	7
Red hydrocorals <i>Errina</i> spp.	ERR	1
Long polyp soft coral - <i>Telesto</i> spp.	TLO	36

## 11. Other threats to deep-sea corals

Trawling is undoubtedly the most immediate threat to deep-sea corals; however, Freiwald *et al.* (2004) outlined additional threats as being:

- Other bottom fishing
- Hydrocarbon exploration and production
- Cable/Pipeline placement
- Bio-prospecting
- Destructive scientific sampling
- Pollution
- Waste disposal and dumping
- Sequestration of CO<sub>2</sub>
- Other mineral exploitation
- Increased atmospheric CO<sub>2</sub> (drop in ocean alkalinity)

Human-induced changes are likely to be more intense and occur over a shorter time period than natural events, especially in deep-water (Clark and Koslow submitted). Furthermore many corals are thought to be long-lived and slow growing hence their recovery is slow (Wilson 1979, Hall-Spencer *et al.* 2002, Tracey *et al.* 2003). Furthermore threats to any organism or species group are exacerbated at the end of that species geographic range where growth, recruitment, reproduction and gene flow are more likely to be marginal (Johannes *et al.* 1983; Harriott 1999 a,b; Miller *et al.* 2004). It is not known whether this applies to any New Zealand species.

To date there have been no studies on the potential impact of ocean acidification on cold-water corals but their vulnerability may be considerable when one considers the lowered carbonate saturation state in deeper waters/higher latitudes. Furthermore, modelling suggests, the depth at which aragonite dissolves will become shallower, cold-water corals will no longer be able to survive at certain depths (Guinotte 2005).

The greatest risk from drilling is the potential for cuttings to smother any local coral populations, but evidence of wide-spread damage is lacking (Roberts *et al.* 2006). As any effects will be localised this is not perceived to be a major threat, though considerable impact on local endemics should not be discounted.

Natural processes can also affect reefs and deep-sea corals in general e.g. bioerosion (through boring organisms), large sediment outfall following flood run-off as well as predation and parasitism. Freiwald *et al.* (2004) report on numerous studies examining parasitism but no studies have examined the effect that parasites have on coral fitness. It is imperative to understand the life history of a species to predict how that species may respond to various threats/changes. Deep-sea corals are important to the deep-sea however, their life history characters increase their vulnerability to disturbance and stress, from which their ability to recover is currently unquantified (Auster 2005).

## 12. Ongoing research into deep-sea corals in New Zealand

In New Zealand, deep-sea coral research addresses four core research themes (not exhaustive): (1) Biodiversity (including taxonomy) and biogeography (2) Reproduction and Recruitment (3) Growth and ageing and (4) Impacts of trawling. To understand (4) requires knowledge of (1), (2) and (3).

Several policies in the Department of Conservation Services Plan refer to protected deep-sea coral species as requiring research owing to the fact that they “may be impacted by commercial fishing”.

The awareness of deep-sea corals continues to grow with continued interest in their life histories as well as susceptibility to human activities. As a first step, international and national research efforts e.g. Census of Marine Life, Species 2000 and the NZ Foundation for Research, Science and Technology (FRST) funded Outcome Based Investment Programme on Aquatic Biodiversity and Biosecurity are working towards completing an inventory of species of New Zealand’s rich biota.

The FRST and New Zealand’s Ministry and Fisheries (MFish) has funded NIWA to carry out a 4 year scientific research programme called “Seamounts: their importance to fisheries and marine ecosystems”. This research includes the systematics, distribution mapping, and growth and age validation of various deep-sea coral groups. Some of the potentially at-risk coral taxa fall within these studies.

NIWA is also contracted by MFish to investigate fishing effects on benthic assemblages and to provide identification guides to ensure accurate information is obtained on the numbers of invertebrate species (including corals) caught in deep-sea bottom trawls. NIWA’s research is intended to help managers to mitigate the effects of fishing.

### **13. Future science and challenges to deep-sea coral research in New Zealand**

Overall, our knowledge of deep-sea coral fauna in the New Zealand region is poor. It is imperative that scientists and managers work together to increase our understanding of coral biodiversity so that action can be taken to manage vulnerable habitats.

Hubbs (1959) asked the following questions about seamounts (1) What species inhabit seamounts and with what regularity and abundance? (2) How do species disperse and become established on seamounts? (3) Do seamounts represent stepping stones for transoceanic dispersal of species? (4) What factors are responsible for the diversity of life over seamounts? Rogers (1999) discussed how these are as relevant today as they were then, and that they are relevant questions for deep-sea corals research.

More specifically, Freiwald *et al.* (2004) outlined the major knowledge gaps in deep-sea corals world wide as relating to:

- Mapping
- Oceanographic data
- Geology and geomorphology
- Biology and physiology
- Ecology
- Human activities
- Socio-Economic data
- Time series data

**The following recommendations are made for deep-sea coral research in New Zealand:**

### **Increase sampling efforts and raise scientific profile**

Deep-sea coral research is most prolific in the Atlantic, even though New Zealand has exceptionally high deep-sea coral diversity. Whilst research into New Zealand's deep-sea corals is ongoing, more time and personnel are clearly required. The 4th International Coral Reef Symposium will be held in Wellington in 2008 and will increase world-wide interest in the region.

