Mapping Key Ecological Areas in the New Zealand Marine Environment: Data collation

Prepared for the Department of Conservation (DOC)

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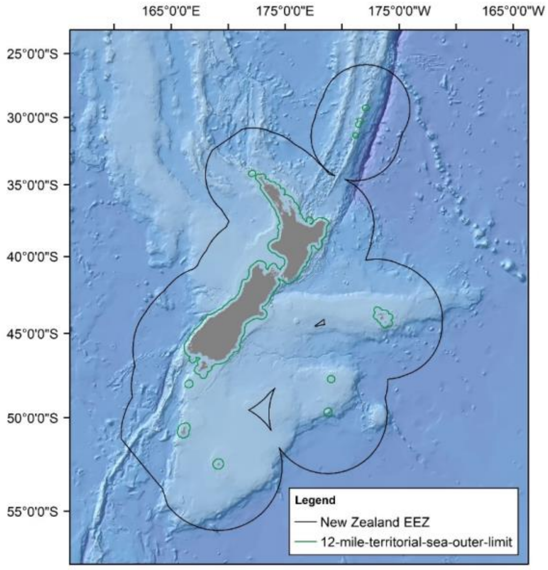

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Contents

Tables

Figures

Executive summary

Marine habitats and ecosystems are under increasing pressure from human activities such as sedimentation, pollution, eutrophication, bottom fishing, oil drilling, waste disposal, and seafloor mining. One management tool that can help maintain ecosystem health and resilience is the use of networks of marine protected areas (MPAs) to facilitate the protection/restoration of biodiversity and ecosystem functions. At the time of writing, the Ministry for the Environment (MfE), Department of Conservation (DOC), and Ministry for Primary Industries (MPI) were reviewing New Zealand's approach to establishing MPAs. As part of this review, DOC, MPI and MfE are exploring criteria that could assist with mapping ecologically important areas to be considered as part of future marine protected area processes, for identifying gaps in the existing marine protected area network, and potentially to inform other resource management planning in the coastal and marine environment. The nine Key Ecological Areas (KEA) criteria proposed for further investigation, based on the Convention on Biological Diversity's criteria for Ecologically and Biologically Significant Areas (EBSAs), were: 1) Vulnerability, fragility, sensitivity, or slow recovery; 2) Uniqueness/rarity/endemism; 3) Special importance for life history stages; 4) Importance for threatened / declining species and habitats; 5) Biological productivity; 6) Biological diversity; 7) Naturalness; 8) Ecological function; and 9) Ecosystem services.

The aim of this project was to assess the availability of spatial datasets that could be used to identify KEA in the New Zealand Territorial Sea (TS) and Exclusive Economic Zone (EEZ). This involved collating candidate datasets, working with experts and stakeholders to identifying which of these were relevant for each of the KEA criteria (undertaken during two workshops held on the 18th June and 27th September 2018 at NIWA, Wellington), and producing a series of maps showing these datasets, as well as making available the associated GIS files. Overall, 27 datasets were collated and mapped for this report, many of which had multiple data layers. For example, the *New Zealand marine reef fish records* dataset included individual abundance distribution layers for 72 species of marine reef fish. For each dataset, an example figure of the types of areas or data relevant to each of the KEA criteria, and an overview the data was provided. The data was then described in detail, the matching criteria were listed, and data limitations and consideration for their future use were discussed.

In many cases the datasets matched multiple criteria. For example, two of the datasets matched seven of the criteria: *Regional Council identified important areas* and *Sensitive Environments / biogenic habitats*. Most KEA criteria were well represented by the data collated. Seven of the nine criteria were represented by more than four datasets. However, some KEA criteria were poorly represented, e.g., 'Ecosystem services' and 'Ecological function'. Datasets for several criteria overlap with 'Ecosystem services' and 'Ecological function', but were not specifically included in the report since the links to these have not been specifically established with the current data.

The use of the EBSA concept, and by extension the concept of KEAs, provides a sound basis for developing the scientific advice and data to support national and international management of the world's oceans, including through identifying sites of particular significance for biodiversity conservation that could be included in a representative MPA network. Critically the next step of identifying KEAs and/or incorporating the individual data layers into any broader spatial planning process, requires careful consideration of the weaknesses of the datasets in order to both assess whether the criteria are adequately described by the available datasets, and also to ensure that the weaknesses of the data are not overlooked and adequately addressed when combining these in any future analyses. With the large number of datasets collected, in various data formats, the conservation planning software Zonation appears to be the most promising tool to help identify

possible KEAs and/or incorporate the individual layers into a conservation planning or prioritisation process. Additionally, Zonation has a strong track record of success in New Zealand and has been socialised with stakeholders who have expressed appreciation for the iterative process that this tool facilitates for designing effective spatial planning measures. Such a process should not only incorporate the data layers identified in this report (where appropriate) but also incorporate data relating to habitat distribution, other ecological, social and cultural values, as well as constraints and costs, as part of a systematic conservation planning approach.

1 Introduction

1.1 Background

Marine habitats and ecosystems are under increasing pressure from human activities such as sedimentation, pollution, eutrophication, fishing, oil drilling, waste disposal, and seafloor mining (Halpern et al. 2008). These anthropogenic impacts threaten biodiversity which in turn can affect the ecosystem functioning and services, resulting in a need for management and conservation of the marine environment (Ramirez-Llodra et al. 2011). One management tool that can help maintain ecosystem health and resilience is the use of networks of marine protected areas (MPAs) to facilitate the protection/restoration of biodiversity and ecosystem functions (Halpern et al. 2010). A substantial scientific literature now demonstrates that well-designed MPA networks can be highly effective tools for conserving biodiversity and ecosystem services (Edgar et al. 2014;Rowden et al. 2018).

Protected areas are “a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (IUCN, 2012). Broadly, the purpose of a network of marine protected areas is to provide spatial protection to the full suite of marine biodiversity. In the absence of complete information on the distribution and abundance of biodiversity, it is common practice to use physical surrogates for biodiversity, through application of a multidimensional habitat classification scheme (IUCN-WCPA, 2008). Such classifications can provide, for example, a proxy for species richness, enabling management decisions to be made regarding the value of the site as reservoirs of biodiversity in the absence of detailed species-level data (Roberts et al. 2003). However, there are several instances where it has been demonstrated that protection of large-scale features identified by physical-based classifications alone may not adequately represent finer scale heterogeneity and areas of particular biodiversity importance (Hewitt et al. 2015), or where selection of sites based on perceived representativeness may exclude areas of known distinct biodiversity e.g., (Williams et al. 2008). To ensure a comprehensive, adequate and representative marine protected area network, an approach that identifies and selects examples of broadscale habitats, should therefore be complemented by the identification of sites of particular significance for biodiversity conservation, including consideration of pelagic, demersal and air-breathing species. The former is intended to ensure that species and habitats are protected through inclusion of biodiversity surrogates in protected areas, including in data poor areas. The latter ensures that particular features of known importance for biodiversity are also included in protected area networks; without this, there is a risk that representation of broadscale habitats alone will not adequately protect the full suite of species, habitats and ecosystems (although some definitions of “representativeness” do include reference to a full suite of biodiversity, which would include features that are, for example, rare, important or unique) (Freeman et al. 2017).

1.2 Key Ecological Areas

To guide marine protected area planning, an objective and consistent approach to the identification of sites of particular importance for biodiversity is required (Freeman et al. 2017). Internationally, there have been several attempts to achieve this, e.g., defining criteria for the identification of “key biodiversity areas” as defined by the IUCN (IUCN, 2016), and “Ecologically and Biologically Significant Areas” (EBSAs) developed as part of the scientific guidance for selecting areas to establish a representative network of MPAs under the Convention on Biological Diversity

(UNEP/CBD/COP/DEC/IX/20). While initially intended for application in the high seas, there are instances within national jurisdictions where EBSA-type designations have been or are being used to inform the selection of areas for MPA designation e.g., Canada, Australia, Korea and Japan (Dunn et al. 2014). A recent review of international marine biodiversity initiatives found similarities in selected criteria across 15 conservation initiatives, suggesting eight internationally relevant criteria for designating areas of significant biodiversity: (1) contains unique and rare habitats; (2) includes fragile and sensitive habitats; (3) is important for ecological integrity; (4) is representative of all habitats, (5) contain species of conservation concern; (6) contain restricted range species; (7) have high species richness; and (8) are important for life history stages (Asaad et al. 2017). Information required to inform these criteria include: habitat cover, species occurrence, species richness, species' geographic range and population abundance.

The Ministry for the Environment (MfE), Department of Conservation (DOC), and Ministry for Primary Industries (MPI) are currently reviewing New Zealand’s approach to establishing MPAs (proposed Marine Protected Areas Act; MfE (Ministry for the Environment) (2016)). DOC, MPI and MfE science staff held an internal workshop on 21 September 2016, to review the requirement and criteria for considering biodiversity feature data in marine protected area planning. Building on the Convention on Biological Diversity’s criteria EBSAs, the workshop proposed criteria for identifying New Zealand’s key ecological areas in the marine environment, that would assist with mapping areas that should be considered in future marine protected area processes, and for identifying gaps in the existing marine protected area network.

The workshop attendees developed a table with the listed criteria, along with definitions, rationale and New Zealand examples of features that could potentially meet the criteria for consideration in protected area planning (summarised in Table 1-1). In addition to the seven EBSA criteria (criteria 1 – 7), two additional criteria relating to ecological function and ecosystem services were added (criteria 8 and 9 respectively, Table 1-1), to ensure that the services not adequately captured by the other criteria could be considered in protected area planning, in line with Aichi target 11. However, it was acknowledged that there was some overlap between these criteria and the existing EBSA criteria. The workshop named the resulting nine criteria “Key Ecological Areas” (KEAs) criteria, to distinguish them from EBSA criteria, but also to acknowledge the addition of two criteria to the EBSA criteria.

Table 1-1: Criteria for consideration of Key Ecological Areas for marine protected area planning in New Zealand. Note that these criteria are additional to the requirement to represent broad-scale physical habitats in a network of marine protected areas. Table from Freeman et al. (2017). The number in the first column will be used to refer to individual criteria throughout this report.

	Criteria	Definition	Rationale	New Zealand Examples
1	Vulnerability, fragility, sensitivity, or slow recovery	Areas that contain a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.	In the absence of protection, associated biodiversity may not be able to persist.	Biogenic habitats, including bryozoan beds, sponge communities and coldwater corals. Low fecundity and, or high longevity (fish) species such as bramble sharks, hapuku, king tarakihi, orange roughy.
2	Uniqueness/rarity/endemism.	Area contains either (i) unique (“the only one of its kind”, rare (occurs only in a few locations) or endemic species, populations or communities; and/or (ii) unique, rare or distinct, habitats or ecosystems; and/or (iii) unique or unusual geomorphological or oceanography features.	These areas contain biodiversity that is irreplaceable; non-representation in protected areas may result in loss or reduction in biodiversity or features. These areas contribute towards larger-scale biodiversity.	Hydrothermal vents; seeps; areas containing co-occurring geographically restricted species; biogenic habitats.
3	Special importance for life history stages.	Areas that are required for a population to survive and thrive.	Species’ particular requirements make some areas more suitable for carrying out life history stages.	Fish spawning or nursery grounds; pinniped breeding colonies; migratory corridors; sites where animals aggregate for feeding.
4	Importance for threatened / declining species and habitats.	Area containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species.	Protection may enable recovery or persistence of these threatened / declining species or habitats.	Estuaries with populations of threatened shorebirds; foraging areas for marine mammals and seabirds.
5	Biological productivity.	Area containing species, populations or communities with comparatively higher natural biological productivity.	These areas can support enhanced growth and reproduction, and support wider ecosystems.	Hydrothermal vents; frontal zones; areas of upwelling.
6	Biological diversity.	Area contains comparatively higher diversity of ecosystems, habitats, communities or species, or has higher genetic diversity.	These areas are important for evolutionary processes, for species’ and ecosystem resilience and contribute towards large-scale biodiversity.	Structurally complex communities such as deepwater sponge and coral communities; seamounts. Areas with high diversity of fish and invertebrate species.

	Criteria	Definition	Rationale	New Zealand Examples
7	Naturalness.	Area with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation.	Provides enhanced ability to protect biodiversity that is in better condition; reduces need to rely on recovery from degraded state (recovery may occur on a different trajectory); these areas may include species and/or habitats that do not occur or are not represented well in more degraded areas; important role as reference sites.	Remote areas; marine areas adjacent to protected terrestrial areas; areas not impacted by bottom trawling or invasive species.
8	Ecological function.	Area containing species or habitats that have comparatively higher contributions to supporting how ecosystems function.	Some species, habitats or physical processes play particularly important roles in supporting how ecosystems function – their protection provides coincidental protection for a range of other species and wider ecosystem health.	Soft sediment habitats containing high densities of bioturbators; areas of high functional trait diversity; areas with functionally important mesopelagic communities (including myctophids).
9	Ecosystem services.	Area containing diversity of ecosystem services; and/or areas of particular importance for ecosystem services.	Provides for ability to protect species and habitats that provide particularly important services to humans. Provides ability to better contribute to CBD Aichi Target 11.	Areas containing dense populations of filter-feeding invertebrates; areas important for seafood provisioning. Areas important for supporting or regulating ecosystem services (e.g., areas of nutrient regeneration, biogenic habitat provision, carbon sequestration, sediment retention, gas balance, bioremediation of contaminants, storm protection) that underpin the delivery of provisioning or cultural ecosystem services.

1.3 Aims and objectives

The aim of this project was to assess available spatial datasets for New Zealand against the KEA criteria and provide this information to DOC in a consistent Geographical Information System (GIS) format. This involved:

- Working with experts and stakeholders to define and identify which datasets are relevant to each of the criteria contributing to the identification of KEAs in the marine environment (Objective 1).
- Collating the spatial data and undertaking further analyses, and producing resulting data layers in a series of maps, as well as their associated uncertainty/confidence if available (Objective 2).
- Providing a concise and comprehensive report (Objective 3) identifying the criteria that each dataset meets, the relative importance of that data for these criteria, constraints or issues around the data or analyses, and the identification of any gaps for further work.

In this report (Objective 3) we describe the process undertaken for Objective 1, present results for Objective 2 and provide further detail on the adequacy of these datasets in meeting KEA criteria.

2 Methods

Clark et al. (2014) provide a transparent, sequential process for identifying candidate EBSAs consisting of four key steps. The authors note that the process was conceptually transferable to other habitat types and regions beyond those included in their study as a pilot (South Pacific seamounts, also reported on in Dunstan et al. (2011)) and was therefore adapted for use here to apply to the KEA criteria, although point 4 of the process was outside the scope of the present work.

1. Identification of an area to be examined.
2. Determination of appropriate data sets and thresholds to be examined in the evaluation.
3. Evaluation of data against the criteria.
4. Identification and assessment of candidate EBSAs.

The area to be examined in this work was the Territorial Sea and Exclusive Economic Zone of New Zealand, as well as (where relevant) areas on land that may be important for marine species or ecological processes in terms of the identified criteria (Figure 2-1) (point 1 of the process described by Clark et al. (2014). Where datasets that met one or more of the criteria were located close to the boundary of the EEZ, the full extent of these datasets were mapped where possible.

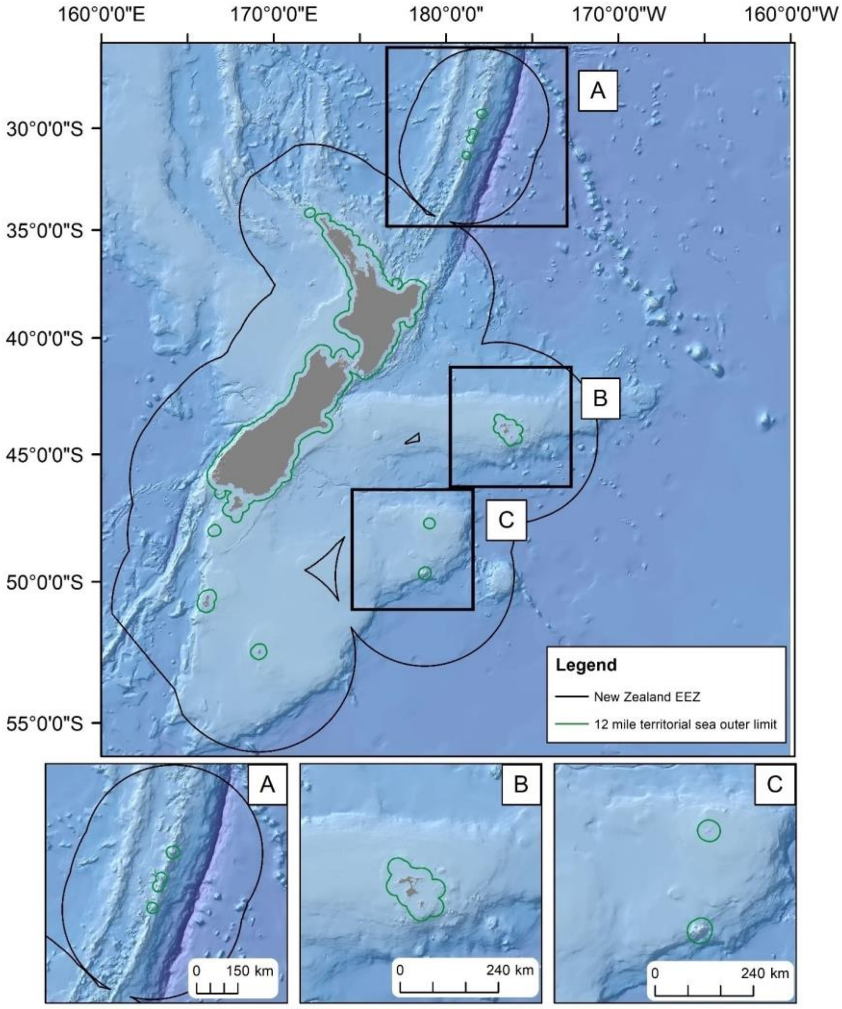

Figure 2-1: Map template used throughout the report showing the extent of the study area. Inset maps: A) Colville, Kermadec ridges and Kermadec Trench; B) Chatham Islands; C) Bounty Plateau.

