Pilot ecological risk assessment for protected corals

Prepared for Marine Species and Threats, Department of Conservation

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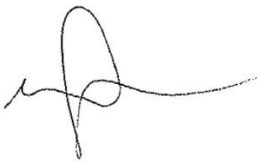

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Executive summary

Protected corals are diverse and widespread in the New Zealand region. They are vulnerable to impact from bottom trawling, and other human activities in the deep sea such as mineral exploration. In this study we undertake a preliminary assessment of the relative risk to protected coral species from deepwater bottom trawling. We apply the methodology to the orange roughy fishery on the Chatham Rise as a case study.

A Productivity-Susceptibility-Analysis (PSA) was carried out for 15 species or groups of coral. These were chosen to encompass a range of characteristics to illustrate the type of results from such a risk assessment, and how this could inform management. The analysis considers the extent of impact on the relevant species due to fishing activity ("susceptibility"), and the potential of the species to recover from the impact ("productivity"). The corals selected included reef-forming scleractinian stony corals, "tree-like" gorgonian corals and black corals, and smaller scleractinian cup corals and hydrocorals.

The assessment considered various sources of information on the distribution of corals and fishing that provided information on the "availability" and "encounterability" attributes. Knowledge of the shape and size of corals, and studies on trawling impacts helped assess the "selectivity" of a trawling encounter, and then biological data such as age, growth, reproduction, colonisation, and dispersal were used to rank the "productivity" of a coral species or group, which reflects its ability to recover from trawling.

The PSA produces a plot of susceptibility and productivity scores, and also derives an overall relative risk index. Black corals (at the order level, and the genus *Bathypathes*) and the gorgonian coral genus *Paragorgia*, were classified as high risk. Most reef-building scleractinian corals, as well as other gorgonian coral taxa, were medium risk, and cup corals and hydrocorals were relatively low risk. These results were consistent with expectations based on the form and biology of the corals, and knowledge of trawling impacts.

The method allows sufficient transparency to track and understand where and how certain attribute scores affect results. It also enables the sources of susceptibility or productivity to be evaluated when considering the efficacy of management options to reduce or mitigate risk. Although only a pilot assessment, the study should provide scientists and managers with a better understanding of this type of ERA methodology, as well as the various aspects and characteristics of coral species and the fishery that contribute to risk determination, and inform potential management approaches.

1 Introduction

The New Zealand region supports a diverse coral fauna and the distribution of protected deep-sea coral groups is reasonably well known (e.g., Sanchez 2005; Consalvey et al. 2006; Tracey et al. 2011a & b; Baird et al. 2013; Opresko & Tracey 2013).

Coral structures are often fragile and hence vulnerable to physical disturbance with slow recovery from physical damage (see review in Tracey et al. 2013). This means that deep-sea corals may be at risk from anthropogenic activities such as bottom trawling (Clark & O'Driscoll 2003, Clark & Rowden 2009, Williams et al. 2010), oil and gas exploration and extraction, the laying of cables and telecommunications links, and waste disposal (e.g., Ramirez-Llodra et al. 2011). The key threatening processes identified for marine invertebrates including corals were fishing and land-use associated impacts such as sedimentation (Freeman et al 2010).

For deep-sea corals in New Zealand waters, the risk of damage or destruction by fishing activities was recognised in the 2010 amendment of Schedule 7A of the Wildlife Act 1953. All hard corals are protected. These are:

- black corals (all species in the Order Antipatharia)
- gorgonian corals (selected species in the Order Alcyonacea †)
- stony corals (all species in the Order Scleractinia)
- hydrocorals (all species in the Family Stylasteridae)

(†Previously Order Gorgonacea, all gorgonians are now in Order Alcyonacea as revised by Watling et al. (2011)).

The nature and extent of the threat to protected coral species has been the subject of several research projects undertaken for the Department of Conservation (DOC). Tracey et al. (2011a) analysed depth and spatial extent of bycatch of nine groups of protected corals from observed trawl effort for 2007–10. Most corals were caught at 800–1200 m depths, with over 80% from tows that targeted orange roughy, black oreo (*Allocyttus niger*), smooth oreo (*Pseudocyttus maculatus*), and black cardinalfish (*Epigonus telescopus*). Overall, 19% of observed deep-water tows for these target species had coral catch records.

Baird et al. (2013) further added to the knowledge of the distribution of protected corals in relation to fisheries by using data from research sampling and commercial fishing effort where observers had been present. This work helped improve understanding the risk to protected corals by characterising the nature and extent of the commercial fishing impacts. They showed that the fisheries that pose the most risk were the deep-water trawl fisheries for species such as orange roughy, black oreo, smooth oreo, black cardinalfish, and alfonsino (*Beryx* spp.).

The present study has two components to progress the overall DOC objective to describe the distribution of deep sea corals in relation to areas where they are at risk of interactions with commercial fishing gear.

1.1 Specific objectives

The project has two objectives:

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

This report describes an extension of the second objective, and carries out a preliminary ecological risk assessment (ERA) in order to inform managers of the type of outputs a risk assessment may produce, where there might be major knowledge gaps that limit the ERA, and provides an indication of the relative vulnerability of different corals relevant for developing management options to reduce impacts from trawling.

This report has been prepared for the Marine Species and Threat Group of DOC under Project DOC14302_POP2013-05.

2 Methods

The methods applied in this study were presented to the Marine Species and Threat Group of DOC and members of the Marine Species and Threat Technical Working Group in January 2014.

2.1 Region of focus

The Chatham Rise was selected as a trial region for application of the ERA as it is one where the distribution of corals, as well as fishing, is well known, and has recently been the subject of both coral modelling and trawl footprint analyses. Its geographical extent is defined approximately by the Northwest Rise, East & South Rise, and Arrow BPA subdivisions of the ORH 3B Quota Management Area, extending to a depth of about 1500 m (see http://deepwater.co.nz/wp-content/uploads/2013/03/3_ORH-OEO-2013-14-v5.pdf).

2.2 Selection of coral species

A number of coral species and groups were selected to reflect the variability in physical characteristics, distribution, and their ecological importance. Baird et al. (2013) assigned coral species to four "functional" groups, based on overall form and size: "reef-like", "tree-like", "whip-like", and "solitary small". These groups are sufficiently different in their structure that they provide varying forms of habitat and associated value to other animals, and hence are useful to illustrate relative risk.

In total, 15 coral species or groupings were used in the PSA. These included the reef-like species *Solenosmilia variabilis*, *Goniocorella dumosa*, *Madrepora oculata*, and *Enallopsammia rostrata* as well as the northern and relatively shallow water *Oculina virgosa*. Within the order Scleractinia there is considerable species level variation and solitary small cup corals were included as contrast (e.g., cup corals *Flabellum* and *Stephanocyathus* found on soft sediment and *Desmophyllum dianthus* and *Caryophyllia* spp. found attached to other corals or on hard substrate). Tree-like black corals and selected gorgonian corals, bubblegum corals *Paragorgia* spp., bamboo corals *Keratoisis* spp., *Lepidisis* spp. (these genera were combined as the taxonomy for these genera is still being reconciled (Juan Sanchez pers comm. Universidad de los Andes, Santafé de Bogotá);and the golden coral *Metallogorgia* spp., that has a long whip-like stem, were assessed. The solitary small hydrocorals of Family Stylasteridae were also included, as having different age and growth characteristics. The list is not comprehensive, but covers a wide range of features that enable definition of appropriate risk criteria for some typical New Zealand deep-sea corals, and an evaluation of how the different characteristics affect their risk profiles.

2.3 The risk assessment approach

Risk assessment is a developing concept within New Zealand fisheries management. Risk assessments have been carried out for a number of New Zealand situations including deep-water fisheries, Antarctic benthos, South Pacific High Seas fisheries, seabird bycatch, and a variety of marine habitats, including seamounts (see brief review in Baird et al. 2013). However, to date, such assessments have not been conducted specifically for protected species of deep-sea coral.

The Ecological Risk Assessment for the Effects of Fishing (ERAEF, Hobday et al. 2007, 2011) is a framework developed in Australia and adopted by the Marine Stewardship Council. This method has a scoping phase and a three-stage analysis that rates fishing activities for their effects on five ecological components of the ecosystem:

- target species
- by-product and bycatch (non target) species
- threatened, endangered, and protected species (TEP)
- habitats
- ecological communities

The scoping phase describes the activities and management of the fishery and its ecological components, and compiles all available data and information. The subsequent process becomes more complex with each of the three stages. Each level, however, screens out issues of low or lesser concern, so that the focus is on high-risk issues.

1) A Level 1 assessment for a fishery scores each fishing activity for its impact on the five ecological components. Each fishery/sub-fishery is assessed using a scale, intensity, and consequence analysis (SICA). If the impact is higher than an agreed standard, an assessment may be required at Level 2. From this scoring process, some risks from a fishery may be acceptable, requiring no further action, while others go on for more detailed analysis.
2) A Level 2 analysis considers the extent of impact on the relevant ecological component due to fishing activity (“susceptibility”), and the potential of the component to recover from the impact (“productivity”) for each species or habitat in a semi-quantitative manner. This stage of analysis considers aspects such as the reproductive capacity of species, and species composition and trophic linkages in communities. This stage has been reached for over 1000 species in Australian waters.
3) Level 3 takes a quantitative approach, using stock assessment or ecosystem models. It has been applied to many bycatch species comparing exploitation rates to overfishing reference points, but is less developed for habitats and communities.

The structure of the assessment framework is shown in Figure 2-1.