The Chatham Rise is the only area of New Zealand's EEZ where deepwater benthic biodiversity has been moderately well studied (Key 2002). To achieve a thorough understanding of the distribution of deep-sea corals in the New Zealand region it is essential to expand the areas sampled e.g. deep-sea corals can occur in discrete and dispersed patches that can be hard to find. Research to date has primarily focussed on seamounts, however, other habitats e.g. gullies/canyons can also provide hard substrate suitable for coral growth (Mortensen and Buhl-Mortensen 2005) and warrant further investigation. An increased understanding of what drives the biogeography of deep-sea corals (e.g. substrate type, water flow) may aid increasingly well informed conservation/management decisions.

It should also be recognised that huge sources of material are already available e.g. in NIWA collection (Key 2002; Cairns *et al.* in prep). A great deal of New Zealand's sampled coral biodiversity data have not yet been examined in sufficient detail nor included in recognised databases.

### **Develop and improve methodology**

The habitats which favour deep-sea corals can be difficult to sample e.g. without causing damage to equipment/samples. Sampling requires considerable financial input. The advent of improved sampling technologies (e.g. deep-towed imaging systems) has increased our understanding of deep-sea coral distribution and a considerable and growing archive of images exists within NIWA. Work is ongoing to improve databasing which will ultimately increase our understanding of the distribution and abundance of deep-sea corals as well as their interaction with other species.

Ecological Niche Factor Analysis (ENFA) has been used to predict habitat suitability of deep-sea corals. ENFA related species presence information to background environmental data to determine species' niche (Leverette and Metaxas 2005; Data Analysis Working Group (CenSeam: a global census of marine life on seamounts) in press), and could prove to be a valuable conservation tool.

Rowden *et al.* (2005) determined 12 seamount groupings within the New Zealand region. It is possible that these physical groupings could serve as indicators of biodiversity but considerably more sampling would be required to test such a hypothesis. However, if biological validity could be attached to such a classification it could represent a credible base for improved resource management, and possibly a world first (Rowden *et al.* 2005).

Many of the techniques used in deep-sea coral research are challenging e.g. genetics, ageing, and there is a clear need for scientists to work towards standardising methodology e.g. Etnoyer *et al.* (2006). Within New Zealand, NIWA's research and methods are contributing to, and benefiting from, global research initiatives such as the Census of Marine Life programmes CenSeam (a

global census of marine life on seamounts, see Stocks *et al.* 2004), CHES (biogeography of deepwater chemosynthetic ecosystems), OBIS (Ocean Biogeographic Information System), MAR-ECO (patterns and processes of the ecosystems of the northern Mid-Atlantic) and Bar-coding as well as GBIF (Global Biodiversity Information Facility) ensuring that New Zealand scientists establish and maintain links with researchers across the world.

## Improve taxonomic knowledge

Deep-sea coral systematics are poorly resolved, based on a combination of insufficient material, high biodiversity as well as a limited skill-base of ecologists and taxonomists (Key 2002), however, that is not to dismiss the high effort of those involved in this field. At present there is no full time Cnidarian taxonomist in New Zealand and few researchers are qualified to make distinctions within coral groups (Etnoyer and Morgan 2005). Worldwide, coral expert Stephen Cairns estimates there to be less than a dozen researchers with systematic expertise in deep-sea stony corals/gorgonians (pers. comm. in Etnoyer and Morgan 2005). Many taxonomists are ageing, and it is essential that the next generation of taxonomists begin training in earnest.

Of the taxonomy that has been completed to date, there remains the need to move from putative species/numbers with more time given to taxonomical revisions (including type material comparisons) to clarify the status of these species (Sánchez and Rowden 2006). This should be a priority, as correct species identification is the most basic question, but is not yet completed for New Zealand corals.

Amongst observers and the industry there is confusion to what constitutes “red coral” with other species e.g. *Paragorgia* spp., *Oculina virgosa*, *Corallium* spp. and even *Goniocorella dumosa* and *Solenosmilia variabilis* having been classified as “red corals”. There is a clear need to remove any ambiguity associated with these protected species. Corals collected as a bycatch in trawl fisheries are likely to remain the most significant source of deep-sea coral, and it is important to ensure that they are correctly identified.

Phylogenetic analyses and DNA sequencing are becoming essential tools in conjunction with morphological taxonomy, particularly in cases of cryptic species. However, many of the traditionally used markers used in invertebrates show no/little variation in corals and while microsatellites have shown promise further time and money is required to develop this field and further unravel the evolutionary histories and taxonomic status of these long lived faunas.

It is also imperative that we are able to classify deep-sea coral biodiversity correctly in order to assess the current and potential threats of human disturbance.

## General Conclusions

The Fisheries Act 1996 states that the following environmental principles should be taken into account (Section 9):

- (a) *Associated or dependant species should be maintained above a level that ensures their long term viability;*
- (b) *Biological diversity of the aquatic environment should be maintained*
- (c) *Habitat of particular significance for fisheries management should be protected*

However, without adequate research determining what is the long term viability and biodiversity of deep-sea benthic assemblages, as well as a greater understanding of their ecology, good

management practice is more difficult. In 1997 Probert *et al.* said there was “*urgent need to assess more fully the impact of trawling on seamount biotas, and in consequence, possible conservation measures*”. In the absence of appropriate research there is more reason to adopt management measures which invoke the Precautionary Principle.

Outside New Zealand, researchers e.g. Rogers *et al.* (submitted) recognise the southwestern Pacific as being a seamount coral diversity hotspot. Nevertheless, the life histories of our deep-sea corals remain unknown, but their important role in deep-sea community biology should dictate the need for investment and research.

The vulnerability of some New Zealand deep-sea corals has been recognised by their classification as protected species, but we need to increase our understanding of their life histories in order to implement informed conservation and management measures to maintain their biodiversity, and prevent population collapse. Because of their ecological importance, by protecting such corals we will also help to maintain habitats important to commercial fish species. Furthermore, deep-sea corals may also provide us with a unique and valuable tool for investigating past climatic changes.