A list of the appropriate datasets and thresholds to be used in the evaluation (point 2 of the process described by Clark et al. (2014)) was co-developed iteratively throughout the course of two workshop meetings with experts from NIWA and University of Auckland, and stakeholders from DOC, MfE, MPI, and Regional Councils. During the first meeting (18 June 2018, NIWA Wellington) datasets of relevance, which were based on suggested datasets listed in Clark et al. (2014) and Freeman et al. (2017), were presented to form the basis for discussion on the types of data which could match KEA criteria. A longer, wider ranging list of datasets (some of which already existed and some of which needed to be created), was drafted during the meeting and the KEA criteria that matched these datasets was noted. The expert and stakeholder group prioritised the datasets in the list from most important to least important: data which already existed and would be accessible for this project (most important); datasets which did not yet exist but which were both achievable and deemed to be the most important in being able to help designate KEA (moderate importance); datasets which did not yet exist but which were either not achievable within the timeframe of this project, or which were deemed to be less important for designation of KEA (least importance).

Prior to the second workshop, datasets prioritised as most important were collated from their respective sources. Datasets prioritised as moderately important were created – for detailed methodology and results for these newly created data see Appendix 7.2. Both the previously existing and newly created datasets were presented at the second workshop meeting (27 September 2018, NIWA Wellington) where further discussion took place on the relevance of these datasets for designating KEAs. A stronger focus during the second workshop was placed on discussing the evaluation of data against the criteria (point 3 of the process described by Clark et al. (2014)).

All final datasets were stored in geodatabases (Projection: custom WGS_1984_Mercator with -41.00 standard parallel) and mapped in ESRI ArcMap (v10.6). Metadata for each dataset was recorded following best practice guidelines both as ArcGIS metadata and as word files. All file paths of datasets, layer files and metadata are provided in Appendix 7.1.

For each KEA criteria, descriptions of datasets that match the criteria were provided. For certain datasets not all layers matched the criteria described, however, these were included if most of the layers provided relevant information for that criteria. Results included: an example map of the dataset, the data format, resolution if applicable, source data, how these datasets match the KEA criteria, as well as limitations and consideration for future use. In addition, for each data layer the quantity and quality of data used were qualitatively rated according to a modified version of the methodology described in (Hobday et al. 2011;Ford et al. 2018) (Table 2-1). This somewhat subjective confidence assessment relates to the dataset as whole, providing a broad scale indication of confidence, rather than a detailed confidence assessment of each individual layer. Although out of the scope of this report, the latter would be of value for any future analyses using these data layers. Where low confidence was assessed for the dataset, this was based on the absence of important information (the information lacking is specified in the confidence section of the results for each data layer). Moderate confidence in a dataset meant data were limited, unreliable or conflicting. High confidence in the dataset meant quantitative or semi-quantitative data exists and ideally modelled predictions have some measure of uncertainty (Table 2-1).

Table 2-1: Qualitatively defined data layer confidence score (table adapted from Ford et al. (2018)).

Data confidence score	Data	Description and rationale
Low	Few data.	Few data exist and are restricted in extent. Limited descriptive data and indirect evidence, large gaps in knowledge.
Moderate	Data exist.	A reasonable amount of data exists, but significant gaps remain. The absence of information or data bias occurs (these are described in the 'confidence' section of the results for each data layer).
High	Data exist and are considered sound.	Quantitative or semi-quantitative data exists, or excellent description at many locations (allows for some gaps in information). Modelled predictions have estimates of uncertainty.

3 Spatial data for mapping Key Ecological Areas

3.1 Overview of Data collated

A summary of all the datasets collated for this report is provided in Table 3-1. This table includes a brief description of the data, and source and properties of the data (data format, extent, resolution, validation and confidence score). Finally, the KEA criteria that match the dataset are provided against each dataset. Overall, 27 datasets are presented here, many of which have multiple data layers (see sections 3.2 – 3.10 for further details).

In each of the sub-sections below, we first provide an example figure of the types of areas or data relevant to each of the KEA criteria, and an overview the data which includes a list of the layers contained within the dataset. For datasets with a large number of layers, these are either listed in broad categories or listed in full in Appendix 1. We then go on to describe the data in detail, list the matching criteria, and discuss and data limitations and consideration for their future use.

Table 3-1: Overview of data matching Key Ecological Area criteria. For KEA criteria codes see Table 1-1. Note for polygon or points data the data resolution is not applicable (not gridded data). Note for point data there is no measure of validation. * the confidence score is for each layer within the datasets resulting in some datasets having a range of confidence scores. Na is used for those data where the measure is not applicable, e.g., polygons do not have a gird resolution.

Data Name	Brief description	Data format	Data extent	Data resolution	Validation	Confidence score *	KEA criteria
Regional Council identified important areas (e.g., SEAs, SNAs, SCAs)	Various layers representing important areas identified in regional council plans: Significant Ecological Areas (Auckland Council); Significant Conservation Areas (Canterbury RC); Indigenous Biodiversity (Greater Wellington RC); Significant Conservation Areas (Hawkes Bay RC); Natural Character (Waikato RC & Northland RC); Outstanding Natural Features and Landscapes (Northland RC & Otago RC); Marine Areas of Conservation (Gisborne RC & Northland RC); Coastal Natural Character Rating (Marlborough RC); Threatened Environments (Marlborough RC); Marine Mammal Bird Sites (Otago RC).	Polygons	Regional	Na	Not known	Low – high	1; 2; 3; 4; 6; 8; 9
Sensitive Environments	15 biogenic habitats defined, and mapped (from a number of sources) (Anderson et al. 2018).	Various	Regional - National	various		Low – high	1; 3; 4; 5; 8; 9
Vulnerable Marine Ecosystems (VME)	Predicted distribution of occurrence and associated uncertainty layers of 11 indicator taxa for Vulnerable Marine Ecosystems (VME) (Anderson et al. 2016b).	Raster	National - only deep water	1 km2	semi-validated (bootstrapped models)	High	1
Marine reef fish	Predicted distribution (occurrence) and relative abundance of 72 shallow coastal species of rocky reef fishes (Smith et al. 2013).	Raster	National only shallow water	1 km2	semi-validated (bootstrapped models)	High	3; 5; 8
Seabird distributions	Population and at-sea distributional data for 70 species of seabird (separate maps for the non-breeding and breeding distributions)(BirdLife International and NatureServe, 2015).	Raster	National	1 km2	No	Moderate	2; 3; 6

Data Name	Brief description	Data format	Data extent	Data resolution	Validation	Confidence score *	KEA criteria
Vulnerable fragile, sensitive, or slow to recover species.	Example data collated: species records (locations) for all shark species with consequence scores greater or equal to 4 from Qualitative shark risk assessment report for both Quota Management system and non QMS species (Ford et al. 2018).	Point data	National	Na	Na	High	1; 2
Fish records	Fish records (locations) extracted from OBIS, TRAWL & NIWA invert (2015 extract for project: Lundquist et al. (2015b). Records were groomed and quality controlled.	Point data	National	Na	Na	Low – high	2; 4
Benthic invertebrate records	Benthic invertebrate records (locations) extracted from OBIS, TRAWL & NIWA invert (2015 extract for project: Lundquist et al. (2015b). Records were groomed and quality controlled.	Point data	National	Na	Na	Low – high	2; 4
Marine mammal and reptiles sightings	Marine reptile records (locations) extracted from OBIS, TRAWL & NIWA invert (2015 extract for project: Lundquist et al. 2015). Records were groomed and quality controlled. Marine Mammal records (locations) from MPI database (collated from multiple sources - 2014) (Stephenson et al. unpublished).	Point data	National	Na	Na	High	4; 6
Hydrothermal vents	Locations of known hydrothermal vents from the Global Database of Active Submarine Hydrothermal Vent Fields (InterRidge, 2016).	Point data	National	Na	Na	High	2; 5
Cold seeps	Locations of methane seeps resulting from three cruises in 2006-2007 using multibeam backscatter data, water column hydroacoustic and visual data (Greinert et al. 2010).	Point data	National	Na	Na	High	2; 5
Marine mammal distributions	Predicted distribution (occurrence) of 33 cetacean species (Stephenson et al. in prep).	Raster	National	1 km2	semi-validated (bootstrapped models)	High	4; 6

Data Name	Brief description	Data format	Data extent	Data resolution	Validation	Confidence score *	KEA criteria
Demersal fish species turnover and classification	Predicted demersal fish species turnover and community assemblages (30; 50; 100 groups) (Stephenson et al. 2018).	Raster	National	1 km2	Validated	High	2; 6
Benthic invertebrate species turnover and classification	Predicted benthic invertebrate species turnover and community assemblages (30; 50; 100 groups) (Stephenson et al. unpublished – see appendix 0 for further details on results and methodology).	Raster	National	1 km2	No	Moderate	2; 6
Demersal fish species richness	Predicted demersal fish species richness (Leathwick et al. 2006).	Raster	National	1 km2	semi-validated (bootstrapped models)	High	6
Benthic invertebrate species richness	Predicted benthic invertebrate species richness (Stephenson et al. unpublished – see appendix 0 for further details on results and methodology).	Raster	National	1 km2	semi-validated (bootstrapped models)	Moderate	6
Naturally uncommon habitats in NZ coastal environment	Identification and mapping of naturally uncommon habitats in NZ coastal environment (Wiser et al. 2013).	Polygons	National - only coastal			Moderate	2; 4
Fish spawning grounds	Annual spawning distribution for 39 species (NABIS, 2012). Hotspot of annual spawning distribution (Stephenson et al. unpublished).	Polygons	National			High	3
Seal breeding grounds	Location of seal colonies and haul-outs (NABIS (2012); DOC, unpublished).	Polygons	National			Moderate	3

Data Name	Brief description	Data format	Data extent	Data resolution	Validation	Confidence score *	KEA criteria
Bird feeding and breeding grounds	Location of Important Bird Areas (IBA) (Forest & Bird, 2014).	Polygons	National			Moderate	3
Inshore and offshore Productivity	Near-surface chlorophyll-a concentration (mg m^{-3}, proxy for water column primary productivity) estimated from satellite ocean colour observations (Pinkerton, 2016;Pinkerton et al. 2018).	Raster	National	500m – 4 km	Some regional validation	Moderate - high	5
Ecosystem service: Biogenic habitat provision	Predicted biogenic habitat provision using ecosystem services rule based mapping (Townsend et al. 2014b).	Raster	National – only coastal	1 km2	Validated (regionally)	Moderate	8
Bottom fishing footprint	Trawl footprint (swept area), targeting deepwater Tier 1 and Tier 2 fishstocks from the 1990 to 2016 (offshore) (Baird and Wood, 2018) and area swept by the trawl gear in New Zealand waters shallower than 250 m (inshore) (Baird et al. 2015).	Polygons	National			High	7
Other trawl/dredge/ recreational footprint	Heat maps and spatial estimates of commercial fishing (all methods); dredging effort; and recreational fishing (annual estimates provided here for a subset of the data from 2007 - 2016) (Osborne, 2018).	Raster	National	1 km2		Moderate - high	7
Area-based marine protection	Location of protected areas including: Benthic Protected Areas; Seamount Closures; Type II MPAs; Marine Mammal Sanctuaries; Marine reserves.	Polygons	National			NA	7
Land use layers	Land use layers as indication of land-sea connectivity of stressors: includes, Land cover class, protected areas, population mesh grid, river catchments (Lundquist et al. unpublished).	Polygons	National			High	7
Depth-related refuge areas	Unfishable depths of the marine environment were defined as deeper than 1600m (NIWA, 2016).	Raster	National	1 km2		High	7

3.2 Criteria: Vulnerability, fragility, sensitivity, or slow recovery

3.2.1 Regional Council identified important marine areas

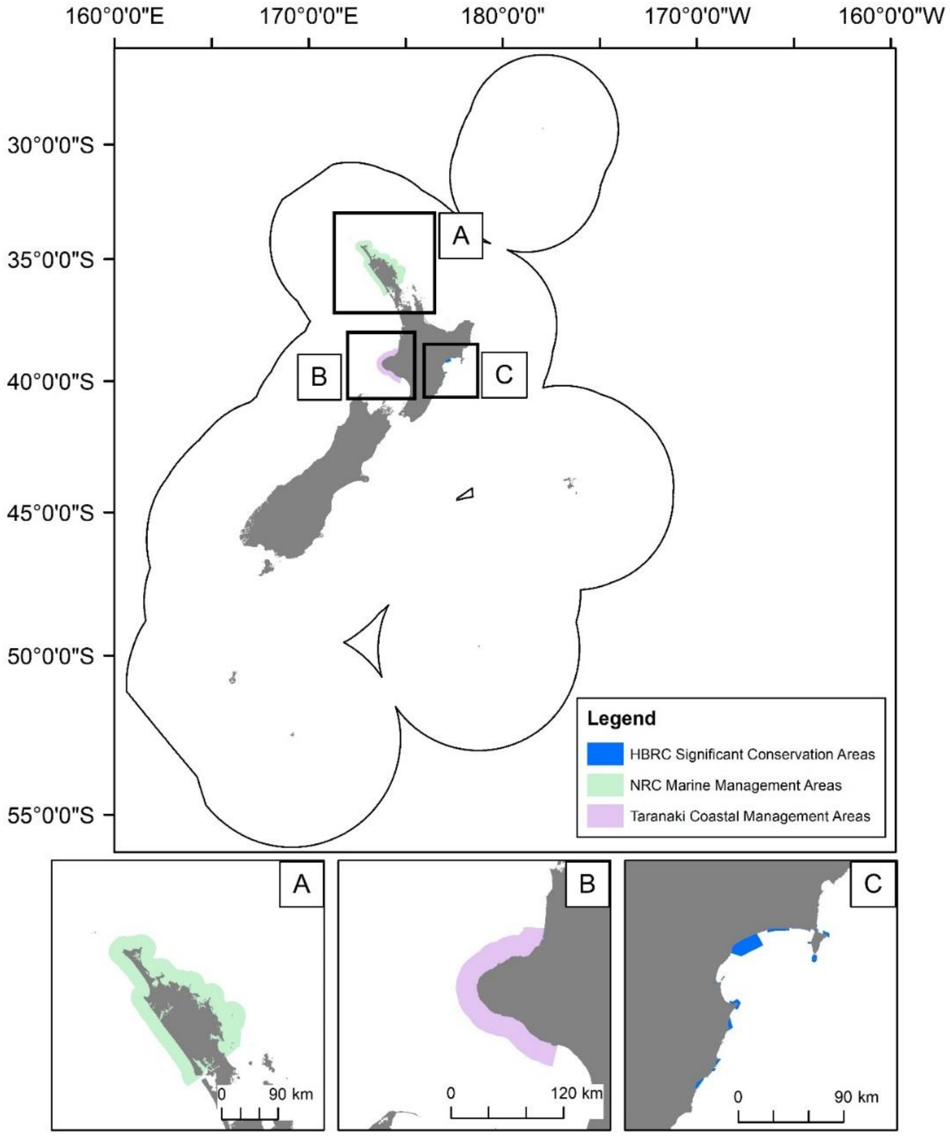

Figure 3-1: Example significant coastal marine areas designated by New Zealand Regional Councils. Inset maps: A) Outstanding Natural Features and Landscapes (Northland); B) Coastal Management areas (Taranaki); C) Significant Conservation Areas (Hawkes Bay).

1. Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Varies depending on council; most are polygons, however some are only available as text descriptions of approximate geographic locations.	Regional.	Varies between regional councils.	Low – High.	Significant Conservation Areas; Indigenous Biodiversity; Natural Character; Outstanding Natural Features and Landscapes; Marine Areas of Conservation; Coastal Natural Character Rating; Threatened Environments; Marine Mammal Bird Sites.

Description of data

Many Regional and District Councils have assessed the ecological significance of the coastal marine area to assist in fulfilling obligations under Policy 11 of the 2010 New Zealand Coastal Policy Statement (NZCPS) and Section 6(c) of the Resource Management Act and in many cases have mapped these ecologically important areas (for example Significant Ecological Areas – Marine (Auckland Council); Significant Coastal Areas (Canterbury). Some Councils have "first generation" Coastal Plans, which refer to the 1994 version of the NZCPS. Criteria used to identify regionally important marine areas overlap heavily with KEA criteria; in order to avoid confusion, matching of the KEA criteria is described in this section (section 3.2.1) rather than in multiple KEA criteria sections.

