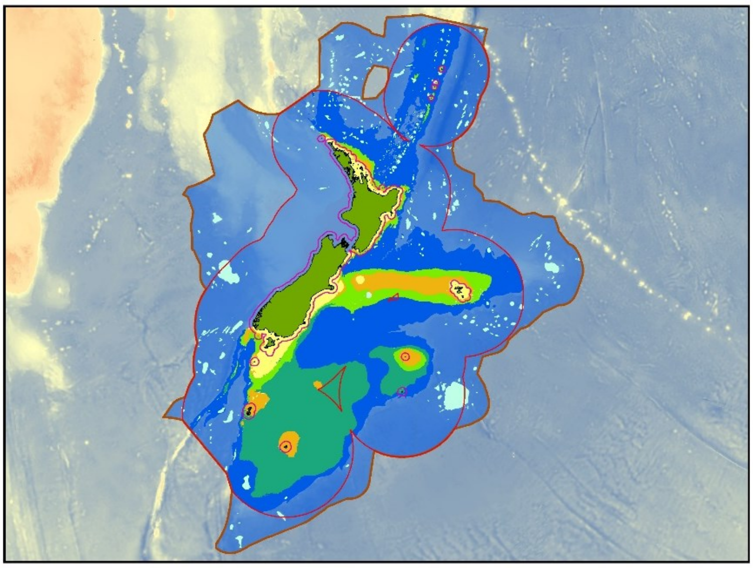
Ecological Risk Assessment of the impact of debris from space launches on the marine environment

Prepared for Ministry for the Environment

April 2017



Prepared by:
Geoffroy Lamarche - NIWA
Alison MacDiarmid - NIWA
Owen Anderson - NIWA
Susan Jane Baird - NIWA
David Bowden - NIWA
Malcolm Clark - NIWA
Kim Goetz - NIWA
Chris Hickey - NIWA
Yoann Ladroit - NIWA
Kareen Schnabel - NIWA
David Thompson - NIWA
Dave Lundquist - DOC

For any information regarding this report please contact:

Geoffroy Lamarche
Principal Scientist
Ocean Geology
+64-4-386 0465
geoffroy.lamarche@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

NIWA CLIENT REPORT No:	2017068WN
Report date:	April 2017
NIWA Project:	MFE17303

Cover image: The environment classes used for this risk assessment based on the Benthic Optimised Marine Environmental Classification and the NIWA seamount database for the NZ Exclusive Economic Zone and Extended Continental Shelf.

Quality Assurance Statement		
	Reviewed by:	Dr Ashley Rowden
	Formatting checked by:	P Allen
	Approved for release by:	Dr Julie Hall

Contents

Tables

Figures

Executive summary

A rapidly developing and potentially new activity in New Zealand is the launching of space vehicles. Consequently, the Ministry for the Environment requested NIWA to conduct an ecological risk assessment (ERA) associated with the fall of debris jettisoned during successful launches of space vehicles over a wider area of the Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS). The area considered was limited to the north, east and south of New Zealand on the assumption that no launching will be undertaken westward. The area assessed did not include the Territorial Sea. The ecological risks associated with a catastrophic failure near the rocket launch facility and potential effects on near-shore locations were not assessed.

A panel of experts undertook the ERA using a Level 1 likelihood-consequence risk analysis approach in which risk is calculated as the product of the consequence for components of the marine environment potentially threatened by the falling debris, and the likelihood of the threats arising.

For the ERA, the area was divided into six benthic environment classes. Five classes were based on the Benthic Optimised Marine Environmental Classification (BOMEC), which uses taxonomic groups and environmental variables to generate environmental classes for New Zealand's EEZ shallower than 3000 m. The five BOMEC classes used were: Shelf, Upper Slope, Northern Mid-depths, Southern Mid-depth and Deep and Very Deep Waters. The latter class was extended to the boundaries of the EEZ and the ECS to include the abyssal plain and trenches. A sixth benthic environment class was used that corresponds to the seamounts that occur throughout the EEZ and ECS, and frequently harbour sensitive environments.

The ERA Panel considered the potential ecological impacts of seven threats arising from the fall of debris on five components of the ecosystem in each environmental class. The seven threats were (1) Direct strike causing mortality; (2) Noise disturbance; (3) Toxic contaminants; (4) Ingestion of debris; (5) Smothering of seafloor organisms, preventing normal feeding and/or respiration; (6) Provision of biota attachment site; and (7) Floating debris. The five ecosystem components were: (1) Benthic Invertebrate Community; (2) Demersal fish and mobile invertebrates; (3) Air breathing fauna, comprising marine mammals and seabirds; (4) Sensitive environments; and (5) the Pelagic Community.

For each component of the ecosystem in each of the six benthic environment classes, the consequences of the potential threats were scored on a scale of 0 (negligible) to 5 (catastrophic) and the likelihood of the threat was score on a range from 1 (remote) to 6 (likely). The risk was calculated as the product of likelihood and consequence. A level of confidence in each risk score was also scored.

The Level 1 likelihood-consequence risk analysis approach adopted in this study found that the ecological risk to all ecosystem components of each environmental class from the activities considered here is low. This was primarily a result of the consequence of the potential effect from a single splashdown of 40 tonnes of debris at any point being negligible or minor.

The panel considered that 10 repeated launches resulting in 40 t of debris per launch would still have a minor risk, but at 100 launches the risks could be moderate, and with 1000 could become high. The specific level of risk will depend on whether repeated launches prove to affect the same general area, or if debris is more widely scattered across larger areas of the EEZ.

Assessing the potential for cumulative impacts from multiple sectors and sources of stress is a major task, and was beyond the scope of this study. However, the panel concluded that that it is very likely

that rocket debris will be a much less important element of a cumulative impacts assessment than commercial fishing operations in a number of areas around New Zealand, and that for up to 50 launches resulting in 40 t of debris per launch it is likely that the environmental risk would not be increased over that resulting from fishing alone. The panel also noted that the impacts of climate change over the life span of rocket launches in the deep-sea environments may be more significant than the potentially local effects of the proposed rocket operations.

Risk assessment usually proceeds from a Level 1 qualitative assessment at the early "exploratory" stages of a project to a semi- or fully-quantitative assessment once full-scale production or operation is reached. From that perspective the panel recommends that such a semi-quantitative assessment is undertaken after 50 launches when more data are available on the location, nature and extent of the debris field. This would focus on appropriate areas and more specific scales of impact on ecological components, and enable further evaluation of likely risks, and allow any modifications in the assessment, or in operational practices, to be done before the 100 launch threshold where impacts may shift from minor to moderate for repeated exposure in one general area.

1 Introduction

1.1 Background

The Ministry for the Environment (the Ministry) is developing Ecological Risk Assessments (ERAs) of the environmental effects of activities not yet regulated or permitted in certain geographic areas, in view a pending revision of the Exclusive Economic Zone and Extended Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2014.

A rapidly developing and potentially new activity in New Zealand is the launching of space vehicles. Consequently, in August 2016 NIWA was contracted by the Ministry to undertake an ERA of debris resulting from the launch of Electron space rockets (MacDiarmid et al. 2016). The study focused on two flight paths to the east of the North Island and south of the Chatham Rise (Figure 1-1). Subsequently, the Ministry requested NIWA to assess the ecological risks associated with the impact of space vehicle debris over a wider area of the Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS) (Figure 1-2).

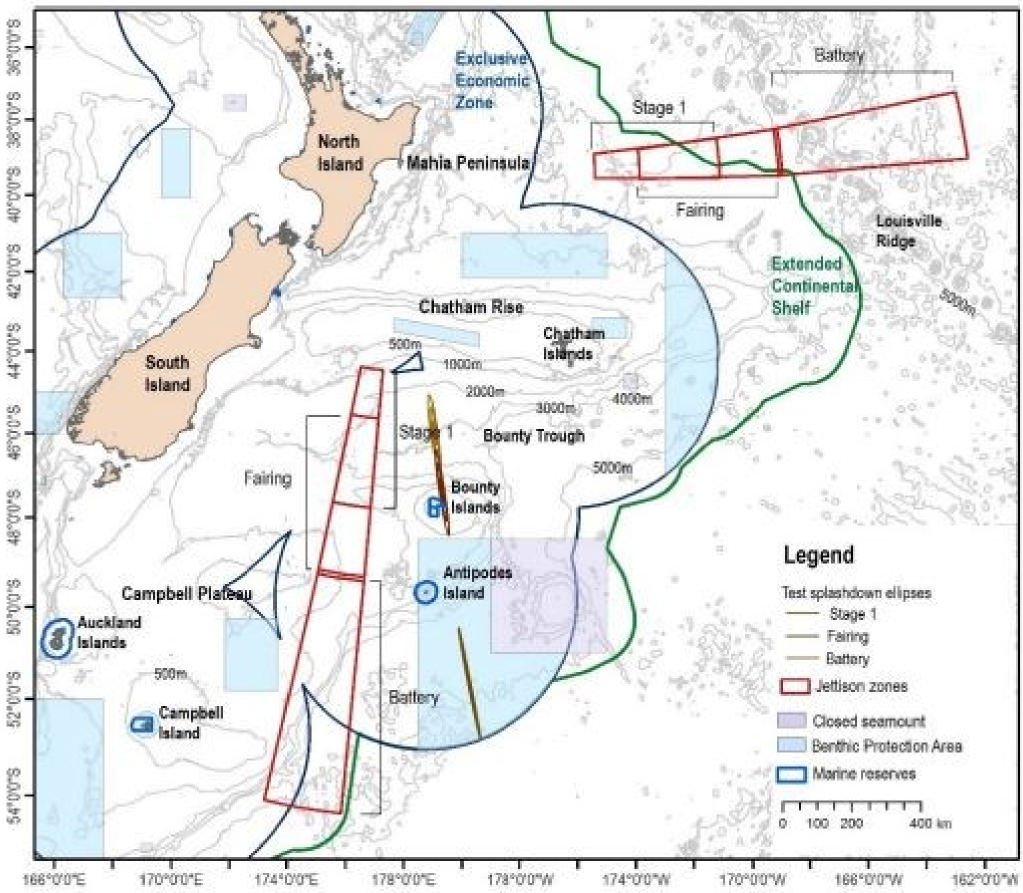


Figure 1-1: The two rocket debris splashdown zones (in red) previously assessed. From MacDiarmid et al., (2016).

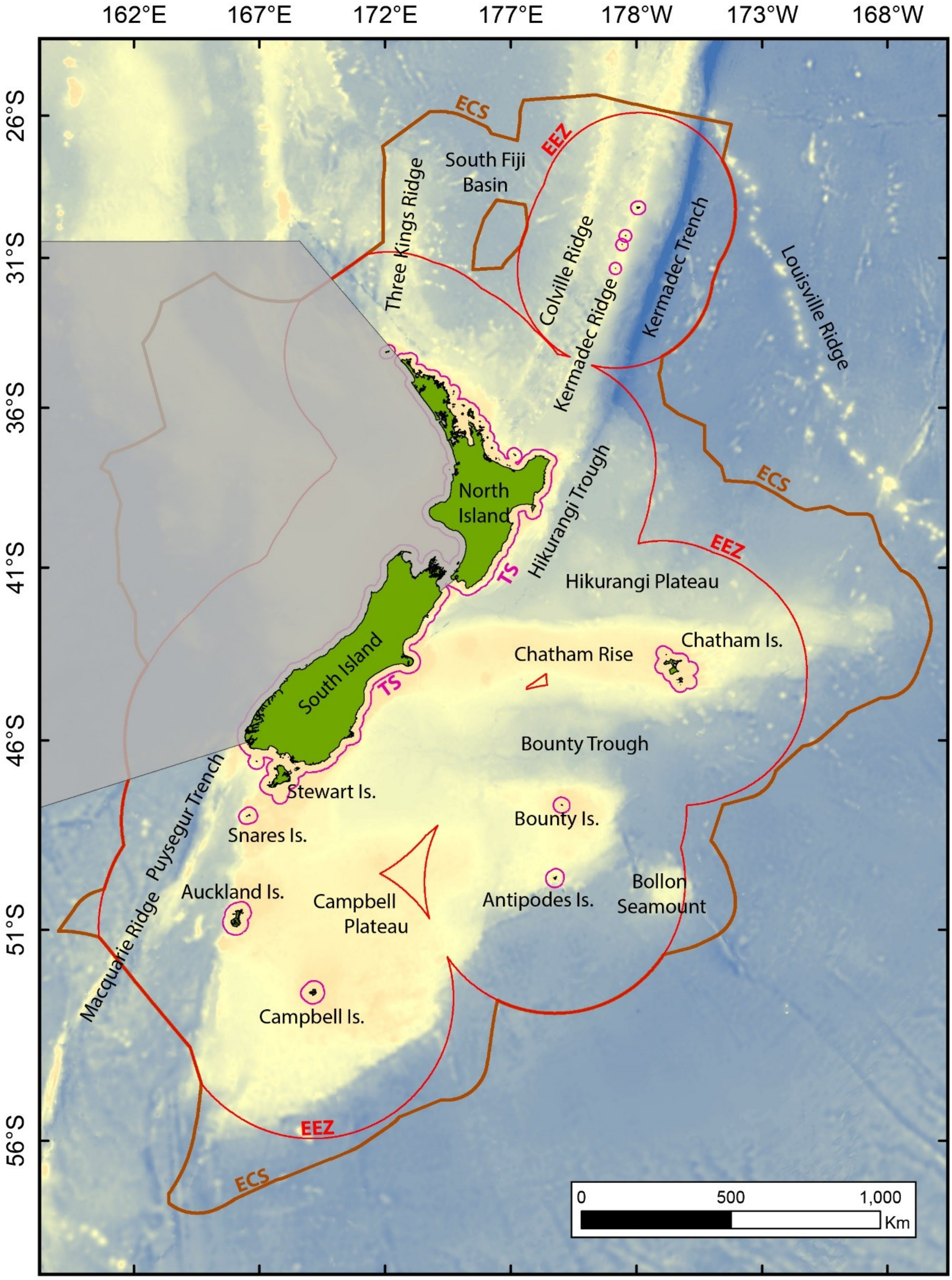


Figure 1-2: Boundaries of the New Zealand Territorial Sea (TS), Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS). The shaded area is not considered in this report (see text). Locations referred to in the report are indicated.

1.2 Approach

A number of approaches and methods have been developed and applied to conduct ERAs in the New Zealand context (Rowden et al. 2008; Baird and Gilbert 2010). In cases for which the assessed activity is rare or unpredictable, such as the direct hit of rocket debris causing adverse effects on marine organisms, then a likelihood-consequence approach is the most suitable. Such an approach summarises risk as the product of the expected likelihood of an event occurring and the ecological consequence of that event. This approach contrasts with the approach taken to assess effects of activities that are deliberate and programmed to take place regularly and repeatedly such as fishing at a particular location. In these cases, where the effects are highly likely and predictable, an exposure-effects approach (Smith et al. 2007; Sharp et al. 2009) is more suitable. Although the outcome is very similar in both cases, the different approaches are easier to apply in the contrasting situations.

Risk assessment typically consists of three levels, increasing in detail from a qualitative assessment (Level 1) to fully quantitative (Level 3). Level 1 assessments are generally used in data-poor situations where the scale of activity or its impacts on particular species, habitats or the ecosystem are uncertain or only partially described (Hobday et al. 2011).

The approach adopted for this assessment was based on a Level 1 likelihood-consequence risk analysis (Hobday et al. 2011), in line with accepted New Zealand and Australian risk assessment standards (AS/NZ4360 standard 2004). Such an approach is warranted as in this case no debris from rocket launches has previously impacted New Zealand marine ecosystems and the effects are not quantified, and by the very large size of the area considered and the low to very low density of observations, samples and geophysical data available for all the ecosystem components in most areas of the EEZ and ECS. This approach has been used by NIWA to undertake ERAs for the Ministry over the last 5 years (MacDiarmid et al. 2011; MacDiarmid et al. 2014; MacDiarmid et al. 2015; MacDiarmid et al. 2016) and has also recently been applied in risk assessments by MPI for sharks in New Zealand waters (Ford et al. 2015), and by SPC for deep-sea mining in South Pacific islands (Clark et al. 2016).

1.3 Aim of the report

This report describes the approaches and methodology taken to develop the risk assessment over the New Zealand EEZ and ECS, presents the consequence score and confidence rating in tabular form as well as a brief text description, and provides a summary and conclusions

1.4 Limitations

The ecological risks associated with a catastrophic failure near the rocket launch facility were not assessed, in other words, only the potential environmental effects of successful launches were considered during the assessment.

The area considered was limited to the New Zealand's EEZ and ECS to the north, east and south of New Zealand because no rocket launches will be undertaken in a westerly direction as this conflicts with the launch physics associated with the rotation of the earth, and a flight path over Australia would pose serious operational restrictions. The area assessed also does not include the Territorial Sea as management of activities and environmental effects in this area falls under the remit of the Resource Management Act 1991 (RMA), and is therefore out of the scope of this report.

2 Methods

2.1 Ecosystems and habitats potentially affected

The entire New Zealand EEZ and ECS covers approximately 4.1m km^2 and 1.6m km^2, respectively, totalling 5.9m km^2. Clearly assessing such a wide area as one single entity is not practical nor scientifically robust to properly account for the various components of the marine ecosystems and habitats within the EEZ and ECS.

We used the Benthic Optimised Marine Environmental Classification (BOMEC, Leathwick et al. 2012) as a basis to segment New Zealand's EEZ and ECS into a workable number of environmental classes with similar biological and ecological characteristics.

The BOMEC focuses on the benthos, unlike the Marine Environment Classification (MEC, Snelder et al. 2005) which also classifies the New Zealand marine environment using surface and mid-water variables. We used the BOMEC rather than the MEC because the previous ERA (MacDiarmid et al., 2016) showed that the environmental impact of debris from space launches will particularly affect the benthic environment, and the EEZ Act restricts the deposit of any material or substance on the seabed.

The BOMEC uses eight taxonomic groups and thirteen environmental variables (including depth, water temperature, salinity, and tidal current) to generate 15 classes for New Zealand's EEZ shallower than 3000 m (Figure 2-1). The classes are strongly separated in relation to three large depth groups: inshore, shelf, and deeper waters, and can be further divided by northern and southern latitude. BOMEC proposes a 5-region classification as inshore and shelf, upper slope, northern mid-depths, southern mid-depth and deeper water.

We base our segmentation of the marine environment on the five BOMEC regions, which we considered more practical than the 15-class division of the environment for the purposes of this ERA, but added a sixth specific class for seamounts. While seamounts occur in all but the Shelf class, we considered that this habitat required separate consideration because these features frequently harbour sensitive marine environments. Seamounts have a small geographical extent compared with that of the other classes, and thus their importance with regard to the benthic environment would be diluted if assessed in each class. Hence we placed them in separate class for this ERA.

The six classes used for this ERA include the significant regional geomorphological features of New Zealand ocean realm which host various components of the marine ecosystems and habitats (Table 2-1).

The six benthic-focussed environmental classes used in the assessment (hereafter called environmental classes) were:

Shelf. This class corresponds to the BOMEC regions 1 to 5 (inshore and shelf). It covers an area of approximately 54,000 km^2. It is limited inshore by the limit of the Territorial Seas and offshore by the slope break that mark the top of the continental slope at 100-150 of water depth.

Upper Slope. This class corresponds to BOMEC regions 6 to 8 (upper slope) and covers an area of c. 150,000 km^2. It corresponds to the upper part of the continental slope and mostly is comprised of seafloor between 100 and 350 m of water depth, with frequent records of foraminifera, polychaetes and sponges. The region was defined primarily by moderately high temperatures and salinity, often strong tidal currents and coarse sediments. Fauna are influenced by subtropical water masses.

Importantly this class include the crests of the Chatham Rise and Bollons Seamount. The former being of significant importance for benthic biodiversity and fisheries.

Northern Mid-depths. This class corresponds to BOMEC regions 9 to 11 (Northern mid-depths) and covers an area of 195,000 km^2. It is limited between ca. 500 and 1250 m of water depth. Benthic fish are common, as are octocorals and stony corals. Water is typically sub-tropical, and relatively warm. It includes the flanks of the Chatham Rise and the Kermadec and Puysegur ridges, and the slopes around the Stewart and Snares Shelf.

Southern Mid-depths. This class corresponds to BOMEC regions 12 and 13 (southern mid-depths) and covers 430,000 km^2. South of the Chatham Rise, water masses are more temperate, with lower temperatures, salinity, and productivity. It essentially includes the Campbell Plateau between the depths of 500 to 1250 m.

Deep and Very Deep Waters. This class includes BOMEC regions 14 and 15 (deeper water) which only extend to 3000 m of water, and has been extended to the outer boundaries of New Zealand's EEZ and ECS, where there are low tidal currents, low temperature gradients, and fine sediments. Stony and octocorals are common faunal groups. Although somewhat arbitrary this extension enables us to assess the deep and very deep waters environments that include troughs, rises, deep channels, abyssal plains, and trenches (Table 2-1).

Seamounts were included as a sixth class. Seamounts occur throughout the EEZ and ECS, varying in size from 'hills' and 'knolls' of a few hundred metres elevation, to much larger seamounts such as Bollons Seamount that are thousands of metres high and kilometres in diameter (Figure 2-2). Many have been reasonably well sampled as part of NIWAs deep-sea research over the last 20 years (NIWA data includes about 750 features in the EEZ-ECS. Together with ridges (which are an ecologically similar form of topography), these can be subject to high current flows and oceanographic complexity enhancing biodiversity. Although an environmental classification has been done for seamounts using physical variables (Clark et al., 2011; Rowden et al., 2005), the faunal composition is known to be highly variable, and we cannot generalise on taxonomic composition or abundance. However, habitat-forming stony corals are frequently recorded from seamount features, especially in the mid-depth and deeper waters where in particular *Solenosmilia variabilis* and *Madrepora oculata* can occur in high densities (Clark and Rowden, 2009; Tracey et al., 2011). Hence this makes them potential sensitive environments as defined in the EEZ Act regulations.

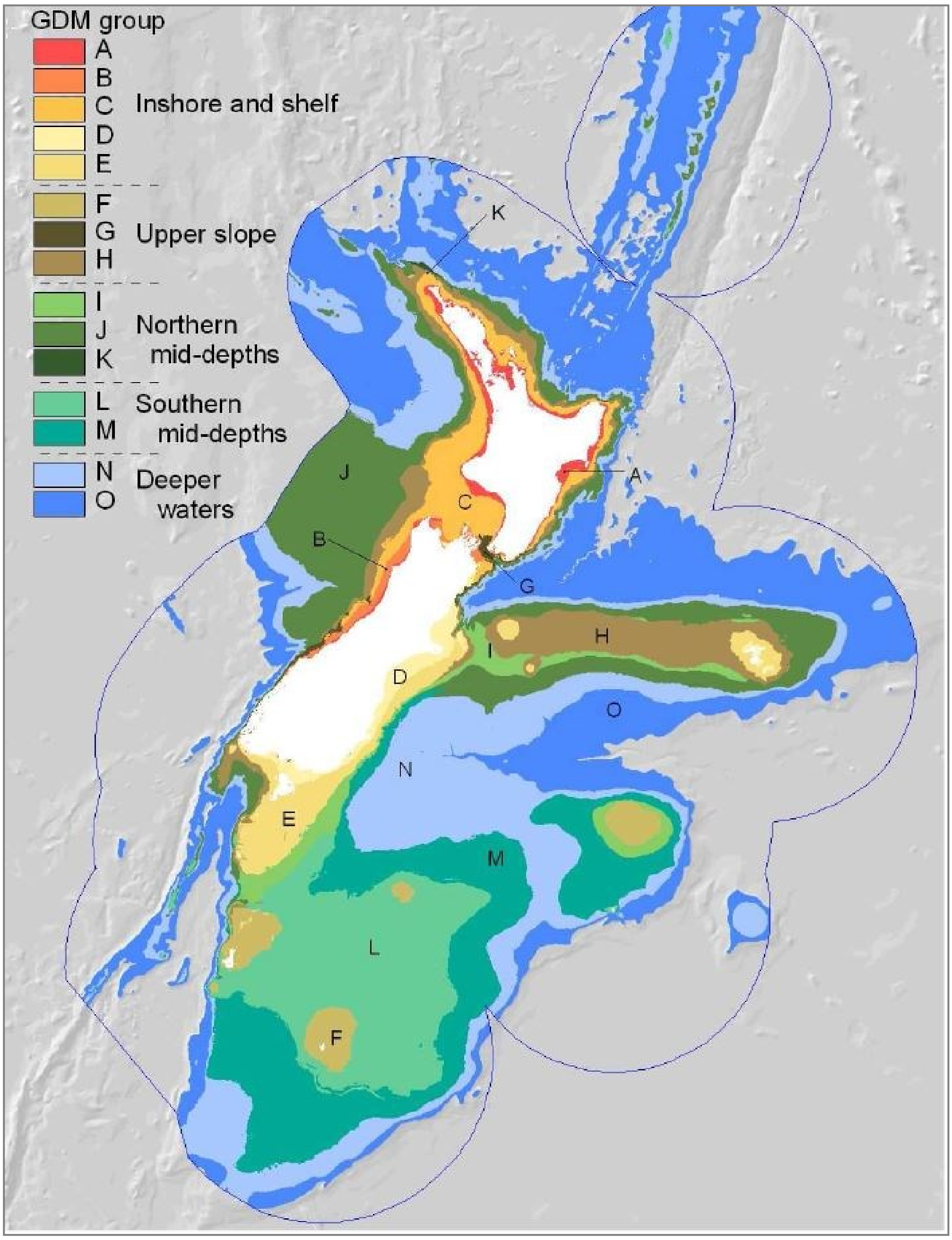


Figure 2-1: THE BOMEC 15 classes showing their aggregation into 5 benthic environment classes used in this assessment. From Leathwick et al. (2012).