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## 16. Appendices

### Appendix 1: Methods

#### Literature review

A literature search was undertaken on deep-sea/cold-water corals in the New Zealand region. Overall there was determined to be a world wide paucity of information on the life histories of all deep-sea corals (protected and non-protected), and New Zealand is no exception. In certain instances the literature review was further broadened e.g. including studies on cosmopolitan species from outside the New Zealand EEZ, to allow some general ecological points to be discussed.

#### Distribution/known locality plots

Distribution plots were prepared within the New Zealand region for (a) all black corals (Order Antipatharia), (b) all gorgonians (c) All *Paragorgia* spp. / *Sibogorgia* spp. (Order Gorgonacea; Family Paragorgiidae), which included the proposed protected *Paragorgia arborea* (d) all precious corals *Corallium* spp. (Order Gorgonacea; Family Corallidae) (e) all corals classified as “red” (f) the protected red hydrocoral *Errina* spp. (Order Hydroida; Family Stylasteridae). NB “Red” has previously been used to include any coral with pink to red or red to orange colouration and could represent Stylasterid hydrocorals such as *Errina* spp., gorgonian corals such as *Corallium* spp. *Paragorgia* spp., and *Sibogorgia* spp, and possibly some Scleractinian stony corals such as *Solenosmilia*, *Goniocorella*, and *Oculina*.

Data sources for the distribution figures were from both scientific and commercial (e.g. fishing industry) sources:

(1) NIWA *AllSeaBio* seamount specific surveys and *Specify* databases, where almost all the study species are identified by expert taxonomists to species and / or genus. *Specify* includes NIWA stations previously listed as New Zealand Oceanographic Institute (NZOI) station records.

(2) Ministry of Fisheries owned and NIWA managed research *trawl* and *observer* databases. Coral data extracted from *trawl* were from numerous research surveys targeting deepwater and middle depths fish species. The *observer* database coral records were extracted from commercial trips where vessels were targeting orange roughy, smooth oreo, black oreo squid, hoki, or scampi.

Both generic and actual species codes are used by at-sea researchers and observers. Codes extracted from the *trawl* and *observer* databases for this report are as follows: black coral (COB), gorgonian coral (GOC), *Paragorgia* (PAB), red Coral (COR) *Errina* spp. (ERR), *Corallium* spp. (CLL).

In many instances the corals recorded in the *trawl* and *observer* databases have not been identified by expert taxonomists to genus or species. Research *trawl* and *observer* location data included in the red coral plot (Figure 5) are likely to include any coral with pink to red or red to orange colouration and could represent Stylasterid hydrocorals such as *Errina* spp., gorgonian corals such as *Corallium* spp. *Paragorgia* spp., and *Sibogorgia* spp, and possibly some Scleractinian stony corals such as *Solenosmilia variabilis*, *Goniocorella dumosa*, and *Oculina*

*virgosa*. The code COR may also have mistakenly been used as a generic code to record any corals.

Location data included in the gorgonian corals plot (Figure 2) could include records for any gorgonian species such as *Corallium* spp., *Paragorgia* spp., *Thourella*, and possibly for bamboo corals from the family Isididae (see complete list for Order Gorgonacea in Appendix 2) Observers have several records for the code PAB for bubblegum corals and so these records are included in Figure 2. The observer database had only one record for gorgonian coral code GOC.

Records in both the *trawl* and *observer* databases show recent use of the new at-sea invertebrate guide codes (Tracey *et al.* 2005). For *Errina* spp. the code ERR, which would have been originally grouped in with red corals (COR) is now in use but few records exist to date. For *Corallium* spp. the code CLL, which would have been originally grouped in with red corals or possibly gorgonians (GOC), is also in use, but again very low numbers using this code have been recorded to date.

## Appendix 2: New Zealand coral species inventory

This list is taken from Cairns *et al.* (in prep). All corals are found in the Exclusive Economic Zone. Single-letter codes indicate: A, alien; E, endemic; Z, zooxanthellate (subtropical, restricted to the Kermadec Islands) - if Z is absent, the species is azooxanthellate. Genera endemic to New Zealand are underlined.

Please note in conducting this review one mistake was found in classification listed below - STYLASTERIDAE should not be in the Suborder CAPITATA, rather Suborder FILIFERA. The authors have been notified.