Typically assessed at regional spatial scales, the focus of the areas is the Coastal Marine Area (CMA; mean high water of spring tides to the 12-mile territorial seas boundary), and areas are identified for their significance both as habitats and in supporting species/biodiversity Figure 3-1. There is no nationally-accepted set of criteria for defining or identifying significant coastal biodiversity, as required by Section 6(c) of the Resource Management Act, 1991, and New Zealand territorial authorities currently use differing approaches. However, guidance for applying Policy 11 of the NZCPS is nearing publication and older versions of Coastal Plans referred to criteria for identifying Areas of Significant Conservation Value.

As an example, the Auckland Council Significant Ecological Areas (SEAs) are areas of significant indigenous vegetation or significant habitats for indigenous fauna which are locations of national importance under section 6(c) of the RMA (Lundquist and Smith, 2014). The designation of sites as SEAs assists Auckland Council in fulfilling statutory and non-statutory obligations within the Auckland Plan, the Resource Management Act 1991 (RMA), the New Zealand Coastal Policy Statement (NZCPS) and Auckland Council's Indigenous Biodiversity Strategy (Auckland Council, 2011). The identification and protection of marine SEAs contributes to the maintenance and protection of indigenous marine biodiversity. SEAs for coastal and marine habitats have been identified using five criteria that were initially developed for identification of terrestrial significant areas. These include:

1. representativeness
2. threat status and rarity
3. diversity
4. stepping stones, migration pathways and buffers, and
5. uniqueness or distinctiveness.

SEAs have been identified in the Auckland CMA and specified as to the following categories:

- SEAM1: Areas which, due to their physical form, scale or inherent values, are considered to be the most vulnerable to any adverse effects of inappropriate subdivision, use and development.
- SEAM2: Areas are of regional, national or international significance which do not warrant an SEAM1 identification as they are generally more robust.
- SEAM1w and SEAM2w: Areas that are identified as significant wading bird areas.

Existing SEA-Ms vary substantially in scale, from individual beaches or intertidal flats (e.g., shell and sand banks at the entrance to Waipipi Creek) or small bays (e.g., Te Matuku Bay, Waiheke Island) to entire large estuaries or coastal expanses (e.g., Long Bay and Okura Estuary; Whangaparaoa Peninsula). Features listed in the site descriptions for these SEA-Ms are variable, and include: being significant habitat for wading birds; having intact vegetation sequences; containing one of few remaining intact habitats or areas important for threatened species; being a best example of a representative habitat type found in the Auckland region; and/or having unusually high diversity of marine species and habitats.

Auckland SEAs were determined to be significant on an individual basis and based on available information rather than a comparative assessment of the whole coastal marine area. A systematic identification of these areas was completed in the early 1990s using available information at the time; however, it included primarily nearshore coastal habitats and/or are areas of importance for wading birds from legacy Coastal Protection Areas (CPAs) and did not extend offshore. Therefore, some habitats (particularly subtidal habitats) and life cycle requirements of key species have not been comprehensively assessed, and are under-represented in the current list of SEA-Ms. Details of other designated areas are provided in the metadata (Appendix 1, section 7.1).

Matching criteria: All KEA criteria listed (1, 2, 3, 4, 6, 8, 9).

Fenwick (2018) recently reviewed regional criteria against eight internationally recognised significance categories (Asaad et al. 2017), with these categories broadly overlapping the criteria identified by iSAG (Table 3-2). This review suggests that regional and district council derived areas of significance commonly cover most of the identified KEA criteria; however individual sites are selected for the satisfaction of at least one criteria, and typically are not prioritised higher if they happen to satisfy multiple significance criteria.

Table 3-2: Matching significance criteria used by various regional and district councils. Table data refer to sections within council policy documents and schedules where each criteria is found. Table content based regional review of criteria presented in Fenwick et al. (2018). Note not all regional data presented in this report are in the table below.

Significance criteria		Unique, rare habitat	Fragile, sensitive habitat	Ecological integrity	Representa-tiveness	Species of conservation concern	Restricted range species	Biological diversity	Important for species' life history
Equivalent criteria in Table 1-1		2	1	8		4	2	6	3
Auckland CMA (Auckland unitary plan, Schedule 4)	Significant Ecological Areas – Marine (SEAs)		2f	4a-b, 5a-b, 5d, 6d	6a-b, 6e	1a, 2a-e, 3a-b, 5d,		4a-c, 6e	2a-e, 5c, 6c, 6f
Waikato CMA (The Waikato regional policy statement, Chapter 11a)	Areas of significant indigenous biodiversity (ASIB)	2, 5	2	7, 9, 10	6, 7	1, 2, 3, 4	4	10, 11	8
West Coast (proposed regional coastal plan (2016), Schedule 2	Wetlands (Terrestrial environment categories)	2, 7a-c, 8b,	8	1d, 3a(ii), 7e, 8a,	3a(i), 3a(ii), 3b(i), 7e	7a-b, 7d,	8c	1a, 1c	1b, 1c
Northland CMA (Regional coastal plan for Northland)	Areas of important conservation value	4c,		4a,	4a,	3, 4, 5a, 5b, 6			4b, 4d, 5c,

Significance criteria		Unique, rare habitat	Fragile, sensitive habitat	Ecological integrity	Representa-tiveness	Species of conservation concern	Restricted range species	Biological diversity	Important for species' life history
Wellington CMA (Proposed regional policy statement (2010): Policy 22 AND Proposed natural resources plan for the Wellington region (2018): Policy P40 (d))	Ecosystems & habitat-types in the CMA	a(ii)		d(i)	a(i)	b, d(ii)		c, d(i)	d(ii)
Tasman District Council Coastal Areas (Tasman resource management plan (2018): Schedule 10C)	Ecosystems & areas	3		4, 5, 6	2, 4	1		2, 6	7
Marlborough District Council CMA (Proposed Marlborough environment plan (2016))	Habitat, area, ecosystem	4, 8	14	1, 2, 3, 7, 10, 13, 14	1, 10	5, 6	6	7, 11	12
Environment Southland CMA (Southland regional policy statement (2017))	Habitat, area, ecosystem	b(i), b(iv)	d(i)	c(i), d(i), d(ii), d(iii)	a(i), a(ii)	b(ii)	b(iii), b(iv)	c(i), d(iii)	d(iii)

Data limitations and consideration for future use

While regional councils broadly overlap in most criteria for designation of significant ecological areas, all councils have slight differences in which criteria are emphasised, in the process by which the areas were identified (as shown in Table 3-2) and in the version of the NZCPS used in development of their planning documents. Significant ecological area layers are occasionally developed through systematic mapping exercises; however, most were ad-hoc processes where known high value areas were identified based on anecdotal evidence, occasionally supported by further systematic assessment (though in no case has the entire CMA been systematically surveyed, including both intertidal and subtidal habitats) (Bellingham et al. 2017). Typically, these areas are over-weighted toward the protection of wading bird habitat and pristine coastal vegetation. Bellingham et al. (2017) reviewed national significance criteria, and identified a key limitation for marine significance assessments being a combination of significant gaps in regional and national data (including historical data) which make it difficult to assess the quality and state of marine habitats. A further lack of habitat classification that adequately represents the biodiversity in soft sediment habitat challenges the identification of representative (and high quality) habitat types that cover the spatial variation in diversity of marine ecosystems. Changing ecological values from invasion by indigenous and non-indigenous species, and sea level rise weaken these as a planning tool, as SEA designations are rarely revised.

The data layers and information utilised in the mapping of significant areas identified in coastal planning documents may be useful for filling data gaps relating to KEAs, particularly at regional scales, however, further work would be required to match these individual areas or component data layers to the specific KEA criteria.

3.2.2 Vulnerable Marine Ecosystems (VME)

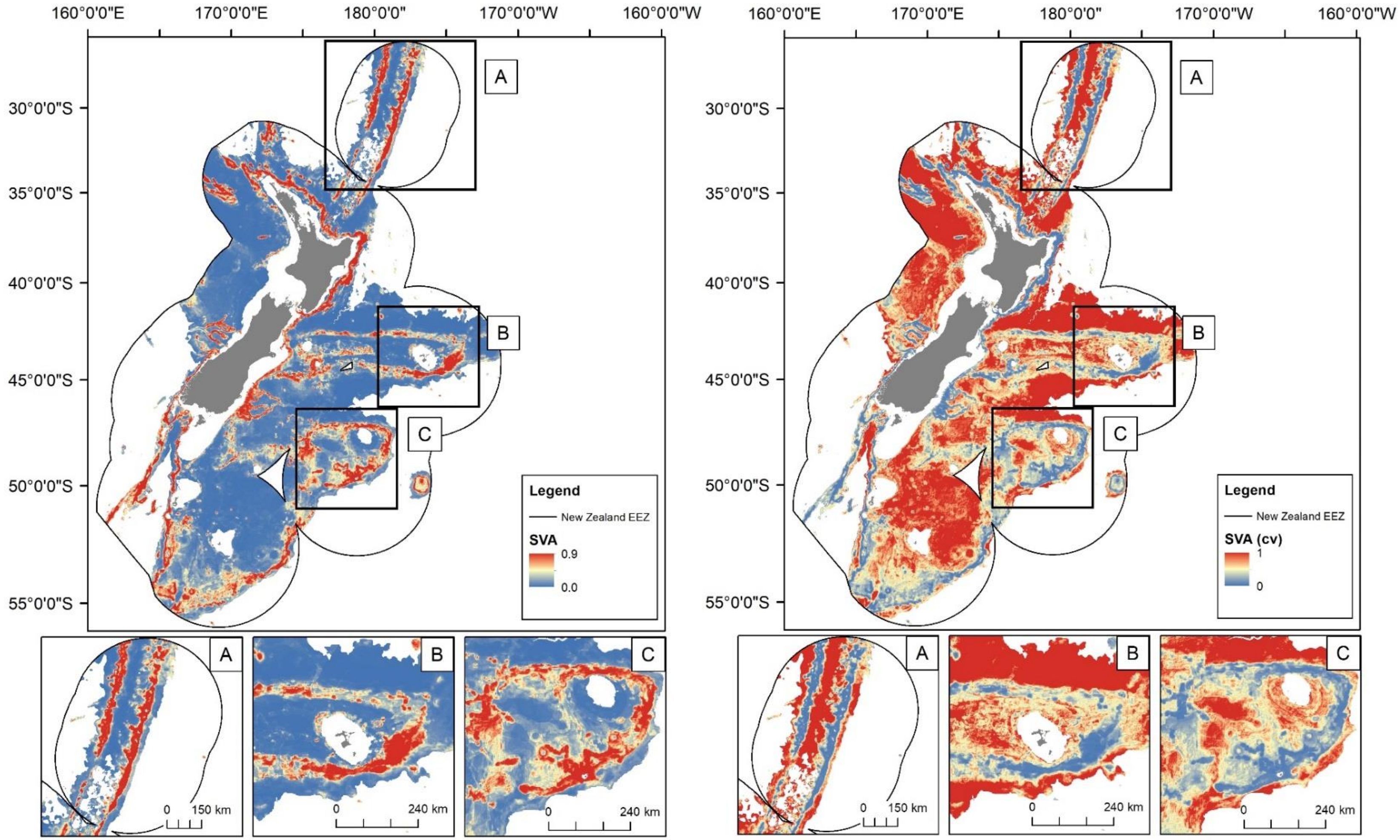

Figure 3-2: Probability occurrence (scale = 0-1) of *Solenosmilia variabilis* (SVA) and associated uncertainty measured as the coefficient of variation (CV) for depths 300 – 3000 m. Inset maps: A) Colville and Kermadec Ridges; B) Chatham Islands; C) Bounty Plateau. Data layers from Anderson et al. 2016.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	NZ EEZ in depths 200-3000m at 1km grid resolution.	Not validated but bootstrapped mean and uncertainty layers created.	High	Scleractinia (stony corals): *Enallopsammia rostrata, Madrepora oculata, Solenosmilia variabilis, Goniocorella dumosa*; Demospongiae and Hexactinellida (sponges); Pennatulacea (sea pens); Antipatharia (black corals); and Stylasteridae (hydrocorals).

Description of data

The predicted distribution of suitable habitat of nine indicator taxa for Vulnerable Marine Ecosystems (VMEs), and associated model uncertainty layers, were sourced from Anderson et al. (2016b). VME indicator taxa modelled included: Four species of reef forming Scleractinia (stony corals) (*Enallopsammia rostrata, Madrepora oculata, Solenosmilia variabilis, Goniocorella dumosa*); Demospongiae and Hexactinellida (sponges); Pennatulacea (sea pens); Antipatharia (black corals); and Stylasteridae (hydrocorals). These taxa are a sub-set of the VME indicator taxa identified by Parker et al. (2009) for the South Pacific Ocean.

Location data of VME indicator taxa collated from multiple databases (New Zealand and Australian museum records, fisheries research databases, and online biodiversity databases, with additional records for the Louisville Seamount Chain from a 2014 survey (Clark, 2015)) were combined with relevant environmental predictor variables to produce habitat suitability models using two machine-learning model approaches, MaxEnt (Phillips et al. 2006) and Boosted Regression Trees (BRT) (Elith et al. 2006) which were combined into ensemble models. Predictions of habitat suitability were then made for each 1 km grid cell of the modelled area (New Zealand TS and EEZ in water depths 300-3000 m). This process was repeated 200 times for BRT, 100 times for MaxEnt allowing for mean habitat suitability estimates, as well as coefficient of variation (CV) to be produced for each grid cell in the model extent. Figure 3-2 shows an example of the habitat suitability prediction for the stony coral *Solenosmilia variabilis*. The ensemble models had a range of model fits (BRT AUC of evaluation data: 0.82 – 0.94; MaxENT AUC of evaluation data: 0.78 - 91), but all results provided a robust estimate of the distribution of habitat suitability for these taxa, and therefore their likely distribution, given the available input data (Anderson et al. 2016).

Matching criteria: Vulnerability, fragility, sensitivity, or slow recovery.

VMEs are ecosystems which are at significant risk from the effects of fishing activity, as determined by the vulnerability of their components (FAO, 2009). The following list of characteristics are used as criteria in the identification of VMEs: uniqueness or rarity; functional significance of the habitat; fragility; life-history traits of component species that make recovery difficult; and structural complexity (FAO, 2009). According to these criteria, Parker et al. (2009) identified 8 major taxonomic groups as VME indicator taxa in the South Pacific Ocean, and a further two taxa that (although not satisfying the VME criteria themselves) were also indicators of VMEs because they were often found in association with VME habitat formed by VME indicator taxa such as stony corals. The 8 major taxonomic VME indicator taxa match the KEA criterion of Vulnerability, fragility, sensitivity, or slow recovery, which is why the modelled distribution of suitable habitat for representatives of most of these groups are included here. Habitat suitability models for the VME habitat associating taxa Brisingida (sea-stars) and Crinoidea (crinoids) are not included here because high resolution models have shown that they are not a particularly good proxy for the predicted distribution of the stony coral *Solenosmilia variabilis* (Rowden et al. 2017).

Data layers for some of the VME indicator taxa could arguably be used to match other KEA criteria. For example, coral reefs and sponge gardens are biologically productive and diverse, can provide habitat to support key life history stages of some species, and thus support ecosystem function and provide ecosystem services (e.g., for deepwater coral reefs: Henry and Roberts (2007);Rowden et al. (2010);Baillon et al. (2012);Cathalot et al. (2015)) (criteria 3, 5, 6, 8, 9, respectively). However, the habitat suitability predictions for the VME indicator taxa associated with coral reefs and sponge gardens are for probability of presence only, rather than for the habitat itself. The data layers for habitat suitability presented here for coral and sponge VME indicator taxa could be modified to represent a particular probability level of occurrence that is likely to better predict the presence of coral reefs and sponge gardens (e.g., habitat suitability of > 0.5). However, there is uncertainty about the level of probability of occurrence that should be used for the different taxa, and the general applicability of such levels over the entire EEZ. As such, it is more sensible to represent the additional criteria using data layers detailed in the sections describing those criteria.

Data limitations and consideration for future use

The modelled taxa represent the majority of the taxa deemed to be VME indicator taxa for the Pacific Ocean by Parker et al. (2009); however, Actiniaria (sea anemones) and Alcyonacea (gorgonians and other alcyonaceans) are also considered to be VME indicator taxa by Parker et al. (2009). These latter two taxa were not modelled by Anderson et al. (2016b) since these are large and diverse groups which previous work has shown to result in low model performance (Anderson et al. 2014).

The raster data format, and the fine-scale resolution of the models (compared to the study area as a whole), makes these data layers particularly suitable for use in spatial management planning tools, e.g., *Zonation* or *Marxan* (Anderson et al. 2016b). However, the models have not been validated using new and targeted field data (i.e., independently 'ground-truthed'). Until such field validation has been conducted (see Anderson et al. (2016a) for an example of a field validation for a model of a VME indicator taxon across the entire South Pacific) an assessment of the uncertainty associated with these models is incomplete.

However, the robustness of the spatial model predictions can somewhat be assessed using the bootstrapped estimates of variability (measured as the coefficient of variation). The availability of these uncertainty layers are important to include in systematic conservation planning (e.g., using *Zonation*) so as to ensure that negative consequences of using an unreliable model for conservation are avoided (i.e., avoid selecting of areas with high predicted conservation value, but low model certainty (Moilanen et al. 2009;Kujala et al. 2013).