Table 2-1: The environment classes used for the ERA.

Class	Name	Depth range (approx)	Notable geomorphic features included in each class (delimited by geographic region)	Area (km²)	Comments
1	Shelf	0-150 m	North Cape Reinga shelf (v. small); Ranfurly Bank, Northern Hikurangi and Hawkes Bay shelves; Cook Strait canyon system; Mernoo Bank; Canterbury, Otago and South Otago shelves; South Stewart and Snares islands shelves	54,427	Approximate as area inside Territorial Seas excluded
2	Upper Slope	150- 500 m	King Bank; Northland Shelf; Ranfurly Bank, Northern Hikurangi and Hawkes Bay slopes; Wairarapa slope, Cook Strait canyon system; Chatham Rise (all); Bounty Seamount; Canterbury, Otago, and South Otago slopes; South Stewart and Snares islands slopes; Puysegur Bank, Auckland Island shelf and slope; Pukaki Bank; Campbell Island shelf and slope?	150,013	
3	Northern Mid-depths	500-1250 m	King Bank; Northland and Outer Bay of Plenty slopes; Kermadec Ridge; Hikurangi Slope: Ranfurly Bank, Northern Hikurangi, Poverty and Hawkes Bay slopes; Wairarapa slope and Cook Strait canyon system; Northern and Southern Chatham Rise flanks, Mernoo Saddle; Bounty Seamount; Canterbury, Otago, and South Otago slopes; South Stewart and Snares islands slopes; Puysegur Bank, Snares Trough, Puysegur Ridge	195,360	
4	Southern Mid-depths	500-1250 m	Southern Chatham Rise flanks; Bounty Seamount; Canterbury, Otago, and South Otago slopes; Great South Basin, Campbell Plateau; South Stewart and Snares island slopes, Puysegur Ridge	432,397	
5	Deep and Very Deep Waters	>1250 m	South Fiji Basin; Havre Trough, Kermadec Trench, Hikurangi Plateau to limit of ECS; Bounty Trough, Circum Campbell Plateau; Snares Trough, Puysegur, Macquarie, and Tasman basins; Puysegur Trench	3,754,894	BOMEC region 5 and the remainder of EEZ+ECS
6	Seamounts	50-3000 m	Seamounts in NIWA seamount database (Rowden et al., 2008).		

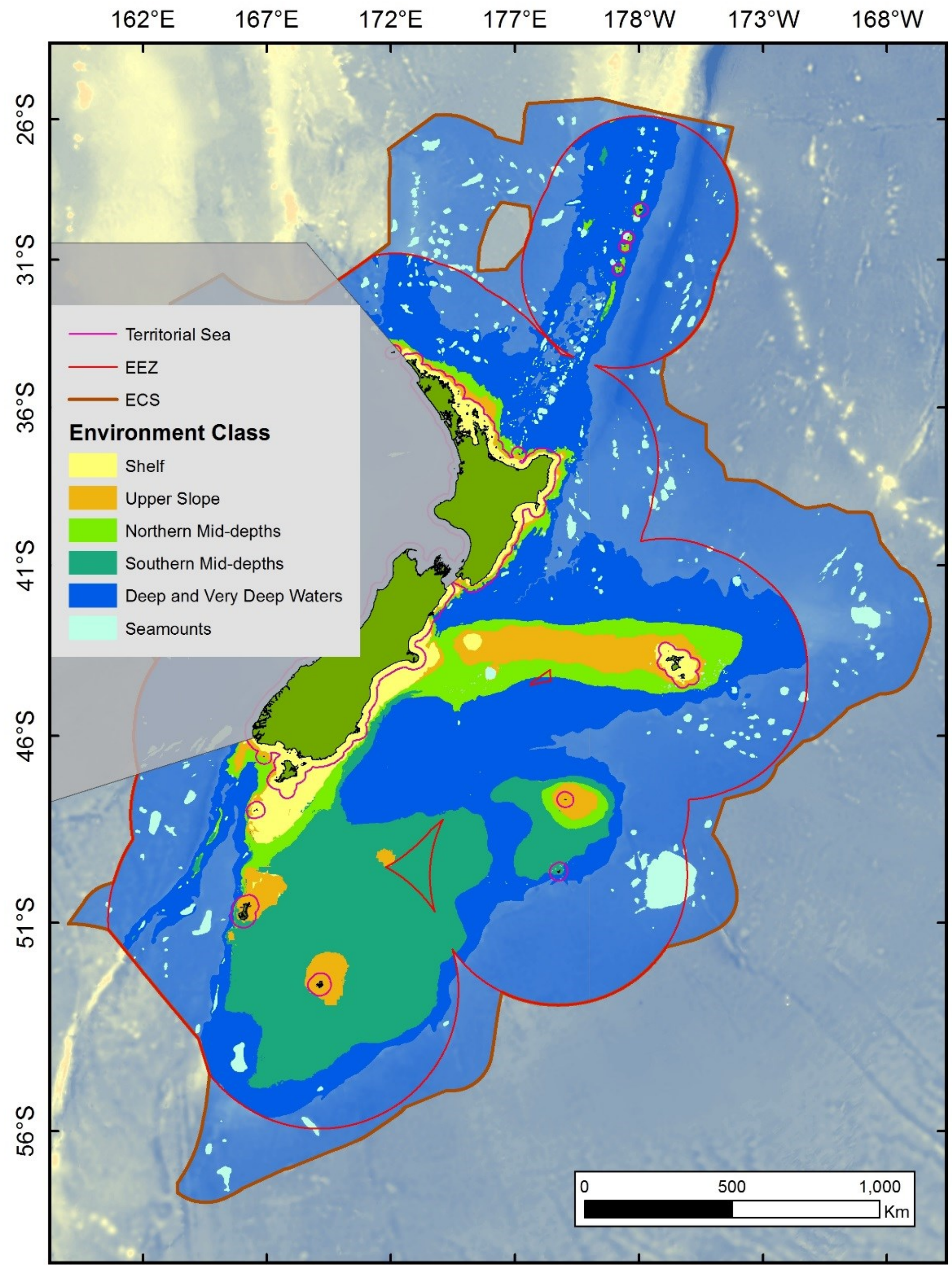


Figure 2-2: The distribution of the six environment classes used in the assessment. The classes are based on the Benthic Optimised Marnie Environmental Classification (BOMEC, Leathwick et al. 2012) (Figure 2-1) and NIWA's SEAMOUNT database (Rowden et al. 2008). Seamounts are delimited at their base. The grey shade is the area that has been excluded west of New Zealand. For this ERA the Deeper waters class from BOMEC has been extended to include very deep waters to the limit of the EEZ and ECS (transparent blue).

2.2 Ecological Risk Assessment

The ERA of the impact of space rocket debris on components of each of six environment classes was broken into the following six steps: 1) Panel of experts convened; 2) Activities subject to assessment identified; 3) Potential effects arising from the fall of debris agreed; 4) Identification of ecosystem components at risk; 5) Assessment of consequences, likelihoods, and confidence; 6) Classification of ecological risk.

2.2.1 Panel of experts convened

An ERA panel of experts (the Panel), made up of relevant NIWA staff based at Wellington and Hamilton, and one member from the Department of Conservation, was convened. ERA panellists included those with knowledge of likely consequences of the debris for different components of the ecosystem. The panel consisted of:

- Dr Geoffroy Lamarche, Project Manager and Panel Chairperson, Marine Geophysics, NIWA Wellington
- Dr Alison MacDiarmid – Marine behavioural and pelagic ecology, NIWA Wellington
- Dr Owen Anderson – Deep-sea fisheries, NIWA Wellington
- Dr David Bowden – Marine mega- and macro-epifaunal communities, NIWA Wellington
- Dr Malcolm Clark – Deep-sea benthic ecology and fisheries, NIWA Wellington
- Dr Kim Goetz – Marine mammal ecology, NIWA Wellington
- Dr Chris Hickey – Marine chemistry and toxicology, NIWA Hamilton
- Dr Yoann Ladroit, Marine acoustics, NIWA Wellington
- Dr Kareen Schnabel – Marine invertebrate ecology, NIWA Wellington
- Dr David Thompson – Seabird ecology, NIWA Wellington
- Mr Dave Lundquist, Marine mammal conservation, Department of Conservation, Wellington

2.2.2 Activities subject to assessment identified

The Panel assessed the ecological impact on the ocean and ocean floor of debris resulting from the successful launch of space rockets in any location along the north, east and south coast of the North and South islands. While MacDiarmid et al. (2016) considered the effects of multiple launches, we have formally assessed the effects of debris from just a single launch impacting anywhere in each of the six environment classes specified above. However, in the Discussion (Section 5) we consider the effects of repeated launches and cumulative effects from other human activities.

The information on debris composition provided by Rocket Lab relates to the Electron launch vehicle, which is the smallest of the presently used launched vehicles worldwide. However, while debris from the Electron vehicle totals 1 t. (from an initial 17 t. launch vehicle empty of fuel), for this assessment we assumed the debris would total up to 40 tonnes per launch as this is the amount of debris that is likely to originate from the largest vehicle proposed to be used in New Zealand in the foreseeable future (pers comm. Rocket Lab).

Our assessment was undertaken based on similar assumptions as those of MacDiarmid et al. (2016), which were provided by Rocket Lab, but adjusted for the launch of larger vehicles. More specifically:

- It is expected that after being jettisoned, Stage 1 will break up into multiple fragments (at least 280 and some as heavy as 360 kg for the Electron launch vehicle) in the atmosphere before impact with the ocean surface.
- While most of the debris, including the carbon-fibre components, would fall to the seafloor, some components may float. For example, the Electron launch vehicle includes approximately 23 kg of cork and 8 kg of foam.
- The potential total fragment surface area from an individual launch of the Electron rocket is 50 m^2. For a larger vehicle this may be 150-200 m^2.
- There is no combustion of components during descent. This is a highly conservative assumption as it is highly likely that some components will burn during descent.
- As in the previous assessment the propellant is assumed to be kerosene and liquid oxygen. After a successful launch it was assumed that very small amounts of residual fuel may be retained in the debris reaching the sea surface (although it is likely that this would be burnt during descent).
- Rupture of the batteries would release highly reactive Lithium (Li) to the seawater.
- All types of debris have the same likelihood of falling on any one part of the ocean.

2.2.3 Potential effects arising from the fall of debris agreed

The Panel assessed the risk associated with seven distinct potential effects for each of the six environment classes identified.

- **Direct strike causing mortality.** Direct strikes could impact seabirds in the air or on the sea-surface, marine mammals when at or near (<10m) the sea surface, pelagic invertebrates and fish near the sea surface, and sedentary or attached invertebrates on the seafloor.
- **Noise disturbance.** The impact of the debris on the sea surface is likely to cause noise above and below water, and perhaps a small acoustic shock wave underwater. This noise is likely to disturb nearby birds, marine mammals and fish. Effects of underwater noise include temporary and permanent impacts. Only the potential for immediate hearing injury was considered taking into account possibilities of behavioural responses, Temporary Threshold Shift (TTS) in hearing sensitivity, potential physiological injuries; or Permanent Threshold Shift (PTS) in hearing sensitivity. Accumulated hearing injury was not assessed.

- **Toxic contaminants.** There is potential for some debris including any lithium batteries to be toxic to some organisms. The toxicity of these components is evaluated in Appendix A.
- **Ingestion of debris.** The breaking apart of the launch vehicle in the air, and/or on impact with the sea surface may develop splinters or particles small enough to be ingested by a wide range of organisms at the sea surface, in the water column, or on the sea floor. This ingestion could cause injuries or mortalities.
- **Smothering of seafloor organisms, preventing normal feeding and/or respiration.** Smothering could occur if large debris completely cover organisms or small particles from the debris accumulated on the seafloor, perhaps aided by currents, in sufficient thickness to impact on the normal feeding and/or respiration of attached benthic invertebrates. Smothering of small animals could also occur if a sediment plume is created when debris impact soft seafloor.
- **Provision of biota attachment site.** Larger fragments that do not bury in the seafloor sediments will provide settlement surfaces for benthic invertebrates. Additional attachment sites would be positive for populations of invertebrates living on hard surfaces, but negative for others requiring soft sediments. In the assessment the Panel estimated the net effect of these potentially opposing mechanisms. This effect is only applicable to the sessile community and not to Demersal fish and mobile invertebrates, Air breathing fauna, and the Pelagic community.
- **Floating debris.** This effect is only applicable to the pelagic community. Debris floating at the sea surface may provide shelter for pelagic organisms such as juvenile fish, and attachment and dispersion for organisms such as goose barnacles and marine algae. Effects of ingestion by marine fauna were considered separately.

2.2.4 Identification of ecosystem components at risk

The effects or consequences of the potential threats arising from the rocket debris were evaluated by the Panel for the following ecosystem components within each environment class:

1. the benthic invertebrate community;
2. the demersal (bottom-associated) fish and mobile invertebrate (squid, octopus, large crabs) community;
3. the air-breathing fauna, comprising marine mammals and seabirds;
4. “sensitive benthic environments”, as defined in the Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2013 (the Permitted Activities Regulations); and
5. the pelagic community, including phytoplankton, zooplankton, larger invertebrates and fish.

NIWA databases, other data sources, and the published literature were used to assemble information on these ecosystem components for the assessment of impacts. The *Specify* database of

NIWA's Invertebrate Collection (NIC) was used to assess the benthic invertebrate community and mobile invertebrate ecosystem components. *Specify* currently (March 2017) holds 118,698 registered catalogue items from 45,394 localities, and includes 7,856 species in 24 invertebrate phyla (Figure 2-3).

Distributions of demersal fish were obtained from existing species distribution models describing the relationships between environment variables and catch as recorded in data from 21 000 research trawls sampling demersal waters throughout New Zealand's EEZ from 1979-1997 (Leathwick et al. 2006b; Leathwick et al. 2006c) (Figure 2-4).

Data for marine mammals was obtained from (1) incidental sightings collated and administered by the Department of Conservation (DOC), (2) incidental cetacean sighting records by transiting ships between New Zealand and the world collated by Martin Cawthorn, (3) observations of cetaceans collected by Ministry of Fisheries inshore fisheries observers from the Centralised Observer Database (COD), and (4) incidental cetacean sightings made by NIWA staff while at sea on various research vessels. To date, these datasets amount to over 12,000 sightings (Figure 2-5).

The mix of seabird species will vary throughout New Zealand waters, largely based on proximity to breeding sites. For example, the seabird assemblage in far northern waters around the Kermadec archipelago will be quite different to that around Campbell Island, the southern-most sub-Antarctic island in the New Zealand sector. Data for seabirds were obtained from Richard & Abraham (2015), together with additional published and unpublished tracking data acquired by electronic data-logging and transmitting devices deployed on seabirds. Maps of the distribution for 38 species or species groups of seabirds as recorded by MPI Fisheries Observers were obtained from https://seabird-counts.dragonfly.co.nz/explore/counts/xsb/all-seabirds.html (e.g. Figure 2-6) and for 48 species available from the national Aquatic Biodiversity Information System (NABIS) http://www.nabis.govt.nz/map.aspx?topic=Birds.

For the distributions of sensitive environments (MacDiarmid et al. 2013) we used a combination records in *Specify* for indicator species as well as modelled distributions. For Stony coral thickets or reefs, Sponge gardens, and Seapen fields we used modelled distributions for four species of Scleractinia, the classes Demospongiae and Hexactinellida, and the order Pennatulacea made by (Anderson et al. 2016)). For Bryozoan thickets we used the models for 11 habitat-forming bryozoan species by Wood et al. (2012). For the remaining sensitive benthic environments we relied on data records from *Specify* (i.e., for Xenophyophore beds, Calcareous tubeworm thickets, Beds of large bivalve molluscs, Brachiopods, Chaptopteridae worm fields, Deep-sea hydrothermal vent and Methane or cold seeps). For these vents and seeps we also used positional data for these environments held in NIWA databases. One (Rhodolith (maerl) beds) of the 13 sensitive environments listed in the EEZ Act regulation occur only in the Territorial Sea, and was therefore not assessed by this ERA.

For the pelagic community component we relied on a variety of published and unpublished information including a description of zooplankton biomass in the New Zealand region (Bradford 1980), and information on oceanic primary production in the New Zealand region (Pinkerton 2007) (Figure 2-7), and sub-tropical and subantarctic waters (Nodder et al. 2016). Information for pelagic fish originate from the *trawl* and *fish comm* databases from Fisher and Bagley (2015), MacKay (1993) and Ministry of Primary Industry (MPI, 2016), as well as from the work of Anderson et al. (1998;

2016a) and Leathwick et al., (2006b). Information on the distribution of major water masses and currents in New Zealand's EEZ and ECS (Figure 2-8) was obtained from Chiswell et al. (2015).

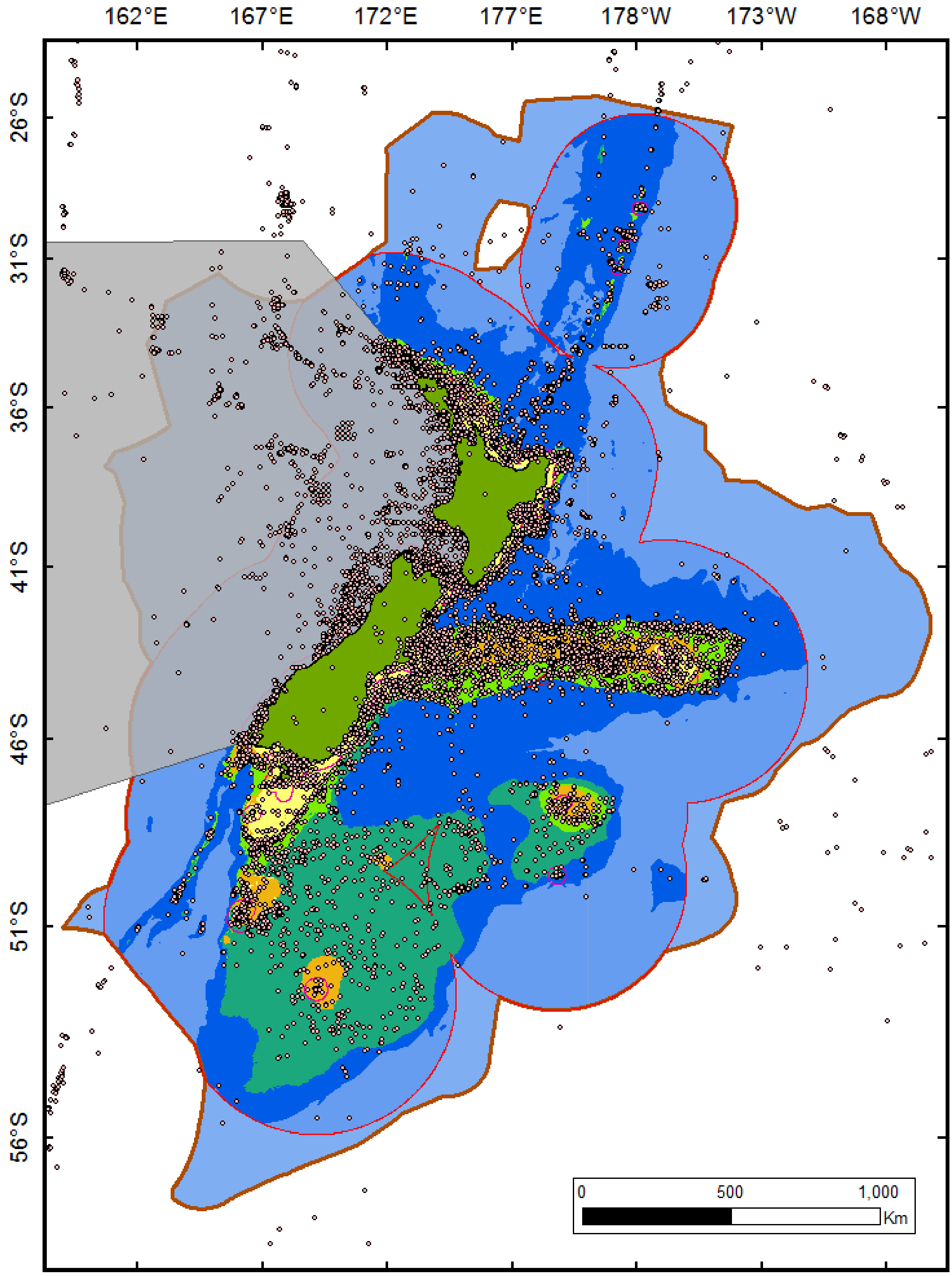


Figure 2-3: Sampling locations from which marine benthic invertebrate species records exist in the *Specify* Database, overlain on the environment classes used in this ERA as per Figure 2-2.

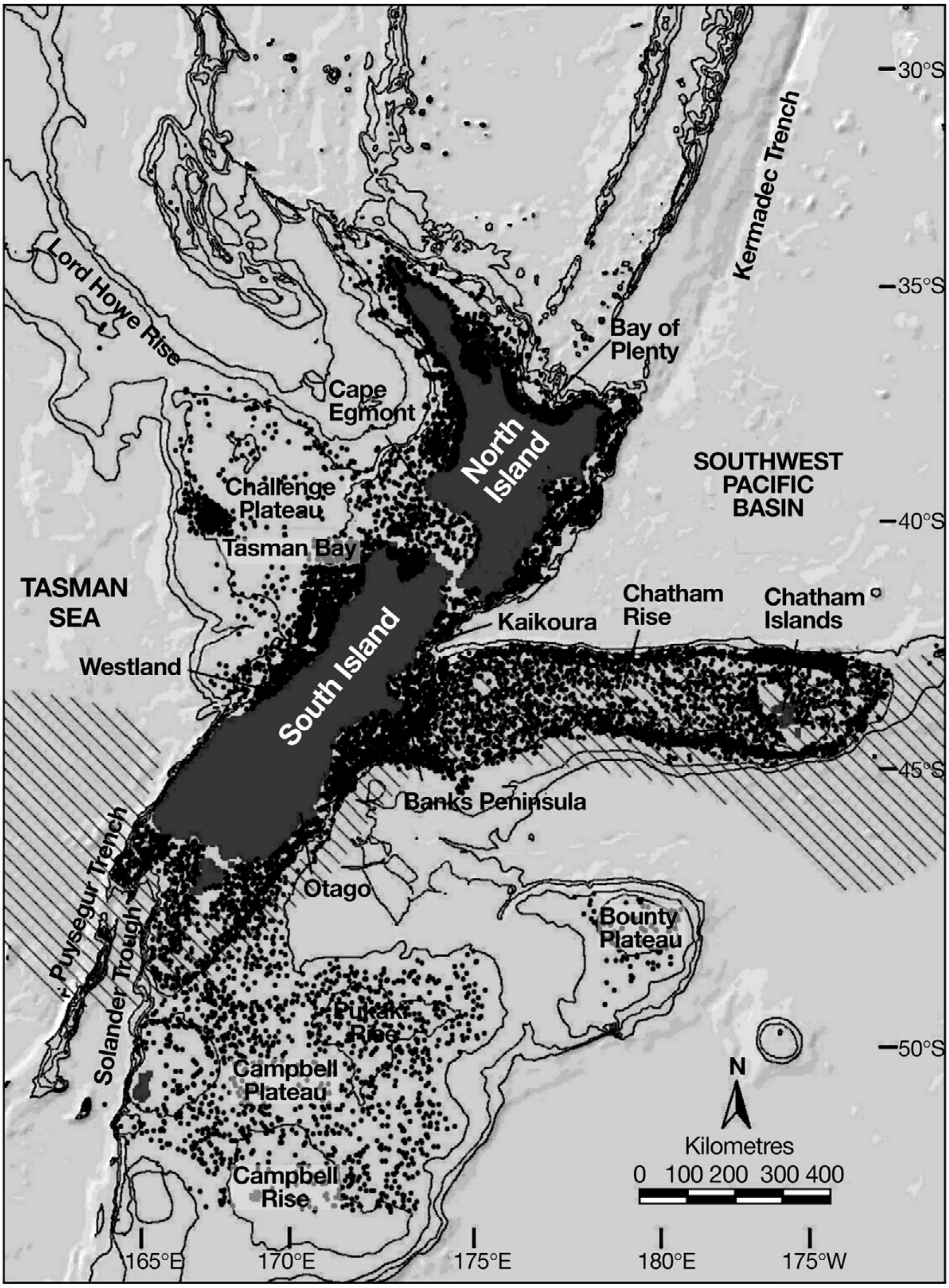


Figure 2-4: Locations of NIWA research trawls used to describe demersal and pelagic fish distributions. The 500, 1000, 1500 and 2000 m isobaths are given. Locations of trawl sites are indicated by dots, and the approximate position of the subtropical front (STF) is shown by diagonal hatching. Figure from Leathwick et al. (2006c).