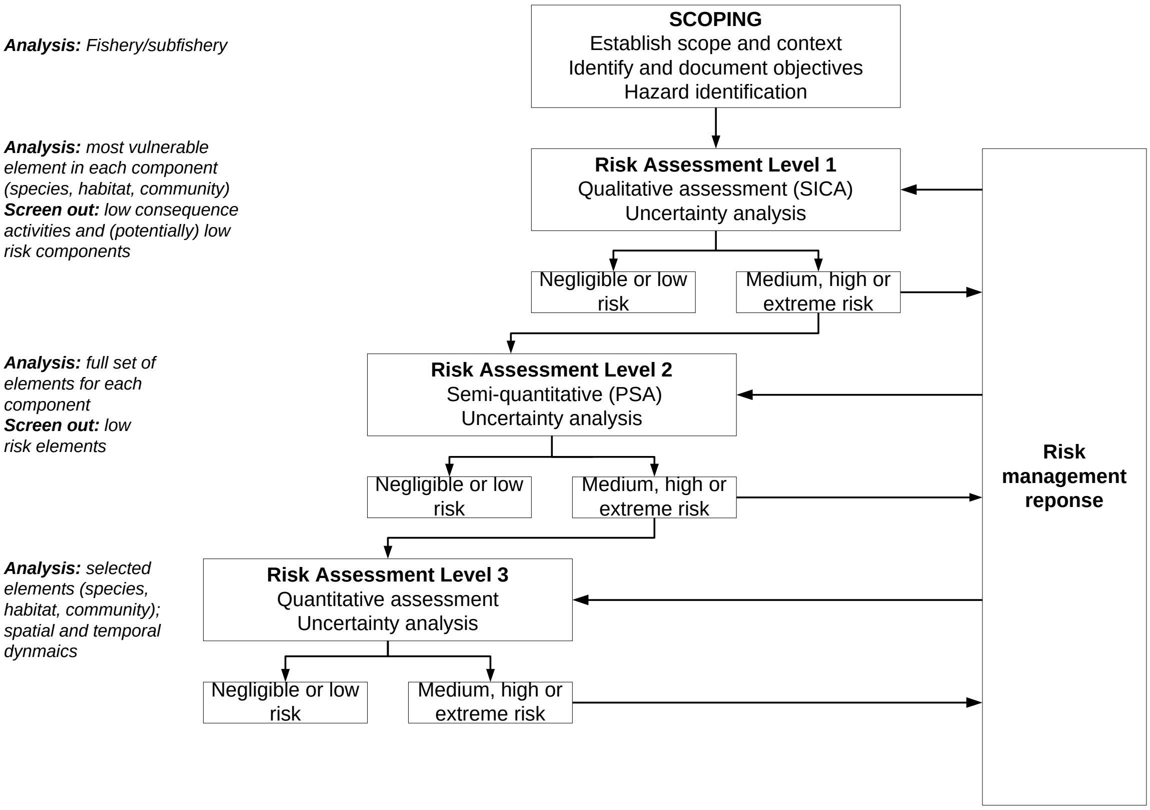


Figure 2-1: Overview of ERAEF showing focus of analysis for each level at the left in italics (from Hobday et al. 2007).

2.4 Productivity-Susceptibility-Analysis (PSA)

In this study we use the level 2 “Productivity-Susceptibility Analysis” (PSA) method to assess the risk to protected coral species from the orange roughy trawl fishery on the Chatham Rise. This is a pilot assessment in order to evaluate the suitability of the method, as well as the adequacy of available data on coral distribution and vulnerability to bottom trawling.

The PSA approach examines the extent of the impact due to the fishing activity (determined by the susceptibility of the unit to the fishing activities), and the productivity of the unit which determines the recovery potential. Susceptibility is assessed by 3 aspects (availability, encounterability and selectivity), and a single productivity aspect (see section 2.5 below). More detailed attributes are scored, and then overall susceptibility and productivity scores are derived. Whereas the productivity values are all given equal weight and an average value used, species susceptibility is estimated as the product of the availability, encounterability, and selectivity (with corrections for the number of attributes scored (after Hobday et al. 2007, 2011)). Resultant susceptibility and productivity are plotted on a 2 dimensional graph (Figure 2-2). An overall risk score is taken as the Euclidean distance from the origin, which allows a single risk ranking. Units with high susceptibility and low productivity are at highest risk, while units with low susceptibility and high productivity are at lowest risk.

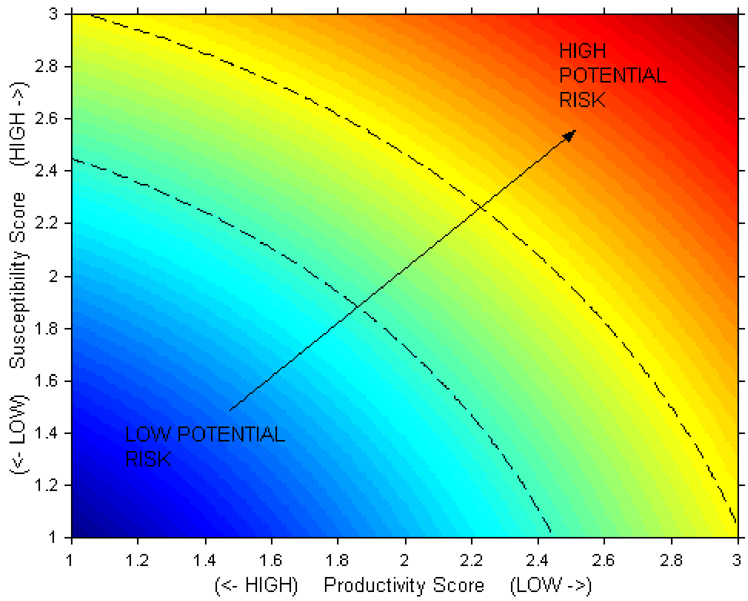


Figure 2-2: The Productivity-Susceptibility plot, which displays risk to the ecological unit. The contour lines divide regions of equal risk and group units of similar relative risk levels (from Hobday et al. 2007).

2.5 Attributes and scoring

The aspects of Availability, Encounterability, Selectivity and Productivity were evaluated under the criteria for the "Habitat" component of the ERAEF, rather than the "Threatened, Endangered, or Protected" component. The reason for this is that many fisheries ERAs are focused more towards fish, seabird, or mammal interactions, and use different assessment parameters from those appropriate for sessile corals on the seafloor. The latter are more similar to benthic habitat than benthic fish species.

The methodology of Hobday et al. (2007), and slightly modified by Clark et al. (2011) for evaluating the risk of bottom trawling on the benthic habitat of seamounts, was used.

2.5.1 Availability

Availability refers to the overlap of the region of focus with a species distribution.

	Aspect	Concept and Rationale		Ranks	
	Attribute (s)		1 (low risk)	2 (medium)	3 (high risk)
	Availability				
A1	Spatial overlap (geographical and depth range)	Spatial overlap of the general geographic area with the geographical and depth range of the coral taxon.	Very little overlap (<10% of its distribution in NZ is located in the region of focus)	Partial overlap (10-50%)with its distribution range around NZ	Considerable overlap (>50%) with species distribution (e.g., Chatham Rise endemic)

The degree of overlap was assessed by comparing the distribution and depth range of the coral species throughout the New Zealand region with its distribution on the Chatham Rise (see section 2.6.1.

2.5.2 Encounterability

Encounterability is the likelihood that fishing gear deployed within the region of focus will encounter a given taxon (based on adult habitat and depth range).

	Aspect Attribute (s)	Concept and Rationale	Ranks 1 (low risk)	 2 (medium)	 3 (high risk)
	Encounterability				
E1	Depth zone	The depth distribution of the coral species relative to the depth at which fishing activity occurs	Depth overlap <10% (generally <500 m or > 1200 m)	Depth overlap 10-50% (generally 500-800 m)	Depth overlap > 50% (800-1200 m)
E2	Geographical area	Encounters driven by expectation of finding target fish species. Overlap of the trawl footprint and modelled distribution	<10% overlap between trawl footprint and species distribution	10-50% overlap between trawl footprint and species distribution	>50% overlap between trawl footprint and species distribution
E3	Ruggedness	Relief, rugosity, hardness and seabed slope influence accessibility to bottom trawling and coral occurrence	Predominantly high relief (>1.0 m), rugged, difficult to trawl (crevices, overhangs, boulders); > 30° slope.	Predominantly low relief (<1.0 m), rough surface but trawlable (rubble, small boulders); <30° slope.	No relief to impede trawling, smooth simple surface; < 30° slope.
E4	Level of disturbance	The degree of impact that an encounter will have on individual colonies of a taxon	Many encounters needed for a significant impact on individual colonies	Several encounters needed to damage individual colonies	Single trawl will cause significant damage to individual colonies

Four attributes of encounterability were included. For the depth and area overlap attributes, the orange roughy trawl footprint layer generated for the Chatham Rise for the fishing years 1990–91 to 2012–13 was used (based on Black et al. 2013). The overlap by depth was assessed from comparing the known depth distribution of orange roughy fisheries (primarily 800–1200 m) with frequency distribution plots of coral depth records compiled for habitat suitability modelling (Tracey et al. 2013) (see Section 2.6.1). Geographical overlap compared the trawl footprint with the average values of the likelihood of coral presence from the predictive model distributions (Anderson et al. 2014).

Ruggedness was evaluated by the authors based on their own experience with trawling grounds in the region, and knowledge of coral habitat from seafloor photographs obtained during NIWAs biodiversity and seamount ecology research voyages. The level of disturbance component (E4) was evaluated using literature on trawling impacts where the frequency or number of trawls had been studied (section 2.6.3).

2.5.3 Selectivity

Selectivity considers the potential of the fishing gear to capture or retain species.

	Aspect	Concept and Rationale		Rank	
	Attribute (s)		1 (low risk)	2 (medium)	3 (high risk)
	Selectivity				
S1	Removability/ mortality of morphotypes	Erect, large, rugose, inflexible, delicate forms incur higher impacts	Low, robust or small (<5 cm), smooth or flexible types.	Erect or medium sized (5-30 cm), moderately robust/inflexible.	Tall, delicate or large (> 30 cm high), rugose or inflexible.
S2	Associated faunal diversity	Diversity/species richness associated with the coral species or biogenic habitat, including relative ecological importance for other species.	Diversity low. Few, if any, species grow on or with the coral	Diversity medium. Some species grow or live on or in the coral	Diversity high. Many species utilize the matrix of a biogenic form
S3	Areal extent	Proportion of predicted coral distribution relative to total area considered. Larger areal extent means less risk for maintaining biodiversity and community function.	Common (> 10%) within the area)	Moderately common (1-10%) within the area	Rare (<1%) within the area. Small impacts may affect a large proportion of the taxon

The attributes S1 and S2 were assessed by the author's knowledge of the morphology of the coral species, and their experience with research voyage catches and literature on associated species. The Area Extent attribute used the predicted coral distribution from habitat suitability modelling work (see section 2.6.1).