Modelled predictions for VME indicator taxa in New Zealand waters have been produced iteratively, with the reliability of the outputs increasing with each new iteration (Anderson et al. 2014;Anderson et al. 2016a;Anderson et al. 2016b). Further iterations of these models have been produced (Georgian et al. in review – which include models for Alcyonacea) but are not yet available, or are planned (Anderson et al. pers comm). Planned models including predicting changes in distribution of

VME indicator taxa over time and the influence of climate change and ocean acidification, and predicting the distribution of VME indicator taxa are not yet modelled. These datasets will be useful for future KEA analysis.

The VMEs indicator taxa presented here, are specifically vulnerable, fragile, sensitive, or slow to recover from the effects of bottom fishing. Although these same taxa possess the same characteristics that make them likely to be susceptible to impacts from a number of other anthropogenic activities, these have not been formally assessed. In the future it would be useful to formally identify VME indicator taxa with respect to their vulnerability to anthropogenic disturbances that are, or could occur in the New Zealand TS and EEZ (e.g., seabed mining), and generate spatial predictions of their distribution for use in MPA planning.

3.2.3 Sensitive Environments / Biogenic Habitats (marine)

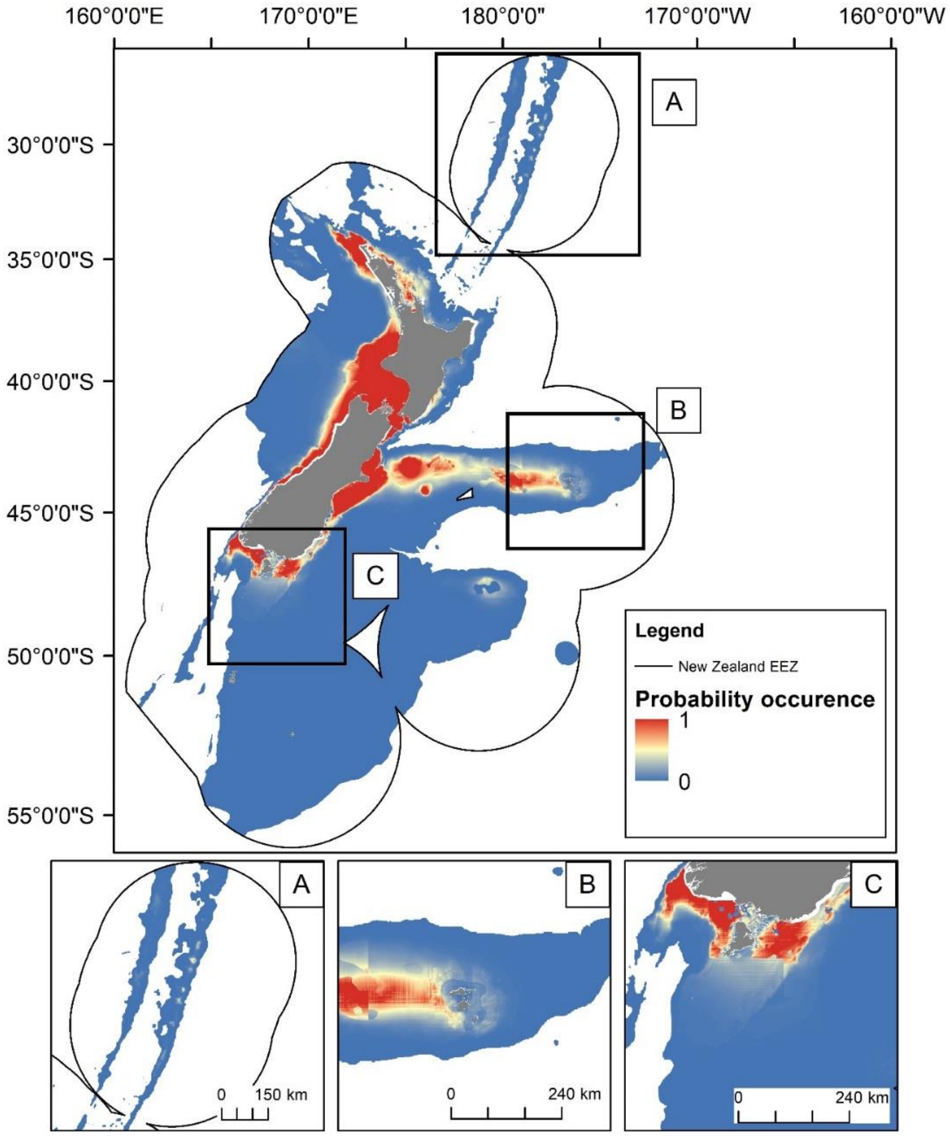

Figure 3-3: Probability occurrence (scale = 0-1) of *Cellaria immersa* to depths of 2500m (Wood et al. 2013). Inset maps: A) Colville and Kermadec Ridges; B) Chatham Islands; C) southern tip of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Point data; polygon; raster.	Regional – national.	Not validated. Some modelled data were bootstrapped and uncertainty layers created.	Low – high.	Seagrass; Mangroves; Kelp forest (incl. Macrocystis as a significant species); Algal Meadows (e.g., Caulerpa and Adamsiella); Rhodoliths; Bryozoan Thickets; Sponge Gardens; Large habitat-forming shellfish; Calcareous Tubeworms; Non-Calcareous Tubeworms; Stony Corals (reefs and thickets) and other 3D Corals (Trees, Bushy, Fans); Seapens – Whips; Xenophyophores.

Description of data

Collated data for 15 key biogenic habitats that occur within New Zealand's EEZ and territorial waters were sourced from and are described in Anderson et al. (2018). The purpose of Anderson et al. (2018) was to collate information on New Zealand's coastal and oceanic biogenic habitats to be used in the New Zealand government's 2019 State of the Marine Environment Report, to improve the public's understanding of the current state, impacts and pressures on the marine environment. Data for these habitats were collated from multiple databases and sources (e.g., New Zealand and Australian Museum records, fisheries research databases, and online biodiversity databases, research institutes and agency databases, VME indicator taxa [as described in Anderson et al. (2018)). Of the 15 key biogenic habitats reviewed, all, except for possibly mangroves, can be considered either vulnerable, fragile, sensitive, and/or slow to recover. National distribution and spatial data layers exist for seagrass (and mangrove) habitats in DOC's 2018 online Seasketch database (described in Anderson et al. 2018). National scale data for other habitat-forming species rely mostly on presence-only point data from specimen collections (Table 2-1 in Anderson et al. 2018), with some limited abundance data from targeted research and fisheries surveys (e.g., bryozoans, sponges, scallops, horse mussels) used to provide stronger evidence for the presence of biogenic habitats. Additional spatial data layers, are also available, these include: The predicted distribution of 11 frame-building (habitat-forming) bryozoan and associated model uncertainty layers (Maxent at 1 km2 grid) sourced from Wood et al. (2013) (see Figure 3-3). Local Ecological Knowledge (LEK) interviews of long-time fishers depict the areas (hand-drawn polygons) of known biogenic-habitat or foul ground around New Zealand. These data provide valuable insight not only into where biogenic habitats may occur (Table 2.2. in Jones et al. (2016)), but, in combination with benthic fishing effort data, also infer the importance of these habitats to fisheries (e.g., bryozoan reefs, sponge gardens, tubeworm fields) and their likely vulnerability to benthic fishing activities (e.g., Morrison et al. (2014a), table 65 of Jones et al. (2018), figure 3-4 in Anderson et al. 2018). Some areas designated in the LEK maps, such as the tubeworm fields off Timaru, the bryozoan reefs off

Otago and Foveaux Strait and the sponge gardens off Spirits Bay have been verified by research surveys (e.g., Batson and Probert (2000);Carbines and Cole (2009);Jones et al. (2018)), some corroborated by historical fishery catch data (e.g., Batson and Probert (2000);Carbines and Cole (2009)), while others remain unverified. Distribution data on some of the key biogenic habitats (e.g., non-calcareous tubeworms, rhodoliths and Xenophyophores) is very limited - reflecting few specimen collections and low numbers of targeted surveys in New Zealand waters.

Matching criteria: Vulnerability, fragility, sensitivity, or slow recovery.

Biogenic habitat are *habitats created or brought about by living organisms*. The majority of the 15 key biogenic habitats defined and reviewed in Anderson et al (2018) are also listed as sensitive environments in MacDiarmid et al. (2013). Each of these 15 key biogenic habitats are either vulnerable, fragile or sensitive, with many also known to be slow to recover from impacts. Of these habitats, several are comprised of hard and fragile structures (e.g., bryozoan reefs, cold-water corals [but see VME's for this group] and calcareous tubeworm mounds/towers) that are highly vulnerable to physical disturbance (e.g., benthic fishing activities, dredging and even anchor damage), and are very slow to recover following impacts (Anderson et al. 2018). Other biogenic habitats (e.g., sponge gardens, non-calcareous emergent tubeworms, algal meadows and sea pens) are comprised of softer or less rigid structures that may provide some physical flexibility in the face of physical disturbance, whereby providing some initial resilience to low-frequency physical impacts, but not too frequent or intense impacts, such as dredging or ongoing benthic fishing activities. Biogenic habitats such as seagrass, mangroves, kelp-forests are known to be sensitive to local land-based impacts and environmental change (Morrison et al. 2009) and may provide key indicators of climate change (review in Anderson et al. 2018). Distribution data on a few key biogenic habitats (e.g., non-calcareous tubeworms, rhodoliths, sea pens and Xenophyophores) is very limited, with vulnerability, sensitivity and recovery rates thought to be of concern.

Limitations and consideration for future use

Most of the 15 key biogenic habitats are represented by presence-only data (i.e., no abundance or absence data) for those species known to form-habitats. As most species that form biogenic habitats can also grow as singletons, presence-only records cannot guarantee the presence of spatially significant biogenic habitats. The lack of absence data (i.e., locations searched but where no animal or plant was found) means there is no way to determine if areas with no records represent unsearched areas or areas searched where no specimens were found. Therefore presence-only data should be used cautiously and be combined or verified by other datasets wherever possible. These data have been used to predicted distribution of 11 frame-building bryozoans by Wood et al. (2013). These data span almost a century (1918-2011) as do many of the other biogenic data sets. Consequently, it is unknown whether historic data represent habitats that persist today or no longer exist. Spatially explicit surveys and abundance data for biogenic habitats in New Zealand is limited to targeted and localised studies, but where available, can be used to provide additional weight to those sites where abundance records show high numbers of one or more habitat-forming species. These abundance data rarely have associated sampling effort (area sampled) to compare relative densities between surveys or sites. However, integration of these data with other data layers in the KEA criteria may provide additional weighting to discern some level of comparative importance.

3.2.4 Vulnerable chondrichthyan species

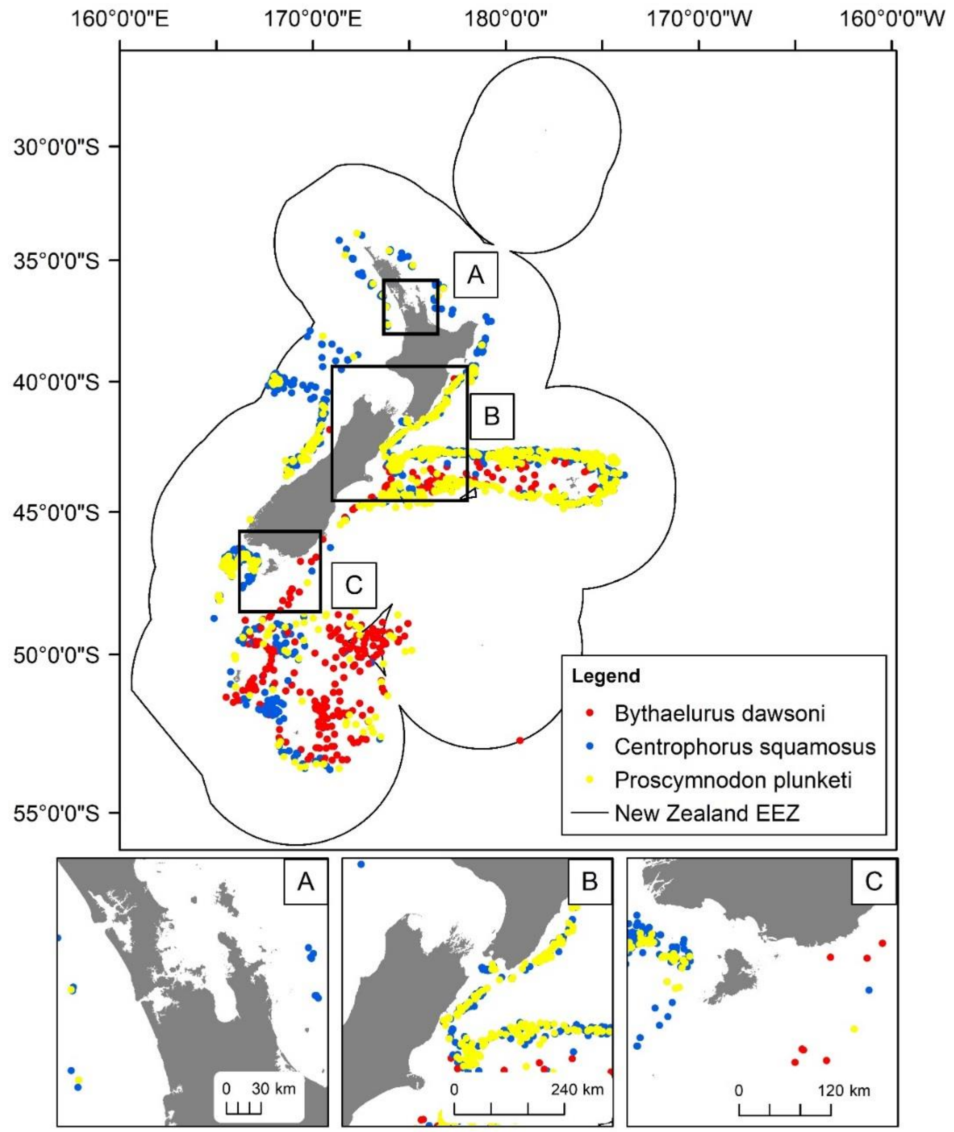

Figure 3-4: Species records (locations) for all shark species with consequence scores greater or equal to 4 from the Qualitative shark risk assessment report for both Quota Management system and non QMS species (Ford et al. 2018). Example species shown here are the most vulnerable species assessed: Dawsons catshark (*Bythaelurus dawsoni* – red circles), Plunkets shark (Pro*scymnodon plunketi* – yellow circles) and leafscale gulper shark (*Centrophorus squamosus* – blue circles). Inset maps: A) north of the North Island; B) Cook Strait – Tasman Bay and Chatham Rise; C) southern tip of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	High	See Appendix 1, section 7.2, for list of species.

Description of data:

A number of chondrichthyan species (sharks, skates and rays, chimaeras) are slow growing, long-lived, and have low fecundity. These taxa are not covered by the data described in sections 3.2.1, 3.2.2 and 3.2.3. In order to consider such species, the results of a qualitative risk assessment of the impact of commercial fishing on New Zealand chondrichthyans (Ford et al. 2015;Ford et al. 2018) was used to identify species which were deemed to be vulnerable, fragile, sensitive, or slow to recover. The overall risk assessment values were the product of a fishing intensity score (1-6) and a consequence score (1-6) derived from assessment of the literature by an expert panel. Fishing intensity was not considered relevant in this case, but the consequence scores (derived from an evaluation of the productivity of a species) were. Distributional records (from the New Zealand fish records described in section 3.3.1), for all species with consequence scores of 4 or greater were extracted since this was deemed to be a biologically useful breakpoint defined as “Actual or potential for unsustainable impacts” (Ford, pers comm.). Locations of chondrichthyan records, species name, and consequence score were imported to ArcGIS as a feature class of point data.

In total, 32 species were assessed as having a consequence score of 4 or greater (Ford et al. 2018). None of these were species in the QMS. They included a mix of pelagic sharks and rays (e.g., thresher shark, bronze whaler, pelagic stingray), but most were deep-sea shark species (slender smoothound, Portuguese dogfish, Lucifer dogfish, catsharks (*Apristurus* spp.), prickly dogfish, Owstons dogfish, longnose velvet dogfish, shovelnose dogfish, seal shark, Baxters dogfish), skates (Deepwater spiny skate, longnosed deep-sea skate, longtail skate, Brichiraja species) and chimaeras (Pacific spookfish, brown chimaera). Of particular concern with a score of 4.5 were Dawsons catshark, Plunkets shark and leafscale gulper shark (shown in Figure 3-4).

Matching criteria: Vulnerability, fragility, sensitivity, or slow recovery.

A number of chondrichthyan species are either target commercial species, or occur in the same area as other commercial fish species, and are taken as unintentional bycatch in bottom trawl, midwater trawl, or longline fisheries. This makes them potentially vulnerable to fishing pressure. On account of many species having slow growth rates, relatively high age at maturity, high longevity, and low reproductive capacity, they are relatively unproductive compared with many of the commercial fish species. Hence they are slow to recover from overfishing. Such species are effectively equivalent to VME indicator taxa as defined by FAO (2009) and covered in section 3.2.2.