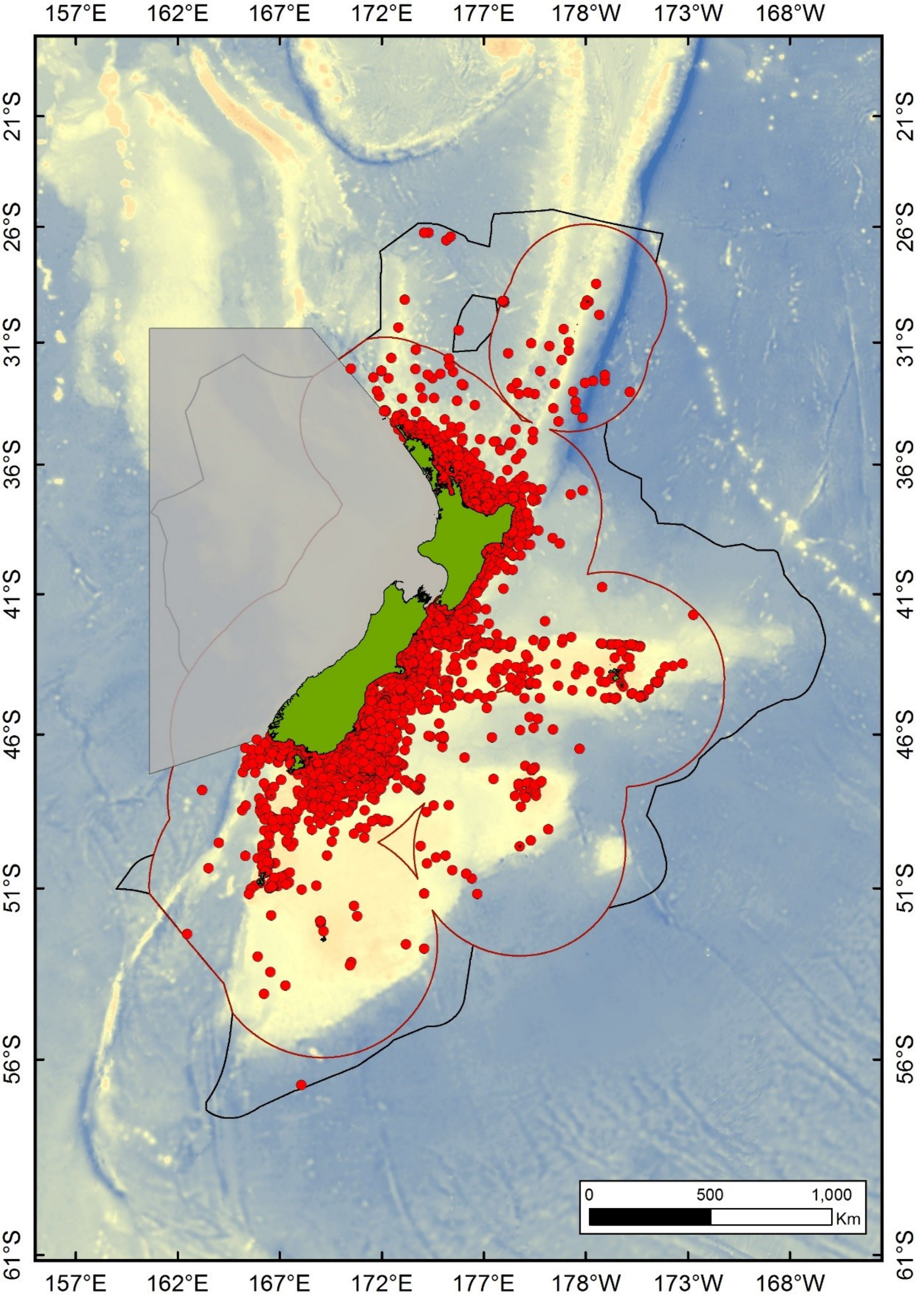


Figure 2-5: Distribution of marine mammal sightings in the EEZ and ECS, excluding areas to the west of New Zealand. See Table 3-2 for details.

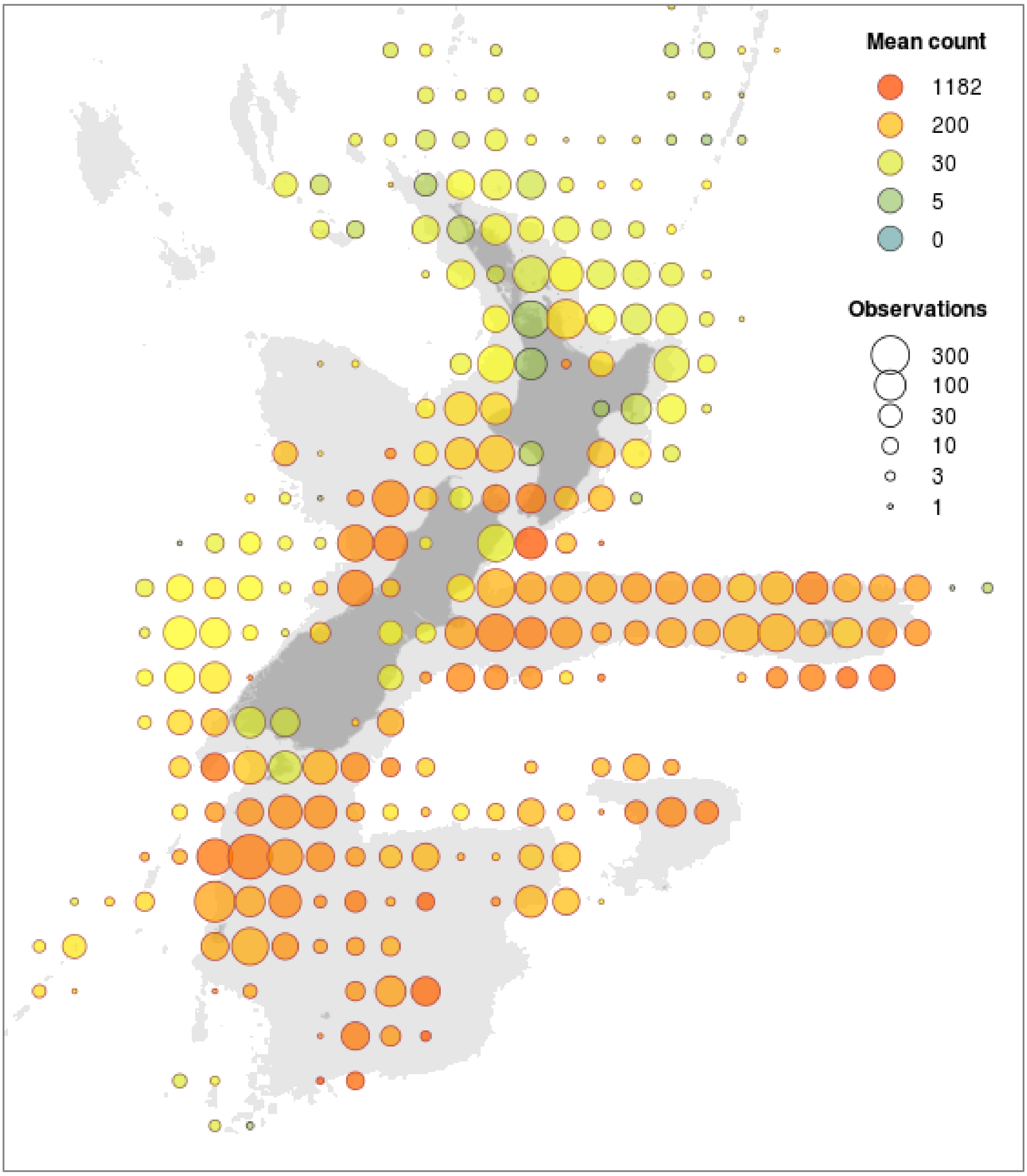


Figure 2-6: Mean number of all seabirds recorded around fishing vessels during counts carried out by government observers. Counts are binned to 1 degree of longitude and latitude. The size of the circle indicates the number of observations, whereas the colour indicates the mean number of birds recorded during counts. Empty circles indicate that no birds were observed. The grey areas indicate water depths of less than 1000 m. Image from https://seabird-counts.dragonfly.co.nz/explore/counts/xsb/all-seabirds.html

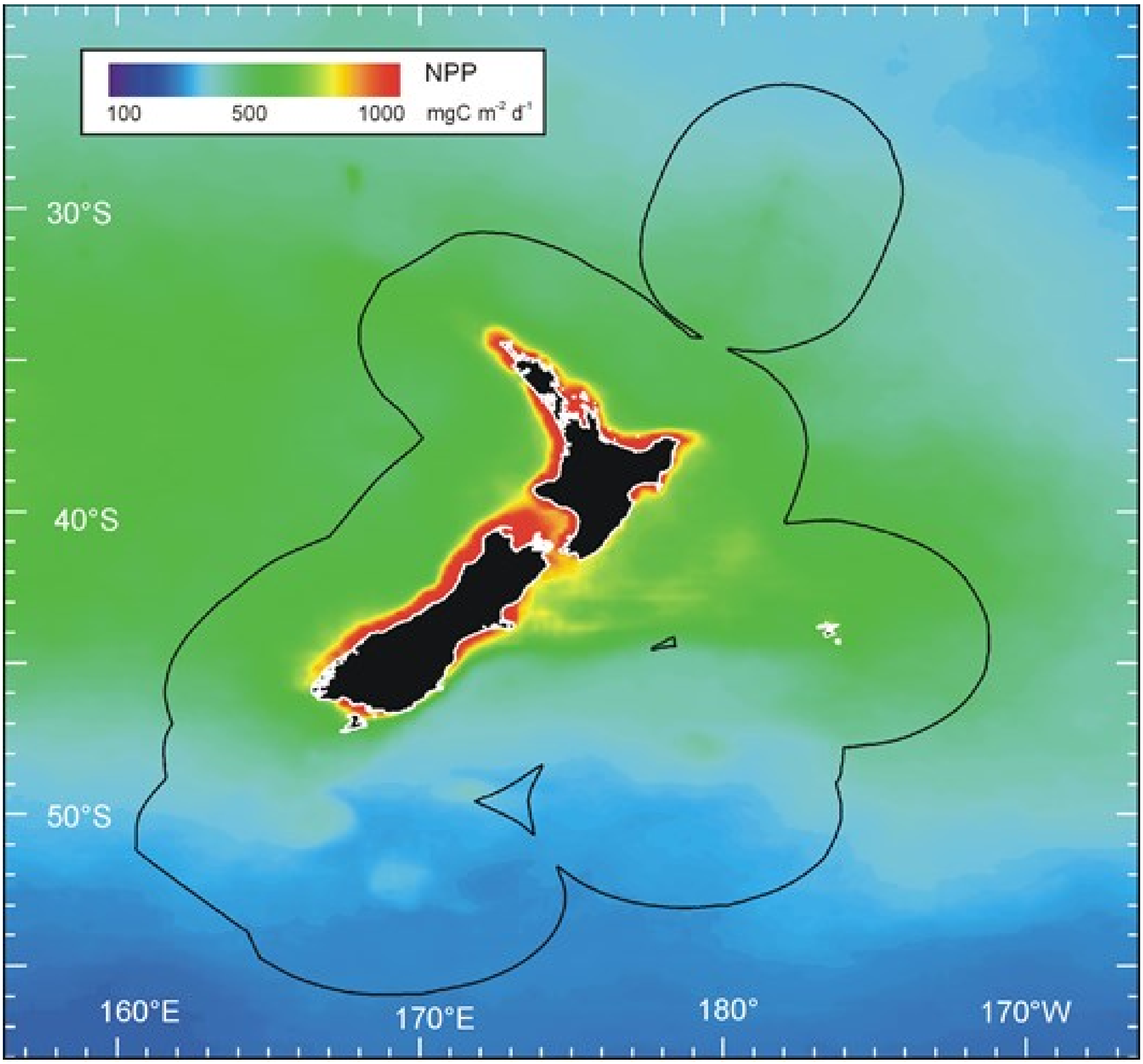


Figure 2-7: Primary production for the New Zealand region. Data estimated from the Vertically Generalized Production Model of Behrenfeld & Falkowski (Behrenfeld and Falkowski 1997) and based on MODIS satellite ocean colour data. Data shown are the log-average values for July 2002 – October 2006.

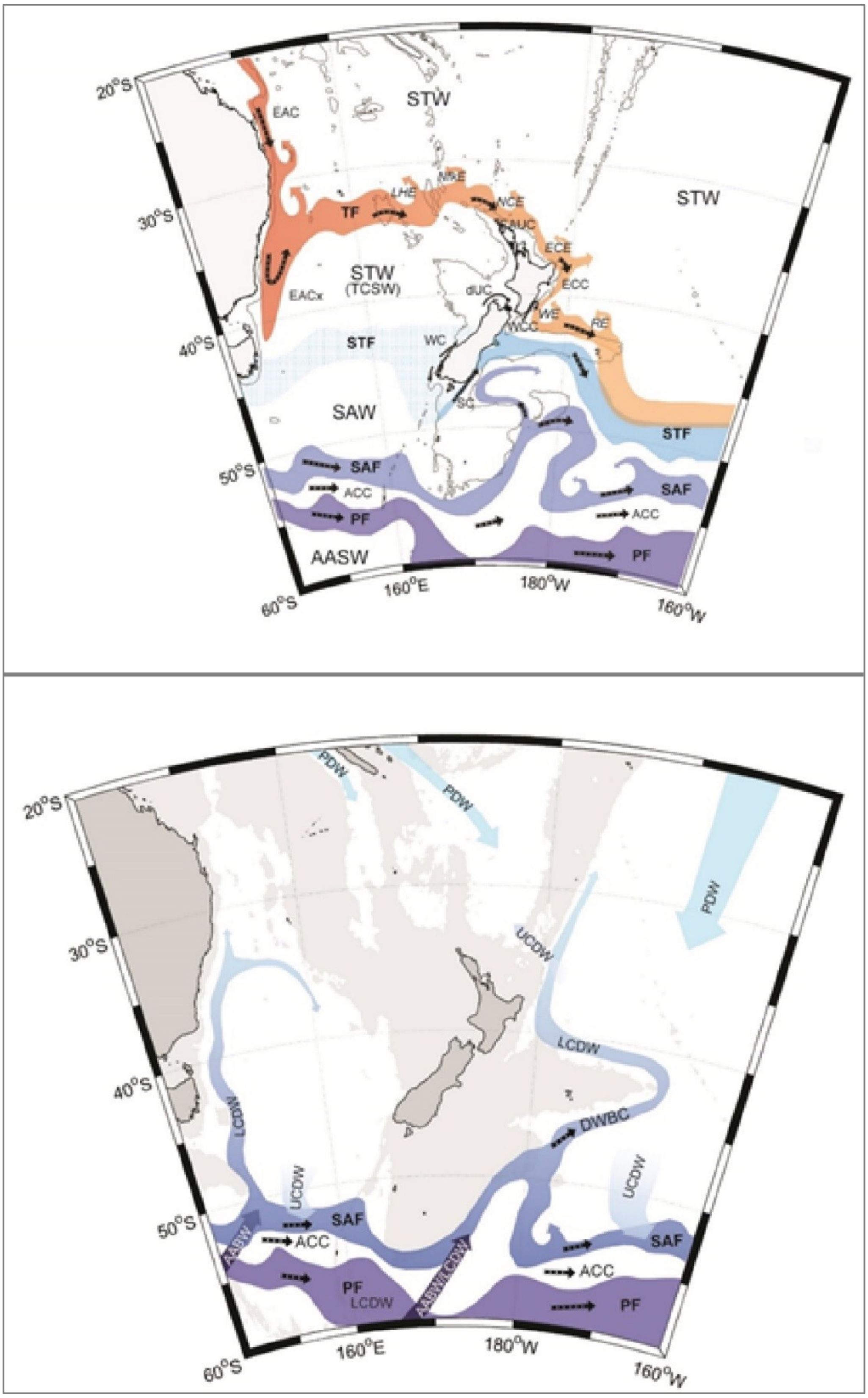


Figure 2-8: Major surface (top panel) and bottom (lower panel) currents around New Zealand. From Chiswell et al. (2015).

2.2.5 Assessment of consequences, likelihoods, and confidence

The effects or consequences of the potential threats arising from the rocket debris were evaluated by the Panel for each component of the ecosystem being considered and scored on a scale of 0 to 5, using a standardised set of prepared consequence descriptions, ranging from negligible to catastrophic (Table 2-2). The panel considered consequences with regard to three aspects of the environment: the proportion of habitat affected by a threat, the functional impact on populations, communities of organisms or the habitat, and the time for these functions to recover if the threat stopped. These are all key indicators of ecological response at a range of scales. The proportion of a habitat affected by an activity is critical to assessing the spatial extent of any impact. The ecological functional impact is likewise a broad indicator of the ecological significance of a disturbance. Lastly recovery period provides an indication of the affected species and habitat ability to recover from the threat taking into account knowledge of the biology and ecology. Following the scoring of the consequence, the Panel discussed, assessed and then scored the likelihood of the threat from rocket debris occurring for each component of the ecosystem in each of the six environment classes identified. Likelihood scores can range from 1 (remote) to 6 (likely) (Table 2-3).

Following the scoring of the consequences and likelihoods the panellists assessed the level of confidence in the information available to make each assessment based on the categories provided in Table 2-4.

To reach a decision, the Panel engaged in open discussion until a consensus was reached for a draft score of each threat to each ecosystem component. The draft table of scores was then assessed independently by each panellist and suggested changes offered to the whole Panel. Final score values were again reached by consensus.

2.2.6 Classification of ecological risk

Using the tables of defined levels and scores of environmental consequences (Table 2-2) and likelihoods (Table 2-3) ecological risk scores were calculated as the product (multiplication) of consequence and likelihood. Risk scores can therefore range from a minimum of 0 to a maximum of 30 (Table 2-5). This approach identified the level of risk for each ecosystem component from each threat arising from the fall of rocket debris into each of six environment classes.

Following the classification adopted by MacDiarmid et al. (2011), activities with risk scores of 6 or less are categorised as low. These scores arise from the lowest two levels of consequence (0 - negligible and 1- minor) (see Table 2-5) at all levels of likelihood (including 6, likely), from moderate levels of consequence (2) at unlikely (3) or lower levels of likelihood, from severe levels of consequence (3) at rare (2) or remote (1) levels of likelihood, or from major and catastrophic levels of consequence at remote levels of likelihood. At the upper end of the score scale, activities with risk scores of 24 or more are categorised as extreme (Table 2-5). These levels of risk arise only from those activities judged to have major (4) consequences at the highest level of likelihood (6) and catastrophic consequences (5) at the two highest levels of likelihood (5 and 6).

Between these extremes, activities with risk scores from 8 to 12 are categorised as moderate, and those with risk scores from 15 to 20 are categorised as high (Table 2-5).

Table 2-2: Consequence levels for the assessed activity. Summary descriptions of the six sets of consequence levels for the percent overlap of population distribution with debris area, the impact on the population, community or habitat, and the likely recovery period. Adapted from MacDiarmid et al. (2016).

Consequence level	Percent overlap of population distribution with debris area	Population/ community/ habitat impact	Recovery Period
0 - Negligible	Affects <1% of distribution	Interactions may be occurring but unlikely to be ecologically significant (<1% changes in abundance, biomass, or composition) or be detectable at the scale of the population, habitat or community	No recovery time required
1 - Minor	Measurable but localised; affects 1-5% of distribution	Possibly detectable with 1-5% change in population size or community composition and no detectable impact on dynamics of specific populations	Rapid recovery would begin if activity stopped – less than 8 weeks
2 - Moderate	Impacts more common; >5-20% of distribution affected	Measurable with >5-20% changes to the population, habitat, community, or biodiversity components without there being a major change in function. There may some change in species ranges.	Recovery in >2 months to 1-2 years if activity stopped
3 - Major	Impacts very widespread; >20-50% of distribution is affected	Populations, habitats, communities, and biodiversity measures substantially altered (>20-50%), with some function or components missing/ declining/ increasing well outside historical ranges. Some additional species appear in the affected environment while others have shrinking ranges.	Recovery occurs in 2-10 years if activity stopped
4 - Severe	Impact extensive; >50-80% of distribution affected	Likely to cause local extinctions of vulnerable species if impact continues, with a >50-80% change to habitat and community structure and function. Significant change in range of some species. Different population dynamics now occur with biodiversity measures greatly affected.	Recovery period 1-2 decades if activity stopped
5 - Catastrophic	Almost entire distribution is affected; >80%	Local extinctions or surges of a variety of species are imminent/immediate. Total change in habitat, community or ecosystem processes. The abundance, biomass or diversity of most groups is drastically changed (by >80%).	Long term recovery to former levels will be greater than 1-2 decades, perhaps centuries, even if activity stopped

Table 2-3: Threat likelihood categories.

Level/score	Descriptor	Likelihood
1	Remote	Highly unlikely
2	Rare	May occur in exceptional circumstances
3	Unlikely	Uncommon, but has been known to occur elsewhere
4	Possible	Some evidence to suggest this is possible
5	Occasional	Will occasionally occur
6	Likely	It is expected to occur

Table 2-4: Confidence rating, score and description.

Confidence rating	Score	Rationale for confidence score
Low	1a	No data exist and no consensus among experts
	1b	Some sparse data exist allowing tentative agreement amongst the experts
	1c	Agreement among experts, but with low confidence in the data
High	2a	Consensus among experts, but with high confidence, even though data may be lacking
	2b	Consensus among experts supported by unpublished data (not peer-reviewed but considered sound)
	2c	Consensus among experts supported by reliable peer-reviewed data or information (published journal articles or reports)

Table 2-5: Risk levels and categories.

Risk Level	Risk score range	Risk score derivation	
		Consequence level	Likelihood levels
Low	0-6	0 – negligible	1-6 (remote to likely)
		1 – minor	1-6 (remote to likely)
		2 – moderate	1-3 (remote, rare or unlikely)
		3 – severe	1-2 (remote or rare)
		4 – major	1 (remote)
		5 – catastrophic	1 (remote)
Moderate	8-12	2 – moderate	4-6 (possible, occasional, likely)
		3 – severe	3-4 (unlikely, possible)
		4 – major	2-3 (rare, unlikely)
		5 – catastrophic	2 (rare)
High	15-20	3 – severe	5-6 (occasional, likely)
		4 – major	4-5 (possible, occasional)
		5 – catastrophic	3-4 (unlikely, possible)
Extreme	24-30	4 - major	6 (likely)
		5 – catastrophic	5-6 (occasional or likely)

3 Receiving Environments

3.1 Shelf

The Shelf environment class between the boundary of the territorial sea and the edge of the shelf is mainly limited to the Stewart and-Snares islands shelf and northwards to the Canterbury Bight and Pegasus Bay in the South Island, and small areas offshore of Hawke Bay and north of Cape Reinga. This benthic environment class is defined by depth, out to about 200m water depth, with temperature, salinity, and sediment resuspension being relatively high and overlaying waters in the subtropical front typically productive (Figure 2-7 and Figure 2-8). Seabed substrates include land-derived gravel and sand, with coarseness varying across the entire spectrum from sand to tidal mud (Orpin et al. 2008).

The *Specify* database has 558 records for 224 separate taxonomic groups (ranging from high-level species identification to low-level identification (phylum) for this benthic environment class. The 20 most commonly collected invertebrates (Table 3-1) (includes nine different common crustacean groups (decorator crabs, swimming crabs, squat lobsters and hermit crabs), echinoderms (starfish, urchins) and cnidarian (hydroids, anemones). These are typically representatives of a range of soft and hard substrate types.

Table 3-1: The 20 most frequently occurring benthic invertebrate species in the Shelf environment class (data from NIWA *Specify* database).