- PHYLUM CNIDARIA  
Class ANTHOZOA  
Subclass OCTOCORALLIA  
Order ALCYONACEA (soft corals)  
ALCYONIIDAE  
*Alcyonium* cf. *aurantiacum* Quoy & Gaimard, 1834  
*Alcyonium* sp. 1 NIWA G. Williams  
*Alcyonium* sp. 2 NIWA G. Williams  
*Alcyonium* sp. 3 NIWA G. Williams  
*Alcyonium* sp. 4 NIWA G. Williams  
*Anthomastus* (*Bathyalcyon*) *robustus* (Versluys, 1906)  
*Anthomastus zealandicus* Benham, 1928 E  
*Anthomastus* sp. NIWA G. Williams  
*Cladiella* sp. NIWA G. Williams  
*Eleutherobia* sp. NIWA G. Williams  
*Minabea phalloides* (Benham, 1928) E  
*Sinularia* sp. NIWA G. Williams  
CLAVULARIIDAE  
*Clavularia thomsoni* Benham, 1928 E  
*Clavularia* sp. 1 NIWA G. Williams  
*Clavularia* sp. 2 NIWA G. Williams  
*Clavularia* sp. 3 NIWA G. Williams  
*Rhodolinda gardineri* (Gohar, 1940)  
*Sarcodictyon* sp. 1 NIWA G. Williams  
*Sarcodictyon* sp. 2 NIWA G. Williams  
*Telesto* sp. 1 NIWA G. Williams  
*Telesto* sp. 2 NIWA G. Williams  
*Telesto* sp. 3 NIWA G. Williams  
*Telestula* sp. 1 NIWA G. Williams  
*Telestula* sp. 2 NIWA G. Williams  
*Telestula* sp. 3 NIWA G. Williams  
NEPHTHEIDAE  
*Daniela* sp. NIWA G. Williams  
*Dendronephthya* sp. NIWA G. Williams  
*Drifa* sp. NIWA G. Williams  
*Scleronephthya* sp. NIWA G. Williams  
*Stereonephthya* sp. 1 NIWA G. Williams  
*Stereonephthya* sp. 2 NIWA G. Williams  
NIDALIIDAE  
*Chironephthya* sp. NIWA G. Williams  
*Siphonogorgia* sp. 1 NIWA G. Williams  
*Siphonogorgia* sp. 2 NIWA G. Williams  
TAIAROIDAE E  
*Taiaroa tauhou* Bayer & Muzik, 1976 E  
  
Order GORGONACEA (gorgonians)  
ACANTHOGORGIIDAE  
*Acanthogorgia* sp. NIWA G. Williams  
*Acanthogorgia* sp. 2 NIWA J. Sánchez  
ANTHOTHOLIDAE  
*Anthothela* sp. 1 NIWA G. Williams  
*Anthothela* sp. 2 NIWA G. Williams  
*Semperina macrocalyx* (Nutting, 1911)  
  
*Spongioderma? vickersi* Benham, 1928 E  
*Stereogorgia claviformis* Kükenthal, 1916  
CHRYSOGORGIIDAE  
*Chrysogorgia* sp. 1 NIWA G. Williams  
*Chrysogorgia* sp. 2 NIWA G. Williams  
*Chrysogorgia* sp. 3 NIWA G. Williams  
*Iridogorgia* sp. NIWA G. Williams  
*Metallogorgia* cf. *melanotrichos* (Wright & Studer, 1889)  
*Radicipes* cf. *verrilli* (Wright, 1885)  
*Xenogorgia* sp. NIWA J. Sánchez E  
CORALLIIDAE  
*Corallium* sp. 1 NIWA J. Sánchez E  
*Corallium* sp. 2 NIWA J. Sánchez E  
*Corallium* sp. 3 NIWA J. Sánchez E  
*Corallium* sp. 4 NIWA J. Sánchez E  
ELLISELLIDAE  
*Ellisella* sp. NIWA G. Williams  
*Junceella* sp. NIWA G. Williams  
*Nicella* sp. NIWA G. Williams  
*Viminella* sp. NIWA G. Williams  
IFALUKELLIDAE  
*Plumigorgia* sp. NIWA J. Sánchez E  
ISIDIDAE  
*Acanella japonica* Kükenthal, 1915  
*Acanella sibogae* Nutting, 1910  
*Acanella eburnea* (Pourtales, 1868)  
*Acanella* sp. 1 NIWA G. Williams  
*Acanella* sp. 2 NIWA G. Williams  
*Acanella* sp. 3 NIWA G. Williams  
*Chathamisis bayeri* Grant, 1976 E  
*Circinisis circinata* Grant, 1976 E  
*Echinisis eltanin* Bayer & Stefani, 1987 E  
*Echinisis spicata* (Hickson, 1907)  
*'Isidella'* sp. NIWA G. Williams  
*Keratoisis flexibilis* (Pourtales, 1868)  
*Keratoisis glaesa* Grant, 1976 E  
*Keratoisis hukurangiensis* Grant, 1976 E  
*Keratoisis projecta* Grant, 1976 E  
*Keratoisis tangensis* Grant, 1976 E  
*Keratoisis zelanica* Grant, 1976 E  
*Keratoisis* sp. 1 NIWA G. Williams  
*Keratoisis* sp. 2 NIWA G. Williams  
*Keratoisis* sp. 3 NIWA J. Sánchez E  
*Keratoisis* sp. 4 NIWA J. Sánchez E  
*Keratoisis* sp. 5 NIWA J. Sánchez E  
*Lepidisis solitaria* Grant, 1976  
*Lepidisis* sp. 1 NIWA J. Sánchez E  
*Lepidisis* sp. 2 NIWA J. Sánchez E  
*Lepidisis* sp. 3 NIWA J. Sánchez E  
*Lepidisis* sp. 4 NIWA J. Sánchez E  
*Lepidisis* sp. 5 NIWA J. Sánchez E  
*Lissopholidisis nuttingi* (Grant, 1976) E  
*Lissopholidisis* sp. NIWA J. Sánchez E  
*Minuisis pseudoplana* Grant, 1976 E  
  