Limitations and consideration for future use:

Productivity information is limited for many chondrichthyan species, especially deep-sea species where for a number of species age and growth, and maturity estimates are poorly known. Nevertheless, the assessment included as much information as possible, including that of similar genera outside New Zealand waters. Ford et al. (2018) note limitations on the overall risk scores due to considering only species distributions within the New Zealand EEZ, and fishing effort and catches over just the last five years. However, neither of these factors influence the consequence score, which is largely based on biology. As further research is carried out on the biology and ecology of deep-sea species, our confidence in this layer will improve.

3.3 Criteria: Uniqueness, rarity and/or endemism

3.3.1 New Zealand fish records

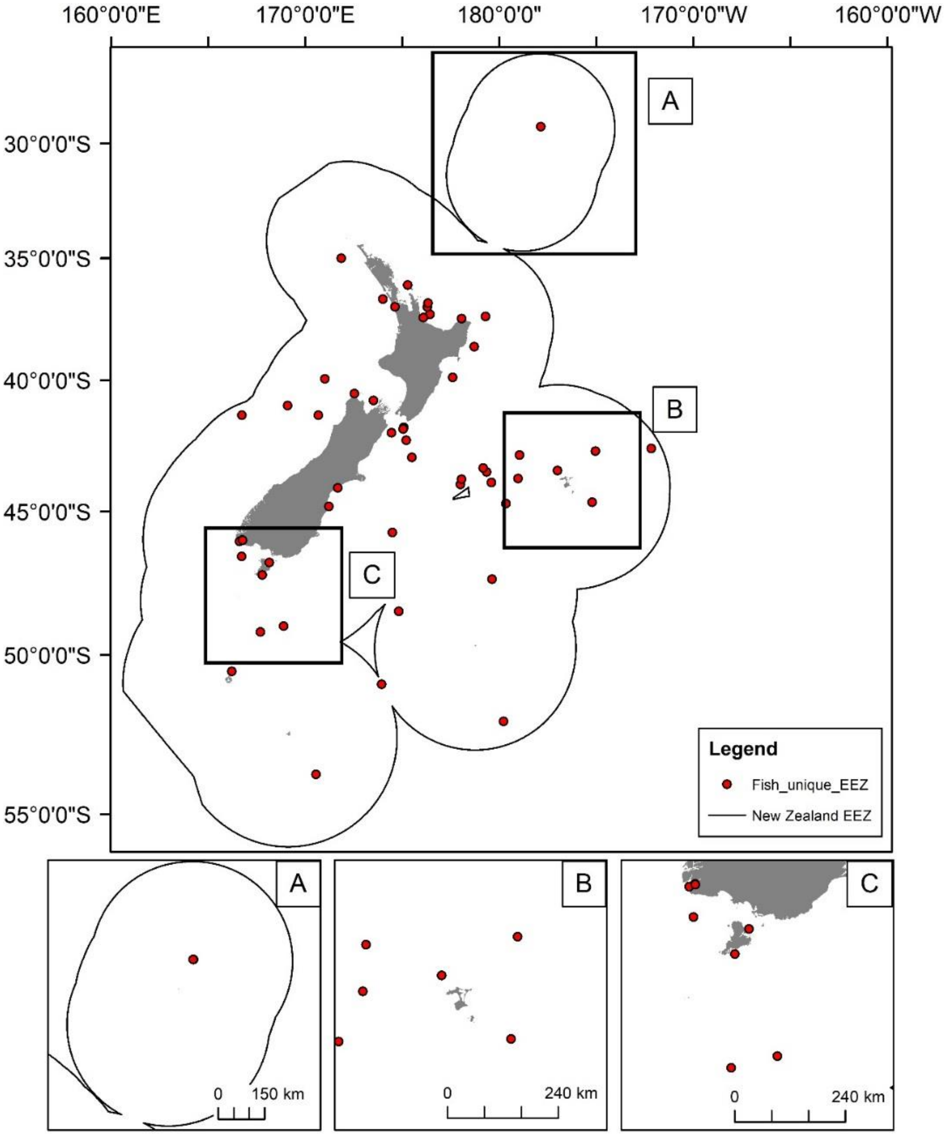

Figure 3-5: Fish records (locations) extracted from OBIS, TRAWL & NIWA invert databases (Lundquist et al. 2015). Example shows unique species: species with a single record in the NZ EEZ. Inset maps: A) Colville and Kermadec Ridges; B) Chatham Islands; C) southern tip of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	High	Single layer.

Description of data:

Fish species records (locations) were extracted from OBIS, TRAWL & NIWA invert databases, and were groomed and quality controlled for an earlier report (2015 records extract; for further details on methods see Lundquist et al. (2015b)).

Fish species records were split into several datasets in order to more accurately match the different aspects of the 'Uniqueness, rarity and/or endemism' criteria:

- Fish species with a single record in the New Zealand EEZ were extracted to reflect 'Unique species' that are extremely rare. These were error checked against likely mis-identification, or a change in taxonomy where the species name has been updated. There were 39 species with a single record which were imported to ArcGIS as a feature class (point data - Figure 3-5).
- Fish species with 2 - 10 records in the New Zealand EEZ were extracted to reflect 'Rare species' and were imported to ArcGIS as a feature class (point data). The values used to reflect rarity were subjectively selected by a group of experts during the first stakeholder meeting. In total, 97 species met this criterion.
- Fish species records were cross-referenced to endemic species listed in Gordon (2009) (information available online at the *New Zealand Organisms Register* - http://www.nzor.org.nz/), extracted and imported to ArcGIS as a feature class (point data) to reflect 'endemic species'. This lists 193 endemic bony fish species/subspecies, and 29 chondrichthyan species/subspecies. Data presented here had records for 79 of these species.

Matching criteria: Uniqueness, rarity, endemism.

The criteria used above separate a unique record (and hence the species is very rare in the New Zealand region) from those that are rare (2-10 records only), and more common species that are only recorded from the New Zealand region.

Unique and rare species are also in a way vulnerable, as they are so rare that accidental capture or a change in environmental conditions in a small area could negatively affect individuals or a small population.

The dataset was also used for identifying threatened/declining species (section 3.5.3).

Limitations and consideration for future use:

Data on rarity are always difficult to interpret, as the rarity might be real, or an artefact of a limited sampling distribution or effort. Several of the species recorded as singletons are small pelagic species, and as such are not well sampled by standard commercial fishing or research trawl nets. Throughout the EEZ, pelagic sampling is much less common than demersal (bottom) sampling. It is likely that a number of species are much more common than indicated here. The databases used often record small fish at a higher taxonomic level-the identification occurs to species level in a research/museum situation, and although museum registers are updated, often the original data records are not. Sampling effort and the type of gear used is also a consideration for whether a species is truly endemic-and over what spatial scale endemism applies. The most recent collation of verified data on species composition and distribution (Roberts et al. 2015) reports 274 species endemic to the New Zealand region, which is almost 22% of the total species number. Future use of these data could benefit from incorporating records from Te Papa and Auckland Museum where these have not been uploaded into OBIS or FishBase.

3.3.2 New Zealand benthic invertebrate records

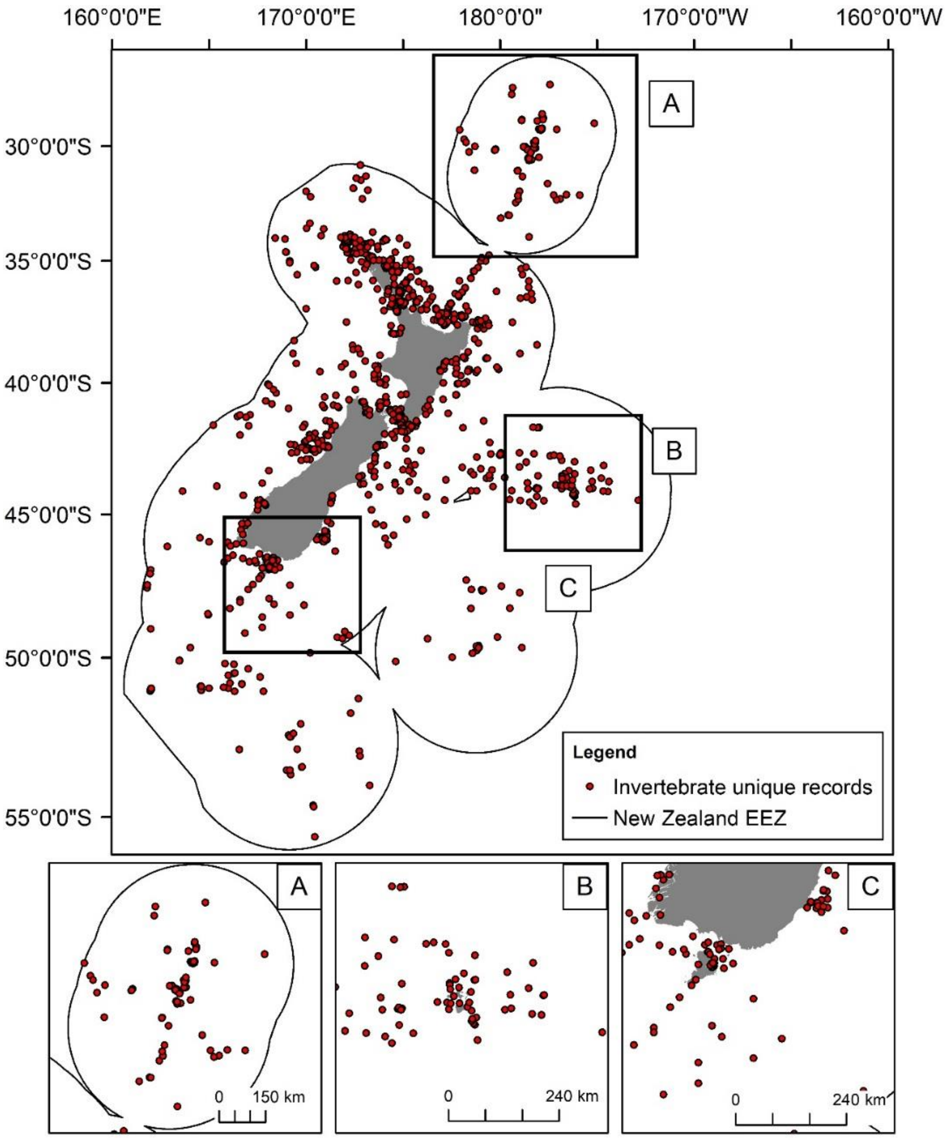

Figure 3-6: Benthic invertebrate records (locations) extracted from OBIS, TRAWL & NIWA invert databases (Lundquist et al. 2015). Example shows unique species: species with a single record in the NZ EEZ. Inset maps: A) Colville and Kermadec Ridges; B) Chatham Islands; C) southern tip of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	Moderate	Single layer.

Description of data:

Benthic invertebrate species records (locations) were extracted from OBIS, TRAWL & NIWA invert, and were groomed and quality controlled for an earlier report (2015 records extract; for further details on methods see Lundquist et al. (2015b)).

Benthic invertebrate species records were split into several datasets in order to more accurately match the different aspects of the 'Uniqueness, rarity and/or endemism' criteria:

- Benthic invertebrate species with a single recording in the New Zealand EEZ were extracted to reflect 'Unique species' and were imported to ArcGIS as a feature class (point data - Figure 3-5).
- Benthic invertebrate species with 2 - 10 records in the New Zealand EEZ were extracted to reflect 'Rare species' and were imported to ArcGIS as a feature class (point data). The values used to reflect rarity were subjectively selected by a group experts during the first stakeholder meeting.
- Benthic invertebrate species records were cross-referenced to endemic species listed in Gordon (2009) (information available online at the *New Zealand Organisms Register* - http://www.nzor.org.nz/), extracted and imported to ArcGIS as a feature class (point data) to reflect 'endemic species'. Data presented here had information for 1627 endemic species.

Matching criteria: Uniqueness, rarity and/or endemism.

This dataset matches the criteria in the same way that the New Zealand fish records do.

Similarly, unique and rare species are also in a way vulnerable, as they are so rare that accidental capture or a change in environmental conditions in a small area could negatively affect individuals or a small population (although see data limitations below). This dataset also offers the opportunity to extend the list of fragile and sensitive species as many benthic invertebrates are liable to damage by bottom disturbance and vary in their sensitivity to numerous stressors (Hewitt et al. 2018).

Limitations and consideration for future use:

The benthic invertebrate records data has similar limitations and considerations for future uses as the fish records discussed in section 3.3.1. However, the limitations, particularly with respect to definitions of uniqueness and rarity are even greater as there are fewer records, larger unsampled areas and probably, a greater number of species to be detected. Further sampling, particularly in presently unsampled environmental space and in areas close to shore is necessary to improve confidence in our results in these locations.

3.3.3 New Zealand marine reef fish records

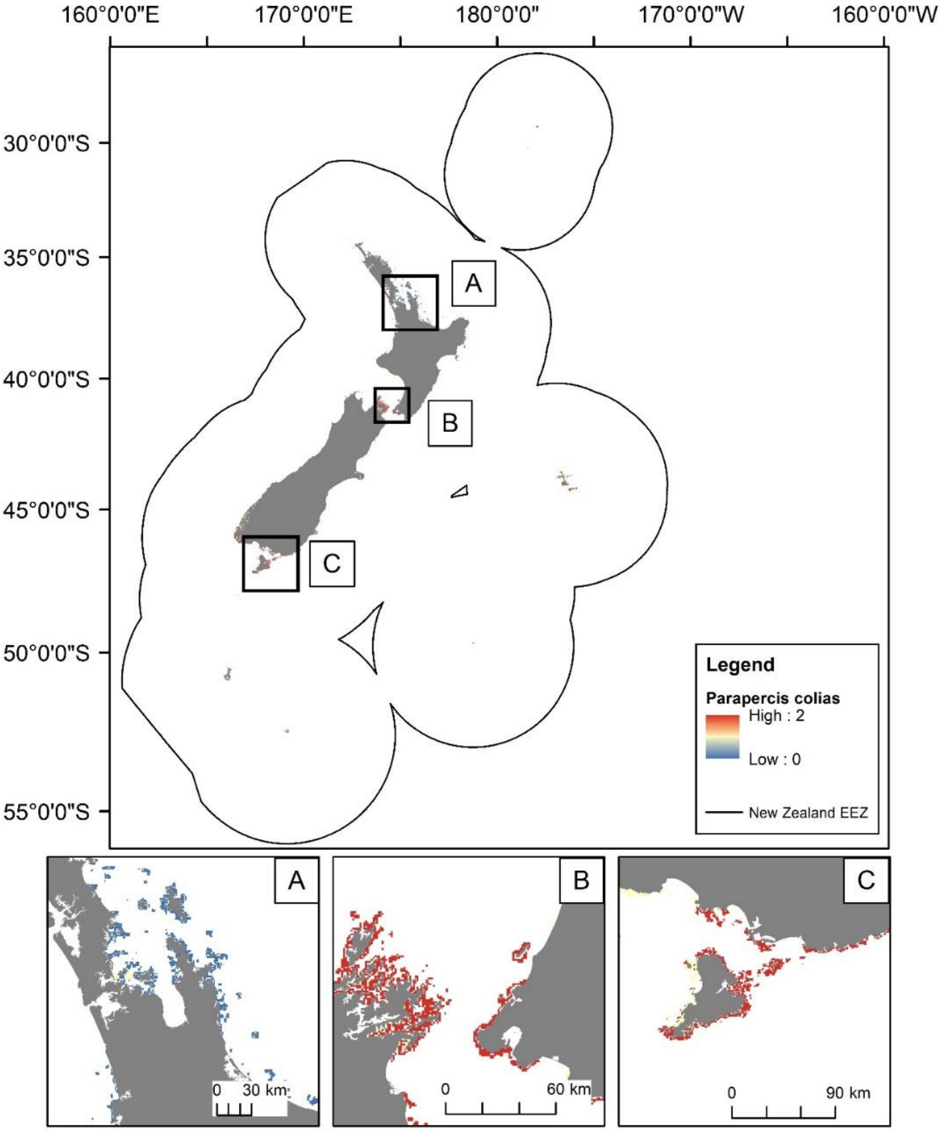

Figure 3-7: Predicted distribution (occurrence) and relative abundance of Blue cod (*Parapercis colias*) on rocky reefs (Smith et al. 2013).Inset maps: A) Hauraki Gulf; B) Cook Strait – Marlborough Sounds; C) Stewart Island.

Overview

Data format	**Extent and resolution**	**Validation**	**Confidence score**	**Overview of layers**
Raster	NZ EEZ – limited to inshore reefs at 1km resolution.	Not validated but bootstrapped mean and uncertainty layers created.	High	See Appendix 1, section 7.2, for list of species.