2.5.4 Productivity

Productivity determines the potential of a unit to recover from impacts due to fishing.

	Aspect	Concept and Rationale		Ranks	
	Attribute (s)		1 (low risk)	2 (medium)	3 (high risk)
	Productivity				
P1	Regeneration of fauna	Accumulation/ recovery of coral habitat to a mature successional state. Based on intrinsic growth and reproductive rates that vary with temperature, nutrient, productivity.	< Decadal	> Decadal	>100 years
P2	Natural disturbance	Level of natural disturbance affects how organisms or communities are adapted to being disturbed, and their intrinsic ability to recover.	High disturbance (e.g.,volcanism, earthquakes, landslides)	Intermediate	Little natural disturbance
P3	Naturalness	The historical level of trawl impact determines present status of benthic habitat	High trawling effort	Medium effort	Low effort
P4	Connectivity	The dispersal distance or connectedness of coral habitats is important for recruitment to trawled areas or patches of coral habitat.	High connectivity (able to disperse large distance, or distance between coral patches <25 km)	Moderate (25-100 km)	Low connectivity (limited dispersal ability, or isolated patches (>100 km)

P1 was assessed using data on age and growth of coral species from the literature (see section 2.6.4). P2 was evaluated using knowledge of the topography on the Chatham Rise (no active volcanism, apart from the northwest corner with the Hikurangi Trough no landslide potential) and the depth distribution of coral species (depths >100 m will not be affected by surface weather events). P3 was scored by the author's judgement of whether the coral habitat overall had been heavily trawled (>100 tows), been impacted by medium levels of effort (50-100 trawls), or been lightly trawled<50 tows) over the duration of the fishery. Connectivity (P4) was a combination of data and knowledge of the patchiness of coral distribution (high density) and their reproductive capacity from the literature.

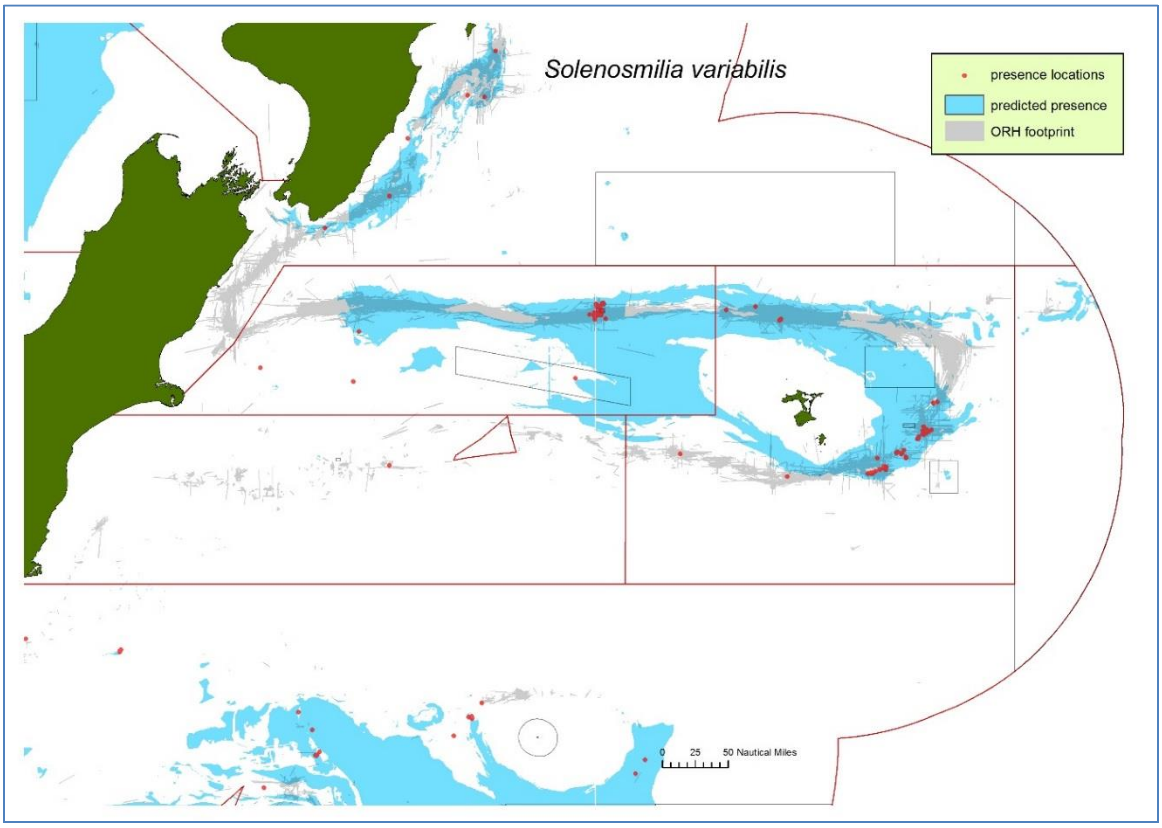
2.6 Data sources and Criteria assessment

Four NIWA staff carried out the risk assessment (Clark, Tracey, Anderson, and Parker), using data on the known distribution, predicted distribution, overlap with commercial fisheries, knowledge of the species or species group's morphology (size, shape, fragility), life history (age and growth, age at maturity, recolonization, reproductive method such as broadcast spawning or brooding), and studies on impacts of trawling. Values were assigned by consensus and with reference to appropriate literature and data summaries described below. For scoring attributes or interactions that were uncertain based on available information, the default was to choose the higher risk category rather than the lower risk category.

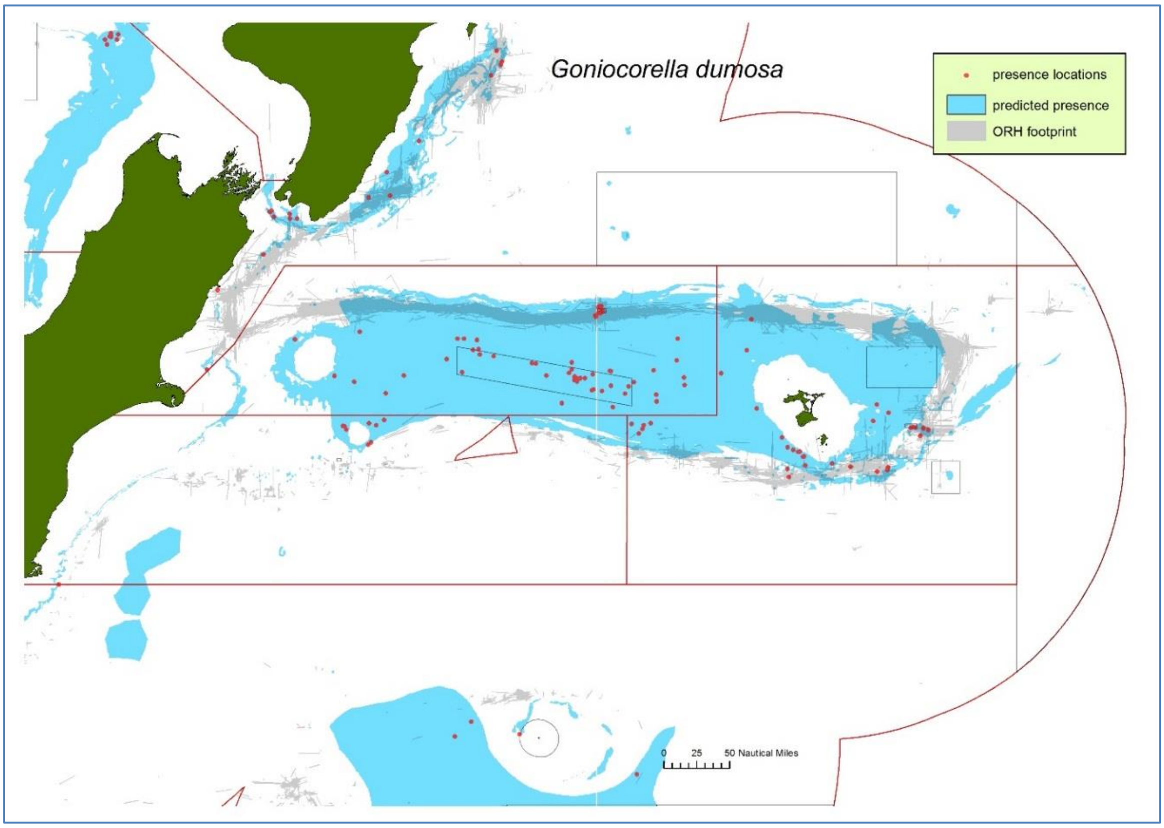
2.6.1 Species geographical distribution (Availability and Encounterability attributes)

The overall species or taxon distributions in the New Zealand region were taken from previous studies which included maps and notes on the recorded occurrence of coral records (known distribution), as well as predicted distributions based on habitat suitability modelling (e.g., Consalvey et al. 2006, Tracey et al. 2011a, b, Tracey et al. 2013a, Baird et al. 2013, Tracey et al. 2013).