	Shelf	
Scientific name	**Higher classification**	**No. records**
Leptomithrax longipes	Decorator crab	32
Odontaster benhami	Starfish	32
Astromesites primigenius	Starfish	24
Munida gregaria	Squat lobster	22
Goniocidaris umbraculum	Pencil urchin	13
Symplectoscyphus johnstoni	Hydroids	11
Thacanophrys filholi	Decorator crab	11
Brachyura	Crabs	10
Phellia aucklandica	Anemone	9
Nectocarcinus sp.	Swimming crab	14
Anomura*	False crabs	7
Bunodactis chrysobathys	Anemone	7
Leptomithrax garricki	Decorator crab	7
Phylladiorhynchus pusillus	Squat lobster	7
Psilaster acuminatus	Starfish	7
Corhiza scotiae	Hydroids	6
Cryptolaria prima	Hydroids	6
Paguridae	Hermit crabs	6
Salacia buski	Hydroid	6
Symplectoscyphus subarticulatus	Hydroid	6
	Total records	**558**

*Includes hermit crabs, squat lobsters and porcelain crabs

The Shelf class is beyond the depth limit of many of the numerous and widespread inshore fish species common around near-shore habitats such as rocky reefs and algal beds, however there are many species, both commercial and non-commercial, which are abundant in this class. The more common fish in this class include witch (*Arnoglossus scapha*), carpet shark (*Cephaloscyllium isabellum*), gurnard (*Chelidonichthys kumu*), school shark (*Galeorhinus galeus*), giant stargazer (*Kathetostoma giganteum*), tarakihi (*Nemadactlyus macropterus*), hapuku (*Polyprion oxygeneios*), barracouta (*Thyrsites atun*) (Figure 3-1), and spiny dogfish (*Squalus acanthias*) (Anderson et al. 1998). Elephantfish (*Callorhinchus milli*) is common in this class only in the Canterbury Bight and Pegasus Bay (Figure 3-1) (Mackay 1993; Fisher and Bagley 2015; MPI 2016).

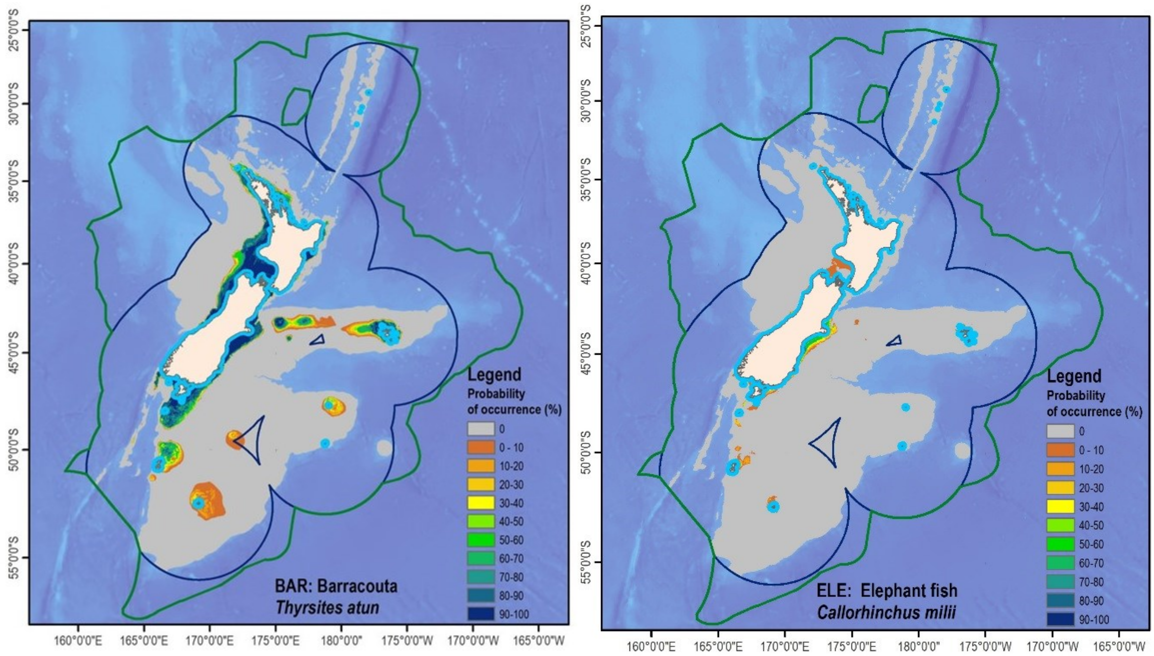


Figure 3-1: Modelled distributions of barracoota and elephant fish. While barracouta is a widespread and common species that is predicted to have a higher probability of occurrence in the Shelf class, elephant fish has a more restricted distribution that is mainly predicted to occur in shelf waters. Modelled distributions are limited to waters shallower than 1600m. Unpublished NIWA data.

There have been no systematic surveys of marine mammals in the EEZ or ECS. The distribution of all visual incidental sightings of marine mammals is provided in Figure 2-5. In total 52 species have been sighted in the EEZ and ECS including 33 species of toothed whales and dolphins, ten baleen whale species, and nine species of seal (Table 3-2). The sightings are heavily biased towards the coast where most observations have taken place. There are few observations recorded from vast areas of EEZ and ECS. Species such as beaked whales that spend little time at the surface are likely to be seriously under-represented in visual sightings records. Baker et al. (2013) assigned four species in the EEZ and ECS a conversation status of Threatened - Nationally critical (Bryde's whale, killer whale, sea lion and elephant seal), two species a conservation status of Threatened – Nationally endangered (bottlenose dolphin and Hectors dolphin), and one species the conservation status of Threatened – Nationally vulnerable (southern right whale). Baker et al. (2013) considered 11 species of marine mammals in the EEZ and ECS to be not threatened with extinction, with the remainder either data deficient or non-resident native migrant or vagrant (Table 3-2).

Thirteen species of marine mammals have been sighted in the Shelf environment class outside the Territorial Sea with dusky and common dolphins accounting for 87% of the 5,844 individuals sighted

(Table 3-3). Neither of these species is threatened, but several of the less commonly observed species are nationally endangered or nationally vulnerable (Table 3-2) No beaked whales have been sighted from these waters.

New Zealand supports the most diverse seabird assemblage on earth, with approximately 162 taxa having been recorded within the Exclusive Economic Zone. Although accurate population estimates for many species are lacking, the number of seabirds using New Zealand waters during the summer months, when most species are breeding, will be in the order of millions of birds. However, there have been no systematic and structured seabird surveys throughout the EEZ. For a comprehensive list of New Zealand seabirds and their current conservation status see Robertson et al. (Robertson et al. 2013).

The Shelf environment class includes seabird species that are typical of coastal, relatively near-shore habitats during the breeding season (e.g., penguins, shags, terns and gulls), but some of these seabirds disperse widely following breeding and can occupy other environment classes. Additionally, species that are typically more pelagic in distribution occur in the Shelf class where this occurs around the Chatham Islands, where the shelf extends south of Stewart Island to the Snares and in the Hauraki Gulf. Seabird breeding sites at these locations result in birds travelling through this class as they commute between feeding locations offshore and their nests. Such species include breeding albatrosses at both the Chatham (e.g., Chatham albatross (*Thalassarche eremita*)) and Snares islands (Buller's albatross (*T. bulleri*)). Shearwaters (e.g. sooty shearwater (*Puffinus griseus*) breeding at the Snares) (Figure 3-2) and petrels (e.g. Magenta petrel (*Pterodroma magentae*) breeding at the Chatham Islands and black petrel (*Procellaria parkinsoni*) breeding at the Barrier islands) also occur in this class.

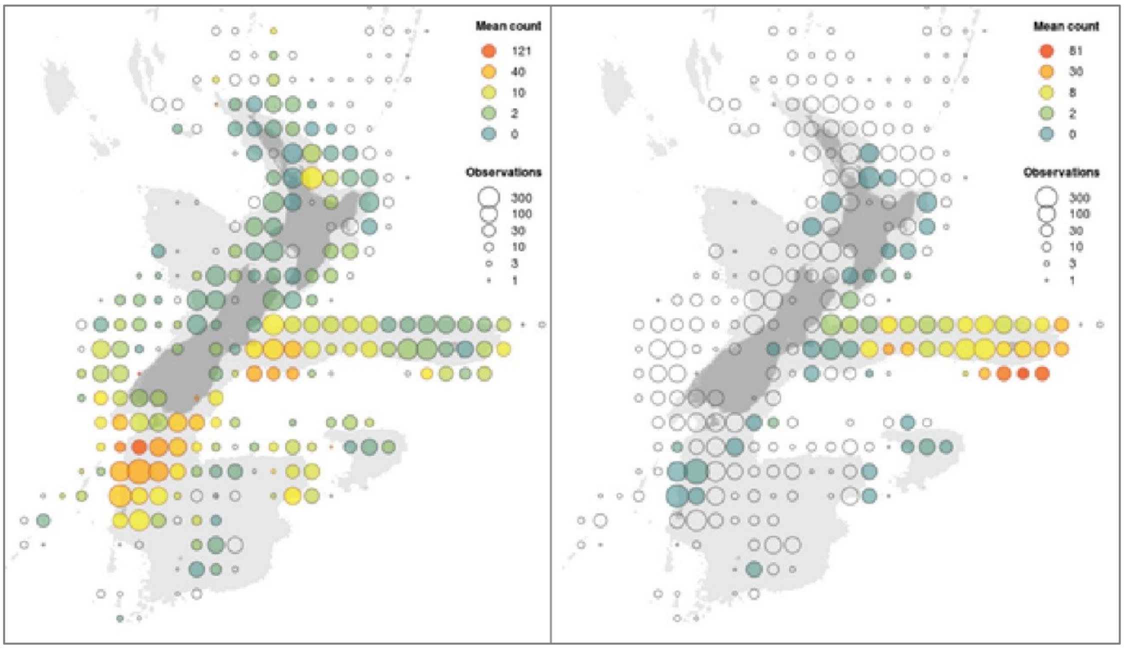


Figure 3-2: Mean number of sooty shearwater (left panel) and Chatham Island albatross (right panel) recorded around fishing vessels during counts carried out by government observers. High counts for both species essentially occur along the crest of Chatham Rise and around the Snares-Auckland islands which correspond to the Shelf and Upper Slope classes. See caption in Figure 2-6 for further details. Images from https://seabird-counts.dragonfly.co.nz/explore/counts/xsb/all-seabirds.html

Bryozoan thickets are the sensitive environment most common in this class, with 27 species providing habitat over hundreds of square kilometres of sea floor. Important habitat-forming bryozoan species in New Zealand shelf waters include *Cinctipora elegans, Celleporaria agglutinans*, and *Hippomenella vellicata* and in shelf waters are particularly abundant along the south-east coast of South Island, on the Snares-Stewart shelf, and around North Cape (Wood et al. 2012).

The pelagic community is this environmental class is moderately to highly productive both in terms of primary production and zooplankton biomass (Bradford and Roberts 1978; Bradford 1980). Jack mackerels are an abundant pelagic fish species in this environmental class (Figure 3-3).

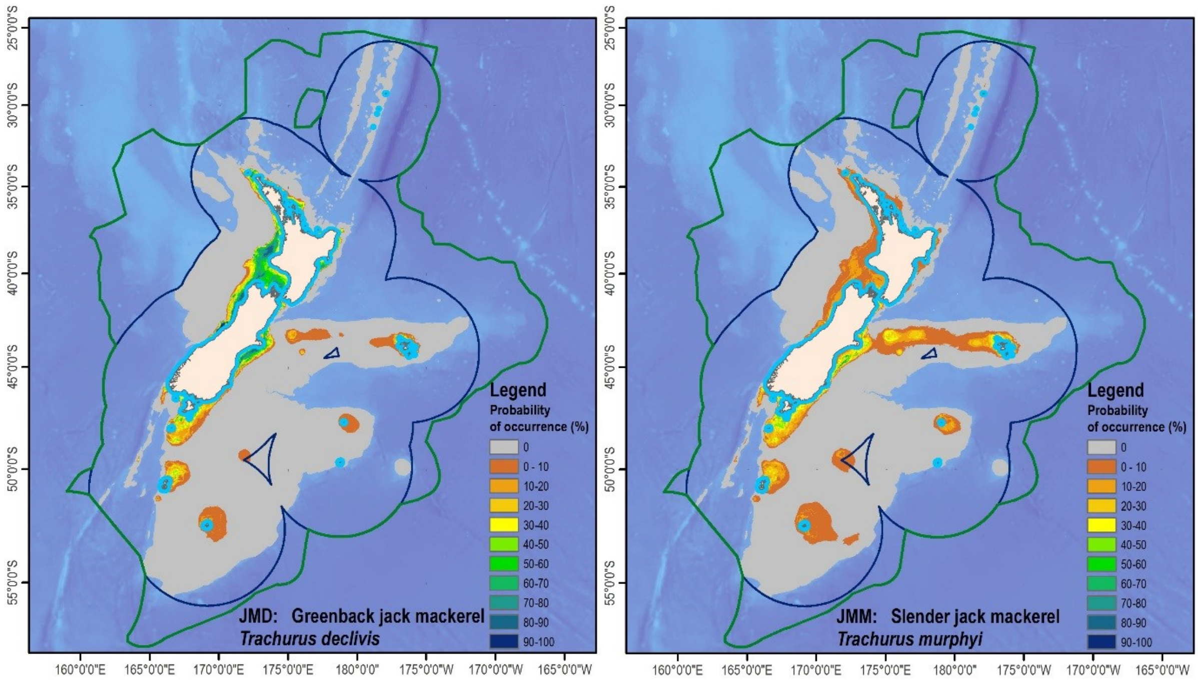


Figure 3-3: Modelled distributions of two species of jack mackerel. Both species are abundant in shelf waters. NIWA unpublished data.

Table 3-2: Marine mammal species occurring in the EEZ and ECS. Also shown for each species is the DOC conservation status and IUCN status from Baker et al. (2013).

Scientific name	Common name	DOC Conservation Status	IUCN status
Mesoplodon bowdoini	Andrews' beaked whale	Data deficient	Data deficient
Ziphius cavirostris	Cuvier's beaked whale	Data deficient	Least Concern
Mesoplodon Densirostris	Dense-beaked whale	Data deficient	Data deficient
Mesoplodon hectori	Hector's beaked whale	Data deficient	Data deficient
Lagenorhynchus cruciger	Hourglass dolphin	Data deficient	Data deficient
Caperea marginata	Pygmy right whale	Data deficient	Data deficient
Tasmacetus shepherdi	Shepherd's beaked whale	Data deficient	Least Concern
Hyperoodon planifrons	Southern bottlenose whale	Data deficient	Least Concern
Mesoplodon traversii	Spade-toothed beaked whale	Data deficient	Data deficient
Phocoena dioptrica	Spectacled porpoise	Data deficient	Data deficient
Mesoplodon layardii	Strap-toothed beaked whale	Data deficient	Data deficient
Mesoplodon mirus True	True's beaked whale	Data deficient	Data deficient
Balaenoptera musculus intermedia	Antarctic blue whale	Non-resident native-migrant	Critically endangered
Berardius arnouxii	Arnoux's beaked whale	Non-resident native-migrant	Data deficient
Balaenoptera physalus	Fin whale	Non-resident native-migrant	Endangered
Megaptera novaeangliae	Humpback whale	Non-resident native-migrant	Least Concern
Balaenoptera musculus brevicauda	Pygmy blue whale	Non-resident native-migrant	Data deficient
Balaenoptera borealis	Sei whale	Non-resident native-migrant	Endangered
Globicephala macrohynchus	Short-finned pilot whale	Non-resident native-migrant	Data deficient
Arctocephalus gazella	Antarctic fur seal	Non-resident native-vagrant	Least concern
Lobodon carcinophagus	Crabeater seal	Non-resident native-vagrant	Least concern
Kogia sima	Dwarf sperm whale	Non-resident native-vagrant	Data deficient
Lagenodelphis hosei	Frasers dolphin	Non-resident native-vagrant	Least Concern
Mesoplodon ginkgodens	Ginkgo-toothed beaked whale	Non-resident native-vagrant	Data deficient

Scientific name	Common name	DOC Conservation Status	IUCN status
Hydrurga leptonyx	Leopard seal	Non-resident native-vagrant	Least Concern
Mesoplodon peruvianus	Lesser/pygmy beaked whale	Non-resident native-vagrant	Data deficient
Peponocephala electra	Melon-headed whale	Non-resident native-vagrant	Least Concern
Stenella attenuata	Pantropical spotted dolphin	Non-resident native-vagrant	Least Concern
Grampus griseus	Risso’s dolphin	Non-resident native-vagrant	Least Concern
Ommatophoca rossi	Ross seal	Non-resident native-vagrant	Least Concern
Steno bredanensis	Rough-toothed dolphin	Non-resident native-vagrant	Least Concern
Stenella coeruleoalba	Striped dolphin	Non-resident native-vagrant	Least Concern
Arctocephalus tropicalis	Subantarctic fur seal	Non-resident native-vagrant	Least concern
Leptonychotes weddellii	Weddell seal	Non-resident native-vagrant	Least Concern
Balaenoptera bonaerensis	Antarctic minke whale	Not threatened	Data deficient
Delphinus delphis	Common dolphin	Not threatened	Least Concern
Lagenorhynchus obscurus	Dusky dolphin	Not threatened	Data deficient
Balaenoptera acutorostrata	Dwarf minke whale	Not threatened	Least Concern
Pseudorca crassidens	False killer whale	Not threatened	Data deficient
Mesoplodon grayi	Gray's beaked whale	Not threatened	Data deficient
Globicephala melas	Long-finned pilot whale	Not threatened	Data deficient
Arctocephalus forsteri	New Zealand fur seal	Not threatened	Least Concern
Kogia breviceps	Pygmy sperm whale	Not threatened	Data deficient
Lissodelphis peronii	Southern right whale dolphin	Not threatened	Data deficient
Physeter macrocephalus	Sperm whale	Not threatened	Vulnerable
Balaenoptera edeni/brydei sp.	Bryde’s whale	Threatened-nationally critical	Data deficient
Orcinus orca	Killer whale	Threatened-nationally critical	Data deficient
Phocarctos hookeri	New Zealand sea lion	Threatened-nationally critical	Vulnerable
Mirounga leonina	Southern elephant seal	Threatened-nationally critical	Least Concern
Tursiops truncatus	Bottlenose dolphin	Threatened-nationally endangered	Least Concern
Cephalorhynchus hectori hectori	Hector's dolphin	Threatened-nationally endangered	Endangered
Eubalaena australis	Southern right whale	Threatened-nationally vulnerable	Least concern

Table 3-3: Marine mammal species in the Shelf environment class in order of decreasing numbers of individuals sighted.

	Shelf	
Scientific name	**Common Name**	**No. individuals**
Lagenorhynchus obscurus	Dusky dolphin	3028
Delphinus delphis	Common dolphin	2051
Globicephala sp.	Pilot whale	212
Cephalorhynchus hectori	Hector's dolphin	140
Arctocephalus forsteri	New Zealand fur seal	117
Tursiops truncatus	Bottlenose dolphin	108
Lagenorhynchus cruciger	Hourglass dolphin	100
Megaptera novaeangliae	Humpback whale	28
Orcinus orca	Killer whale	28
Physeter macrocephalus	Sperm whale	26
Balaenoptera borealis	Sei whale	2
Eubalaena australis	Southern right whale	2
Balaenoptera musculus sp.	Blue whale	1
Balaenoptera bonaerensis	Minke whale	1
	Total Individuals	**5844**

3.2 Upper Slope

This environmental class mainly comprises the shallower regions of the Chatham Rise as well as the smaller areas of slope around the Auckland, Campbell, and Bounty Islands, and a small slope area off the northeastern coast of the North Island. The class is defined primarily by moderately high temperatures and salinity, often with strong tidal currents. While the highly productive waters of the subtropical front lie across the Chatham Rise, the upper slope areas around the Auckland, Campbell, and Bounty Islands lie in lower productivity subantarctic waters (Figure 2-7). Seabed substrates include sand, muddy-sand and carbonate shell gravel (Orpin et al. 2008).

This class includes habitats from depths of 150-200 m to depths of about 400 m, with frequent records of foraminifera, polychaetes and sponges. The *Specify* database includes 3126 invertebrate records and 725 taxa for the Upper Slope environment, with crustaceans most abundant (squat lobsters, shrimps, crabs, isopods and amphipods make up 14 of the top 20), followed by echinoderms (urchins, starfish) and cnidarians (represented by gorgonians and soft corals) (Table 3-4). Most of this fauna is typical of soft-sediment communities.

The Upper Slope environment class includes numerous middle-depth fish species (MPI 2016), the more common of which being silverside (*Argentina elongata*), ling (*Genypterus blacodes*), redbait (*Emmelichthys nitidus*) (Figure 3-5), giant stargazer (*Kathetostoma giganteum*), hoki (*Macruronus novaezelandiae*) (Figure 3-5), arrow squid (*Nototodarus sloanii*), red cod (*Pseudophycis bachus*), smooth skate (*Raja innominata*), silver warehou (*Seriolella punctata*), and spiny dogfish (*Squalus acanthias*) (Anderson et al. 1998).

Seventeen species of marine mammals have been sighted in Upper Slope waters with common and dusky dolphins and pilot whales accounting for 92% of the 8,060 individuals sighted (Table 3-5). Neither of these species is threatened, but several of the less commonly observed species are nationally endangered or nationally vulnerable (Table 3-2). Two Cuvier's beaked whale has been sighted in these waters.

The Upper Slope environment class surrounds some of New Zealand's most important seabird breeding islands (Auckland, Campbell and Bounty islands), and as noted for the Shelf class, seabirds breeding at these locations will commute through the Upper Slope class. Breeding seabirds at these sites include a wide range of albatrosses, petrels, storm petrels, penguins and shags. Additionally, the Upper Slope class includes the shallower areas of the Chatham Rise, in which a very wide range of seabird species could be encountered (Figure 3-6).

Sensitive benthic environments are expected to be widespread in this class, particularly those based around the habitat-forming stony coral *Goniocorella dumosa* (Figure 3-4), as well as those with sea-pens, and sponges, (Anderson et al. 2016a).

The pelagic community is this environmental class is moderately productive both in terms of primary production and zooplankton biomass, with an area of low productivity on the crest of the Chatham Rise (Bradford and Roberts 1978, Bradford 1980).

Table 3-4: The 20 most frequently occurring benthic invertebrate species in the Upper Slope environment class (data from NIWA *Specify* database).

	Upper Slope	
Scientific name	**Higher classification**	**No. records**
Munida gracilis	Squat lobster	195
Goniocidaris parasol	Pencil urchin	105
Phylladiorhynchus sp.	Squat lobster	63
Campylonotus rathbunae	Shrimp	60
Trichopeltarion fantasticum	Crab	58
Psilaster acuminatus	Starfish	57
Anomura	False crabs	56
Decapoda	Decapods	56
Brucerolis hurleyi	Isopod	55
Pseudarchaster garricki	Starfish	49
Alcyonacea unidentified	Gorgonians and soft corals	45
Serolidae	Isopods (family)	44
Notopandalus magnoculus	Shrimp	38
Phoxocephalidae	Amphipods (family)	38
Brachyura	Crabs	37
Leptomithrax garricki	Decorator crab	37
Teratomaia richardsoni	Spider crab	34
Gastroptychus novaezelandiae	Squat lobster	32
Proserpinaster neozelanicus	Starfish	32
Thouarella sp.	Bottlebrush coral	31
	Total records	**3126**

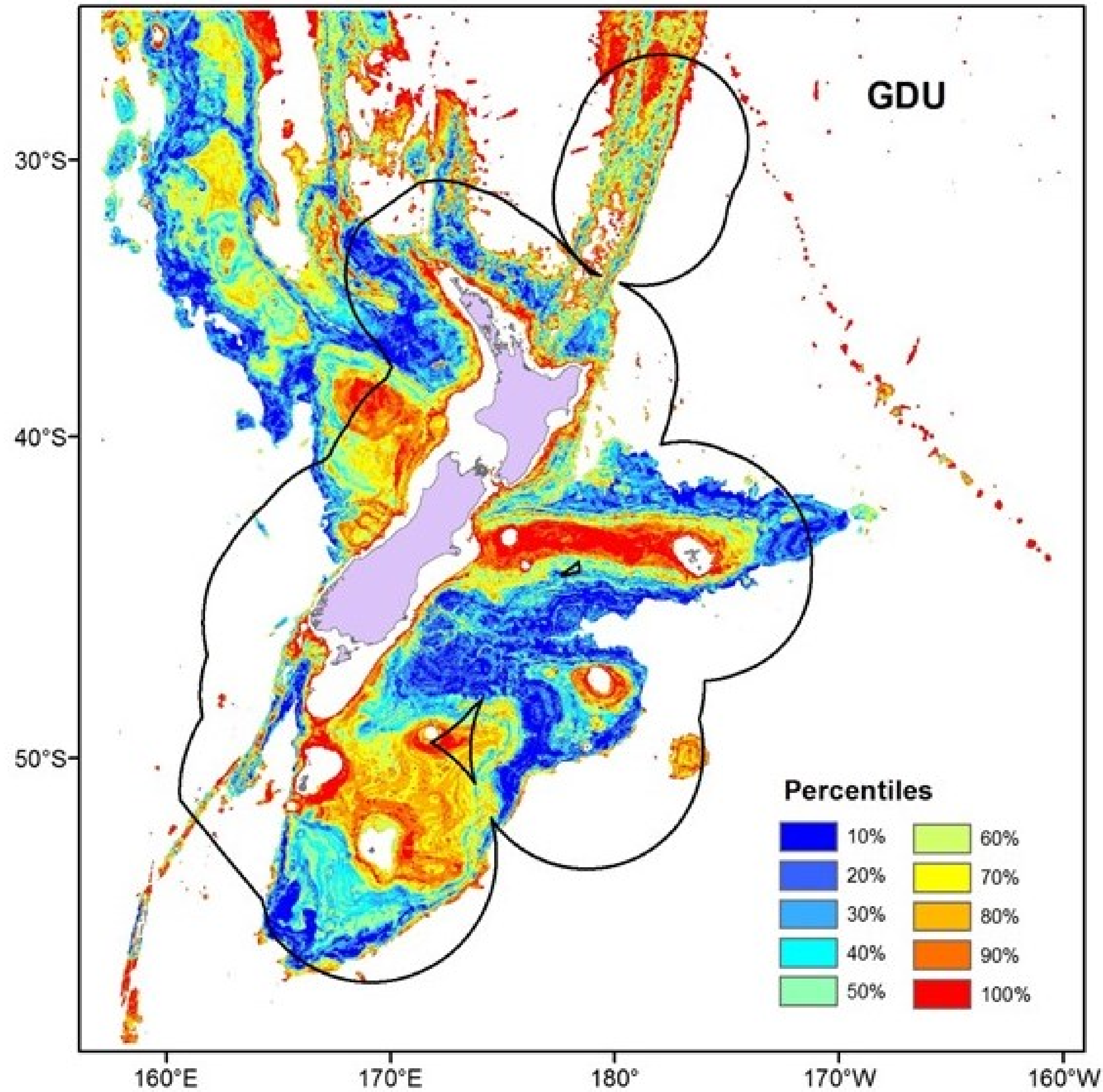


Figure 3-4: Predicted distribution of *Goniocorella dumosa*, a habitat-forming deep-sea coral and sensitive environment indicator taxon. Colours reflect probability deciles (habitat suitability values divided into equal-sized categories), where dark blue represents areas of low probability of presence and red indicates high probability. The highest predicted probabilities of suitable habitat for this species (red areas) are in the Upper Slope class, particularly on the Chatham Rise. From Anderson et al (2016).