Description of data:

The predicted distributions and abundances and associated uncertainty layers of 72 species of rocky reef fishes were sourced from Smith et al. (2013)(for detailed methodology see Smith et al. (2013)). The relative abundance of reef fishes were obtained from 467 SCUBA dives made around the coast of New Zealand over an 18-year period from November 1986 to December 2004, which were combined with 15 environmental predictor layers and Boosted Regression Trees were used to produce spatial predictions of distributions and abundances. Model predictions were limited to within the 50-m depth contour; within 1 km from the shore or within 1 km of a sample site; and only predictions overlapping with subtidal reefs inferred from navigational charts were retained. Estimates of spatial uncertainty (5-95 % prediction intervals of fish abundance) were produced using bootstrap techniques (200 bootstrap models) (see section 3.2.2. or Smith et al. (2013) for further detail on bootstrapping). Models were able to explain between 8% (*Notoclinops caerulepunctus*) and 86% (*Chromis dispulis*) of the deviance in species abundances, with a mean of 43% (Smith et al. 2013). Predicted distribution (occurrence) and relative abundance of Blue cod (*Parapercis colias* – shown in Figure 3-7) explained 60% of the deviance.

In addition to the upper and lower abundance predictions, an added measure of uncertainty was produced: 'coverage of the environmental space by samples' (Smith et al. 2013). The 'environmental space' is the multidimensional space when each variable is treated as a dimension. The species location data can be projected into this space, where some parts of this environmental space will contain many samples (and are therefore well covered by the biological data) and other parts of this environmental space will contain few samples (and therefore the relationship between the environment and the biological samples are poorly understood resulting in potentially less certain predictions). BRTs were used to predict the 'coverage of the environmental space' generating values between 0 and 1, where 0 indicated little understanding of the environmental space and 1 a good understanding.

Matching criteria: Uniqueness, rarity, endemism.

Shallow rocky reef fishes are some of the most conspicuous and recognisable marine species, and are important for recreational, customary and commercial fishing, recreational boating and diving and tourism. New Zealand's fish fauna are known for their high level of endemicity relative to global fish faunas (Costello et al. 2010;Gordon et al. 2010), with some reef-associated groups (e.g., coastal triplefins (Tripterygiidae); clingfishes (Gobiesocidae)) having particularly high endemicity in New Zealand. It should be noted, that not all 72 rocky reef fishes contained within this dataset will match the criteria 'Uniqueness, rarity, endemism'.

Data limitations and consideration for future use

Improvements in methodology that reduce uncertainty and improve our ability to develop distribution and habitat suitability models based on environmental data have been developed since these data were analysed (see e.g., section 3.3.6, Stephenson et al. (2018)). Further, many of the individual species modelled had limited data records contributing to model derivation, and additional data, particularly if collected in areas with limited numbers of prior sightings, could improve model predictions. Finally, rocky reef maps at the timing of the derivation of these models were poorly ground-truthed, likely resulting in inaccuracies and therefore poorer correlation with other environmental variables. Improvements in rocky reef habitat mapping (e.g., as done for the Hauraki Gulf Marine Spatial Plan which involved combining fare charts, anecdotal records, and geospatial analysis of rugosity and seabed slope as likely correlates with rocky reef subtidal habitats or using LEK as in Jones et al. (2016)) could possibly improve mapping of these and other rocky reef associated species.

3.3.4 Hydrothermal vents

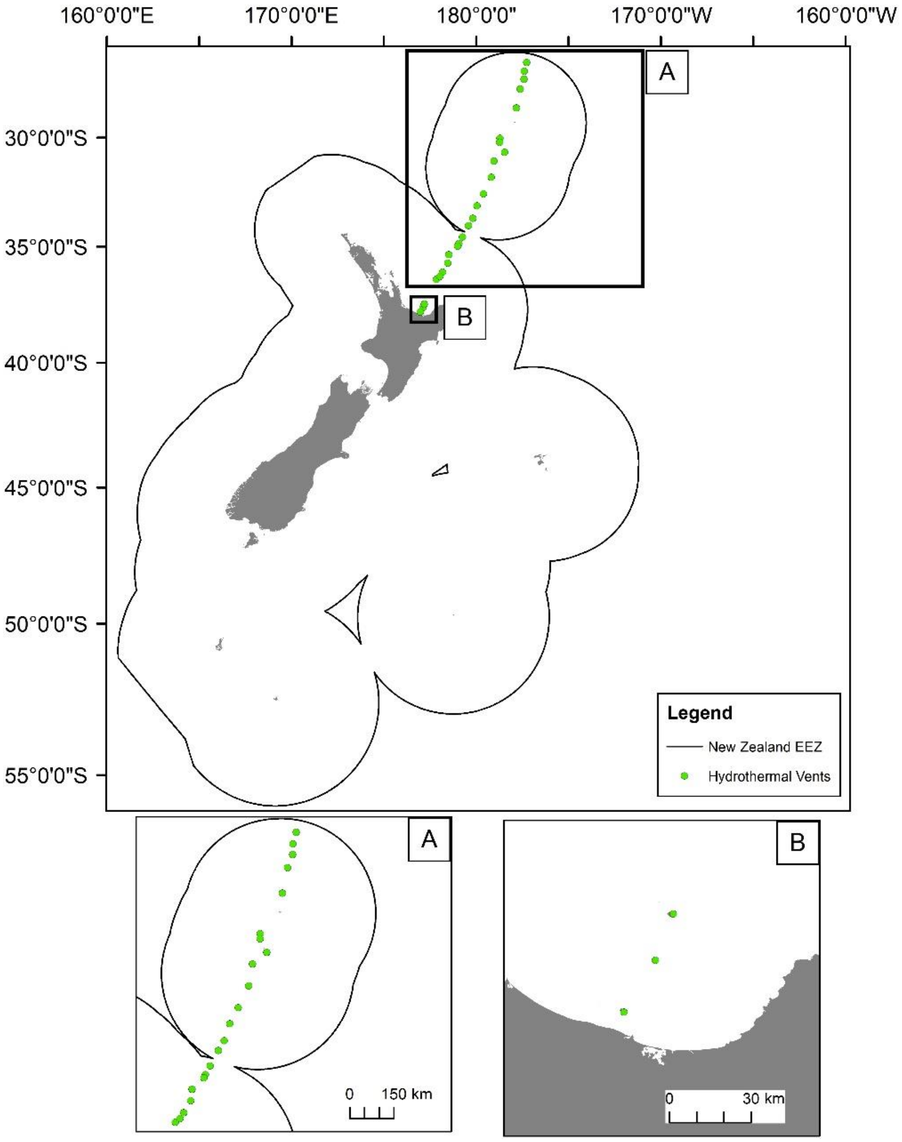

Figure 3-8: Locations of known hydrothermal vents from the Global Database of Active Submarine Hydrothermal Vent Fields. Inset maps: A) Colville and Kermadec ridges; B) Bay of Plenty.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	High	Single layer.

Description of data:

Locations of known hydrothermal vent fields were downloaded from the Global Database of Active Submarine Hydrothermal Vent Fields (InterRidge, 2016) and those contained within the New Zealand TS and EEZ were imported to ArcGIS as a feature class. In the New Zealand TS and EEZ, such venting occurs on the seafloor in the vicinity of the plate boundary as it trends north east from the Bay of Plenty (at water depths as shallow as ~10 m) and along the Kermadec Volcanic Arc (on seamounts to water depths of ~1700 m) (point data - Figure 3-8). Multiple sites of hydrothermal venting can occur within any one vent field, at scales of metres to kilometres apart.

Matching criteria: Uniqueness, rarity and/or endemism.

Hydrothermal vents occur where geothermally heated water emanates through and from fissures in the seafloor. The temperature of the venting fluid and its flow rate varies depending on a number of factors. Chemical compounds in the vent fluid (principally hydrogen sulphide) support special ecosystems, at the base of which are chemosynthetic bacteria and archaea that directly or indirectly support a range of other mostly vent-dependent larger organisms. As such the faunal communities found at hydrothermal vents include a relatively high proportion of species that are endemic to this habitat. In New Zealand waters, such fauna includes the vent mussels *Gigantidas gladius*, the stalked barnacle *Vulcanolepas osheai*, and the tubeworm *Lamellibrachia juni*. Some of these species have only been recorded to date from a single vent location (e.g., *Parachnoidea rowdeni,* Gordon (2013)), and are as such unique records. Hydrothermal vents are rare in themselves as a habitat in New Zealand waters, being only known to occur north of the North Island, and where they occupy a relatively small area of the seafloor (typically, vent habitats cover areas of ~25 to 500 m^2). Thus, overall, vent endemic fauna in New Zealand are rare.

Limitations and consideration for future use:

The Global Database of Active Submarine Hydrothermal Vent Fields is maintained by InterRidge. InterRidge is a non-profit organisation concerned with promoting all aspects of mid-ocean ridge research which can only be achieved by international cooperation. Updates to the database, about unrecorded or new discovered vents, are supplied adhoc to InteRidge by interested individual scientists or representatives of InterRidge member states. Records for the New Zealand area have been supplied by scientists from NIWA and GNS, as well as international researchers. Examination of the current version (2016) of the database indicates that the records for vent fields in New Zealand waters are up-to-date. However, in the future it is likely that discoveries of new vent fields will take place and the dataset supplied here will need to be updated.

It is important to remember that the dataset used here indicates a nominal location for a vent field (a general area that might cover 10s or 100s of km^2), and not the precise locations of individual hydrothermal vent sites within a field. While precise locations are known for vent sites in some fields (e.g., on Brothers Seamount), this spatial site information is not currently contained in a single publicly accessible database. In the future, for MPA spatial planning purposes, it would be useful to construct such a database, maintained for example by NIWA and/or GNS. Furthermore, it would be useful to link records for vent endemic fauna (e.g., in NIWA specimen databases) to the sites detailed in a New Zealand vent site database. Information on both the precise location and number of sites within a vent field, and the composition of the vent fauna at these sites, would be more useful for identifying KEAs than the dataset from InterRidge presented here.

3.3.5 Cold seeps

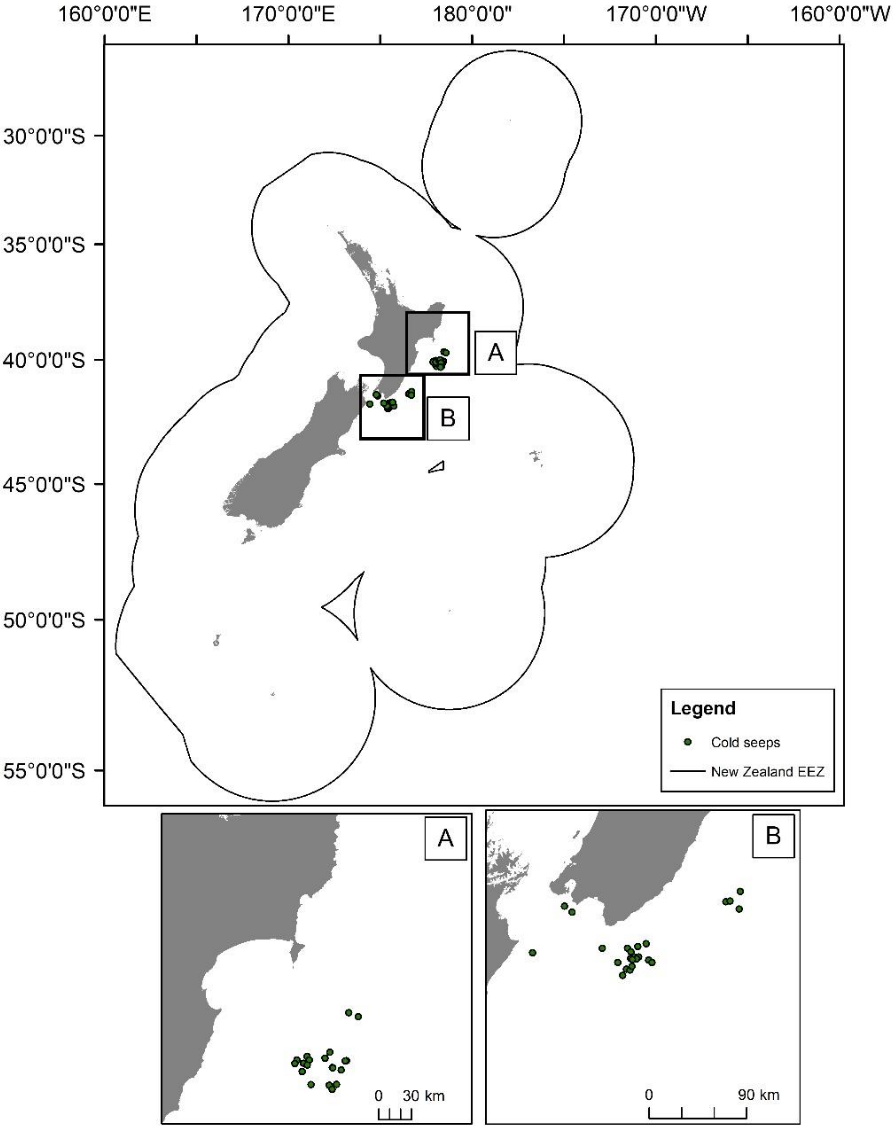

Figure 3-9: Locations of cold or methane seeps from Greinhart et al. (2010). Inset maps: A) northern Hikurangi Margin of Hawkes Bay; B) southern Hikurangi Margin.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	High	Single layer.

Description of data:

Locations of cold or methane seep sites resulting from three research voyages in 2006-2007 using multibeam backscatter data, water column hydro-acoustic, and visual data (Greinert et al. 2010) were imported to ArcGIS as a feature class. In the New Zealand TS and EEZ, known cold seeps are primarily located on the Hikurangi Margin off the east coast of the North Island (point data - Figure 3-9). Multiple sites of seepage can occur at any one of the seep sites.

Matching criteria: Uniqueness, rarity and/or endemism.

Seeps occur where hydrocarbon-rich fluid emanates through and from the seafloor, forming via a number of mechanisms that generate different types of seeps. Chemical compounds in the seep fluid (principally methane) support special ecosystems, at the base of which are chemosynthetic bacteria and archaea that directly or indirectly support a range of other mostly seep-dependent larger organisms. As such the faunal community found at cold seeps includes a relatively high proportion of species that are endemic to this habitat. In New Zealand waters, such fauna includes the seep clams *Calyptogena* spp., the seep mussel *Bathymodiolus tangaroa*, and seep tubeworms *Lamellibrachia* sp. (Baco et al. 2010). Some of these species have only been recorded to date from a single seep location (e.g., unidentified bathymodiolin mussel, Baco et al. (2010)), and are as such unique records. Cold seeps are not particularly rare in themselves as a habitat in New Zealand waters (see below about the potential extent of seep habitats), but where they do occur they occupy a relatively small area of the seafloor (typically, seep habitats cover areas of 20,000 to 70,000 m^2). Thus, overall, seep endemic fauna in New Zealand can be considered rare.

The faunal communities found at seep sites have been hypothesised to develop through a process of succession with concomitant changes that occur in the seepage flow, microorganism assemblages, and the populations of key macrofauna over time (Cordes et al. 2006). This successional process has been hypothesised to take 1000s of years at New Zealand seep sites to develop a 'climax' community, and individual species could be ~100 years-old (Bowden et al. 2013). Furthermore, there is indirect evidence that cold seep habitats and seep faunal communities on the Hikurangi Margin have been impacted by bottom trawling (Bowden et al. 2013), and therefore it is possible that seep communities at some sites also satisfy the 'Vulnerability, fragility, sensitivity, or slow recovery' KEA criterion.

Limitations and consideration for future use:

The dataset for cold seeps presented here, compiled from just three research voyages (admittedly the most important seep discovery voyages to date), is incomplete. Numerous other seeps have been identified along the Hikurangi Margin since 2007, including some in relatively shallow water (~100-300 m) on the shelf off Poverty Bay in 2015. A recent voyage in 2018 has also discovered additional deeper water seeps on the Hikurangi Margin, and further voyages to seep areas are planned on this margin in 2019 during which it is likely that more seep sites will be identified. Beyond the Hikurangi Margin there are many other areas around New Zealand where geological or circumstantial data indicate that seeps will occur (Lewis and Marshall, 1996). These areas include the shelf and continental margins off the Otago and Taranaki coasts, as well as off East Cape. Thus, in the future, the dataset supplied here will need to be updated.

It is important to remember that the dataset used here indicates a nominal location for a seep site (a general area that might cover 10s of km^2), and not the precise locations of individual seeps within a site. While precise locations are known for seeps at some sites (e.g., at North and South Tower site), this spatial site information is not currently contained in a single publicly accessible database. In the future, for MPA spatial planning purposes, it would be useful to construct such a database, maintained for example by NIWA and/or GNS. Furthermore, it would be useful to link records for seep endemic fauna (e.g., in NIWA specimen databases) to the locations detailed in a New Zealand cold seep database. Information on both the precise location and number of seeps within a site, and the composition of the seep fauna at these seeps, would be more useful for identifying KEAs than the dataset presented here.