*Minuisis granti* Alderslade, 1998 E  
*Mopsea elongata* Roule, 1908  
*Muricellisis* cf. *echinata* Kükenthal, 1915  
*Primnoisis ambigua* Wright & Studer, 1889  
*Primnoisis antarctica* (Studer, 1878)  
*Primnoisis formosa* Gravier, 1913  
*Sclerisis* sp. NIWA J. Sánchez E  
KEROEIIDAE  
*Keroeides* sp. NIWA J. Sánchez  
MELITHAEIDAE  
*Acabaria* sp. NIWA G. Williams  
PARAGORGIIDAE  
*Paragorgia weberi* (Stiasny, 1937)  
*Paragorgia* cf. *arborea* (Linnaeus, 1758)  
*Paragorgia* cf. *sibogae* Bayer, 1993  
*Paragorgia* cf. *splendens* Thomson & Henderson, 1906  
*Paragorgia* sp. 1 NIWA J. Sánchez E  
*Paragorgia* sp. 2 NIWA J. Sánchez E  
PLEXAURIDAE  
*Bebryce* sp. NIWA J. Sánchez  
*Dentomuricea* sp. NIWA J. Sánchez  
*Echinogorgia* sp. NIWA G. Williams  
*Euplexaura* sp. 1 NIWA G. Williams  
*Euplexaura* sp. 2 NIWA G. Williams  
*Muriceides* sp. 1 NIWA J. Sánchez  
*Muriceides* sp. 2 NIWA J. Sánchez  
*Paracis squamata* (Nutting, 1910)  
*Paracis* sp. NIWA G. Williams  
*Paramuricea* sp. NIWA J. Sánchez  
*Placogorgia* sp. 1 NIWA J. Sánchez  
*Placogorgia* sp. 2 NIWA J. Sánchez  
*Placogorgia* sp. 3 NIWA J. Sánchez  
*'Swiftia'* sp. NIWA G. Williams  
*Villogorgia* sp. 1 NIWA J. Sánchez  
*Villogorgia* sp. 2 NIWA J. Sánchez  
*Villogorgia* sp. 3 NIWA J. Sánchez  
*Villogorgia* sp. 4 NIWA J. Sánchez  
PRIMNOIDAE  
*Ainigmaptilon* sp. NIWA G. Williams  
*Callogorgia* cf. *ventilabrum* Studer, 1878  
*Callogorgia* sp. NIWA G. Williams  
*Callozostron acanthodes* Bayer, 1996 E  
*Callozostron mirabile* Wright, 1885  
*Callozostron* sp.  
*Calyptrophora* sp. NIWA J. Sánchez  
*Fannyella eos* Bayer, 1998  
*Narella* sp. 1 NIWA G. Williams  
*Narella* sp. 2 NIWA G. Williams  
*Narella* sp. 3 NIWA J. Sánchez E  
*Narella* sp. 4 NIWA J. Sánchez E  
*Narella* sp. 5 NIWA J. Sánchez E  
*Plumarella* cf. *aurea* (Deichmann, 1936)  
*Plumarella* cf. *longispina* Kinoshita, 1908  
*Plumarella* sp. NIWA G. Williams