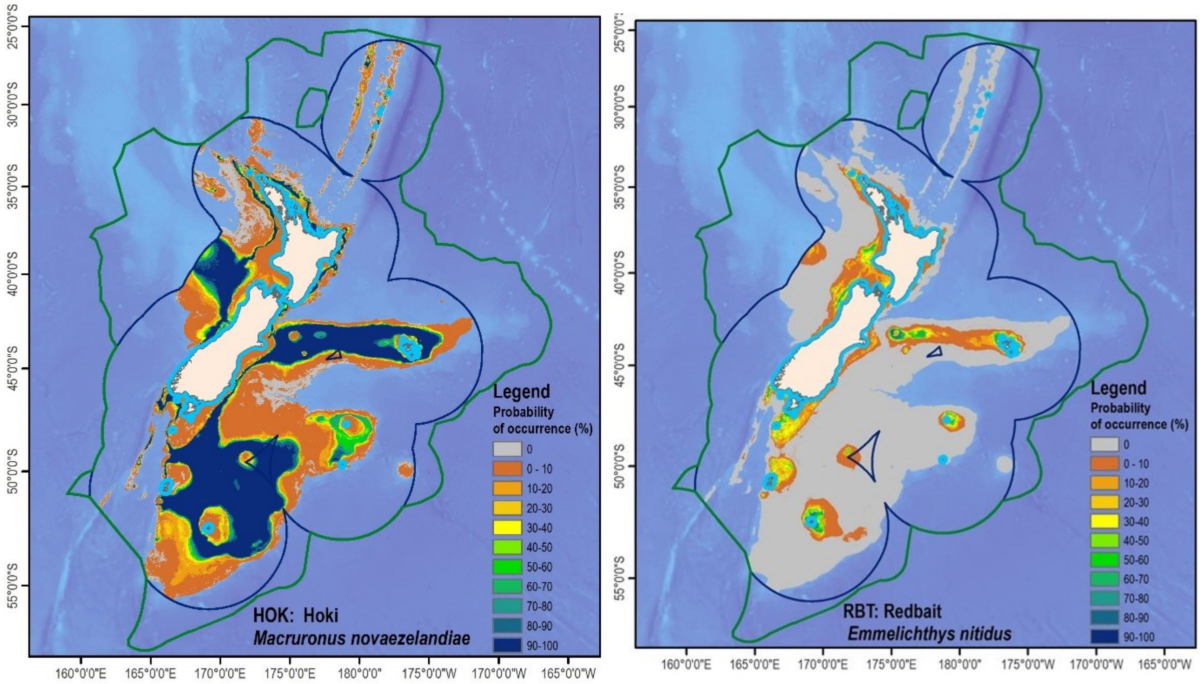


Figure 3-5: Modelled distributions of hoki and redbait. While hoki is a widespread and common species, there is a higher probability that it will occur in the Upper Slope class, particularly on the Chatham Rise, Campbell and Challenger plateaux. Redbait has a more restricted distribution, but its predicted distribution includes the Upper Slope class. Modelled distributions are limited to waters shallower than 1600m. Unpublished NIWA data.

Table 3-5: Marine mammal species in the Upper Slope environment class in order of decreasing numbers of individuals sighted.

	Upper Slope	
Scientific name	**Common Name**	**Individuals**
Delphinus delphis	Common dolphin	3948
Lagenorhynchus obscurus	Dusky dolphin	2994
Globicephala sp.	Pilot whale	475
Tursiops truncatus	Bottlenose dolphin	200
Orcinus orca	Killer whale	141
Eubalaena australis	Southern right whale	100
Balaenoptera physalus	Fin whale	55
Physeter macrocephalus	Sperm whale	39
Megaptera novaeangliae	Humpback whale	32
Globicephala macrohynchus	Short finned pilot whale	30
Balaenoptera musculus sp.	Blue whale	25
Balaenoptera borealis	Sei whale	6
Balaenoptera edeni/brydei sp.	Bryde's whale	4
Balaenoptera bonaerensis	Minke whale	4
Cephalorhynchus hectori	Hector's dolphin	3
Ziphius cavirostris	Cuvier's beaked whale	2
Arctocephalus forsteri	New Zealand fur seal	2
	Total Individuals	**8060**

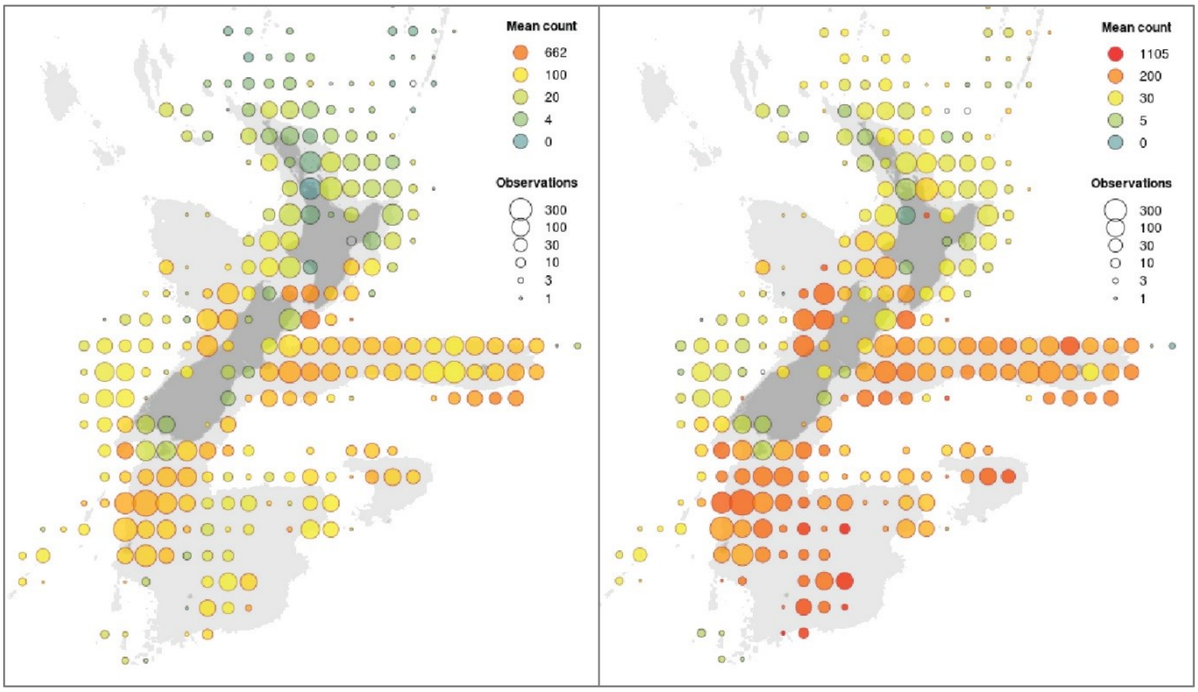


Figure 3-6: Mean number of albatross (left panel) and petrels (right panel) recorded around fishing vessels during counts carried out by government observers. High counts for both species essentially occur along the crest of Chatham Rise and around the Snares-Auckland islands which correspond to the Shelf and Upper Slope classes. See caption in Figure 2-6 for further details. Images from https://seabird-counts.dragonfly.co.nz/explore/counts/xsb/all-seabirds.html

3.3 Northern Mid-depths

The Northern Mid-depths environment class includes a narrow strip of slope running along the east coast of New Zealand from North Cape to the Auckland Islands, including the deeper slopes of the Chatham Rise to about 1000 m. North of the Chatham Rise surface waters in this class are typically sub-tropical, and relatively warm. South of the Chatham Rise surface waters are subantarctic and relatively cooler. Seabed substrates include sandy mud, carbonate ooze and authigenic sediment (Orpin et al. 2008).

Benthic fish are common in this class, as are octocorals and stony corals. The *Specify* database contains a total of 6454 collection records for 1566 taxa (Table 3-6). The most abundant invertebrate taxa, the cnidarians (topped by the bottle brush coral *Thouarella* sp., anemones, unidentified gorgonians and soft corals and cup corals), are mostly inhabitants of rocky substrates. Other taxa include the echinoderms (urchins and starfish), crustaceans (squat lobsters, hermit crabs and true crabs) and molluscs (represented by two very common whelks). The soft sediments found within this environment class are also inhabited by the quill worm *Hyalinoecia longibranchiata* and sipunculids (peanut worms).

Table 3-6: The 20 most frequently occurring benthic invertebrate species in the Northern Mid-depth environment class (data from NIWA *Specify* database).

	Northern Mid-depth	
Scientific name	**Higher classification**	**No. records**
Thouarella sp.	Bottlebrush coral	87
Goniocidaris parasol	Pencil urchin	68
Gracilechinus multidentatus	Urchin	68
Munida isos	Squat lobster	64
Sympagurus dimorphus	Hermit crab	63
Actiniaria	Anemones	54
Alcyonacea unidentified	Gorgonians and soft corals	54
Campylonotus rathbunae	Shrimp	52
Decapoda	Decapods	52
Munida gracilis	Squat lobster	51
Serolidae	Isopods (family)	51
Psilaster acuminatus	Starfish	48
Goreopagurus poorei	Hermit crab	47
Fusitriton laudandus	Gastropod	45
Trichopeltarion janetae	Crab	43
Nassarius ephamillus	Gastropod	41
Caryophyllia	Cup corals	40
Bryozoa	Lace corals	38
Hyalinoecia longibranchiata	Quill worm	38
Sipunculidea	Sipunculids	38
	Total records	**6454**

The Chatham Rise and the region of the Solander Trough west of Stewart Island are areas of exceptionally high fish diversity and abundance. The fish in this class include numerous commercial and non-commercial species, some of the more common ones include big-scaled and small-scaled brown slickheads (*Alepocephalus antipodianus* and *A. australis*), black oreo (*Allocyttus niger*), hoki (*Macruronus novaezelandiae*), catsharks (*Apristurus* spp.), banded bellowsfish (*Centriscopus humerosus*) (Figure 3-7), longnose velvet dogfish (*Centroscymnus crepidater*), the four rayed rattail (*Coryphaenoides subserrulatus*), shovelnose dogfish (*Deania calcea*), basketwork eels (*Diastobranchus capensis*) (Figure 3-12), Baxter's dogfish (*Etmopterus baxteri*), Johnson's cod (*Halargyreus johnsonii*), orange roughy (*Hoplostethus atlanticus*) (Figure 3-7), pale ghost shark (*Hydrolagus bemisi*), and numerous other species of rattails and deepwater sharks (Mackay 1993; Fisher and Bagley 2015; MPI 2016).

Nineteen species of marine mammals have been sighted in the waters of Northern Mid-depths environment class, with common and dusky dolphins and pilot whales accounting for 87% of the 7,260 individuals sighted (Table 3-7). Neither of these species is threatened, but several of the less commonly observed species have a higher threat status (Table 3-2). Three beaked whales have been sighted in these waters.

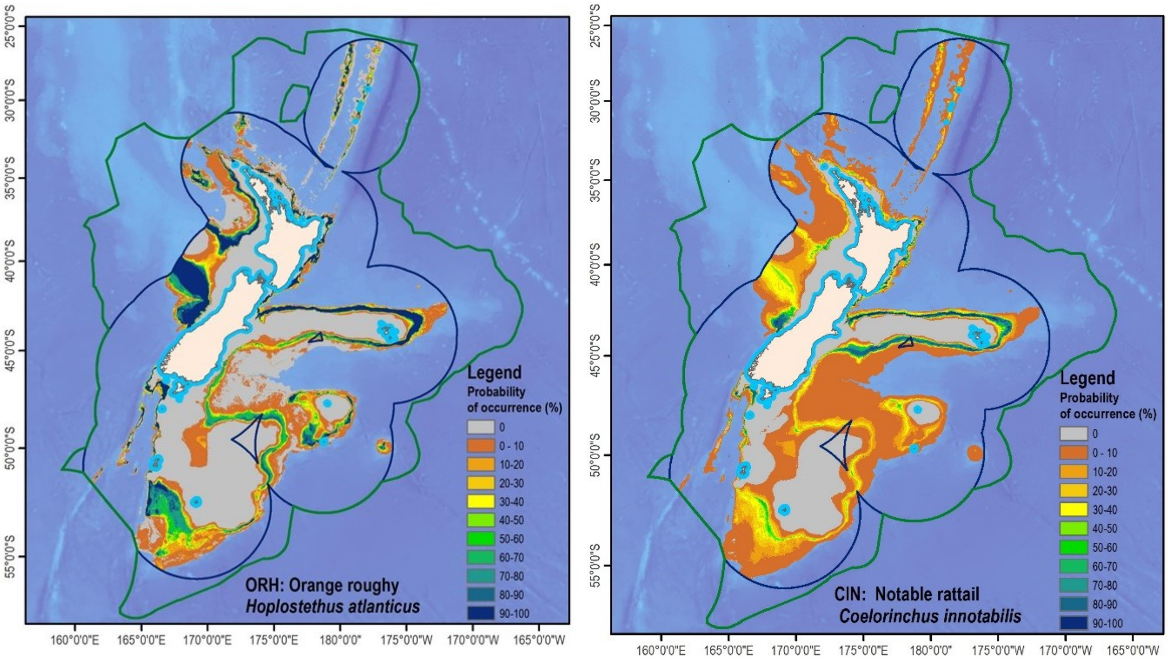


Figure 3-7: Modelled distributions of orange roughy and notable rattail. For both species the highest predicted probabilities of occurrence occur mainly in the Northern Mid-depths. Modelled distributions are limited to waters shallower than 1600m.

Table 3-7: Marine mammal species in the Northern Mid-depths environment class in order of decreasing numbers of individuals sighted.

Northern Mid-depths		
Scientific name	**Common Name**	**Individuals**
Delphinus delphis	Common dolphin	3251
Lagenorhynchus obscurus	Dusky dolphin	2070
Globicephala sp.	Pilot whale	961
Physeter macrocephalus	Sperm whale	272
Arctocephalus forsteri	New Zealand fur seal	253
Orcinus orca	Killer whale	139
Tursiops truncatus	Bottlenose dolphin	138
Pseudorca crassidens	False killer whale	50
Megaptera novaeangliae	Humpback whale	31
Cephalorhynchus hectori hectori	Hector's dolphin	25
Eubalaena australis	Southern right whale	20
Balaenoptera borealis	Sei whale	19
Globicephala melas	Long finned pilot whale	16
Balaenoptera bonaerensis	Minke whale	6
Balaenoptera musculus sp.	Blue whale	3
Balaenoptera physalus	Fin whale	2
Mesoplodon grayi	Gray's beaked whale	2
Balaenoptera edeni/brydei sp.	Bryde's whale	1
Ziphius cavirostris	Cuvier's beaked whale	1
	Total Individuals	**7260**

The Northern Mid-depths environment class includes areas likely to be frequented by a similar suite of seabird species occurring in the Upper Slope environment class. Species will be primarily pelagic, able to cover large distances when foraging during the breeding season, and more coastal species that disperse widely following breeding. Tracking data have revealed that white-capped albatross, which breeds primarily at the Auckland Islands, can forage over the Chatham Rise, through Cook Strait and even in Australian waters (Figure 3-8).

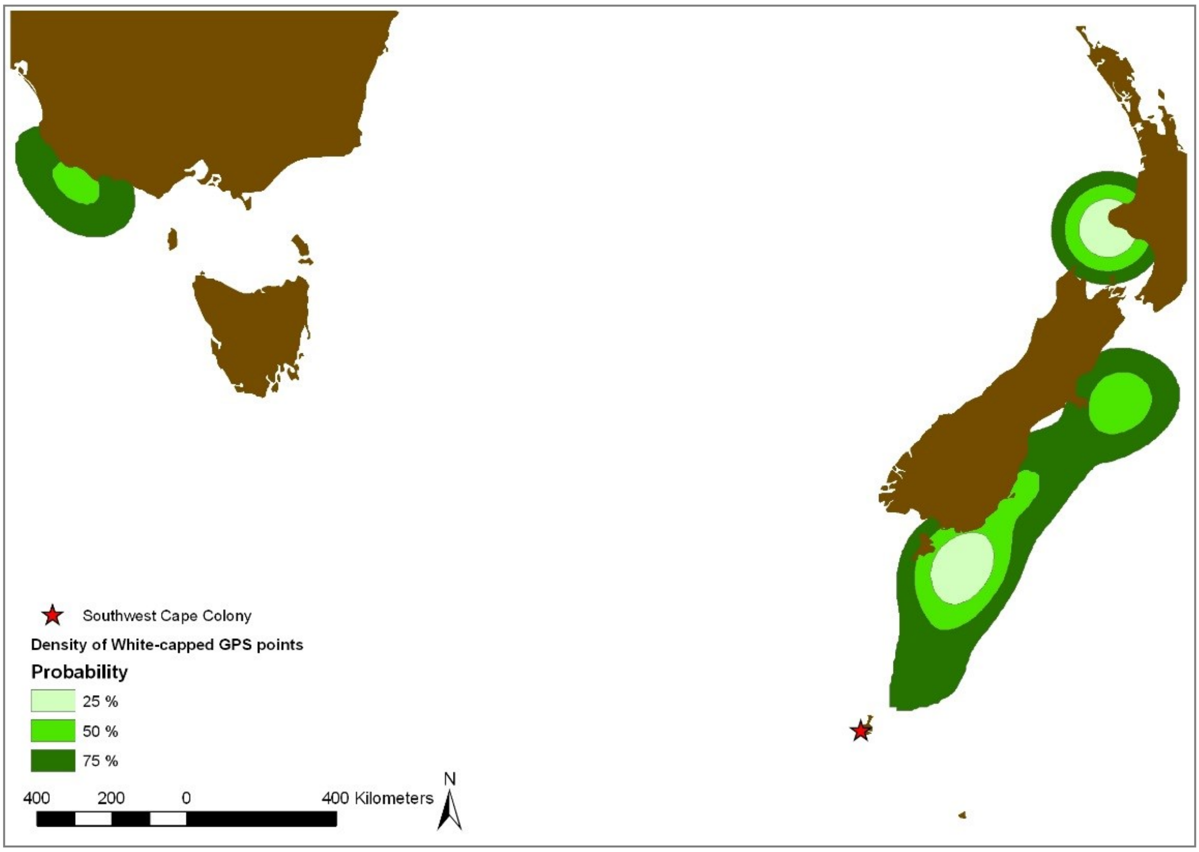


Figure 3-8: Density distribution of satellite tagged white-caped albatross indicating the extent of foraging areas from nesting islands. The highest probability of occurrence overlap the shelf and Northern Mid-slope classes.

Sensitive environments are expected to occur in this class, especially around the Chatham Rise and Bounty Plateau, including those based around the habitat-forming stony corals *Solenosmilia variabilis* (Figure 3-9) and *Madrepora oculata* (Figure 3-11), as well as sponges (Anderson et al. 2016).

The pelagic community is this environmental class is moderately to highly productive both in terms of primary production and zooplankton biomass (Bradford and Roberts 1978, Bradford 1980).

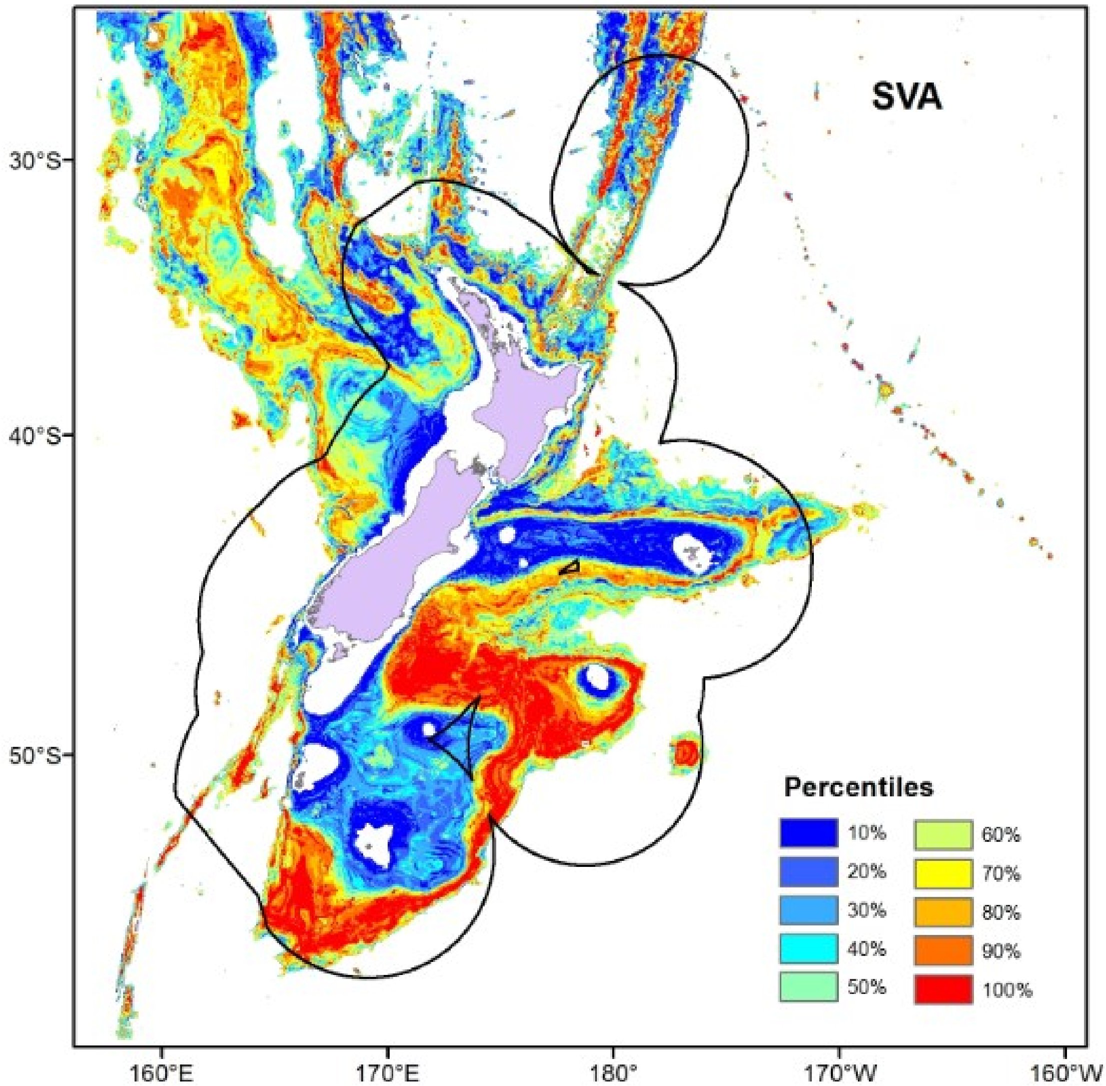


Figure 3-9: Predicted distribution of *Solenosmilia variabilis*, a habitat-forming deep-sea coral and sensitive environment indicator taxon. Colours reflect probability deciles (habitat suitability values divided into equal-sized categories), where dark blue represents areas of low probability of presence and red indicates high probability. Habitat suitability for this species is predicted to be high along the Kermadec Ridge and on the periphery of Campbell Plateau, which correspond to the Seamounts and southern Mid-depths classes, respectively. From Anderson et al. (2016b).