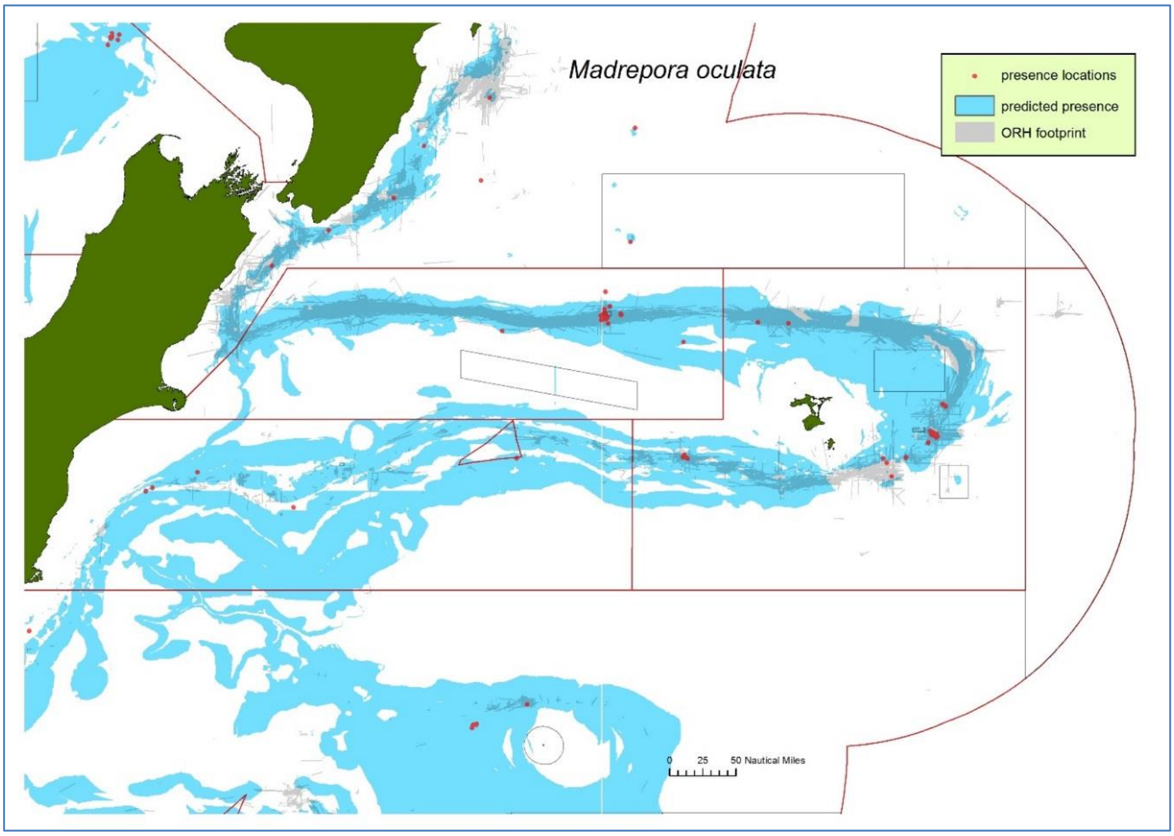
More detailed plots were produced of known and predicted distributions (see Anderson et al. 2014) for the Chatham Rise area. These plots were the basis of estimating the extent of distribution on the Chatham Rise for the availability attribute (A1), as well as the geographical overlap between the trawl footprint and modelled distribution for the Geographical Area (E2) attribute). Figure 2-3 shows the modelled distributions of some of the taxa that are included in this study: black corals Order Antipatharia, *Bathypathes* spp.; bamboo corals of the genera *Keratoisis* and *Lepidisis*; the gorgonian genera *Primnoa* and *Paragorgia*; and four species of scleractinians, *Solenosmilia variabilis*, *Madrepora oculata*, *Enallopsammia rostrata*, and *Goniocorella dumosa*

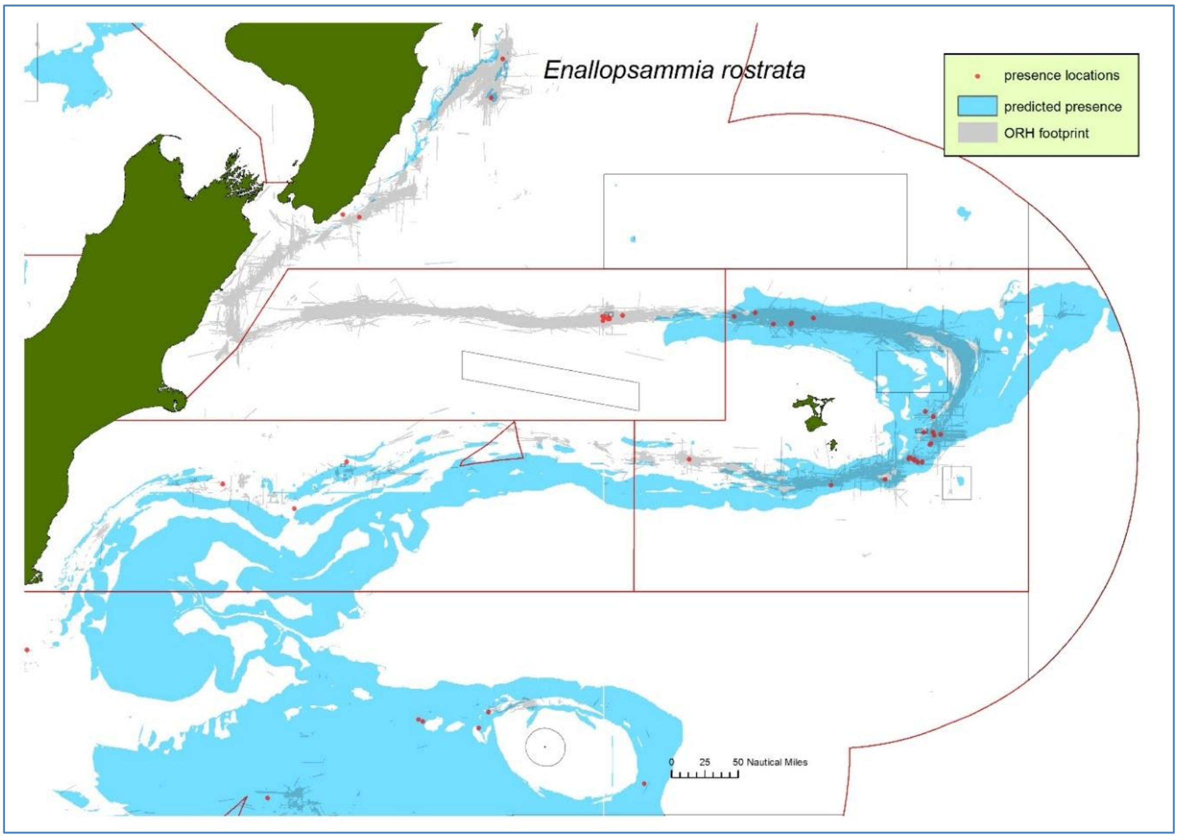


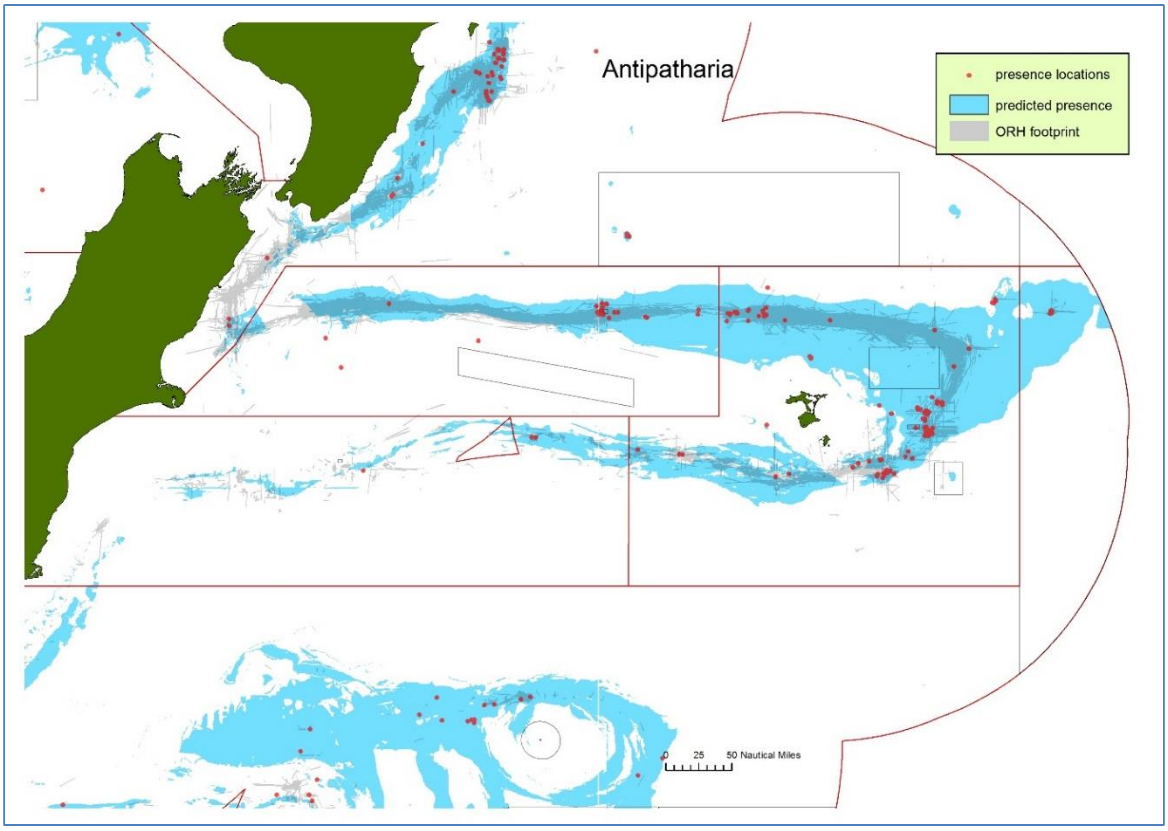
Solenosmilia variabilis
presence locations
predicted presence
ORH footprint
0 25 50 Nautical Miles