- Primnoa* sp. NIWA G. Williams  
*Primnoella australasiae* (Gray, 1850)  
*Primnoella* sp. NIWA Williams  
*Primnoides* sp. NIWA J. Sánchez  
*Pterostenella* sp. NIWA G. Williams  
*Thouarella* cf. *moseleyi* Wright & Studer, 1889  
*Thouarella* sp. 1 NIWA G. Williams  
*Thouarella* sp. 2 NIWA G. Williams  
*Thouarella* sp. 3 NIWA G. Williams  
*Thouarella* sp. 1 NIWA J. Sánchez E  
*Thouarella* sp. 2 NIWA J. Sánchez E  
*Thouarella* sp. 3 NIWA J. Sánchez E
- Order PENNATULACEA (sea pens)  
 ANTHOPTILIDAE  
*Anthoptilum grandiflorum* (Verrill, 1879)  
*Anthoptilum murrayi* Kölliker, 1880  
 CHUNELLIDAE  
*Calibelemonn indicum* (Thomson & Henderson, 1906)  
 ECHINOPTILIDAE  
*Echinoptilum* cf. *echinatum* (Kükenthal, 1910)  
*Echinoptilum* sp. 1 NIWA G. Williams  
*Echinoptilum* sp. 2 NIWA G. Williams  
 FUNICULINIDAE  
*Funiculina quadrangularis* (Pallas, 1766)  
*Funiculina* sp. NIWA G. Williams  
 HALIPTERIDAE  
*Halipterus* sp. 1 NIWA G. Williams  
*Halipterus* sp. 2 NIWA G. Williams  
 KOPHOBELEMNIDAE  
*Kophobelemonn stelliferum* (Müller, 1776)  
*Kophobelemonn* sp. 1 NIWA G. Williams  
*Kophobelemonn* sp. 2 NIWA G. Williams  
*Sclerobelemonn* sp. NIWA G. Williams  
 PENNATULIDAE  
*Pennatula indica* Thomson & Henderson, 1906  
*Pennatula naresi* Kölliker, 1880  
*Pennatula phosphorea* Linnaeus, 1758  
*Pennatula prolifera* Jungersen, 1904  
*Pennatula* sp. NIWA G. Williams  
*Gyrophyllum sibogae* Hickson, 1916  
*Gyrophyllum* sp. NIWA G. Williams  
*Pteroeides bollonsi* (Benham, 1906)  
*Pteroeides* sp. 1 NIWA G. Williams  
*Pteroeides* sp. 2 NIWA G. Williams  
 PROTOPTILIDAE  
*Distichoptilum gracile* Verrill, 1882  
 UMBELLULIDAE  
*Umbellula* cf. *lindahli* (Kölliker, 1874)  
*Umbellula* sp. NIWA G. Williams  
 VIRGULARIIDAE  
*Acanthoptilum* sp. NIWA G. Williams  
*Stylatula* sp. NIWA G. Williams  
*Virgularia* cf. *gracillima* Kölliker, 1880
- Subclass HEXACORALLIA  
 Order ANTIPATHARIA  
 ANTIPATHIDAE  
*Antipathes* cf. *chamaemorus* Pax & Tischerrek, 1932  
*Antipathes* cf. *columnarus* (Duchassaing, 1870)  
*Antipathes* cf. *densa* Silberfeld, 1909  
*Antipathes fruticosa* Gray, 1857 E  
*Antipathes glutinata* Totton, 1923 E  
*Antipathes* cf. *gracilis* Gray, 1860  
*Antipathes* cf. *grandis* Verrill, 1928  
*Antipathes* cf. *pauroclema* Pax & Tischerrek, 1932  
*Antipathes* cf. *spinulosa* (Schultz, 1896)  
*Antipathes tenuispina* (Silberfeld, 1909)  
*Antipathes* cf. *triadocrada* (Opresko, 1999)  
*Antipathes* sp. 1 D. Opresko
- Aphanipathes* cf. *colombiana* Opresko & Sanchez, 1997  
*Aphanipathes* cf. *reticulata* (Esper, 1795)  
*Aphanipathes* cf. *sarothamnoides* Brook, 1889  
*Aphanipathes undulata* van Pesch, 1914  
*Aphanipathes* n. sp. 1 D. Opresko  
*Aphanipathes* n. sp. 2 D. Opresko  
*Cirripathes propinqua* Brook, 1889  
*Cirripathes spiralis* (Linnaeus, 1758)  
*Cirripathes* sp. D. Opresko  
*Stichopathes variabilis* van Pesch, 1914  
*Stichopathes* sp. D. Opresko  
 CLADOPATHIDAE  
*Cladopathes plumosa* Brook, 1889  
*Chrysopathes tetracrada* Opresko, 2003  
*Cladopathes?* cf. *A. intermedia* Brook, 1889  
*Cladopathes* sp. D. Opresko  
*Sibopathes* n. sp. D. Opresko  
*Trissopathes pseudotristicha* Opresko 2003  
*Trissopathes tristicha* (van Pesch, 1914)  
*Trissopathes* sp. D. Opresko  
 LEIOPATHIDAE  
*Leiopathes* cf. *acanthophora* Opresko, 1998  
*Leiopathes secunda* Opresko, 1998  
*Leiopathes* sp. D. Opresko  
 MYRIOPATHIDAE  
*Antipathella aperta* (Totton, 1923) E  
*Antipathella fiordensis* (Grange, 1990) E  
*Antipathella strigosa* Brook, 1889 E  
*Antipathella* cf. *subpinnata* (Ellis & Solander, 1786)  
*Cupressopathes* cf. *abies* (Linnaeus, 1758)  
*Myriopathes catharinae* (Pax, 1932)  
*Myriopathes japonica* (Brook, 1889) / *stechowi* (Pax, 1932)  