3.4 Southern Mid-depths

The Southern Mid-depth benthic environment class covers a large area, including the bulk of the Campbell Plateau and Bounty Rise. Here south of the Chatham Rise, water masses are more temperate, with lower temperatures, salinity, and productivity. Seabed substrates include sandy mud, carbonate ooze and authigenic sediment (Orpin et al. 2008).

The *Specify* database includes 972 records for 300 taxa for this class, which are entirely dominated by echinoderms (10 different urchins and starfish) and crustaceans (10 different, crabs, shrimp, squat lobster and an isopod) (Table 3-8). These taxa are mostly indicative of soft sediment habitats.

Table 3-8: The 20 most frequently occurring benthic invertebrate species in the Southern Mid-depth environment class (data from NIWA *Specify* database).

Southern Mid-Depth		
Scientific name	**Higher classification**	**No. records**
Goniocidaris parasol	Pencil urchin	60
Ceramaster patagonicus	Starfish	45
Teratomaia richardsoni	Spider crab	34
Pseudarchaster garricki	Starfish	32
Decapoda	Decapods	29
Campylonotus rathbunae	Shrimp	27
Brachyura	Crabs	26
Psilaster acuminatus	Starfish	25
Anomura	False crabs	23
Pillsburiaster aoteanus	Starfish	19
Brucerolis brandtae	Isopod	17
Munida gregaria	Squat lobster	17
Serolidae	Isopods (family)	17
Pteropeltarion novaezelandiae	Crab	14
Hippasteria phrygiana	Starfish	13
Lithosoma novaezealandiae	Starfish	13
Mediaster arcuatus	Starfish	12
Brucerolis osheai	Isopod	11
Dermechinus horridus	Urchin	10
Dipsacaster magnificus	Starfish	10
	Total records	**972**

The Campbell and Bounty Plateaus which make up most of this zone are areas of low to moderate fish species diversity (Leathwick et al. 2006a), but are home to a number of important commercial fisheries and non-commercial species. The main commercial fish species are southern blue whiting (*Micromesistius australis*) (Figure 3-10), hake (*Merluccius australis*), hoki (*Macruronus novaezelandiae*) (Figure 3-5), ling (*Genypterus blacodes*) (Figure 3-10), arrow squid (*Nototodarus sloanii*), ribaldo (M*ora moro*), and silverside (*Argentina elongata*) (NIWA unpublished data). The most abundant non-commercial fishes (MPI 2016) in the zone include Oliver's rattails (*Caelorinchus oliverianus*), Cook's rattail (*C. cookianus*), oblique banded rattail (*C. aspercephalus*), hairy and swollenhead congers (*Bassanago hirsutus* and *B. bulbiceps*), longnose spookfish (*Harriotta raleighana*), pale ghost shark (*Hydrolagus bemisi*), javelinfish (*Lepidorhynchus denticulatus*), and the warty squids (*Onykia robsoni* and *O. ingens*).

Eighteen species of marine mammals have been sighted in the waters of the Southern mid-depth environment class with dusky dolphins comprising 44% of the 2082 individuals sighted, with pilot whales, New Zealand fur seals, common dolphins and sperm whales comprising another 45% (Table 3-3). None of these species is threatened, but several of the less commonly observed species have a higher threat status (Table 3-2). One beaked whale has been sighted in these waters.

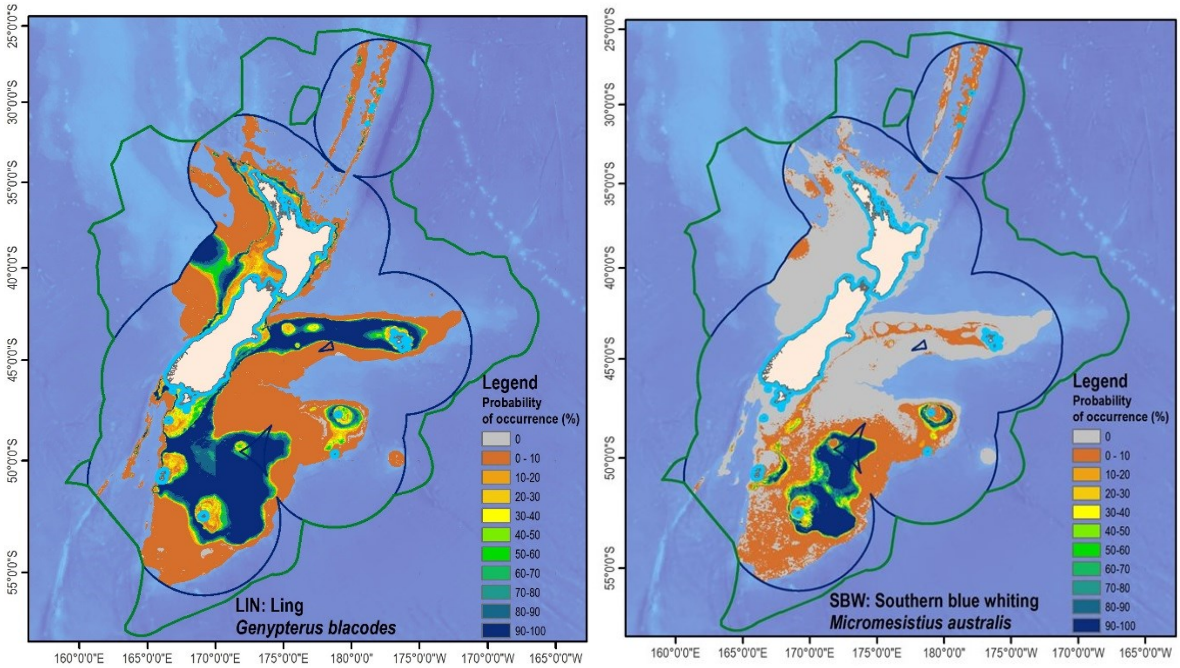


Figure 3-10: Modelled distributions of ling and southern blue whiting. Ling is a widespread and common species throughout the region, including areas within the Southern Mid-depth class. Southern blue whiting has a more restricted distribution, and is predicted to occur more often in the Southern Mid-depth class on the Campbell Plateau. Modelled distributions are limited to waters shallower than 1600m. Unpublished NIWA data.

Table 3-9: Marine mammal species in the Southern Mid-depths environment class in order of decreasing numbers of individuals sighted.

	Southern Mid-depth	
Scientific name	**Common Name**	**Individuals**
Lagenorhynchus obscurus	Dusky dolphin	908
Globicephala sp.	Pilot whale	437
Arctocephalus forsteri	New Zealand fur seal	283
Delphinus delphis	Common dolphin	110
Physeter macrocephalus	Sperm whale	109
Orcinus orca	Killer whale	93
Cephalorhynchus hectori	Hector's dolphin	50
Globicephala melas	Long finned pilot whale	29
Pseudorca crassidens	False killer whale	24
Eubalaena australis	Southern right whale	12
Balaenoptera physalus	Fin whale	8
Balaenoptera bonaerensis	Minke whale	6
Megaptera novaeangliae	Humpback whale	5
Lissodelphis peronii	Southern right whale dolphin	4
Mesoplodon bowdoini	Andrews' beaked whale	1
Balaenoptera musculus sp.	Blue whale	1
Hydrurga leptonyx	Leopard seal	1
Balaenoptera borealis	Sei whale	1
	Total Individuals	**2082**

The Southern Mid-depths environment class includes areas likely to be frequented by a similar suite of seabird species occurring in the Upper Slope and Northern Mid-depths environment classes. Species will be primarily pelagic, able to cover large distances when foraging during the breeding season, and more coastal species that disperse widely following breeding. This latter group will include species such as rockhopper penguin (*Eudyptes filholi*), which disperses far to the east of Campbell Island during the winter non-breeding period (NIWA unpublished data).

The deeper parts of this class contain sensitive environments including Stony coral thickets and reefs based on habitat suitability models for *Madrepora oculata* (Figure 3-11), *Solenosmilia variabilis* (Figure 3-9), and *Enallopsammia rostrata* and sponges.

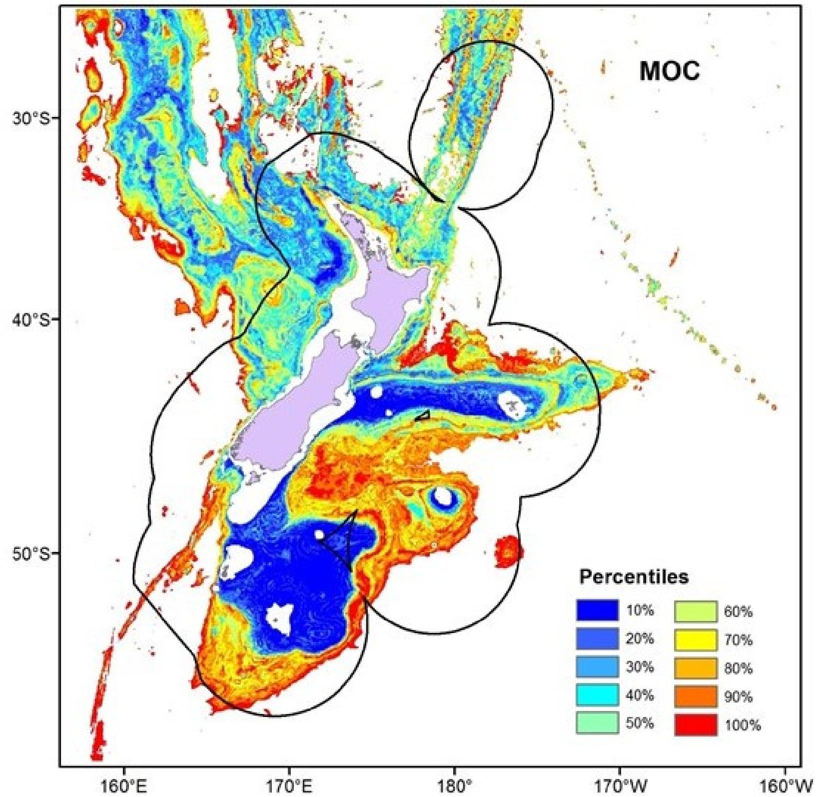


Figure 3-11: Predicted distribution of *Madrepora oculata*, a habitat-forming deep-sea coral and sensitive environment indicator taxon. Colours reflect probability deciles (habitat suitability values divided into equal-sized categories), where dark blue represents areas of low probability of presence and red indicates high probability. Highest predicted probability of habitat suitability (red areas) for this species occur mainly in the Southern Mid-depth class, particularly south of the Chatham Rise and around the Campbell Plateau. From Anderson et al. (2016b).

The pelagic community is this environmental class is low to moderately productive both in terms of primary production and zooplankton biomass, with an area of low productivity towards the center of the Campbell Plateau (Bradford and Roberts 1978, Bradford 1980).

3.5 Deep and Very Deep Waters

The Deep and Very Deep Waters environment class includes a vast area mostly well offshore of mainland New Zealand which is largely unfished and poorly sampled, thus less is known about the distribution of seafloor and fish species. This class includes most of the areas at depths greater than 1000 m, where there are low tidal currents, low temperature gradients, and fine sediments, as well as some areas of hard substrata. Seabed substrates include authigenic sediments and deep-ocean clays, land-derived sand may be present in deep channels (Orpin et al. 2008).

The *Specify* database contains a total of 4834 records and 1626 taxa for this environment class. The most abundant recorded species is the urchin *Gracilechinus multidentatus* with three other echinoderms (two starfish, an urchin and a brittle star, *Ophiomusium lymani*) on the list of the 20 most common taxa. While five crustaceans are included in the records (a range of crabs, squat lobster, isopods and the vent shrimp *Alvinocaris longirostris*), the cnidarians appear to be most abundant with a range of anemones, bamboo corals, hydroids, soft corals and gorgonians, including the precious coral *Corallium* sp. Most of these taxa are indicative of rocky substrates. Unidentified sipunculan peanut worms are also recorded from this class, albeit in smaller numbers compared to the Northern Mid-depth class. A sponge, *Neoaulaxinia persicum,* is also included in the list of the most abundant recorded taxa.

Table 3-10: The 20 most frequently occurring benthic invertebrate species in the Deep and Very Deep Waters environmental class (data from NIWA *Specify* database).

Deeper Water		
Scientific name	**Higher classification**	**No. records**
Gracilechinus multidentatus	Urchin	78
Decapoda	Decapods	47
Ophiactis abyssicola	Anemone	40
Keratoisis sp.	Bamboo coral	39
Ophiomusium lymani	Brittle star	36
Psilaster acuminatus	Starfish	29
Actiniaria	Anemones	26
Munida endeavourae	Squat lobster	26
Serolidae	Isopods (family)	26
Thouarella sp.	Bottle brush coral	25
Acanthogorgia sp.	Gorgonian coral	23
Porcellanaster ceruleus	Starfish	23
Dermechinus horridus	Urchin	22
Alcyonacea unidentified	Gorgonians and soft corals	22
Hydrozoa	Hydroid	22
Brucerolis brandtae	Isopod	21
Neoaulaxinia persicum	Sponge	21
Alvinocaris longirostris	Vent shrimp	18
Corallium sp.	Precious coral	18
Sipunculidea	Sipunculids	18
	Total records	**4834**

The diversity of demersal fish species is predicted to be relatively low in this environment class (Leathwick et al. 2006b; Leathwick et al. 2006c). The more common species in these deeper waters include slickheads (*Alepocephalus antipodianus* and *A. australis*, *Rouleina* sp., *Talismania longifilis*), fangtooth (*Anoplogaster cornuta*), basketwork eels (*Diastobranchus capensis*), violet cod (*Antimora* *rostrata*) (Figure 3-12), the rattails *Coryphaenoides mcmillani* and *C. murrayi*, and bigscale fishes (Melamphaidae).

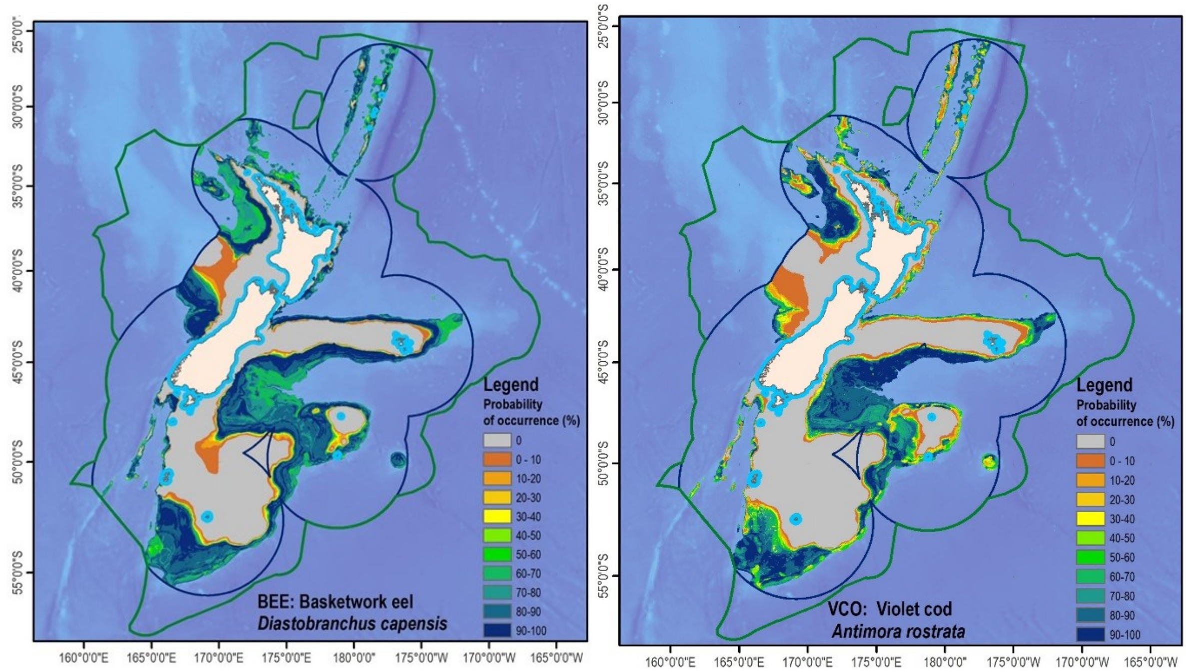


Figure 3-12: Predicted distributions of basketwork eel and violet cod. The probability of occurrence is predicted to be highest for both species is this class throughout the region, to the limits of the modelled area at 1600m. Unpublished NIWA data.

Twenty-eight species of marine mammals have been sighted in the waters of the Deep and Very Deep Waters environment class, with common dolphins comprising 45% of the 10,251 individuals sighted, pilot whales comprising 22%, and New Zealand fur seals, bottlenose dolphins, and sperm whales comprising another 22% (Table 3-11). Apart from bottlenose dolphins which is nationally endangered, none of these more common species is threatened. Several of the less commonly observed species have a higher threat status (Table 3-2). Thirty-two individuals of six species of beaked whale have been sighted in these waters.

The Deep and Very Deep Waters environment class is frequented by pelagic seabirds, and coastal species are unlikely to exploit this zone to any extent. Across this environment class typical species include albatrosses, shearwaters and petrels. Some breeding sites are located very close to the Deep and Very Deep Waters environment class and in these situations it is possible that species that are generally more coastal could be encountered over deeper waters. For example, the Kermadec archipelago lies within a relatively large expanse of Deep and Very Deep Waters and terns and noddies that breed at this location could venture beyond coastal environments without travelling large distances.

The distribution of sensitive benthic environments is poorly known for this environment class, but may include hydrothermal vents (as indicated by the records for the vent shrimp *Alvinocaris longirostris* in Table 3-10), sea pen fields, sponge gardens, and xenophyophore beds (MacDiarmid et al. 2013).

The pelagic community is this environmental class varies in productivity depending on the region. North-east of the North Island subtropical surface water is relatively warm (14oC in winter and 20oC in summer) and saline (around 35.4‰) and becomes macro-nutrient depleted in late spring and summer (Nodder et al. 2016) and productivity is low both in terms of primary production and zooplankton biomass (Bradford and Roberts 1978, Bradford 1980). An area of higher productivity occurs in the Wairarapa Eddy off the east coast of the North Island, north of the Chatham Rise. In sub-Antarctic waters south of the Chatham Rise surface waters are iron-limited and high in nutrients, but low in chlorophyll with highly variable fluxes of organic material to the sea floor which are lower than the global average for mesotrophic to oligotrophic waters (Nodder et al. 2016). Zooplankton biomass in this area can be moderate to high ((Bradford and Roberts 1978, Bradford 1980).

Table 3-11: Marine mammal species in the Deep and Very Deep Waters environment class in order of decreasing numbers of individuals sighted.

Deep and Very Deep water		
Scientific name	**Common Name**	**Individuals**
Delphinus delphis	Common dolphin	4599
Globicephala sp.	Pilot whale	1614
Arctocephalus forsteri	New Zealand fur seal	899
Tursiops truncatus	Bottlenose dolphin	799
Globicephala melas	Long finned pilot whale	660
Physeter macrocephalus	Sperm whale	570
Orcinus orca	Killer whale	443
Lagenorhynchus obscurus	Dusky dolphin	235
Megaptera novaeangliae	Humpback whale	102
Eubalaena australis	Southern right whale	94
Lissodelphis peronii	Southern right whale dolphin	80
Cephalorhynchus hectori	Hector's dolphin	30
Pseudorca crassidens	False killer whale	21
Mesoplodon grayi	Gray's beaked whale	20
Balaenoptera bonaerensis	Minke whale	19
Balaenoptera physalus	Fin whale	13
Balaenoptera musculus sp.	Blue whale	10
Balaenoptera borealis	Sei whale	10
Kogia breviceps	Pygmy sperm whale	9
Lagenorhynchus cruciger	Hourglass dolphin	8
Ziphius cavirostris	Cuvier's beaked whale	5
Mesoplodon densirostris	Dense-beaked whale	4
Balaenoptera edeni/brydei sp.	Bryde's whale	3
Hydrurga leptonyx	Leopard seal	1
Hyperoodon planifrons	Southern bottlenose whale	1
Mirounga leonine	Southern elephant seal	1
Mesoplodon layardii	Strap-toothed beaked whale	1
	Total Individuals	**10251**

3.6 Seamounts

There are over 1000 seamounts in the New Zealand region (Rowden et al. 2008) (Figure 2-2). Seamounts in the region are not all the same; they differ in form, size, depth, and location within the water column (Rowden et al. 2005). The area of individual seamounts ranges from <0.5 km^2 to 34,700 km^2, with Bollons Seamount being the largest seamount in New Zealand's EEZ and ECS. However, few seamounts have areas >1000 km^2, with the majority being small in area (<20 km^2).The distribution of seamounts within the New Zealand region is uneven, with more seamounts in northern latitudes (<42°S). The depth at the base of seamounts ranges from 300 m to over 7000m, but most seamounts rise from depths of 1000 m to 1300 m. Seamount elevation ranges from c. 100 m to over 5000 m, with almost 70% with elevation <1000 m. High concentrations of seamount are notable in the Bay of Plenty, the Kermadec Ridge and the eastern Chatham Rise. Seamounts can be subject to high current flows and other oceanographic features such as Taylor columns.

Species records in the *Specify* database are from about 750 seamount features in the EEZ-ECS, including those on ridges. A total of 4819 invertebrate samples and 1453 taxa have been collected from these seamounts (Table 3-12). Multiple identified and unidentified bryozoan species, recorded as Bryozoa, had the highest number of records followed numerically by cnidarians (gorgonians, anemones, hydroids, hard coral, hydrocorals and soft corals, which make up 11 of the 20 most abundant taxa. These taxa, together with the two sponge species, are indicative of the mostly rocky substrates of found in the Seamounts environment class. While crustaceans are included in the top 10 most abundant taxa, they are only represented by 4 taxa (a squat lobster, two hermit crabs and a crab). The widespread whelk *Nassarius ephamillus*, already mentioned for the Northern Mid-Depth class is also included in this list.

Table 3-12: The 20 most frequently occurring benthic invertebrate species in the Seamounts environment class (data from NIWA *Specify* database).

	Seamounts	
Scientific name	**Higher classification**	**No. records**
Bryozoa	Lace corals	61
Thouarella sp.	Bottle brush coral	57
Gracilechinus multidentatus	Urchin	55
Munida isos	Squat lobster	51
Ophiactis abyssicola	Anemone	43
Goreopagurus poorei	Hermit crab	40
Hydrozoa	Hydroid	37
Neoaulaxinia persicum	Demosponge	35
Sympagurus dimorphus	Hermit crab	35
Trichopeltarion janetae	Crab	35
Solenosmilia variabilis	Hard coral	31
Alcyonacea unidentified	Gorgonians and soft corals	29
Caryophyllia sp.	Cup corals	28
Nassarius ephamillus	Gastropod	28
Stylasteridae	Hydrocoral	28
Acanthogorgia sp.	Gorgonian coral	25
Acryptolaria sp.	Hydroid	23
Desmophyllum dianthus	Cup coral	23
Stelletta sp.	Demosponge	23
Anthomastus sp.	Soft coral	22
	Total records	**4819**

Common fish species that have been recorded on seamounts off New Zealand include alfonsino (*Beryx splendens*) (Figure 3-13), black cardinalfish (*Epigonus telescopus*), orange roughy (*Hoplostethus atlanticus*) (Figure 3-7), bluenose (*Hyperoglyphe* antarctica), rubyfish (*Plagiogenion rubiginosus*), and oreos (smooth oreo *Pseudocyttus maculatus*, black oreo *Allocyttus niger*) (Clark & O'Driscoll 2003), Clark et al. 2010).