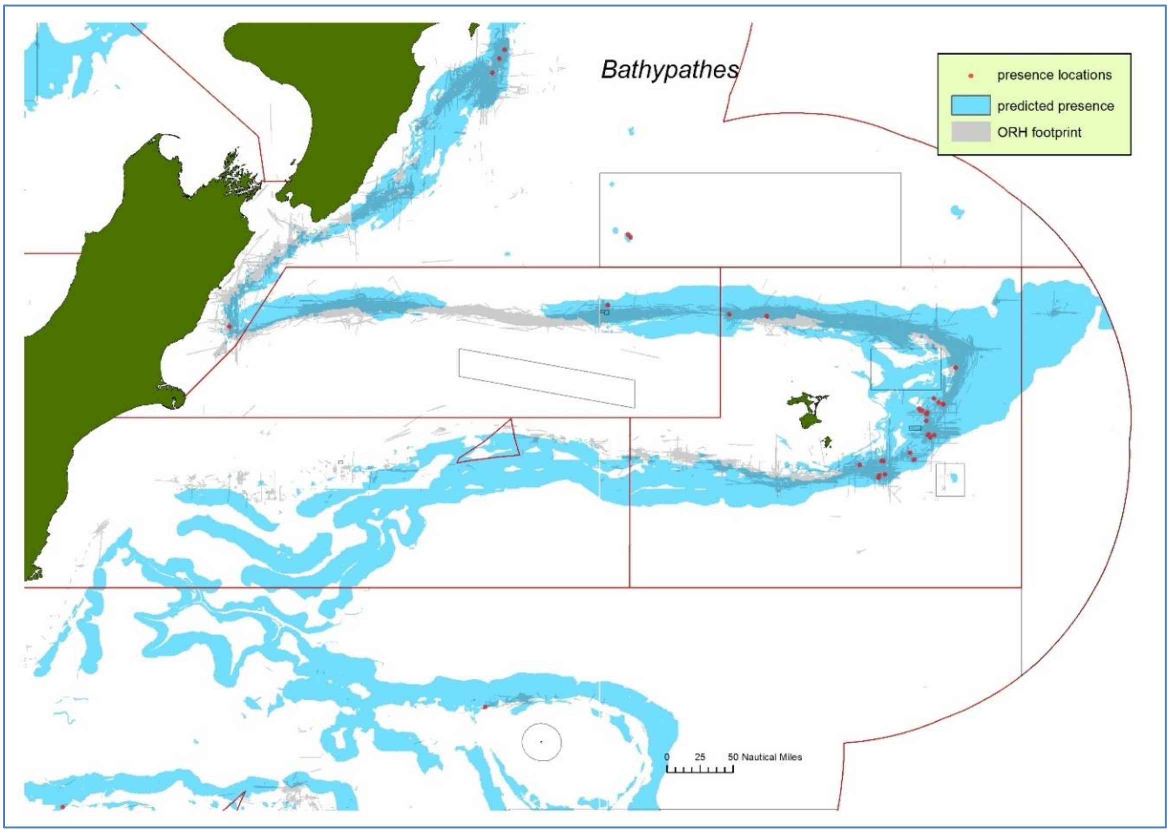


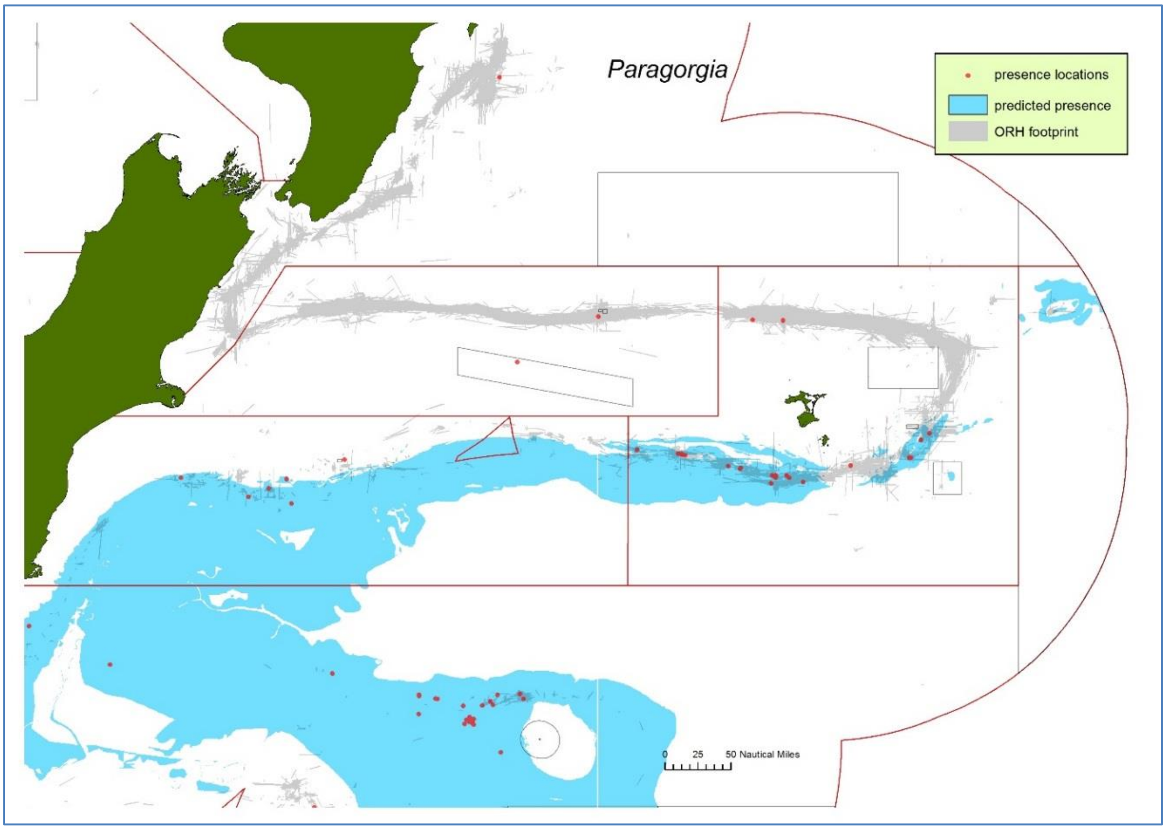
Goniocorella dumosa
presence locations
predicted presence
ORH footprint
0 25 50 Nautical Miles

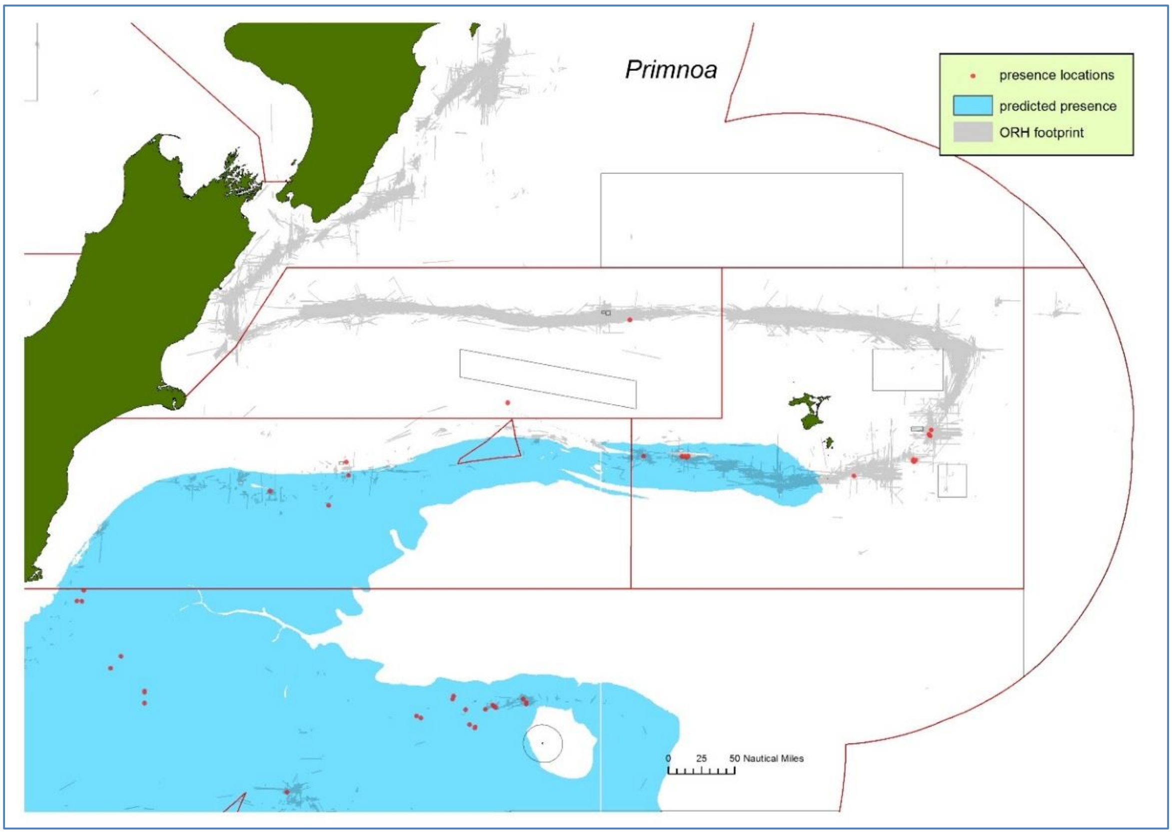

Madrepora oculata
presence locations
predicted presence
ORH footprint
0 25 50 Nautical Miles


Enallopsammia rostrata
presence locations
predicted presence
ORH footprint
0 25 50 Nautical Miles


Antipatharia
presence locations
predicted presence
ORH footprint
0 25 50 Nautical Miles


Bathypathes
presence locations
predicted presence
ORH footprint
0 25 50 Nautical Miles


Paragorgia
presence locations
predicted presence
ORH footprint
0 25 50 Nautical Miles


Primnoa
presence locations
predicted presence
ORH footprint
0 25 50 Nautical Miles