*Myriopathes myriophylla* (Pallas, 1766)  
*Myriopathes ulex* (Ellis & Solander, 1786)  
*Myriopathes* sp. 1 D. Opresko  
*Myriopathes* sp. 2 D. Opresko  
*Plumapathes* cf. *pennacea* (Pallas, 1766)  
 SCHIZOPATHIDAE  
*Bathypathes alternata* Brook, 1889  
*Bathypathes patula* Brook, 1889  
*Bathypathes* n. sp. D. Opresko E  
*Dendrobathypathes isocrada* Opresko, 2002  
*Dendrobathypathes* n. sp. Opresko, 2002 E  
*Lillipathes lilliei* (Totton, 1923) E  
*Parantipathes helicosticha* Opresko, 1999  
*Parantipathes* n. sp. D. Opresko E  
*Saropathes scoparia* (Totton, 1923) E  
*Saropathes* n. sp. D. Opresko E  
*Schizopathes affinis* Brook, 1889  
*Stauropathes* n. sp. D. Opresko E
- Order SCLERACTINIA  
 Suborder ASTROCOENIINA  
 ACROPORIDAE  
*Montipora capricornis* Veron, 1985 Z  
*Montipora spongodes* Bernard, 1897 Z  
 POCILLOPORIDAE  
*Madracis kauaiensis* Vaughan, 1907  
*Pocillopora damicornis* Linnaeus, 1758 Z
- Suborder FUNGIINA  
 AGARICIIDAE  
*Leptoseris scabra* Vaughan, 1907 Z  
*Pavona explanulata* (Lamarck, 1816) Z  
 FUNGIACYATHIDAE  
*Fungiacyathus (Fungiacyathus) fragilis* Sars, 1872  
*Fungiacyathus (F.) pusillus pacificus* Cairns, 1995 E  
*Fungiacyathus (F.) stephanus* (Alcock, 1893)
- Fungiacyathus (Bathyactis) marenzelleri* (Vaughan, 1906)  
*Fungiacyathus (B.) margaretae* Cairns, 1995 E  
*Fungiacyathus (B.) turbinolioides* Cairns, 1989  
 FUNGIIDAE  
*Fungia (Cycloseris) vaughani* Boschma, 1923 Z  
 MICRABACIIDAE  
*Letepsammia fissilis* Cairns, 1995  
*Letepsammia formosissima* (Moseley, 1876)  
*Letepsammia superstes* (Ortmann, 1888)  
*Stephanophyllia complicata* Moseley, 1876  
 PORITIDAE  
*Alveopora spongiosa* Dana, 1846 Z  
 SIDERASTREIDAE  
*Coscinaraea columna* (Dana, 1846) Z  
*Psammocora haimeana* Milne Edwards & Haime, 1851 Z
- Suborder FAVIINA  
 ANTHEMIPHYLLIIDAE  
*Anthemiphyllia dentata* (Alcock, 1902)  
*Anthemiphyllia macrolobata* Cairns, 1999  
*Anthemiphyllia pacifica* Vaughan, 1907  
 FAVIIDAE  
*Cyphastrea serailia* (Forskål, 1775) Z  
*Goniastrea australensis* (Milne Edwards & Haime, 1857) Z  
*Leptastrea bewickensis* Veron, Pichon, & Wijsman-Best, 1977 Z  
*Montastraea curta* (Dana, 1846) Z  
*Plesiastrea versipora* (Lamarck, 1816) Z  
 OCULINIDAE  
*Madrepora oculata* Linnaeus, 1758  
*Oculina virgosa* Squires, 1958 E  
 MERULINIDAE  
*Hydnophora pilosa* Veron, 1986 Z  
 RHIZANGIIDAE  
*Culicia rubeola* (Quoy & Gaimard, 1833) E
- Suborder CARYOPHYLLIINA  
 CARYOPHYLLIIDAE  
*Anomocora* cf. *fecunda* (Pourtalès, 1871)  
*Aulocyathus recidivus* (Denmant, 1906)  
*Bourneotrochus stellulatus* (Cairns, 1984)  
*Caryophyllia (Caryophyllia) ambrosia* Alcock, 1898  
*Caryophyllia (C.) atlantica* (Duncan, 1873)  
*Caryophyllia (C.) crosnieri* Cairns & Zibrowius, 1997  
*Caryophyllia (C.) diomedea* Marenzeller, 1904  
*Caryophyllia (C.) hawaiiensis* Vaughan, 1907  
*Caryophyllia (C.) japonica* Marenzeller, 1888  
*Caryophyllia (C.) lamellifera* Moseley, 1881  
*Caryophyllia (C.) profunda* Moseley, 1881  
*Caryophyllia (C.) quadragenaria* Alcock, 1902  
*Caryophyllia (C.) rugosa* Moseley, 1881  
*Coenocyathus brooki* Cairns, 1995 E  
*Comotrochus brunneus* (Moseley, 1881)  
*Crispatotrochus curvatus* Cairns, 1995 E  
*Crispatotrochus rugosus* Cairns, 1995  
*Dasmosmia lymani* (Pourtalès, 1871)  
*Deltocyathus suluensis* Alcock, 1902  
*Desmophyllum dianthus* (Esper, 1794)  
*Goniocorella dumosa* (Alcock, 1902)  
*Hoplangia durotrix* Gosse, 1860 A  
*Labyrinthocyathus limatulus* (Squires, 1964)  
*Labyrinthocyathus* sp. sensu Cairns, 1995 E  
*Oxysmia circularis* Cairns, 1998  
*Polycyathus norfolkensis* Cairns, 1995 E  
*Premocyathus dentiformis* (Alcock, 1902)  
*Solenosmia variabilis* Duncan, 1873  
*Stephanocyathus (Acinocyathus) spiniger* (Marenzeller, 1888)