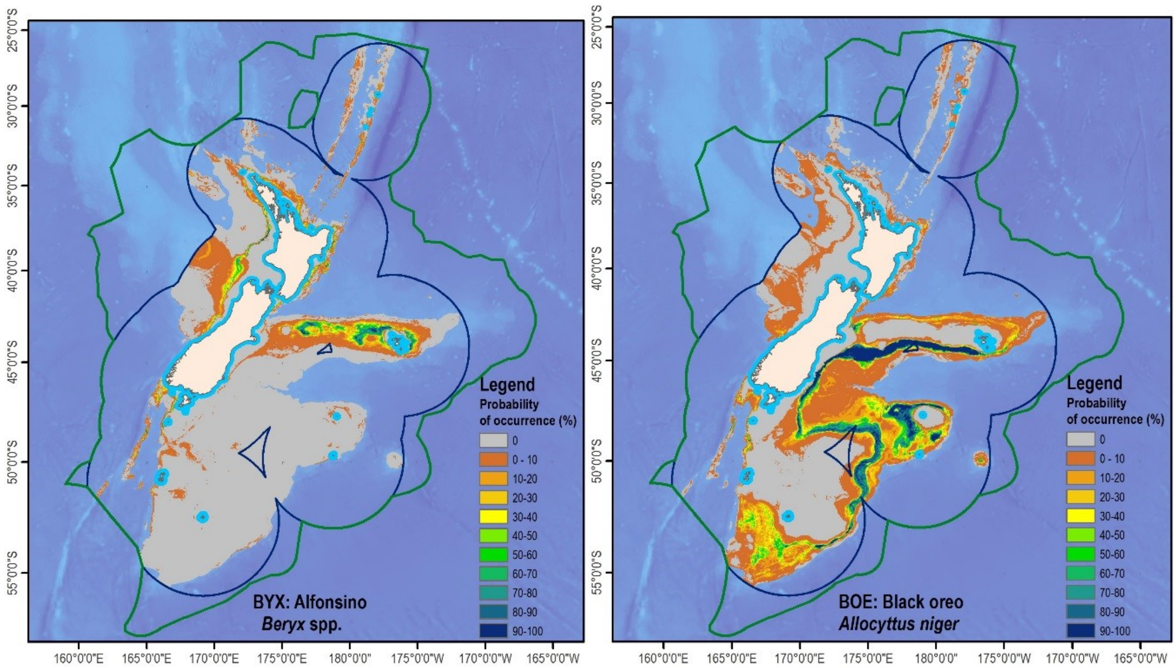


Figure 3-13: Predicted distributions of Alfonsino and black oreo. Both species occur at seamounts, with Alfonsino occurring in schools near the summit of shallow seamounts and black oreo occurring around the deeper flanks. Predicted distributions of occurrence support these depth-stratified distributional observations. Modelled distributions are limited to waters shallower than 1600m. Unpublished NIWA data.

Just seven species of marine mammals have been sighted over seamounts but the observational effort in these areas is likely to be low (Table 3-13). Common dolphins comprised 36% of the 447 individuals sighted, pilot whales comprised 22%, and sperm whales, bottlenose dolphins and killer whales accounted for another 41% (Table 3-13). While common dolphins, pilot whales, and sperm whales are not threatened, bottlenose dolphins are nationally endangered and killer whales are nationally critical. No species of beaked whale have been sighted over seamounts.

Table 3-13: Marine mammal species in the Seamount environmental class in order of decreasing numbers of individuals sighted.

Seamounts		
Scientific name	**Common Name**	**Individuals**
Delphinus delphis	Common dolphin	160
Globicephala sp.	Pilot whale	97
Physeter macrocephalus	Sperm whale	65
Tursiops truncatus	Bottlenose dolphin	60
Orcinus orca	Killer whale	59
Balaenoptera bonaerensis	Minke whale	4
Arctocephalus forsteri	New Zealand fur seal	2
Grand Total		**447**

Globally, a wide range of seabirds have been recorded exploiting resources over seamounts (Thompson 2007), but knowledge of the extent to which seabirds in New Zealand utilise seamounts is scant, reflecting the lack of detailed and systematic at-sea seabird surveys within the EEZ and ECS. The increased use of bird-borne electronic tracking devices should increase our understanding of seamount-use by seabirds. For example, Walker & Elliott (2006), in a tracking study of Antipodean (*Diomedea antipodensis antipodensis*) and Gibson's (*D. a. gibsoni*) albatrosses, presented data indicating seamounts, both within with the EEZ and further afield, were preferentially visited as foraging locations. Generally, the Seamounts environment class will be frequented by pelagic, rather than coastal, seabird species.

Habitat-forming stony corals are frequently recorded from seamount features, particularly *Solenosmilia variabilis* and *Madrepora oculata* which can occur in high densities and thereby represent sensitive environments (Clark and Rowden 2009; Tracey et al. 2011; Anderson et al. 2016). Sponges and bryozoans also occur in this class (see Table 3-12) but it is unknown whether they are sufficiently abundant to qualify as sensitive benthic environments.

The productivity of the pelagic community is this environmental class is highly variable and generally reflects the depth of the seamount crest and the productivity of the surrounding water masses (Clark et al. 2010).

4 Risk assessment

Below (Table 4-1) are detailed the Panel's assessments of the consequences of the potential threats arising from the rocket debris (using Table 2-2) for each component of the ecosystem being considered, the likelihood of the threat occurring (using Table 2-3), and the level of confidence in the supporting information used in reaching the individual decisions (using Table 2-4). Risk was then determined as the product of the individual consequence and likelihood scores (see Table 2-5).

The risk to components of the ecosystem from a single splashdown of 40 tonnes of debris at any point within any environmental class was assessed as low (Table 4-1). Although the threats from the splashdown in many case were very likely to occur, with likelihoods tending to decrease for the Seamounts class and decrease with depth, the consequences to the various ecosystem components at a population, community or habitat scale are negligible (with some exceptions), thus the overall risk is low. In a few cases the consequence rating increased to minor, but the risk level remained low (risk score 6 or less). Below the results for each of the threats are described in more detail.

Direct strike causing mortality

The panel assessed that although the impact of debris on the sea surface and on the seafloor was certain to cause the death of some individual members of the pelagic community and the benthic invertebrate community, the consequences for these widespread populations and communities would be negligible and undetectable (Table 4-1). For patchily distributed and mobile demersal fish and invertebrates and the air breathing fauna the likelihood of individuals killed by a direct strike was assessed as being remote and consequences at the population and community scale negligible. For sensitive benthic environments occurring in all but one environmental class (Deep and very deep waters) the consequences of a direct strike causing mortality was assessed as minor with local but measurable effects on the local population but with a concomitant slight decrease in likelihood due to these environments being patchily distributed within each class. In the vast Deep and Very Deep Water class the wide but patchy distribution of sensitive benthic environments means that direct strikes causing mortality would occasionally occur but that at the population and community scale consequences were negligible.

Underwater noise disturbance

Underwater noise disturbance caused by rocket debris impacting at high speed onto the ocean surface was assessed by the Panel as likely to, or occasionally, affect some demersal fish and mobile invertebrates in the two shallowest classes, and air breathing fauna in all environmental classes. These shallower fauna occur at or near the impact zone (mainly the sea surface) and many species of fish and all marine mammals and sea birds both produce and are responsive to underwater sound. However, for both groups the consequences were assessed as minor with measurable but localised short-term effects at a population or community scale because affected individuals could temporarily change their behaviour or move away (Table 4-1). For the other ecosystem components (benthic invertebrate community, sensitive benthic environment, and pelagic community) the panel assessed the consequences of underwater noise disturbance as negligible. This was either because they were deep, or individuals were not thought to be affected by noise. For all groups, apart from the air breathing fauna and pelagic community, the risk score decreased with increasing depth as the distance between the seafloor and the surface impact area increased.

Toxic contaminants

A detailed assessment of the toxicity of each of the components likely to occur in rocket debris is provided in Appendix A and Table A2. The only potential issue arises from copper components with their slow dissolution having long-term effects on sediment-dwelling species in the vicinity of the fragments. However given the small amounts of copper in the debris and large scale of the receiving environments, the toxic effects from the rocket debris were assessed as low risk in all environmental classes with remote likelihood of effects and negligible consequences.

Ingestion of debris

Ingestion of debris by all ecological components is possible (likelihood of 4) except for the air breathing fauna where the likelihood is rare or remote as splinters or particles small enough to be ingested by organisms are expected to sink rapidly. The consequences of ingestion were always classified as negligible, acknowledging that some ingestion will occur by larger pelagic or benthic predators or sessile filter feeders, but this will be negligible at the population level.

Smothering of seafloor organisms

The likelihood of smothering of organisms from falling debris is possible for benthic invertebrate community and sensitive benthic environment fauna, but rare with the more mobile demersal fish and mobile invertebrates. For the latter, the panel felt the descending speed of any large debris capable of smothering fauna would be slow enough to be avoided by mobile fauna. Smothering is not applicable the Air breathing fauna, and the Pelagic community. The size of both individual pieces of debris, and the overall debris field is small with regard to the size of any environmental class, including the seamounts, so that the consequence is negligible for all ecological components except Sensitive Benthic Environments. For this ecological component, the consequence could reach a minor level, as the recovery rate of biogenic taxa is likely to be slow. For deep and very deep waters the consequence for sensitive benthic environments was negligible because of their low abundance. The overall risk level for all ecological components is low with a maximum risk score of 3 for the Sensitive Benthic Environments.

Provision of biota attachment sites

While this is widely expected to occur (likelihood of 6) for the Benthic Invertebrate Community and Sensitive Benthic Environments, the consequences were assessed as negligible in every case. For a single launch, the number and size of pieces of debris landing on the seafloor would be relatively low compared to the distribution of natural hard substrate. Individuals may benefit, but it was felt unlikely to be significant at a population or community level.

Floating debris

This effect is only applicable to the pelagic community. Effects of ingestion by marine fauna were considered separately. Debris floating at the sea surface may provide shelter for pelagic organisms such as juvenile fish, and attachment and dispersion for organisms such as goose barnacles and marine algae. While this was widely expected to occur (likelihood of 6), the consequences at the population or community scale were assessed as negligible in every case.

Confidence rating

The confidence ratings in the Panel's assessment was mostly 2a (Consensus among experts, but with high confidence, even though data may be lacking) inasmuch that a consensus was reached rapidly with little discussion or disagreement within the Panel. This reflects the well acknowledged paucity of observations, samples and other geophysical data at the scale of the New Zealand's EEZ and ECS, but a general confidence in the data available and their representativeness of the various ecological components. A confidence rating of 1c (Agreement among experts, but with low confidence in the data) was given in some instances (e.g. Ingestion of debris for demersal fish) reflecting a poorly known issue compounding the absence of data for this potential effect.

A confidence level of 1b (some sparse data exist allowing tentative agreement amongst the experts) was given to all potential effects in the Deep and Very Deep Water class for the Benthic Invertebrate Community and Sensitive Benthic Environments. This reflects the very low density of observations, samples and other geophysical data available to support the assessments in this environment classes.

Table 4-1: Likelihood – consequence ecological risk assessment of the impact of debris from space launches in six classes of the environment. NA is not applicable. Note that according to the criteria in Table 2-5, risks of 6 or less are classified as low.

Risk Assessment: Debris from rocket launches		Benthic Invertebrate Community				Demersal fish and mobile invertebrates				Air breathing fauna				Sensitive Benthic Environments				Pelagic Community			
Environmental class	Potential effect	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence
Shelf (outside Territorial Sea)	Direct strike causing mortality	0	6	0	2b	0	1	0	2b	0	1	0	2b	1	5	5	2b	0	6	0	2a
	Underwater noise and disturbance	0	6	0	2a	1	6	6	2a	1	5	5	2a	0	5	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	4	0	2a	0	4	0	1c	0	2	0	2a	0	3	0	2a	0	2	0	2a
	Smothering of seafloor organisms	0	4	0	2b	0	1	0	2a	NA	NA	NA	NA	1	3	3	2b	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
Upper Slope	Direct strike causing mortality	0	6	0	2b	0	1	0	2b	0	1	0	2a	1	5	5	2b	0	6	0	2a
	Underwater noise and disturbance	0	6	0	2a	1	6	6	2a	1	5	5	2a	0	5	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	4	0	2a	0	4	0	1c	0	2	0	2a	0	3	0	2a	0	2	0	2a
	Smothering of seafloor organisms	0	4	0	2b	0	1	0	2a	NA	NA	NA	NA	1	3	3	2b	NA	NA	NA	NA
	Provision of biota attachment site	0	6	NA	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
Northern Mid-depths	Direct strike causing mortality	0	6	0	2a	0	1	0	2b	0	1	0	2a	1	5	5	2a	0	6	0	2a
	Underwater noise and disturbance	0	6	0	2a	0	6	0	2a	1	5	5	2a	0	5	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	4	0	2a	0	4	0	1c	0	1	0	2a	0	3	0	2a	0	2	0	2a
	Smothering of seafloor organisms	0	4	0	2a	0	1	0	2a	NA	NA	NA	NA	1	3	3	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a

Risk Assessment: Debris from rocket launches		Benthic Invertebrate Community				Demersal fish and mobile invertebrates				Air breathing fauna				Sensitive Benthic Environments				Pelagic Community			
Environmental class	**Potential effect**	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence	Consequence	Likelihood	Risk	Confidence
Southern Mid-depths	Direct strike causing mortality	0	6	0	2a	0	1	0	2b	0	1	0	2a	1	5	5	2a	0	6	0	2a
	Underwater noise and disturbance	0	5	0	2a	0	5	0	2a	1	5	5	2a	0	5	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	4	0	2a	0	4	0	1c	0	1	0	2a	0	3	0	2a	0	2	0	2a
	Smothering of seafloor organisms	0	4	0	2a	0	1	0	2a	NA	NA	NA	NA	1	3	3	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a	NA	NA	NA	NA
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
Deep and Very Deep Waters	Direct strike causing mortality	0	6	0	1b	0	1	0	2a	0	1	0	2a	0	5	0	1b	0	6	0	2a
	Underwater noise and disturbance	0	4	0	1b	0	4	0	1c	1	5	5	2a	0	4	0	1b	0	6	0	2a
	Toxic contaminants	0	1	0	1b	0	1	0	2a	0	1	0	2a	0	1	0	1b	0	1	0	2a
	Ingestion of debris	0	4	0	1b	0	2	0	1c	0	1	0	2a	0	3	0	1b	0	2	0	2a
	Smothering of seafloor organisms	0	4	0	1b	0	1	0	1c	NA	NA	NA	NA	0	3	0	1b	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	1b	NA	NA	NA	NA	NA	NA	NA	NA	0	5	0	1b	NA	NA	NA	NA
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a
Seamounts	Direct strike causing mortality	0	6	0	2a	0	1	0	2a	0	1	0	2a	1	5	5	2a	0	6	0	2a
	Underwater noise and disturbance	0	5	0	2a	1	5	5	1c	1	5	5	2a	0	5	0	2a	0	6	0	2a
	Toxic contaminants	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a	0	1	0	2a
	Ingestion of debris	0	4	0	2a	0	4	0	1c	0	2	0	2a	0	3	0	2a	0	2	0	2a
	Smothering of seafloor organisms	0	4	0	2a	0	1	0	2a	NA	NA	NA	NA	1	3	3	2a	NA	NA	NA	NA
	Provision of biota attachment site	0	6	0	2a	NA	NA	NA	NA	NA	NA	NA	NA	0	5	0	2a	NA	NA	NA	NA
	Floating debris	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	6	0	2a

5 Discussion

The Level 1 likelihood-consequence risk analysis approach adopted in this study found that the ecological risk to all ecosystem components of each environmental class from the activities considered here is low. This was primarily a result of the consequence of the potential effect from a single splashdown of 40 tonnes of debris at any point being negligible or minor (consequence scores of 0 or 1). This level of risk is the same as was assessed for up to 100 repeated launches of the much smaller Electron rocket (MacDiarmid et al. 2016).

Risk scores

The overall risk scores are mainly driven by the likelihood of an effect occurring, rather than high levels of consequence. This is due in part to the large spatial scale at which the risk assessment was undertaken. Each of the ecological components is assessed at the scale of a BOMEC class, or the "seamount population" for all of the EEZ. Hence, although localised impacts could be more significant, at the higher level of a population, community or habitat overall consequences were low. In addition, the main focus of discussion by the expert panel was on the level of impact, rather than the recovery period. This aspect is highly variable, between ecological components, and the taxa that comprise them. Typically recovery times are greater in the deep sea than in shallow coastal waters (because of lower water temperatures, ecosystem productivity and individual growth rates), but this is offset to an extent by the smaller relative areas affected offshore. It is an aspect that would become more important at smaller spatial scales.

Although it is not an issue in this particular assessment, the cause of the overall risk score is an important consideration for how the risks are managed. The same risk score can be derived from a low likelihood-high consequence, high likelihood-low consequence, or equal combinations. However, mitigation measures, and management options to cope with certain situations will vary depending on the source of the risk – whether dominated by likelihood, or consequence. Arguably, the activities that have high consequence are likely to be of greater concern to stakeholders and managers, and are the effects that may prioritise mitigation measures.

We stress that the risk profiles with more specific definition of the distribution of debris could be substantially different from those produced here for large areas of the EEZ-ECS, and from just a single rocket launch. At the BOMEC level of large geographic areas, effects are small relative to those that might be estimated at a local scale where there can be more information on the specific environmental and ecological characteristics. For example, the effects of one launch over a large area with many patches of Sensitive Benthic Habitat are negligible because of the widespread distribution of the habitats. However if fall-out is consistently in a small area where such habitats are concentrated, then the local impact could be high. This emphasises the need to monitor the distribution of rocket trajectories and debris field location in order to better understand the scale and extent of impact.

Cumulative impacts

Cumulative impacts are an important consideration in any risk assessment of activities covering large areas of the EEZ. Such impacts arise primarily from additive or interactive processes from multiple impacts (in this case numerous rocket launches), or multiple sources of impact (such as various types of rocket operation, different industries (e.g., fisheries), and environmental change). There is an increasing body of literature dealing with these types of effects (e.g., Solan & Whiteley 2016), but interactions between stressors can be variable, and hard to predict (e.g., Crain et al. 2008). In order to evaluate cumulative impacts adequately, it is necessary to consider temporal accumulation (duration and frequency of launches), spatial accumulation (geographic scales of the debris field, boundaries), perturbation type (single, multiple, continuous, likely trigger for other interactions), processes of accumulation (cause and effect issues, relationships between stressors), the scale of structural changes in communities, and associated functional shifts in ecological processes (e.g., Smit & Spaling 1995). These factors apply both within the rocket operation, other sectors, and need to bear in mind longer term natural changes in environmental factors.

Given the large areas assessed in this present ERA, and the lack of detail on specific debris fall-out fields, it is very difficult to assess how scores would change for the different effects and ecosystem components. The expert panel started to assess how many launches might be needed for the risk levels to become moderate (meaning that consequence levels would increase to moderate or major), but it rapidly proved impractical for every case given the available information. Nevertheless, some indications of cumulative effects from an increasing number of launches can be derived from MacDiarmid et al (2016), who assessed the risk associated with an order of magnitude increase in the number of launches per year (from one to 10,000). Although the rocket debris amount per launch of the Electron type rocket was about 40 times less than assessed here, both the likelihood of an effect, and consequences, clearly increased with the number of launches. As found in the present assessment, the main aspects of risk were direct strike and smothering impacts on Sensitive Benthic Environments and Benthic Invertebrate Communities, and the effects of noise on air-breathing fauna at the sea surface. Risk levels estimated by MacDiarmid et al. (2016) increased from minor to moderate with 1000 to 10,000 launches. Considering the increased amount of debris per launch from the larger rockets in the present assessment, the panel felt that 10 launches would still have a minor risk, but at 100 launches the risks could be moderate, and with 1000 could become high. This will depend on whether repeated launches affect the same general area, or if debris is more widely scattered across larger areas of the EEZ.

Assessing the potential for cumulative impacts from multiple sectors and sources of stress is a major task, and was beyond the scope of this study. Of particular importance is evaluating interactions with the effects of a diverse array of commercial fisheries in New Zealand waters, which are regarded as being amongst the highest threats to marine environments (MacDiarmid et al. 2012). Estimates of the percentage of BOMEC classes covered by bottom-contact fisheries over a 20 year period have been made by Baird & Wood (2012). These estimates are: Inshore and shelf, 26%; Upper slope, 20%; Northern mid-depths, 40%; Southern mid-depths, 8%; and deep-very deep, <1%. Clark & O'Driscoll (2003) reported that 248 of 800 seamounts in the New Zealand region had been fished, with over 80% of features with summit depths of 500-1000m having been repeatedly trawled. These would be equivalent to moderate to major consequences using the definitions in Table 2-2. Hence it is very likely that rocket debris will be a much less important element of a cumulative impacts assessment than commercial fishing operations in a number of areas around New Zealand. For up to 50 launches resulting in 40 t of debris per launch it is likely that the environmental risk would not be increased over that resulting from fishing alone.

The impacts of climate change over the life span of rocket launches in the deep-sea environments may be more significant than the potentially local effects of the proposed rocket operations. Recent analysis by Law et al. (2016) indicates that due to climate change the oceanic waters around New Zealand over the next 80 years are expected to rise in temperature by about 2.5^{o} C and decrease in pH (become more acidic), with concomitant declines in primary production of about 6% and declines in food availability to fish of between 2% and 25%.

Gaps and Recommendations

Cumulative assessment is an important gap in the current assessment, and is one that would need to be addressed in moving beyond the qualitative ERA into a more formal and semi-quantitative assessment. We stress that risk assessment is a dynamic and sequential process. There is not just a single ERA done for a commercial project. This is a "Level 1" qualitative assessment, and one of its major roles is to screen potential risks and identify those that are unlikely to pose any significant risk (meaning those activities/threats need not necessarily be considered further) and those which should be the focus of more detailed risk assessment subsequently (as part of a new "Level 2" semi-quantitative assessment). This is a sequence that normally occurs as any project develops from initial "exploratory" stages through to the larger full-scale production or operation. We recommend that such a semi-quantitative assessment would be undertaken once more real data are available on the nature and extent of the debris field from launches, and a focus on appropriate areas and more specific scales of impact on ecological components.

We recommend that a review is undertaken of available data on actual launch trajectories and the generation of debris after 50 launches. That would enable a further evaluation of likely risks, and enable any modifications in the assessment, or in operational practices, to be done before the 100 launch threshold where impacts may shift from minor to moderate for repeated exposure in one general area.

The effects of noise/vibrations are poorly understood for most fish species. In this risk assessment, they were potentially important factors as launch numbers increase for marine mammals, where avoidance behaviour is documented. There are also guidelines for assessing effects of sound on marine mammals (NMFS 2016). However, clear data on thresholds of noise that cause physiological impacts (such as hearing damage, barotrauma, stress) on fishes are less developed (Popper & Hastings 2009, Hawkins et al. 2014). Natural sources of noise in the marine environment are important for sensing the environment, and for communication. Behavioural responses include fish avoiding large approaching vessels, with potentially reduced catch rates of commercial species in areas of seismic surveys; disruption of spawning sites in shallow coastal waters; and altered predator-prey detection responses (see review by Stanley & Jeffs 2016). This aspect becomes more important as specific areas are identified as receiving the impacts, and would be a more substantial part of a semi-quantitative level 2 assessment.

Community linkages are also a major gap in the knowledge of deep-sea impacts more generally. Impacts from debris on sensitive benthic environments which provide important biogenic habitat complexity for other organisms could be important for affecting community structure, and wider ecosystem dynamics. Hence, more ecological information is needed for assessing impacts that could affect ecosystem structure, or services that support the commercial fisheries. It is recommended that relevant information is shared from other research projects that can help inform an improved risk assessment. Such research includes projects that will improve our knowledge of the distribution and abundance of sensitive benthic communities (e.g., MPI-funded survey of Chatham Rise 2017), and increased cetacean studies (DOC and MBIE-funded). These improved data can be assessed at the same time a review is carried out of rocket debris data after 50 launches, so that a more comprehensive plan for improving uncertainty in risk evaluation can be developed.