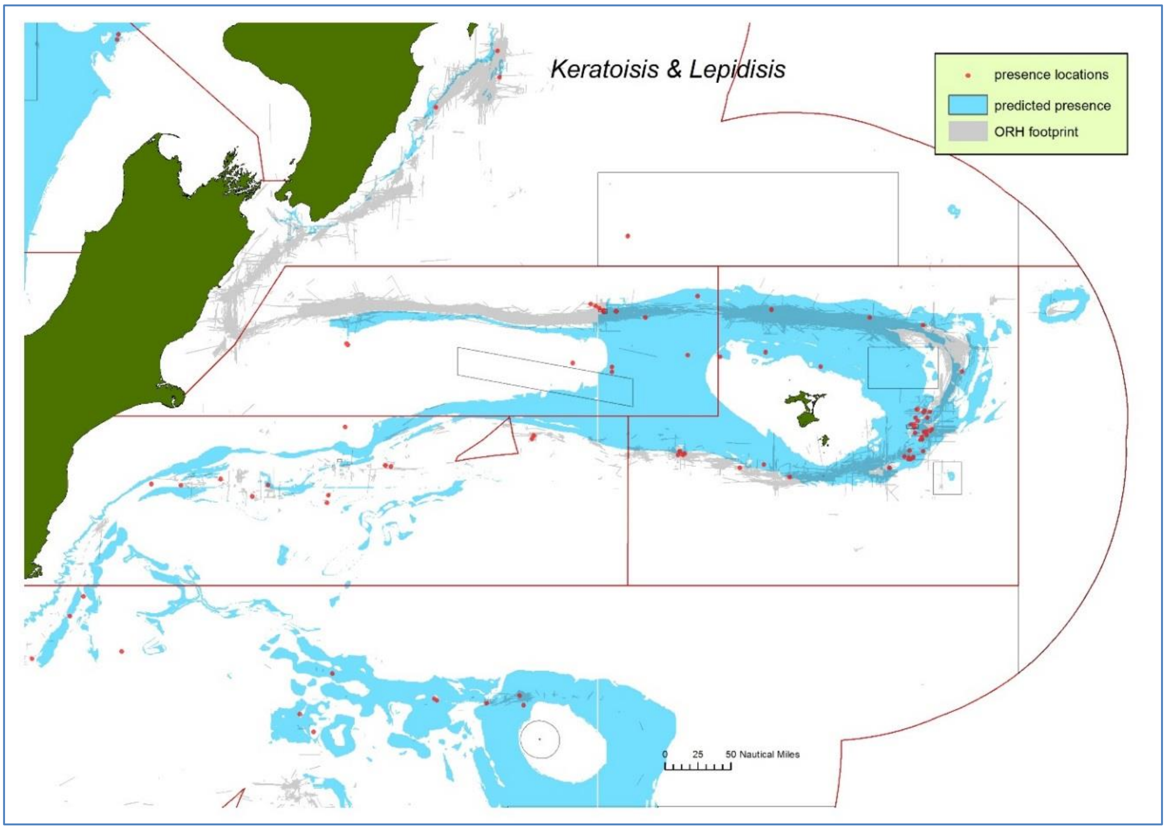


Figure 2-3: The Chatham Rise area, showing the location of coral records (red dots), the modelled distribution of the species or coral group (blue shaded region), and the orange roughy trawl footprint (gray lines, 2008-13). Quota Management Areas (or stock subdivisions) are indicated by red lines and Benthic Protection Areas are shown as grey boxes.

For the Availability attribute A1, an important aspect of distribution is the likelihood of there being endemic species within a region. The proportion of species believed to be endemic to New Zealand, and potentially to smaller areas within the region, is relatively high. Table 2-1 summarises data from "Species 2000" (Gordon et al. 2009) for some of the coral groups considered here.

Table 2-1: A summary of the numbers of coral species known, or estimated, in New Zealand waters, including estimates of the numbers of endemic species and genera within selected orders or family.

Taxon	Described living species	Known undescribed, species	Estimate unknown species	Endemic species	Endemic genera
Gorgonacea	38	129	50	>32	0
Scleractinia	124	5	10	17	4
Antipatharia	28	38	10	14	0
Stylasteridae	138	12	20	43	5

The scleractinian *Oculina virgosa* is known to be endemic to New Zealand, and several other species that are likely to be affected by trawling on the Chatham Rise may also be. However, generally the distribution of sampling means that the spatial scale of rare species is poorly defined. The main genus common on the Chatham Rise that may include endemic species is *Paragorgia*. Within New Zealand there are several species believed to be endemic (Gordon et al. 2009). These include *Paragorgia alisonae*, *Paragorgia kaupeka*, *Paragorgia maunga*, *Paragorgia whero*, *Paragorgia wahine*, and *Paragorgia aotearoa* (Sánchez, 2005). The last two species are only known from the Chatham Rise.

2.6.2 Species depth distribution (Encounterability attributes)

Depth distribution data are used in evaluating attribute E1. Information is presented in many of the reports used for geographical distribution (section 2.6.1), although the most recent compilation of all coral data for the first objective of this project (Anderson et al. 2014) was also used (Figure 2-4).

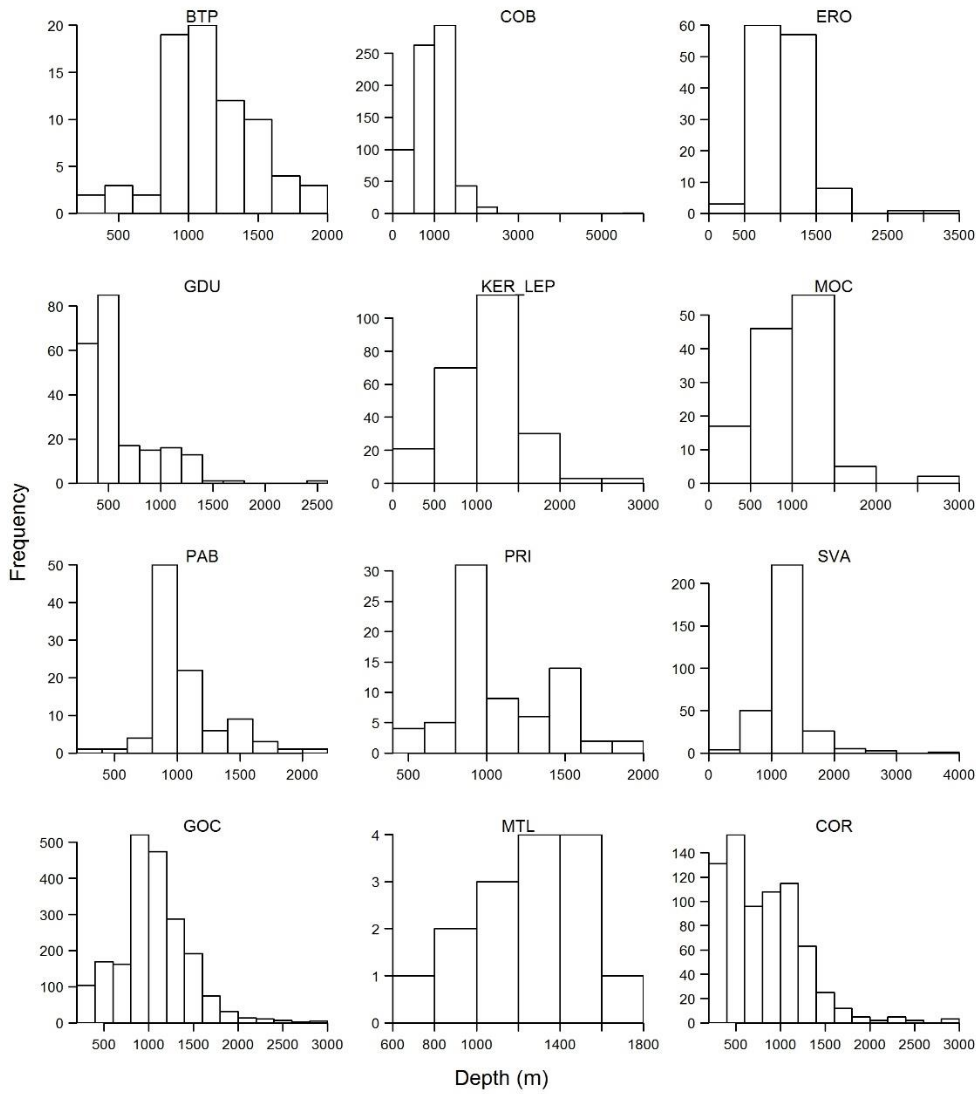


Figure 2-4: Depth distributions of selected coral species used in the ERA. For species codes, refer Table 3-2.

2.6.3 Trawling impacts (Encounterability attributes)

There have been few specific deep-sea studies on trawling impacts that assess damage to corals in relation to the number of trawls (relevant to E4). However, several have occurred at shelf depths that give an indication of what might be expected with similar taxa in the deep sea. Table 2-2 summarises several studies that describe the incidence of damage to the numbers or density of some coral and sponge taxa that are similar in form and size to the New Zealand ETP coral species. This was used to help evaluate the E4 attribute, of "Level of Disturbance".

Table 2-2: Summary of relevant studies documenting damage to sponge and coral taxa from trawling experiments.

Location	Depth	Gear	Effort	Taxon	Damage	Reference
USA	20 m	Fish trawl	1 trawl	Barrel sponges	32%	Van Dolah et al. 1987
Alaska	200-300m	Fish trawl	8 x 1 trawl	Sponges Gorgonians	67% 55%	Freese et al. 1999
NW Australia	50-200m	Fish trawl	1 trawl	Sponges	90%	Sainsbury et al. 1997
NE Australia	20-35m	Prawn trawl	6 x13 trawls	Sponges Gorgonians	80%	Burridge et al. 2003

Results from these studies differ, but in general suggest that a single trawl, or few trawls, can severely damage sponges and certain types of coral. The experimental trawling on the Great Barrier Reef (Burridge et al. 2003) was perhaps one of the best studies, and showed between 10 and 20% of gorgonian corals and large sponges were removed with each trawl event. Studies on the "Graveyard Hills" on the Chatham Rise suggest that a change from 15-25% (unfished densities) coral cover to 0 can occur after as few as 10 trawls on the seamount feature (Clark et al. 2010).

2.6.4 Species biological parameters (Productivity attribute)

Age and growth are life history parameters that inform the P1 attribute, regeneration of fauna. This relates to the time that would be required for a colony to grow back to its unfished state.

Some of the key results of international and New Zealand studies on the age and growth of deep-sea corals are summarised in Table 2-3 below, while more comprehensive growth rate data derived initially from Roberts et al. (2009) for scleractinian and gorgonian corals are summarised in Table 1 of Tracey et al. (2013).

Table 2-3: Summary of some age and growth characteristics of coral species relevant to New Zealand protected coral species.