- Stephanocyathus* (*Odontocyathus*) *coronatus* (Pourtalès, 1867)  
*Stephanocyathus* (*O.*) *weberianus* (Alcock, 1902)  
*Stephanocyathus* (*Stephanocyathus*) *platypus* (Moseley, 1876)  
*Stephanocyathus* (*S.*) *regius* Cairns & Zibrowius, 1997  
*Tethocyathus cylindraceus* (Pourtalès, 1868)  
*Tethocyathus virgatus* (Alcock, 1902)  
*Thalamophyllia tenuescens* (Gardiner, 1899)  
*Trochocyathus* (*Aplocyathus*) *hastatus* Bourne, 1903  
*Trochocyathus* (*T.*) *cepulla* Cairns, 1995  
*Trochocyathus* (*T.*) *gordoni* Cairns, 1995 E  
*Trochocyathus* (*T.*) *maculatus* Cairns, 1995  
*Trochocyathus* (*T.*) *rhombocolumna* Alcock, 1902  
*Vaughanella concinna* Gravier, 1915  
*Vaughanella multipalifera* Cairns, 1995 E
- FLABELLIDAE  
*Falcatoflabellum raulensis* Cairns, 1995 E  
*Flabellum* (*Flabellum*) *arcuatile* Cairns, 1999  
*Flabellum* (*F.*) *impensum* Squires, 1962  
*Flabellum* (*F.*) *knoxi* Ralph & Squires, 1962 E  
*Flabellum* (*Ulocyathus*) *aotearoa* Squires, 1964  
*Flabellum* (*U.*) *apertum apertum* Moseley, 1876  
*Flabellum* (*U.*) *hoffmeisteri* Cairns & Parker, 1992  
*Flabellum* (*U.*) *lowekeyesi* Squires & Ralph, 1965  
*Flabellum* (*U.*) *messum* Alcock, 1902  
*Javania fusca* (Vaughan, 1907)  
*Javania lamprotichum* (Moseley, 1880)  
*Monomyces rubrum* (Quoy & Gaimard, 1833) E  
*Placotrochides scaphula* Alcock, 1902  
*Polymyces wellsi* Cairns, 1991  
*Rhizotrochus flabelliformis* Cairns, 1989  
*Truncatoflabellum angustum* Cairns & Zibrowius, 1997  
*Truncatoflabellum arcuatum* Cairns, 1995 E  
*Truncatoflabellum dens* (Alcock, 1902)  
*Truncatoflabellum paripavoninum* (Alcock, 1894)  
*Truncatoflabellum phoenix* Cairns, 1995
- GARDINERIIDAE  
*Gardinieria hawatiensis* Vaughan, 1907
- GUYNIIDAE  
*Pedicyathus keyesi* Cairns, 1995 E  
*Stenocyathus vermiformis* (Pourtalès, 1868)  
*Temnotrochus kermadecensis* Cairns, 1995 E  
*Truncatogynia irregularis* Cairns, 1989
- TURBINOLIIDAE  
*Alatotrochus rubescens* (Moseley, 1876)  
*Conotrochus zelandiae* Duncan, 1876  
*Cyathotrochus pileus* (Alcock, 1902)¶  
*Kionotrochus suteri* Dennant, 1906 E  
*Notocyathus conicus* (Alcock, 1902)  
*Peponocyathus dawsoni* Cairns, 1995 E  
*Pleotrochus zibrowii* Cairns, 1997  
*Sphenotrochus ralphae* Squires, 1964 E  
*Sphenotrochus squiresi* Cairns, 1995 E  
*Thrypticotrochus multilobatus* Cairns, 1995
- Suborder DENDROPHYLLIINA  
DENDROPHYLLIIDAE  
*Balanophyllia* (*Balanophyllia*) *chnous* Squires, 1962 E  
*Balanophyllia* (*B.*) *crassithea* Cairns, 1995  
*Balanophyllia* (*B.*) *gigas* Moseley, 1881  
*Cladopsammia eguchii* (Wells, 1982)  
*Dendrophyllia alcocki* (Wells, 1954)  
*Dendrophyllia arbuscula* Van der Horst, 1922  
*Dendrophyllia ijimai* Yabe & Eguchi, 1934  
*Eguchipsammia fistula* (Alcock, 1902)  
*Eguchipsammia gaditana* (Duncan, 1873)  
*Eguchipsammia japonica* (Rehberg, 1892)  
*Enallopsammia rostrata* (Pourtalès, 1878)  
*Endopachys grayi* Milne Edwards & Haime, 1848  
*Rhizopsammia* cf. *verillii* Van der Horst, 1922  
*Tabastraea coccinea* Lesson, 1829  
*Tabastraea diaphana* Dana, 1846  
*Turbinaria frondens* (Dana, 1846) Z  
*Turbinaria radicalis* Bernard, 1896 Z
- Class HYDROZOA  
Order ANTHOATHECATA  
Suborder CAPITATA  
STYLASTERIDAE  
*Adelopora crassilabrum* Cairns, 1991 E  
*Adelopora fragilis* Cairns, 1991  
*Astya aspidopora* Cairns, 1991 E  
*Calyptopora reticulata* Boschma, 1968 E  
*Calyptopora sinuosa* Cairns, 1991 E  
*Conopora candelabrum* Cairns, 1991 E  
*Conopora gigantea* Cairns, 1991 E  
*Conopora laevis* (Studer, 1878)  
*Conopora tetrastichopora* Cairns, 1991 E  
*Conopora unifacialis* Cairns, 1991 E  
*Conopora verrucosa* (Studer, 1878)  
“*Conopora*” *anthohelia* Cairns, 1991 E  
*Crypthelia curvata* Cairns, 1991 E  
*Crypthelia cymas* Cairns, 1986  
*Crypthelia fragilis* Cairns, 1983  
*Crypthelia polyzona* Cairns, 1991 E  
*Crypthelia robusta* Cairns, 1991 E  
*Crypthelia studeri* Cairns, 1991 E  
*Distichopora dispar* Cairns, 1991 E  
*Distichopora violacea* (Pallas, 1766)  
*Errina bicolor* Cairns, 1991 E  
*Errina chathamensis* Cairns, 1991 E  
*Errina cheilopora* Cairns, 1983 E  
*Errina cooki* Hickson, 1912 E  
*Errina dendyi* Hickson, 1912 E  
*Errina gracilis* Marenzeller, 1903  
*Errina hicksoni* Cairns, 1991 E  
*Errina laevigata* Cairns, 1991 E  
*Errina novaezelandiae* Hickson, 1912 E  
*Errina reticulata* Cairns, 1991 E  
*Errina sinuosa* Cairns, 1991 E  
*Inferiolabiata labiata* (Moseley, 1879)  
*Inferiolabiata lowei* (Cairns, 1983)  
*Inferiolabiata spinosa* Cairns, 1991 E  
*Lepidopora cryptocymas* Cairns, 1985 E  
*Lepidopora dendrostylus* Cairns, 1991 E  
*Lepidopora microstylus* Cairns, 1991 E  
*Lepidopora polystichopora* Cairns, 1985 E  
*Lepidopora sarmentosa* (Boschma, 1968) E  
*Lepidopora symmetrica* Cairns, 1991  
*Lepidotheca altispina* Cairns, 1991  
*Lepidotheca cervicornis* (Broch, 1942) E  
*Lepidotheca chauliosstylus* Cairns, 1991 E  
*Lepidotheca fascicularis* (Cairns, 1983)  
*Lepidotheca robusta* Cairns, 1991 E  
*Pseudocrypthelia pachypoma* (Hickson & England, 1905)  
*Sporadopora micropora* Cairns, 1991 E  
*Sporadopora mortenseni* Broch, 1942  
*Stenohelia conferta* Boschma, 1968 E  
*Stephanohelia praecipua* Cairns, 1991  
*Stylaster brunneus* Boschma, 1970  
*Stylaster eguchii* (Boschma, 1966)  
*Stylaster gracilis* Milne Edwards & Haime, 1850 E