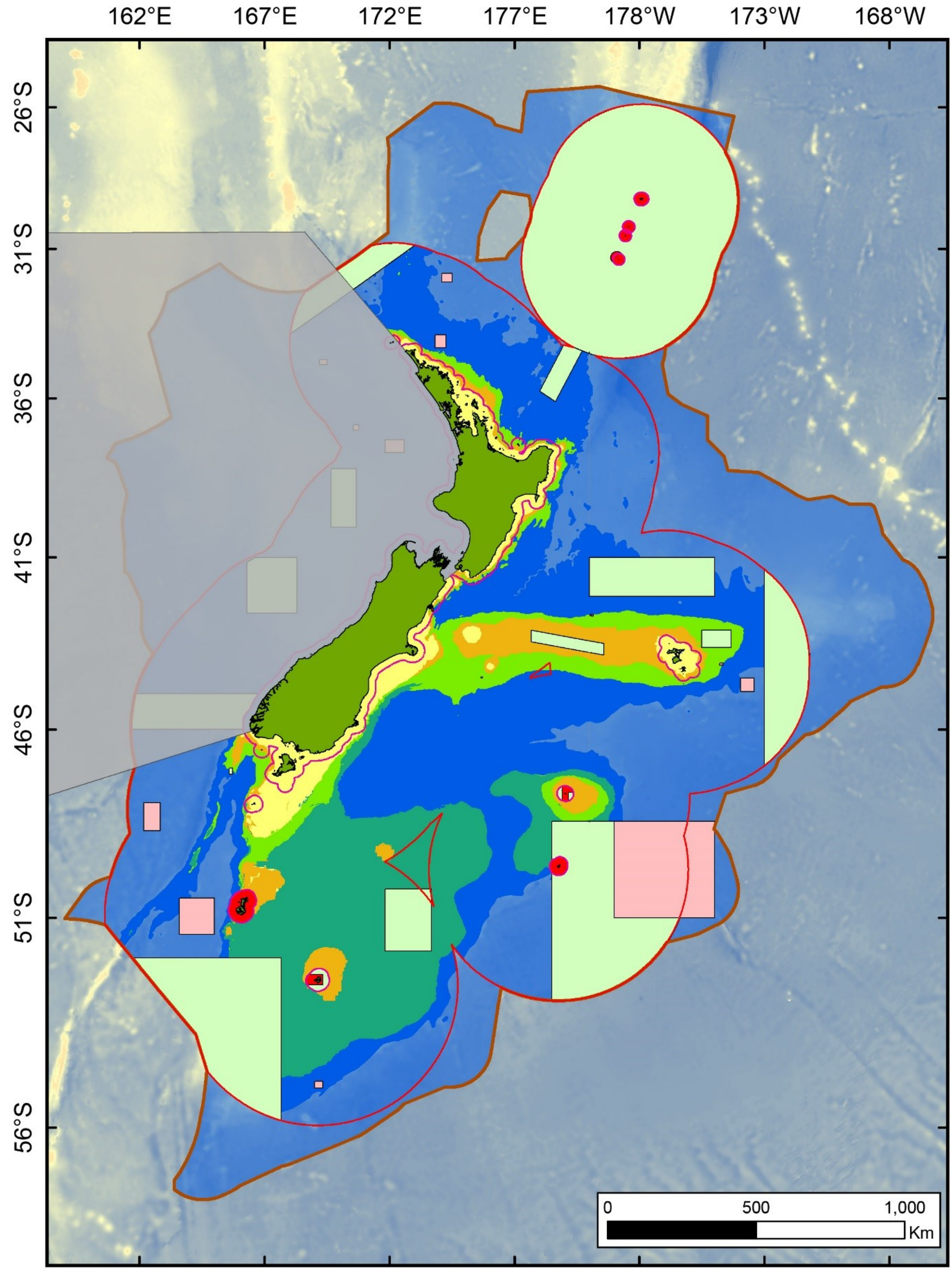


Figure 5-1: Protected areas in the New Zealand EEZ and ECS. Benthic Protected Areas (BPA) are shown in light green, seamount closures are in pink and marine reserves, although restricted to within the Territorial Sea, are in red. The BOMEC classification and the inclusion of very deep waters to the edge of the EEZ and ECS (transparent blue) is in the background.

6 Acknowledgements

We acknowledge the assistance of Jamie Fowler and Gemma Couzens of the Ministry for the Environment for setting the scope of the study, in liaising with Rocket Lab to provide critical information, and for providing critical feedback on the draft report. Ian Baxter (AECOM) provided a very useful external review of the draft report. Ashley Rowden (NIWA) reviewed a draft of the report and suggested many helpful revisions that contributed significantly to the final version.

7 Glossary of abbreviations and terms

BOMEC	Benthic Optimised Marine Environmental classification
BPA	Benthic Protected Area
ECS	Extended Continental Shelf
EEZ	Exclusive Economic Zone
ERA	Ecological Risk Assessment
MPA	Marine Protected Area
NSCD	Nationally Significant Collection and Database

8 References

Anderson, O., Guinotte, J., Rowden, A., Tracey, D., Mackay, K. and Clark, M. (2016) Habitat suitability models for predicting the occurrence of vulnerable marine ecosystems in the seas around New Zealand. *Deep-Sea Research Part I*, 115: 265-292.

Anderson, O.F., Bagley, N.W., Hurst, R.J., Francis, M.P., Clark, M.R. and McMillan, P.J. (1998) Atlas of New Zealand fish and squid distributions from research bottom trawls. NIWA Technical Report 42. 303 p.

Baird, S.J. and Gilbert, D.J. (2010) Initial assessment of risk posed by trawl and longline fisheries to selected seabird taxa breeding in New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report*, Wellington. 99pp.

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

Baker, C.S., Chilvers, B.L., Childerhouse, S., Constantine, R., Currey, R., Mattlin, R., van Helden, A., Hitchmough, R. and Rolfe, J. (2013) Conservation status of New Zealand marine mammals, 2013. *New Zealand Threat Classification Series*, 14, New Zealand. 22pp.

Behrenfeld, M.J. and Falkowski, P.G. (1997) Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnology and Oceanography 42:1-20.

Bradford, J.M. (1980) New Zealand region, zooplankton biomass (0-200 m). New Zealand Oceanographic Institute chart, miscellaneous series 41.

Bradford, J.M. and Roberts, P.E. (1978) Bradford, J.M.; Roberts, P.E. (1978). Distribution of reactive phosphorus and plankton in relation to upwelling and surface circulation around New Zealand. New Zealand Journal of Marine and Freshwater Research 12: 1-15. .

Chiswell, S.M., Bostock, H.C., Sutton, P.J.H. and Williams, M.J.M. (2015) Physical oceanography of the deep seas around New Zealand: a review. New Zealand Journal of Marine and Freshwater Research, 49 (2): 286-317, doi: 10.1080/00288330.2014.992918.

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

Clark, M.R..; Horn, P.; Tracey, D.M.; Hoyle, S.; Goetz, K.; Pinkerton, M.; Sutton, P.; and Paul, V. (2016). Assessment of the potential impacts of deep seabed mining on Pacific Island fisheries. NIWA Client Report No. 2016074WN. 93 p.

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

Clark, M.R. and Rowden, A.A. (2009) Effect of deepwater trawling on the macro-invertebrate assemblages of seamounts on the Chatham Rise, New Zealand. *Deep Sea Research I*, 56: 1540–1554.

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

Crain C.M., Kroeker K. and Halpern B.S. (2008) Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters 11:1304-1315.

Fisher, D.O. and Bagley, N.W. (2015) Database documentation for the fish communities database: fish_comm. NIWA Fisheries Data Management.

Ford, R.B.; Galland, A.; Clark, M.R.; Crozier, P.; Duffy, C.A.J.; Dunn, M.; Francis, M.P.; and Wells, R. (2015). Qualitative (Level 1) risk assessment of the impact of commercial fishing on New Zealand chondrichthyans. New Zealand Aquatic Environment and Biodiversity Report No. 157. 111 p.

Hawkins, A.D., Pembroke, A.E., and Popper, A.N. (2014). Information gaps in understanding the effects of noise on fishes and invertebrates. *Reviews in fish biology and fisheries 25*: 39-64.

Hobday, A.J., Smith, A.D.M. and et al. (2011) Ecological risk assessment for the effects of fishing. Fisheries Research 108(2–3): 372–384.

Leathwick, J.R., Rowden, A., Nodder, S., Gorman, R., Barsley, S., Pinkerton, M., Baird, S.J., Hadfield, M., Currie, K. and Goh, A. (2012) A Benthic-optimised Marine Environment

Classification (BOMEC) for New Zealand waters. New Zealand aquatic environment and biodiverstity report Wellington. 54pp.

Leathwick, J., Dey, K. and Julian, J. (2006a) Development of a marine environmental classification optimised for demersal fish. *NIWA Client Report:*, HAM2006-063, Wellington. 21pp.

Leathwick, J., Francis, M. and Julian, K. (2006b) Development of a demersal fish community map of New Zealand's Exclusive Economic Zone. NIWA Client Report: HAM2006–062. 38p.

Leathwick, J.R., Elith, J., Francis, M.O., Hastie, T. and Taylor, P. (2006c) Variation in demersal fish species richness in the oceans surrounding New Zealand: an analysis using boosted regression trees. Marine Ecology Progress Series 321: 267-281.

MacDiarmid, A., Baird, S.J., Clark, M., Goetz, K., Hickey, C., Mills, S., O'Driscoll, R., Pinkerton, M. and Thompson, D. (2016) Marine Ecological Risk Assessment of the cumulative impact of Electron Rocket launches. *NIWA Client Report*, 2016059WN, Wellington. 55pp.

MacDiarmid, A., Wysoczanski, R.J., Clark, M., Goetz, K., Hadfield, M., Neil, H.L., Pallentin, A., Pinkerton, M., Thompson, D. and Tracey, D. (2015) Environmental risk assessment of discharges of sediment during exploration for seabed minerals - Polymetallic nodules, placer gold, and polymetallic crusts. *NIWA Client Report*, WLG2015-42, Wellington. 53pp.

MacDiarmid, A., Boschen, R.E., Bowden, D., Clark, M., Hadfield, M., Lamarche, G., Nodder, S.D., Pinkerton, M. and Thompson, D. (2014) Environmental risk assessment of discharges of sediment during prospecting and exploration for seabed minerals. *NIWA Client Report*, WLG2013-66, Wellington. 53pp.

MacDiarmid, A., McKenzie, A., Sturman, J., Beaumont, J., Mikaloff-Fletcher, S. and Dunne, J. (2012). Assessment of anthropogenic threats to New Zealand marine habitats. New Zealand Aquatic Environment and Biodiversity Report No. 93. 255 p

MacDiarmid, A., Beaumont, J., Bostock, H., Bowden, D., Clark, M., Hadfield, M., Heath, P., Lamarche, G., Nodder, S.D., Orpin, A., Stevens, C., Thompson, D., Torres, L. and Wysoczanski, R. (2011) Expert Risk Assessment of Activities in the New Zealand Exclusive Economic Zone and Extended Continental Shelf. *NIWA Client Report*, WLG2011-39, Wellington. 145pp.

Mackay, K.A. (1993) Marine research database documentation. 6. trawl. MaF Fisheries Greta Point Internal Report No. 209. 40p. ,

MPI (2016) Fisheries Assessment Plenary, May 2016: stock assessments and stock status. Compiled by the Fisheries Science Group. *Ministry for Primary Industries*, Wellington, New Zealand. 1556pp.

MTCR (2010) Missile technology control regime (MTCR) - Annex Handbook. No. US Government (http://mtcr.info/mtcr-guidelines/), pp. 320.

NMFS (National Marine Fisheries Service) (2016). Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: underwater acoustic thresholds for onset of permanent and temporary threshold shifts. US Department of Commerce, NOAA. *NOAA Technical Memorandum NMFS-OPR-55*. 178 p.

Nodder, S.D., Chiswell, S. and Northcote, L. (2016) Annual cycles of deep-ocean biogeochemical export fluxes in subtropical and subantarctic waters, southwest Pacific Ocean, J. Geophys. Res. Oceans, 121, 2405–2424, doi:10.1002/2015JC011243.

Orpin, A., Carter, L., Goh, A., Mackay, K., Verdier, A.-L., Chiswell, S.M. and Sutton, P.J.H. (2008) New Zealand diverse seafloor sediments. *NIWA Charts, miscellaneous series N.86*. National Institute of Water and Atmospheric Research, Private Bag 14-901, Wellington 6241, New Zealand.

Palaszewski, B. and Zakany, J.S. (1996) Metallized Gelled Propellants: Oxygen/RP-1/ Aluminum Rocket Heat Transfer and Combustion Measurements. NASA Technical Memorandum 107309 - AIAA-96-2622. 32nd Joint AIAA, ASME, SAE, and ASEE Propulsion Conference. Lake Buena Vista, Florida, July 1-3, 1996. 36pp.,

Pinkerton, M.H. (2007) Oceanic primary productivity in the New Zealand EEZ. In: State of the New Zealand Environment: Oceans, report ENZ-07, Ministry for the Environment, New Zealand.

Popper, A., and Hastings, M. (2009). The effects of anthropogenic sources of sound on fishes. *Journal of fish biology 75*: 455-489.

Richard, Y. and Abraham, E.R. (2015) Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2012–13. *New Zealand Aquatic Environment and Biodiversity Report*, 162, 89pp., https://www.mpi.govt.nz/document-vault/10523

Robertson, H.A., Dowding, J.E., Elliott, G.P., Hitchmough, R.A., Miskelly, C.M., O'Donnell, C.F.J., Powlesland, R.G., Sagar, P.M., Scofield, R.P. and Taylor, G.A. (2013) Conservation status of New Zealand birds, 2012. New Zealand Threat Classification Series 4, Department of Conservation, Wellington. 22pp.

Rocket Lab (2016) EEZ and continental shelf effects of Electron launch. Confidential Rocket Lab document, 18 p.

Rowden, A.A., Clark, M.R. and Wright, I.C. (2005) Physical characterisation and a biologically focused classification of "seamounts" in the New Zealand region. *New Zealand Journal of Marine and Freshwater Research*, 39: 1039-1059.

Rowden, A.A., Oliver, M., Clark, M.R. and MacKay, K. (2008) New Zealand's "SEAMOUNT" database: recent updates and its potential use for ecological risk assessment. Aquatic Environment and Biodiversity Report No. 27. 49 p.

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

Smit, B. and Spaling, H. (1995) Methods for cumulative effects assessment. Environmental Impact Assessment Review 15:81-106.

Solan, M. and Whiteley, N.M (eds) (2016). Stressors in the Marine Environment. Oxford University Press, Oxford. 356 p.

Smith, A.D.M., Fulton, E.J., Hobday, A.J., Smith, D.C. and Shoulder, P. (2007) Scientific tools to support the practical implementation of ecosystem-based fisheries management. ICES Journal of Marine Science 64, 633-639.

Stanley, J.A., and Jeffs, A.G. (2016). Ecological impacts of anthropogenic underwater noise. Chapter 16 in: Solan, M., Whiteley, N.M (eds). *Stressors in the Marine Environment*. Oxford University Press, Oxford. pp. 282-297.

Thompson, D.R. (2007) Importance of seamounts to seabirds. In: Pitcher, T.J.; Morato, T.; Hart, P.J.B.; Clark, M.R.; Haggan, N.; Santos, R.S. (eds.) Seamounts: ecology, fisheries and conservation, pp 245-251. Blackwell Publishing, Oxford, England.

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

Walker, K. and Elliott, G. (2006) At-sea distribution of Gibson's and Antipodean wandering albatrosses, and relationships with longline fisheries. Notornis 53: 265-290.

Wood, A.C.L., Probert, P.K., Rowden, A.A. and Smith, A.M. (2012) Complex habitat generated by marine bryozoans: a review of its distribution, structure, diversity, threats and conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 22, 547-563.

Appendix A Rocket debris toxics assessment

Information on the makeup of the launch vehicles and propellant was provided by the Ministry and Rocket Lab (Connaughton, pers comm; Rocket Lab, 2016) and used to assess the potential toxicity of each of the components comprising Stage 1, the nose fairings and the two Stage 2 batteries (Table A-1).

It was assumed that:

- break-up during descent through the atmosphere did not result in combustion of the components during descent.
- the maximum size of the any rockets being launched in New Zealand could be up to 40t., compared with 1t for assessment on the electron launch (MacDiarmid et a., 2016).
- that kerosene is the rocket propellant fuel and not any other solid or liquid fuel propellants.
- a maximum of 3 companies may be launching a space craft at any one time from different locations from northern, eastern and southern New Zealand, i.e., no launch will occur in a westerly direction (towards Australia).

Propellant

In the previous assessment (MacDiarmid et al., 2016), the information was that the propellant was kerosene and liquid oxygen.

We assume that the fuel used in any rocket launches would be the same as that for the Electron launch. We also assume that no significant additives will be included in fuel (Connaughton, pers. comm.), and that no other solid or liquid fuel propellants are used for rocket launches.

Many of other potential propellants are highly toxic (Palaszewski and Zakany 1996; MTCR 2010) (Table A1). However, these compounds at least, do not accumulate in the food-chain and are expected to rapidly disperse and biodegrade in the sea water. We expect that the risks from the fuel propellants for the benthic ecological community is much greater for catastrophic launch failure – which is most likely to occur within the 12 mile territorial sea and outside of the scope of this risk assessment.

If highly toxic propellants are used (e.g., hydrazine) there is an increased likelihood of toxic harm for a scenario where an incomplete fuel burn occurs at the point of stage release. Some of these propellants could result in localised adverse effects in impact areas – particularly for larger (40t) rockets.

Lithium batteries

We do not expect that the quantity of wiring (copper components) and engine masses would directly scale from the 1t. rocket to the 40t. rocket. However, Lithium (Li) batteries would probably scale up as those are needed to drive the turbo-pumps. Rocket Lab's Electron launch vehicle is uncommon in that a sizable fraction (around 25%) of the mass of the first stage is made up of high power lithium-polymer batteries and their casing.

The major chemically active component which could reach the ocean surface and bottom would be the lithium from batteries that would remain after a successful launch. Rupture of the batteries would release highly reactive Li to the seawater – which would produce highly alkaline seawater conditions in the region surrounding the battery and dissolution of the Li into the seawater. However, elevated Li would not add significantly to the naturally elevated Li concentration in the ocean.

The Li-ion batteries could have a potential impact on benthic communities and sensitive environments. This effect would be transient and localised being caused by alkali production.

No information were available on the likely fate of the Lithium battery housing and its contents.

Assessment of risk

The risk from potential kerosene toxicity is very low. This is because the Stage 1 fuel will be effectively exhausted by the time it is jettisoned. Any small amounts reaching the ocean will be lost by evaporation from the surface. This will be the case for any successful rocket launch irrespective of rocket size.

Metal fragments will likely be partially buried in the soft bottom seabed areas but remain on the surface of the seabed in hard-bottom areas (probably a small proportion of the Stage 1 debris impact area).The metal mass components of the engines are constructed of Inconel, which is highly resistant to corrosion and release of any toxic components. Scaling up from the Rocket Lab Electron which has 9 engines with a total mass of 172.9 kg (Table A2) to a 40t rocket will result in a markedly greater mass and number of engines which deposit at a specific location. No specific information has been supplied for a scaled-up rocket, however, these components would not be expected to result in an ecotoxic risk.

The metallic copper is the only metallic component representing a potential toxic issue. The level of potential impact will be related to number and dispersion of small metallic copper fragments. The slowly dissolving copper will add to the natural low background concentrations and disperse from local area. Such effects would be only of potential concern in hard rock bed areas with sensitive benthic communities and environments where there is little chance of the copper fragments being buried in sediment. Because of the persistence of metallic copper in these areas there will be a cumulative and increasing impact with multiple launches to specific target launch areas. Scaling up from the Rocket Lab Electron which has a total mass of 10.3 kg of copper for each rocket (Table A2) to a 40t rocket will result in a greater quantity of copper for each location. No specific information has been supplied for copper content in a scaled-up rocket, however, we would not expect the quantity to directly scale up as the control wiring would not be substantively higher. The general comments provided in Table A2 apply to a risk assessment for the greater EEZ and for larger rockets.

The major metallic mass in the batteries is lithium. Should they reach the ocean surface then the batteries are likely to implode with depth and release the reactive lithium. The lithium present will react with seawater with release of hydrogen and generate highly alkaline conditions in the vicinity of the decomposing battery; and releasing lithium ions. Battery lithium will not be toxic and will add insignificantly to natural background seawater. Lithium is of no concern in seawater for bioaccumulation in the food-chain. Scaling up from the Rocket Lab Electron which has multiple batteries with a total mass of 244.7 kg (Table A2) to a 40t rocket will result in a markedly greater battery mass which deposit at a specific location. No specific information has been supplied for a scaled-up rocket, however, given that the engines are reliant on the lithium batteries we would expect greater than 40x scaling would be required for the battery component. Therefore a much larger quantity of batteries will disperse to the seafloor after an individual launch. We consider that the highly localised deposit of a large number of lithium batteries could cause localised impacts and adverse toxic effects caused by the alkaline conditions generated by the rapid degradation of the lithium in contact with the seawater. The effects of the alkaline exposure would be transient and limited to the near-field area surrounding the individual battery units.

There is insufficient information available on the battery casings to provide a high surety of their fate in deep ocean.

Table A1. Potentially ecotoxic hydrazine-based fuels which may be used as rocket propellants (from MTCR 2010). Note: that the Electron Rocket uses kerosene as a propellant – which would be considered a low ecotoxic risk for marine organism exposure after a successful launch.

4.C.2. Fuel Substances as follows:
a. Hydrazine (CAS 302-01-2) with a concentration of more than 70%;
b. Hydrazine derivatives as follows:

1. Monomethylhydrazine (MMH) (CAS 60-34-4);
2. Unsymmetrical dimethylhydrazine (UDMH) (CAS 57-14-7);
3. Hydrazine mononitrate;
4. Trimethylhydrazine (CAS 1741-01-1);
5. Tetramethylhydrazine (CAS 6415-12-9);
6. N,N diallylhydrazine;
7. Allylhydrazine (CAS 7422-78-8);
8. Ethylene dihydrazine;
9. Monomethylhydrazine dinitrate;
10. Unsymmetrical dimethylhydrazine nitrate;
11. Hydrazinium azide (CAS 14546-44-2);
12. Dimethylhydrazinium azide;
13. Hydrazinium dinitrate;
14. Diimido oxalic acid dihydrazine (CAS 3457-37-2);
15. 2-hydroxyethylhydrazine nitrate (HEHN);
16. Hydrazinium perchlorate (CAS 27978-54-7);
17. Hydrazinium diperchlorate (CAS 13812-39-0);
18. Methylhydrazine nitrate (MHN);
19. Diethylhydrazine nitrate (DEHN);
20. 3,6-dihydrazino tetrazine nitrate (DHTN);

Technical Note:
3,6-dihydrazino tetrazine nitrate is also referred to as 1,4-dihydrazine nitrate.

References

MTCR (2010). Missile technology control regime (MTCR) - Annex Handbook. No. US Government (http://mtcr.info/mtcr-guidelines/), pp. 320.

Palaszewski, B. and Zakany, J.S. (1996) Metallized Gelled Propellants: Oxygen/RP-1/ Aluminum Rocket Heat Transfer and Combustion Measurements. NASA Technical Memorandum 107309 - AIAA-96-2622. 32nd Joint AIAA, ASME, SAE, and ASEE Propulsion Conference. Lake Buena Vista, Florida, July 1-3, 1996. 36pp.,

Haltermann Solutions
(http://www.haltermannsolutions.com/fueltypes/aerospace/overview)

Table A2. Assessment of potentially toxic debris components. Details on the parameter, form and quantity were taken from Rocket Lab (2016) from MacDiarmid et al. (2016). Assessment based on a Rocket Lab Electron rocket with an empty Stage 1 mass of approximately 1000 kg.

Parameter	Form	Fairing	Quantity Stage 1 (2)	Fate in seawater	Comment
Kerosene	Liquid		2785 kg	Float on surface; Volatile so lost by evaporation. Relatively low toxicity of soluble fraction.	Potential greater issue if rocket aborts near launch site. Assumed that fuel will be effectively all exhausted and lost before ocean landing. *No issue anticipated.*
Aluminium	Solid	3.5	117.6 kg	Sink to seabed. Nature of alloy will affect corrosion/dissolution rate. Aluminium toxicity not considered a high risk.	*No issue.*
Brass	Solid		1.2 kg	Sink to sediments.	Very small quantity. *No issue.*
Copper	Solid		10.3 kg	Sink to sediments. Slow dissolution of copper will occur with long-term affects to sediment-dwelling species in vicinity of the fragments.	Level of potential impact will be related to number and dispersion of small metallic copper fragments. Such effects would be only of potential concern in hard rock bed areas with sensitive faunal assemblages. *Potential issue.* Dissolved copper will add to the natural low background concentrations and disperse from local area. Very low total mass of copper being added relative to natural oceanic copper concentrations.
Inconel	Solid		172.9 kg	Sink to sediments. Material is highly resistant to corrosion. No expectation of release of toxic metals which are bioavailable.	*No issue.*
Steel	Solid	5.2	68.5 kg	Sink to sediments. Rapid corrosion likely to occur. Released iron will not be toxic to sediment-dwelling species.	*No issue.*
Batteries (Lithium)	Solid		227.2 kg (17.5 kg)	Sink to sediments. If batteries reach the ocean they are likely to rupture at depth. The lithium present will react with seawater with release of hydrogen. Battery lithium will not be toxic and will add insignificantly to natural background levels in seawater.	Lithium is naturally elevated in seawater. *No issue.*
Adhesives	Solid	30.3	2.8 kg	Slow sinking to seabed of carbon fibre composite. Expected to be very long-lived and resistant to degradation process. Burial will ultimately occur in soft-bottomed areas.	Carbon fibres are not expected to be released from fairing debris pieces. Therefore no potential for ecosystem effects other than physical debris impact and habitat alteration. *No issue.*
Carbon fibre	Solid		37.1 kg	Slow sinking to seabed of carbon fibre composite. Expected to be very long-lived and resistant to degradation process. Burial will ultimately occur in soft-bottomed areas.	Carbon fibres are not expected to be released from fairing debris pieces. Therefore no potential for ecosystem effects other than physical debris impact and habitat alteration. *No issue.*