Faunal group	Age/ growth	Method	Author
Gorgonian corals	67-2377 yo	^{14}C dating	Roark et al. (2006)
Bamboo corals Isididae	75->200 yo 35-197 yo	^{14}C ^{14}C and ^{120}Pb dating	Roark et al. (2005) Rogers et al. (2007)
Bamboo corals *Lepidisis* spp	400 yo 21-57 mm/yr (linear) 0.15-0.32 mm/yr (radial) 0.05–0.16 mm/yr	^{210}Pb dating ^{14}C dating	Tracey et al. (2007) Roark et al. (2006)
Bamboo corals *Keratoisis* spp	400 yo 0.22 mm/yr (radial) 0.11 mm/yr 0.2 mm/yr	^{210}Pb dating ^{210}Pb dating and U/Th dating ^{14}C dating	Tracey et al. (2007) Thresher et al. (2004, 2007) Noe et al. (2008)
Bubblegum coral *Paragorgia* arborea	300-500 y 15-25mm/yr	^{14}C dating	Tracey et al. (2003)
Black coral (*Leiopathes*)	2320 yo 4000 yo	^{14}C dating	Careiro-Silva et al. (2013) Roark et al. (2009)
Black coral (*Antipathes*)	140 yo	^{14}C dating	Love et al. (2007)
Stony corals (*Solenosmilia*)	120 yo (47,000 yo colony)	^{14}C dating	Fallon et al. (2014)
Stony corals (*Solenosmilia*)	150-660 yo (20 cm matrix) 0.3-1.6 mm/yr	^{14}C dating	Neil et al. (unpub)
Stony corals (*Lophelia*)	Various, live possibly <20 yo (9,000 yo colony) 1-35 mm/yr	Various	See Tracey et al. (2014)

In addition to age and growth rate information, there have been several studies on benthic community composition following the cessation of fishing (Clark & Rowden 2009, Althaus et al. 2009, Clark et al. 2010, Williams et al. 2010) that assist scoring P1. These results indicate that recovery of fished habitats comprising stony coral reef (*Solenosmilia variabilis*) is likely to take centuries, as there have been no indications of stony coral settlement or growth after periods of up to 10 years.

The extent of connectivity between coral populations (P4) is an important element of their recovery potential. Work is currently being carried out at NIWA on reviewing available literature and data on the reproductive mode of deep-sea invertebrates, and the nature and extent of their larval dispersal (project DSCA153, "Vulnerable deep-sea communities"). This unpublished compilation of data and results was used to inform decisions about the likely distance over which a species could successfully disperse in the short term, and recolonise impacted areas.

A further consideration of P4 was knowledge of the spatial scale of "patchiness" of coral populations. For example, *Goniocorella dumosa* comprises small thickets over large areas of the Chatham Rise, with relatively small distances between them. In contrast *Solenosmilia variabilis* is more restricted to seamount type environments, and hence the distances between patches of its habitat were considered for this species.

3 Results

The coral species, or grouping of corals, were scored against the criteria for each attribute (Table 3-1). These values were used to derive an overall risk level from a combination of additive (productivity) and multiplicative (susceptibility) functions for each of the 12 attributes (Table 3-2).

Table 3-1: Summary of risk values for each of the coral species/taxon group and the 12 risk attributes. A value of 1 indicates relatively low risk, 2 medium risk, and 3 high risk.

	A1	av	E1	E2	E3	E4	av	S1	S2	S3	av	P1	P2	P3	P4	av
Solenosmilia	2.00	2.00	3.00	2.00	2.00	3.00	2.50	3.00	3.00	1.00	2.33	3.00	3.00	1.00	2.00	2.25
Goniocorella	2.00	2.00	1.00	1.00	3.00	2.00	1.75	2.00	3.00	1.00	2.00	2.00	3.00	3.00	2.00	2.50
Madrepora	2.00	2.00	3.00	2.00	2.00	3.00	2.50	3.00	3.00	1.00	2.33	3.00	3.00	1.00	2.00	2.25
Oculina	3.00	3.00	1.00	1.00	2.00	2.00	1.50	2.00	2.00	3.00	2.33	2.00	2.00	3.00	2.00	2.25
Enallopsammia	2.00	2.00	3.00	2.00	2.00	3.00	2.50	3.00	3.00	1.00	2.33	3.00	3.00	1.00	2.00	2.25
Black corals	2.00	2.00	3.00	2.00	2.00	3.00	2.50	3.00	2.00	1.00	2.00	3.00	3.00	2.00	3.00	2.75
Bathypathes	2.00	2.00	2.00	2.00	2.00	3.00	2.25	3.00	2.00	2.00	2.33	3.00	3.00	2.00	3.00	2.75
Gorgonians	2.00	2.00	2.00	2.00	2.00	3.00	2.25	3.00	2.00	1.00	2.00	2.00	3.00	2.00	3.00	2.50
Paragorgia	3.00	3.00	3.00	1.00	2.00	3.00	2.25	3.00	2.00	2.00	2.33	2.00	3.00	2.00	3.00	2.50
Primnoa	2.00	2.00	2.00	1.00	2.00	2.00	1.75	2.00	2.00	2.00	2.00	2.00	3.00	2.00	2.00	2.25
Bamboo corals	2.00	2.00	2.00	2.00	2.00	3.00	2.25	3.00	2.00	1.00	2.00	2.00	3.00	2.00	2.00	2.25
Metallogorgia	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	2.00	1.33	2.00	3.00	2.00	3.00	2.50
Cup corals COF	2.00	2.00	2.00	1.00	3.00	2.00	2.00	1.00	1.00	1.00	1.00	2.00	3.00	2.00	2.00	2.25
Cup corals CAY	2.00	2.00	3.00	2.00	2.00	2.00	2.25	1.00	1.00	1.00	1.00	2.00	3.00	1.00	2.00	2.00
Hydrocorals	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.33	1.00	3.00	2.00	2.00	2.00

Table 3-2: Summary of Productivity and Susceptibility scores for the 15 taxa, and their overall risk value and ranking.

Coral species	Code	Productivity score (Average)	Susceptibility score (Multiplicative)	Overall Risk Value	Overall Risk Ranking
Solenosmilia	SVA	2.25	1.86	2.92	Med
Goniocorella	GDU	2.50	1.52	2.93	Med
Madrepora	MOC	2.25	1.86	2.92	Med
Oculina	OVI	2.25	1.78	2.87	Med
Enallopsammia	ERO	2.25	1.86	2.92	Med
Black corals	COB	2.75	1.74	3.25	High
Bathypathes	BTP	2.75	1.78	3.27	High
Gorgonians	GOC	2.50	1.67	3.00	Med
Paragorgia	PAB	2.50	2.17	3.31	High
Primnoa	PRI	2.25	1.52	2.71	Med
Bamboo corals	KER-LEP	2.25	1.67	2.80	Med
Metallogorgia	MTL	2.50	1.40	2.86	Med
Cup corals	COF	2.25	1.30	2.60	Low
Cup corals	CAY	2.00	1.33	2.40	Low
Hydrocorals	COR	2.00	1.40	2.44	Low

This identified black corals (at an order level), the black coral genus *Bathypathes*, and the gorgonian *Paragorgia* genus as high risk, with most other scleractinian and gorgonian corals as medium. The cup-coral genera, as well as hydrocorals, were classified as relatively low risk.

The scores for the attributes are briefly explained below:

3.1 Availability attributes

- For A1 (Spatial overlap) most of the corals are widely distributed over the Chatham Rise, as well as the broader New Zealand region. Hence they scored a 2, being 10–50% overlap of the Chatham Rise with their wider range. Several species of *Paragorgia* may be restricted to the Chatham Rise, and *Oculina* is endemic to northern parts of New Zealand. The restricted ranges of these latter species ranked a 3, being high risk.

3.2 Encounterability attributes

- E1 (Depth zone) has a high risk for the three seamount reef-building stony corals, as well as the hard-bottom cup corals that are commonly on seamounts. *Paragorgia* also had a high overlap with the depth of the orange roughy and oreo fisheries. *Oculina* and *Goniocorella* have a shallower depth distribution, and were low risk, with the remaining species intermediate.
- E2 (Geographical area) varied with values of 1 or 2. No taxa had a greater than 50% overlap with the trawl footprint, as all extended beyond the footprint area.
- E3 (Ruggedness) varied, with 2 being the most common score when the corals were associated with exposed rocky seafloor (such as on seamounts or exposed rocky outcrops). *Goniocorell*a and the Flabellum-type cup corals (COF) ranked a 3, because these occur widely on the continental slope as well as seamounts, and hence more of their distribution is on trawlable ground. Some seamounts can be extensively fished in many directions, but often there will be areas where trawling is not possible (e.g., Morgue, Clark et al. 2010) which offers some spatial protection that reduces risk and therefore they rank a 2.

- E4 (Level of disturbance). This attribute relates to the size, shape, and flexibility of the species, in terms of how many trawls may be required to cause substantial damage. Hence it is linked to scores for S1 to an extent (many scores are the same) but the attributes reflect slightly different aspects. The reef-building corals, as well as large and rigid black and gorgonian corals are known to be affected by a very small number of trawls, and all scored a 3. *Goniocorella* is smaller in its form than *Solenosmilia/Enallopsammia/Madrepora* in many areas, and so scored a 2. *Oculina* is commonly seen in crevices and overhangs, and so may be less accessible to single or a few encounters. Primnoid corals are typically less erect than *Paragorgia* species, and along with the smaller-bodied cup corals and hydrocorals, scored 2. No corals, however, were thought to be at low risk, meaning able to cope with many trawl encounters.

3.3 Selectivity attributes

- S1 (Removability of fauna) was ranked high risk for the seamount reef-building corals, as they can form large thicket or reef-like structures, several metres high. Similarly, the erect black and gorgonian corals typically grow to a metre or more height, and are erect. Primnoid corals are typically smaller and less erect than *Paragorgia* species, and along with the smaller-bodied hydrocorals, scored 2. Cup corals are typically low and robust structures, and *Metallogorgia* is whip-like and flexible. These scored a 1 because of their lower risk of being damaged or caught in rough-bottom trawl gear.
- S2 (Associated faunal diversity) was assessed as high for the larger reef-building stony corals (but lower for *Goniocorella* because of its more scattered-thicket distribution) because of the habitat they provide for other animals on their elevated surfaces, or inside the matrix. Many gorgonians and *Paragorgia* have associated brittle star colonies, and although true also to an extent for primnoids, the latter are more variable. *Metallogorgia*, hydrocorals, and cup corals are not known to have associated fauna. Hence their removal will not impact other species directly, and they scored 1.
- S3 (Areal extent) ranked high only for *Oculina*, because it is very rare on the Chatham Rise. The distributions and areal extent of *Bathypathes*, *Paragorgia*, and *Primnoa* species are moderately common, but note the higher risk than the order level grouped taxa of black and gorgonian corals. The more widespread and common scleractinian corals, bamboo corals, cup corals and hydrocorals were all low risk.