3.3.6 New Zealand demersal fish species turnover and classification

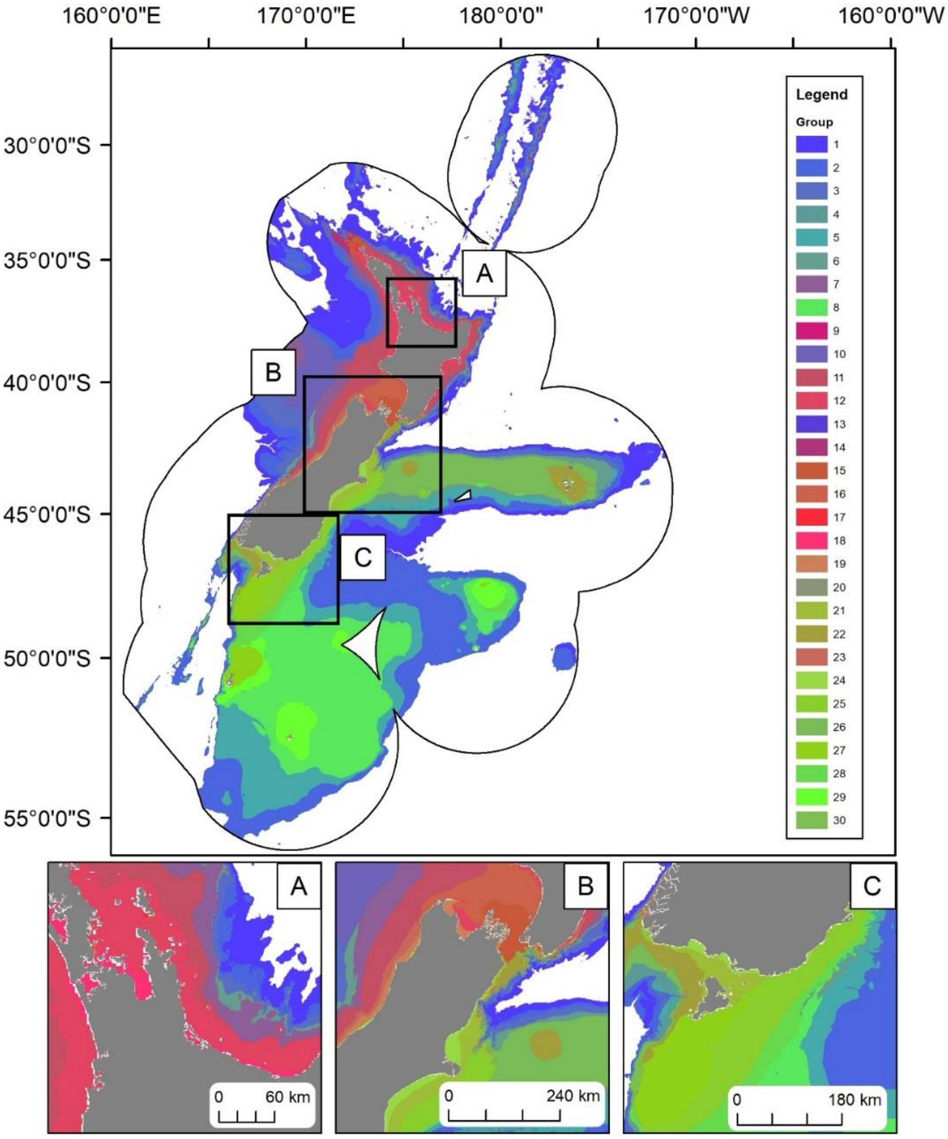

Figure 3-10: Predicted demersal fish community assemblages to depths of 2500m (30-groups – from classification of species turnover) (Stephenson et al. 2018). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) southern end of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	NZ EEZ to depths of 2500m at 1km grid resolution.	Validated using independent evaluation data.	High	30-group classification; 50-group classification; 100-group classification.

Description of data:

Gradient Forest (GF) models were used to analyse and predict spatial patterns of demersal fish species turnover (beta diversity) using an extensive demersal fish dataset high-resolution environmental data layers (1 km^2 grid resolution) (Stephenson et al. 2018). The GF models of species turnover were fitted using 13,917 samples from bottom fishing trawls to transform the environmental layers, which were then classified to produce species groups (inferred assemblages) at different levels of the classification hierarchy. An example of the classification of demersal fish assemblages, at the 30-group level, is shown in (Figure 3-10).

Matching criteria: Uniqueness, rarity and/or endemism.

While a majority of the modelled fish assemblages include wide-ranging groups that cover thousands of square kilometres, a subset of the inferred fish assemblages can be categorised as unique (occurring at a single location in New Zealand's EEZ) and/or rare (occurring in only a few locations or small area compared to other groups). This information is available and summarised for each group of the 30-group classification in Appendix 1 (see metadata for details in section 7.1). Predicted inter- and intra-group similarities in species composition are available for each grid cell in the model allowing identification of unique or rare groups, but also the calculation of the area (at the 1 km^2 resolution of the raster) occupied by each group. At the 30-group classification there are no 'Unique' occurrences of assemblages within the study area – however, the number of unique occurrences of groups will increase with the number of groups included in the classifications. A single assemblage group (group 17) may be considered rare (using here for illustration the subjective criterion of occurring at ≤3 locations and covering ≤1% of the modelled area). Group 17 occurs in a total area of only 500 km^2 of New Zealand's EEZ (to depths of 2500 m), in three separate locations which are characterised by shallow, warm water temperatures, with high salinity and small seasonal fluctuations in sea surface temperature. The species assemblage of group 17 differs to other groups (see Fig 6 in Stephenson et al. 2018), even those groups with closely related environmental conditions (e.g., groups 11, 23, 12, 16, 15), making group 17 a good example of a rare (predicted) demersal fish assemblage (at a 30-group scale). Although Gradient Forest modelling is a novel method, species classifications have already proved useful in identifying areas that have unique or unusual/rare combinations of species for conservation planning (e.g., Leathwick et al. (2011); Ferrier et al. (2002)).

Data limitations and consideration for future use

Gradient Forest is a novel approach that can incorporate a large number of environmental predictors (irrespective of co-linearity) as well as accounting for complex non-linear interactions without overfitting the models. GF is also particularly well suited to the analysis of large datasets, whose size can be limiting in other methods. To date, these models have shown similarities in the offshore classification to environmental classification approaches such as BOMEC (Rowden et al. 2018), though noting that improvements from use of this methodology allows for better reflection of dynamic environments in inshore areas within classifications including both inshore and offshore ecosystems. Given the hierarchical nature of the classification, consideration will be required as to what constitutes the most appropriate level of classification detail for conservation planning purposes. Here, the classification at a 30-group level is presented to facilitate communication; however, testing of correlations between environmental and biological distances at higher levels of classification detail (50; 100 groups, also provided with this report) indicate that these levels can provide even greater discrimination of compositional differences (Stephenson et al. 2018). Using a higher number of classification groups is likely to be more appropriate for regional scale analysis, particularly for inshore areas where there is a greater heterogeneity in environmental conditions (Stephenson et al. 2018). Alternatively, regional patterns may be better described by analyses using regional subsets of the data, particularly if the mix of factors controlling species turnover varies region by region (Stephenson et al. 2018). The classification can also be used for a gap analysis of assemblages currently protected in MPAs (Leaper et al. 2011;Stephenson et al. 2018) allowing an evidence-based targeting of underrepresented assemblages for further sampling and/or protection (Ferrier et al. 2007;Pitcher, 2007).

This analysis had access to a very large dataset which provided the luxury of being able to evaluate the accuracy of the predictions. Although the GF model was found to be highly effective at summarizing spatial variation in both fish assemblage composition and species turnover, estimates of spatial uncertainty are not readily available. Other modelling methods such as Regions of Common Profile (RCP) could be used to estimate confidence of assemblage classification, which can be validated spatially using the probabilities of occurrence for individual species from the training dataset (Foster et al. 2013;Hill et al. 2017). Alternatively, ‘environmental coverage’ can be estimated (i.e., using a BRT model to estimate how extensively the environmental predictors have been sampled) and used as a relative measure of prediction uncertainty (Smith et al. 2013). Estimates of environmental coverage have been produced for several different datasets contained in the report; see section 3.3.3 for further details on methods and interpretation of these.

Finally, although environmental classifications may be easier for managers to use for spatial planning (e.g., 250 species have been reduced to 30 assemblages), it is not well understood whether the use of classifications are more efficient than individual species distribution data (e.g., species distribution models, SDMs) for conservation planning. Some work has been undertaken comparing the effectiveness of using physical habitat data (e.g., rocky reefs, sand, mud, gravel, etc.,) and SDMs in systematic conservation, with results suggesting that protecting physical habitats was less efficient (more protected area required) but protected a greater amount of biodiversity (more conservative) (Ferrari et al. 2018). Further work is required to investigate whether environmental classifications tuned using biological data (as presented here) may differ in effectiveness compared to SDMs for conservation planning – further work is currently in progress to address these questions (Stephenson et al. pers. comm.).

3.3.7 New Zealand benthic invertebrate species turnover and classification

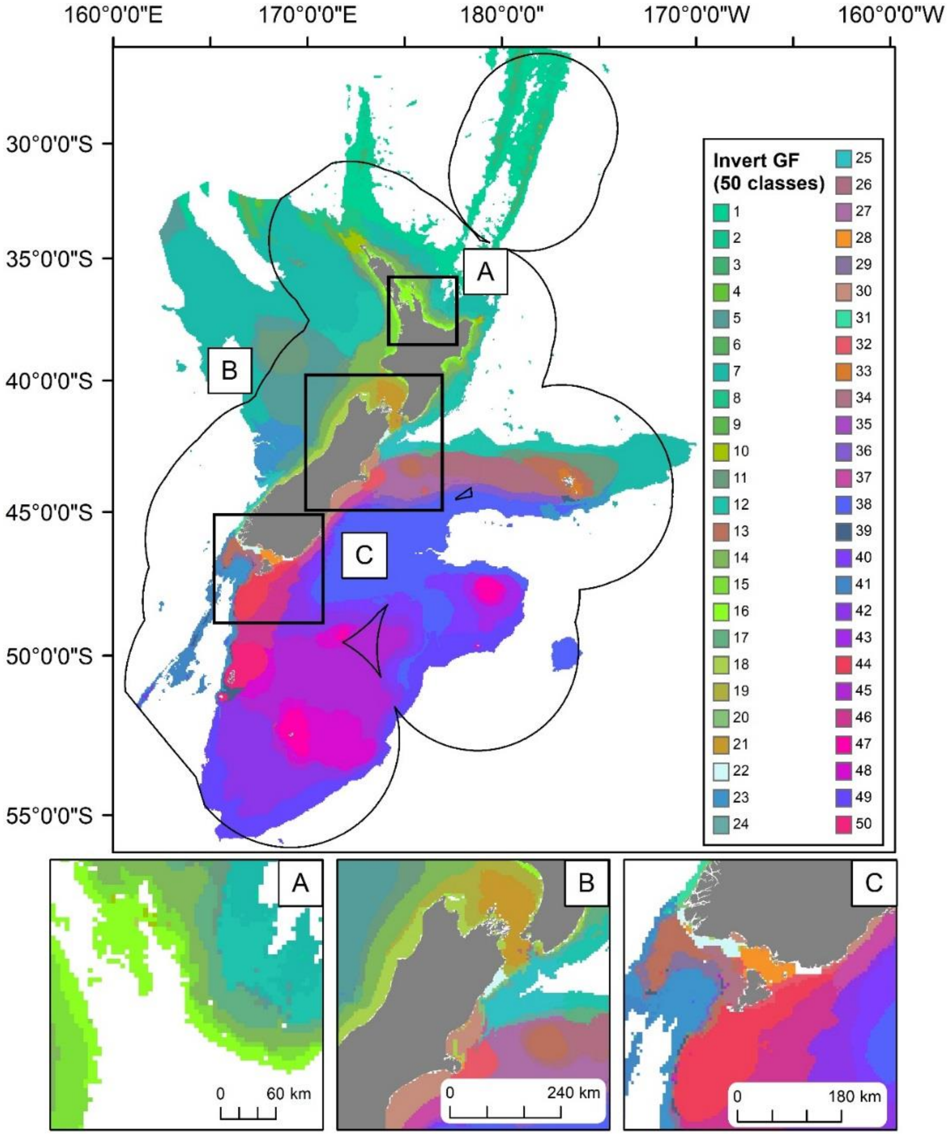

Figure 3-11: Predicted benthic invertebrate community assemblages to depths of 2500m (50-groups – from classification of species turnover) (Stephenson et al. 2018). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	NZ EEZ to depths of 2500m at 1km grid resolution.	Not validated	Moderate	30-group classification; 50-group classification; 100-group classification.

Description of data:

Gradient Forest (GF) models (as per section 3.3.6) were used to analyse and predict spatial patterns of benthic invertebrate species turnover (beta diversity) using benthic invertebrate species records and 15 high-resolution environmental data layers (1 km^2 grid resolution) (Stephenson et al. unpublished). The environmental data layers used, differed to those used for the demersal fish GFs presented in section 3.3.6 – for a complete list of environmental predictors used see Appendix 2, section 7.2). Benthic invertebrate species records from NIWA inverts (1919 – 2015) & Trawl (1961 – 2015) databases (available at: nzobisipt.niwa.co.nz) were collated. Because sampling of benthic invertebrates is highly dependent on gear selectivity, and many different gear types were used to collect these samples, records were selected based on "gear category" (see Appendix 2, section 7.2, for further detail). Only data from 1980 onwards, collected using gear types that were not highly selective, moderate – large, and sampled over moderate areas were used, for example, beam trawls, benthic sleds and Devonport dredges (for detailed description of the gear types, and rationale for sample year cut-offs and sampling gear selection see Appendix 2, section 7.2).

GF models, using samples from 1723 unique locations, were fitted individually for two gear categories: 190 species at 659 unique locations from large gear types with moderate sample areas; 115 species at 1064 unique locations from medium sized gear types with moderate sample areas. Species turnover was then combined (using the *combineGF* function in the R package "GradientForest), which was then classified to produce 5, 30, 50 and 100 spatial groups (inferred assemblages) (the 50 group classification is shown in Figure 3-11). Overall, individual species model fits were relatively high, with R^2 ranging from 0.28 – 0.91 and mean R^2 of 0.50 (see Appendix 2, section 7.2, for further results). Mapped predicted assemblages were visually consistent with previous classifications, e.g., BOMEC (Leathwick et al. 2012), however, due to the lower number of benthic invertebrate records used, it was not possible to evaluate the accuracy of the model as was done for the demersal fish which resulted in the allocation of a lower data confidence score of 2 (Table 3-1).

Matching criteria: Uniqueness, rarity and/or endemism.

The benthic invertebrate species classification match the "Uniqueness, rarity and/or endemism" criteria in the same way as the demersal fish species classification discussed in section 3.3.6.

Data limitations and consideration for future use:

The benthic invertebrate species classification has similar data limitations and considerations for future uses as the demersal fish species classification discussed in section 3.3.6. A notable difference is that the benthic invertebrate species classification was created using fewer records, covering a greater number of species (comparatively to sample number) and is therefore likely to have greater prediction error (although the level of this prediction error is unknown). Further sampling, particularly in areas close to shore (e.g., the Hauraki Gulf, see Appendix 2, section 7.2, for record locations), would most likely improve confidence in our results in these locations.

3.3.8 New Zealand naturally uncommon habitats in coastal environment

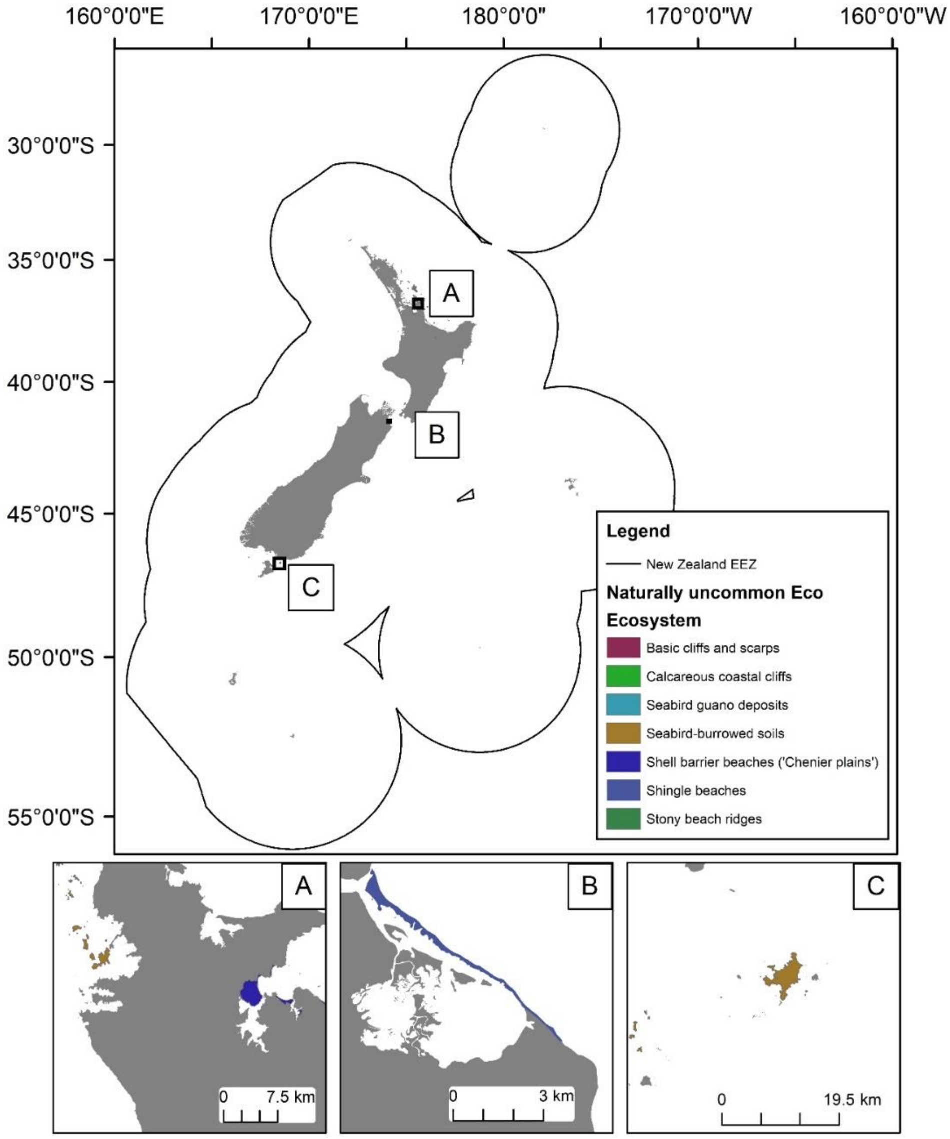

Figure 3-12: Examples of 7 Naturally Uncommon Ecosystems in the coastal environment (Wiser et al. 2013). Inset maps: A) Mercury Bay; B) Big Lagoon (Cloudy Bay); C) Ruapuke Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Polygon	Terrestrial – coastal.	NA	Moderate	Single layer.