3.4 Productivity attributes

- P1 (Regeneration) was ranked high for the large reef-building stony corals, where the matrix can take centuries to rebuild, as well as for black corals which have been aged at hundreds to thousands of years old. *Goniocorella* and *Oculina* are thought to grow more rapidly, as are the other gorgonians where recovery is likely to require several decades. The only low risk species group was the hydrocorals, which are often observed on trawled seamounts (as early colonisers), are known to grow relatively rapidly, and could reach their maximum size in less than a decade.
- Natural disturbance (P2) is a proxy for the ability of a species to cope with disturbance, so risk is low if a species is adapted to a dynamic and variable environment. Natural impacts at the depths and habitats where corals occur on the Chatham Rise is likely to be rare. Chatham Rise seamounts are inactive volcanic cones, so eruptions are unlikely. So too landslides (that can be a factor nearer the coast or associated with canyons). The only species that had potentially lower risk was *Oculina,* which is most commonly found at depths shallower than 200 m.
- Naturalness (P3) was ranked high risk for areas where fishing effort was low (hence the corals are in an undisturbed state). Where species occurred at depths, areas, or habitats that were frequently and heavily fished (e.g., seamounts), they were ranked lower. This was the case for *Solenosmilia*, *Enallopsammia*, and *Madrepora*, as well as their associated cup corals. *Oculina*

and *Goniocorella* are less disturbed by fishing, as their depth range and geographical distributions have lower overlap with the orange roughy fishing footprint. These are less disturbed areas on the Chatham Rise (assuming no interactions with other fisheries). Other species and taxa groups were scored a 2, reflecting medium levels of trawling effort.
- Connectivity (P4) ranked high risk for the black and gorgonian corals because dispersal is believed to be poor based on overseas studies. All other taxa were scored a 2, indicating a moderate dispersal ability (25–100 km) that should enable settlement to suitable habitat, and recolonisation, at a spatial scale that matches their observed distribution.

The risk index was plotted as a combination of susceptibility and productivity on a PSA plot, (Figure 3-1).

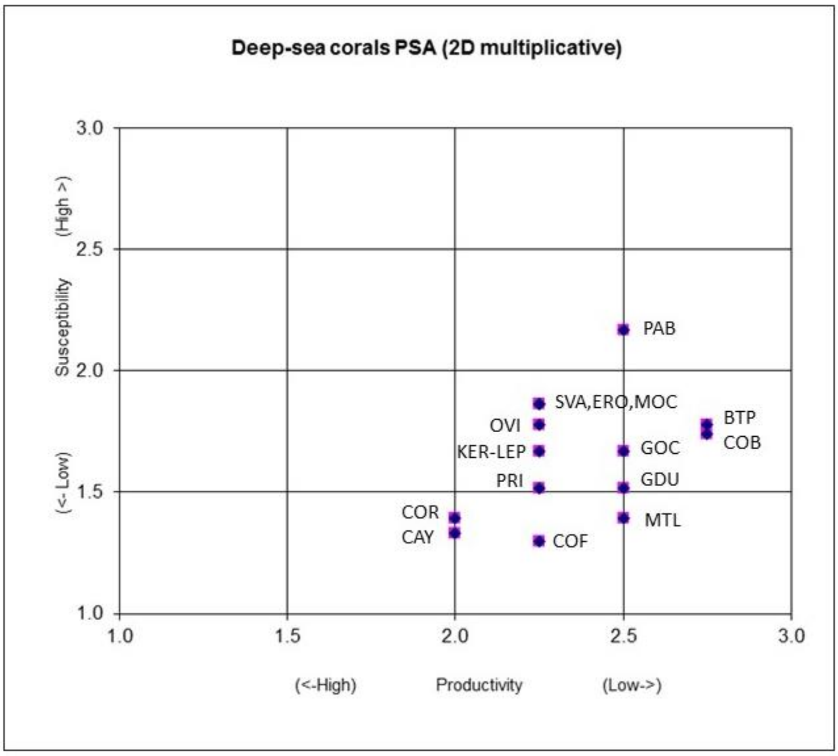


Figure 3-1: PSA plot for the 15 coral species. See Table 3-2 for key to three-letter codes.

4 Discussion

This Level 2 assessment study is the first ERA carried out for New Zealand deep-sea coral species. It is only semi-quantitative, but gives the ability to rank different species, is relatively easy to understand, integrates various levels of data and knowledge, and is transparent. It gave encouraging results ranking the various coral species in a way that was consistent with expectations based on ecological principles and the teams' knowledge and experience. The high ranking of the black corals and *Paragorgia* is logical, given their high susceptibility, and low productivity. It was somewhat surprising that the reef-building scleractinians didn't also rank highly, which was due to their modelled spatial distribution being larger than the fishery footprint. The low risk assigned to hydrocorals and the two types of cup corals was expected due to their higher productivity, and small size lowering their susceptibility. Hence, overall the method appeared to assess relative risk in a sensible way.

The definitions and criteria were tightened and clarified over some of those given by Hobday et al. (2007, 2011) and Clark et al. (2011). Care was taken to ensure that the logic of high and low risk was consistent between attributes, and thresholds were set on measureable values and metrics where readily available. Nevertheless, there is still a degree of overlap between some of the components. The use of attribute definitions from the habitat component of the ERAEF appeared to work well. The main differences are in productivity criteria, where attributes for colonial species (such as the scleractinian corals) are more appropriate as habitat considerations than single species. Life history parameters such as size and reproductive capacity are also better assessed on the habitat or colonial basis. For solitary corals with few associated species, a combination of attributes from the Habitat and ETP components could be considered.

The overall scoring of risk does not weight any particular component. Hence while Susceptibility is derived from 8 components, none are emphasised, and the overall susceptibility score has the same weight in the risk profile as Productivity which is derived from 4 components. Arguably, there could be weighting of some components, and also further consideration of the differences between additive versus the multiplicative nature of combining the attribute scores. However, as long as the method is interpreted as relative risk, then it is internally consistent. There is room for the application of the method to be improved, as this was intended solely as a pilot assessment to see if the PSA approach could be useful for these types of organisms, and whether there were sufficient data available on New Zealand corals to support a Level 2 assessment.

Emphasis was placed on decisions being made on data rather than subjective expert guesses. Nevertheless, there will always be different decisions made by different groups of people who have different knowledge, or view certain data in a different way. However, we believe this method allows sufficient transparency to track and understand where and how certain scores affect results. It also enables the sources of susceptibility or productivity to be evaluated when considering the efficacy of management options to reduce or mitigate risk. There may be little one can do about inherent low productivity, but management that reduces susceptibility can improve the overall risk profile.

No coral species were deemed to have very high susceptibility. This was due largely to most species having a wider geographical and depth distribution than the trawl footprint on the Chatham Rise. The predicted distributions are wide, partly because they are based on the average probability of occurrence for each 1km^2 cell (and not a particular threshold such as 50% or 70%), and because they reflect the likelihood of occurrence, not necessarily abundance. Nevertheless, localised fishing impacts in certain areas could have much higher risk to corals than the Chatham Rise as a whole, and there can be cumulative effects of other fisheries (e.g. hoki) that operate at shallower depths than we have not considered here. In addition, we have tended to evaluate the spatial scale of the species, as very little is known about the spatial scale of the population or stock of many coral species. For example, the scleractinian coral species typically have a wide distribution over the Chatham Rise. These corals are broadcast spawners, and hence produce large numbers of offspring, which could disperse in ocean currents over large distances. However, recent genetic studies of populations of *Solenosmilia variabilis* on several seamounts off southern Tasmania, shows that their populations are genetically isolated, which suggests there are only low levels of larval dispersal among them, and that the corals are largely self-recruiting (http://www.apscience.org.au/projects/APSF_11_6/apsf_11_6.html). Hence, it could be more appropriate to examine smaller units than the entire Chatham Rise or to conduct the analysis in a more spatially explicit way such as done for seabirds and marine mammals (e.g., Richards & Abraham 2013) (we note there are plans by MPI for discussions about developing this concept for habitats and communities, but the approach is not yet clear). This current exercise was conducted with reference to the orange roughy fishery on the Chatham Rise, and did not consider the linked effects of other fisheries with a different spatial footprint on the risk to the taxa investigated.

The study revealed that the level of taxonomic amalgamation is also important. Five species of scleractinian coral were assessed, and although 3 were similar (*Solenosmilia*, *Enallopsammia*, *Madrepora*), the other two (*Goniocorella* and *Oculina*) were different. The risk profile of a combined Order Scleractinia would have looked different, and been misleading for some species. This is emphasised by the differences between the grouped Order Gorgonacea, and the four genus level taxa (*Metallogorgia*, *Paragorgia*, bamboo corals) which varied markedly in their susceptibility or productivity scores from the larger grouping.

This work was not intended to be a definitive ERA, but rather to investigate whether such a level 2 approach could be carried out given the data available, and whether it produced sensible results in terms of relative risk. It is important to emphasise that although the method is semi-quantitative, results are not an absolute measure of risk, as some of the criteria are comparative rather than based on definitive thresholds. Whether such a method should be taken further, with more detailed assessment of more protected coral species, depends largely upon the management objectives that a risk assessment is designed to meet. We hope that the study done here can at least give managers an understanding of how the ecological traits of these taxa contribute to the relative risks of impacts from the orange roughy fishery on the Chatham Rise. This work can stimulate discussion about potential management approaches or methods that could reduce risk where it is high. This work is to be discussed by the DOC Technical Working Group before the assessment and report is finalised.

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