Description of data

Naturally uncommon ecosystems in New Zealand (terrestrial environments) were available from Wiser et al. (2013). Naturally uncommon ecosystems were described as either small (e.g., 100 m^2 to a few hundreds of hectares) but geographically widespread, or larger (e.g., 10 000s of hectares) but geographically restricted. Distributions of each ecosystem based on combinations of modelling from existing spatial layers, interpretation of remotely sensed images, literature, and local knowledge was undertaken (Wiser et al. 2013). 72 ecosystems were identified as naturally uncommon (described in detail on the Landcare Research website), of those, 13 were classified as critically endangered. Of particular interest are those that occur coastally: Shell barrier beaches ('Chenier plains'); Coastal turfs; Geothermal ecosystems; Seabird guano deposits; Marine mammal rookeries and haul-outs (all of which are described in detail in Wiser et al. (2013).

Matching criteria: Uniqueness, rarity, endemism.

Naturally uncommon ecosystems often have highly specialised and diverse assemblages of flora and fauna, characterised by endemic and rare species (Wiser et al. 2013).

Limitations and consideration for future use

The naturally uncommon ecosystems dataset contains spatial information for both coastal and terrestrial ecosystems, which can be important information when considering land-sea connectivity (see section 3.8.4 for further discussion). Confidence in the data will vary between different ecosystems – it is unclear how each individual ecosystems were created or detailed information on the origins of the data used. Nevertheless, this is the best available information, defined and mapped by an inter-agency working group.

More broadly, data on other rare ecosystems, e.g., hydrothermal vents and seeps are described in sections 3.3.4 and 3.3.5. Information on areas containing co-occurring geographically restricted species and rare biogenic habitats is limited and problematic for two reasons. (1) There is the probability of declaring as rare a biogenic habitat or co-occurring species that occurs in the large area of geographic or environmental space presently unsampled. For this reason, analysis across the Territorial Sea and the EEZ for areas of co-occurring species has not presently been done. (2) There is the probability of not considering an area rare or unique because while sampled, it has not been studied in sufficient detail to make this decision.

3.3.9 New Zealand seabird distributions

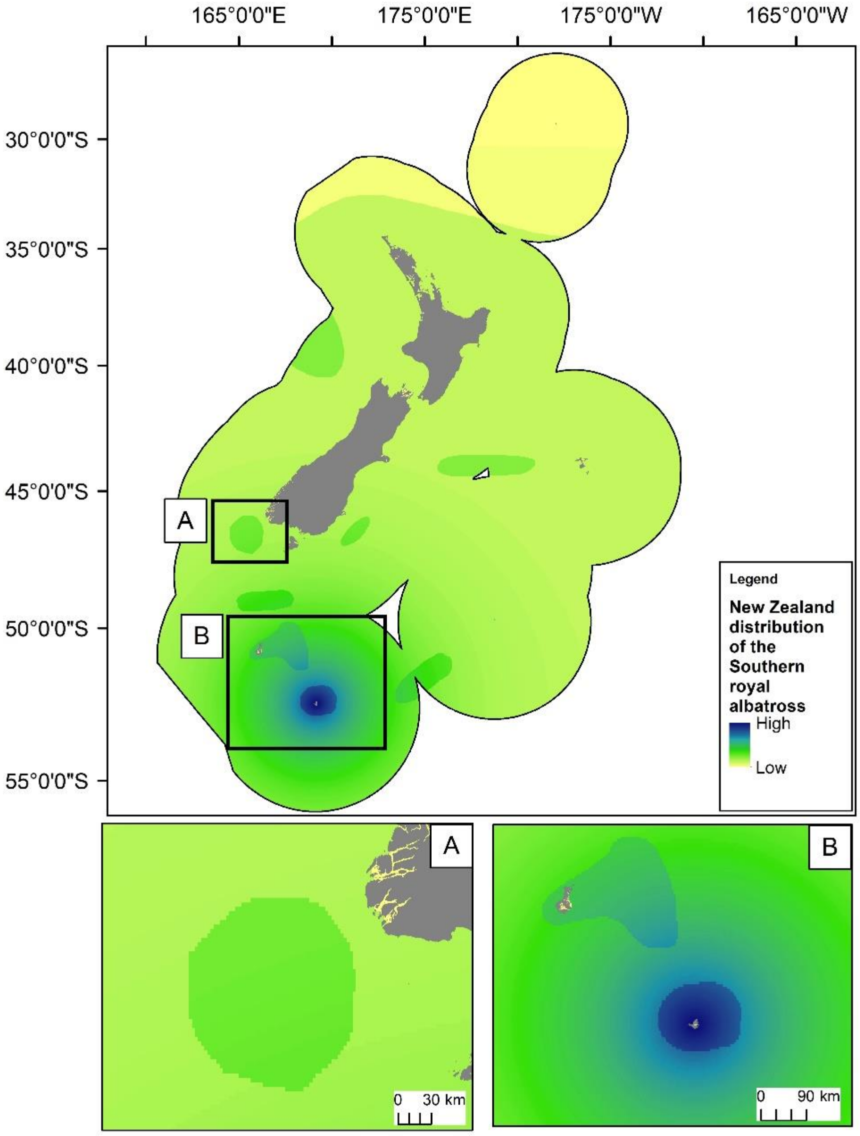

Figure 3-13: Predicted non-breeding, at-sea distribution of Southern Royal Albatross (*Diomedea epomophora*). Inset maps: A) Fiordland; B) Auckland and Campbell Island. (BirdLife International and NatureServe, 2015)

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data)	NZ EEZ with a resolution of 1/13 of degree of latitude and longitude, extending from 57S to 23S and from 160E to 170W.	NA	Moderate	70 species categorised into 8 groups: Albatrosses Diving petrels Gulls terns skuas noddies Other seabirds Penguins Precellariidae petrels Shags Storm petrels

Description of data:

Annual averages of breeding, and non-breeding, at-sea distributions were mapped for 70 species included in a risk assessment of the impact of fishing-related mortalities on seabirds breeding in the New Zealand region (BirdLife International and NatureServe, 2015). Distribution maps were created using a number of sources and data types: annual distribution maps from NABIS (a hot spot layer, the 90% and the 100% of the population distributions), presence layers, at-sea observations, observer data, telemetry, and main colony positions (Richard and Abraham, 2013). These data were combined using various weightings with the density of breeders assumed to decrease exponentially away from colonies. The location and size of colonies, and the exponential rate of decrease, were obtained from the literature (Richard and Abraham, 2013). The final distributions of breeders and non-breeders were normalised so the density summed to unity over the entire region.

There is no validation or estimate of uncertainty of these maps, nor is there a description of the age of the data used to produce these. However, these distributions were created using an extensive literature search, expert opinion and the best available information available.

Matching criteria: Uniqueness, rarity, endemism.

New Zealand is internationally recognised for its diversity of seabirds, and the large proportion of the global seabird population that utilises New Zealand waters within its foraging migrations or for breeding colonies, often on offshore islands. Of the 122 seabirds found in New Zealand waters (Gordon, 2009), particular groups of noted endemicity include 7 of the 12 albatross species (Diomedeidae), and a monotypic penguin genus (of the six penguin species which nest in NZ's EEZ) (Gordon, 2009).

All of New Zealand's seabirds have been assessed within the New Zealand Threatened Species Classification System and many are also listed as internationally threatened; 2 seabirds are categorised as extinct, 10 as nationally critical, 7 as nationally endangered, 10 as nationally vulnerable, 9 as declining, 3 as recovering, 13 as relict populations, and 24 as naturally uncommon (summarised in Lundquist et al. (2015b) based on data presented in Miskelly et al. (2008);Robertson et al. (2017)), clearly placing the majority within biodiversity criteria of unique, rare and endemic taxa.

Limitations and consideration for future use:

Many of the individual species modelled had limited data records contributing to model derivation, and additional data, particularly if collected in areas with limited numbers of prior sightings, could improve model predictions. Finally, seabird distribution models were created primarily based on bycatch observer records, thus showing bias with respect to reporting within proximity of fishing vessels, but limited understanding of the distribution of seabirds when not associated with fishing vessels.

3.3.10 Regional Council identified important marine areas

For an example map and detailed description of the data and how these meet this criteria see section 3.2.1

3.4 Criteria: Special importance for life history stages

3.4.1 Sensitive Environments / Biogenic Habitats (marine)

For an example map and detailed description of the data see section 3.2.3.

Description of data

No specific national scale datasets of key habitats for life history stages exists. Hurst et al. (2000) undertook a review of "*Areas of importance for spawning, pupping, or egg laying, and juveniles of New Zealand coastal fish*". That work included the collation and interpretation of data from research trawl surveys and observer records, and numerous plots of their occurrence, both as presence/absence and abundance. While that report revealed some biogeographic patterns at large spatial scales, no habitat data was included to link to life history stages; largely because such data did not exist at that time (nor as of 2018). A subsequent update of this work was completed in 2014, which summarised new life history knowledge gained since 2000, but did not include updated spatial data maps from surveys conducted since the earlier review (Morrison et al. 2014a).

In the coastal environment, a current MBIE Endeavour Fund Research Programme "Juvenile fish habitat bottlenecks" has systematically collected large scale fish-habitat data for juvenile snapper (10–80 mm) across East Northland and Hauraki Gulf (estuaries to 30 m water depth), and for juvenile blue cod across the Marlborough Sounds and surrounding coastline (also to 30 m). This broad-scale data will be available for wider use as appropriate within the next 1 to 2 years; it is currently in the process of being analysed and written up. The Bottlenecks programme runs until 2021; and includes a range of other projects targeting specific life history (e.g., growth, survival/mortality, and connectivity through ontogenetic movement). Collectively, these will define the key areas/habitats of special significance for these two species/areas, as well as identify where to best apply habitat loss mitigation and restoration approaches.

For invertebrate species, the available information is even more scant. For instance, scallops, like other epifaunal bivalves, require filamentous materials for initial spat settlement, after their larval pelagic phase. Such surfaces are often living (e.g., hydroids, worm tubes), and are vulnerable to land-based effects such as increased sedimentation (Morrison et al. 2009). No large-scale maps of such habitats exist; and the specific species interactions are essentially unknown.

Matching criteria: Special importance for life history stages.

Several biogenic habitats are known to provide ‘Habitats of particular significance to fisheries’ / ‘Essential Fish Habitats’ (EFH) for many species, including fishery species during crucial life stages (e.g., nursery and spawning grounds) (Morrison et al. 2014a). Subtidal northern seagrass meadows (and to a lesser degree structurally complex habitats formed by horse mussels, bryozoans and sponge gardens) provide crucial nursery habitats for juvenile snapper (10–80 mm) (Morrison et al. 2014a;Morrison et al. 2014b). Mangrove habitats provide nurseries for grey mullet (west coast only), parore (east coast only) and short-finned eels (both east and west coasts) (Morrison et al. 2014a). Biogenic habitats, including horse mussel beds, bryozoan thickets, structurally complex shell debris fields and sponge gardens, have recently been identified as an important nursery habitat for juvenile blue cod (Morrison et al. 2014a;Morrison et al. 2014b). Non-calcareous tubeworm fields (e.g., the ‘wireweed’ fields of the North Canterbury Bight, and the ‘Hay Paddock off Oamaru (soft sediment sponge on wireweed assemblage) are known to support tarakihi juveniles and adults (Morrison et al. 2014b;Jones et al. 2018). Kelp forests are important nursery and refuge grounds for various fish life history stages (Francis, 1988;Jones, 2013). Rhodolith beds provide nursery areas for queen scallops, crabs, and fish (review in Nelson et al. (2012)), although evidence in New Zealand is equivocal at present.

A formal definition and framework of what constitutes a fish nursery remain to be applied to most species (spatial areas), with a fundamental lack of data hampering progress. Many fish species use specific areas as nursery grounds for juveniles, with adults often being found in other areas, with ontogenetic migrations linking the two. The definition of what is a nursery habitat/area has received a lot of science attention, following recognition that the simple presence of juvenile fish does not automatically equate to a habitat or area providing an important nursery function.

Beck et al. (2001) led this way of thinking, by specifying what conditions need to be met for a habitat/area to be providing a nursery function. Reviewing the literature, they concluded that ecological processes operating in nursery habitats, relative to those in other habitats, must support greater contributions to adult recruitment from a combination of the following four factors: (1) higher densities per unit area, (2) greater growth rates, (3) higher survival of juveniles, and (4) movement of juveniles to adult habitats. Beck et al. (2001) listed a range of conditions and tests required to be met for a habitat to be considered a nursery habitat. Even very spatially discrete habitats could qualify as important nursery habitats – if they produced relatively more adult recruits per unit of area than other juvenile habitats used by a species. Conversely, some habitats might contribute individuals to adult populations, but make a less than average contribution relative to other habitats – these would not quality as nurseries using Beck et al.’s definition. Measuring the movement of individuals from juvenile to adult habitats was considered an essential component of nursery habitat quantification, with the best integrated measure of a given habitat’s contribution being the total biomass (i.e., production) of individuals recruiting to adult populations from that habitat. Although a habitat might support high densities of juveniles, if those individuals did not reach adult populations (e.g., the habitat was acting as a ‘sink’), then that habitat was not functioning as a productive habitat. Examples of processes which might bring about such a situation included high larval settlement into sites where growth was poor, or where movement to adult habitats was risky or difficult (e.g., no adult habitats nearby, or particularly intense predation (Lipcius et al. 1997).

Beck et al. (2001) also stressed the importance of accounting for variation in habitat values within a given habitat and noted that not all occurrences of a given habitat should be considered equal. Examples included geographic variations in the importance of widely distributed habitats, in habitat quality (e.g., seagrass blade density), in larval supply and settlement, and in the local landscape configuration in which habitats were embedded. As an example, they noted that conservation and management agencies now commonly consider all seagrass and wetlands as nurseries, and that while these broad declarations were useful for generating public interest, they hindered the actual work that needed to be accomplished by these groups because the statement lacked focus. By gaining a clearer understanding of what makes some sites more important than others as nurseries, more efficient use of limited money, time and effort could be achieved by targeting the most critical elements of the system. Beck et al. (2001) concluded that while idealistically the level of evidence required for showing a habitat to be a nursery was very high and very difficult to achieve, it could provide a view of what a definitive test would encompass, "*so that researchers could arrive at the best approximation of it*". Examples of themes researchers might best focus on included: factors of density, growth, survival, and movement in putative nursery habitats; the quantification of multiple habitats for a given species; and a better quantification of the movements of individuals between juvenile and adult habitats. They also commented that correlative and case study analyses could also yield many useful insights – such as correlations between inshore habitat loss and offshore fisheries production (e.g., Butler and Jernakoff (1999)).

Dahlgren et al. (2006) suggested a variant of this approach, to allow areas which supported relatively low juvenile densities, but which collectively provided most recruitment, to also be defined as fish nurseries.

Limitations and consideration for future use:

The Bottlenecks programme broad-scale fish-habitat data will be available within the next year, with other data following as the programme matures and comes to an end point. Associated with that, a 2018/19 MPI funded project to quantify 0+ (10–80 mm) snapper year class recruitment strength across East Northland and the Hauraki Gulf will further add to this regional scale data (2019, planned 215 beam trawl sites across estuarine and coastal nurseries; 56 beach seine sites in key subtidal seagrass dominated estuaries). If successful, that survey may extend out as a time series.

More broadly than these two species/areas (juvenile snapper, East Northland/Hauraki Gulf; juvenile blue cod, Marlborough Sounds), few new data sources are apparent on the horizon. If/when new data is created, well-defined definitions should be used to identify what are areas important for life history stages, e.g., the nursery habitat definitions of Beck et al. (2001), Dahlgren et al. 2006, and the extensive literature following these two papers.

3.4.2 New Zealand marine reef fish records

For an example map and detailed description of the data see section 3.3.3.

Matching criteria: Special importance for life history stages.

A number of species are hypothesised to depend on shallow rocky reefs, kelp forests, and other associated biogenic structures forming on rocky reefs (Morrison et al. 2014a).

Data limitations and consideration for future use

Data limitations and considerations for future use are already discussed in section 3.3.3.

3.4.3 Seal breeding grounds

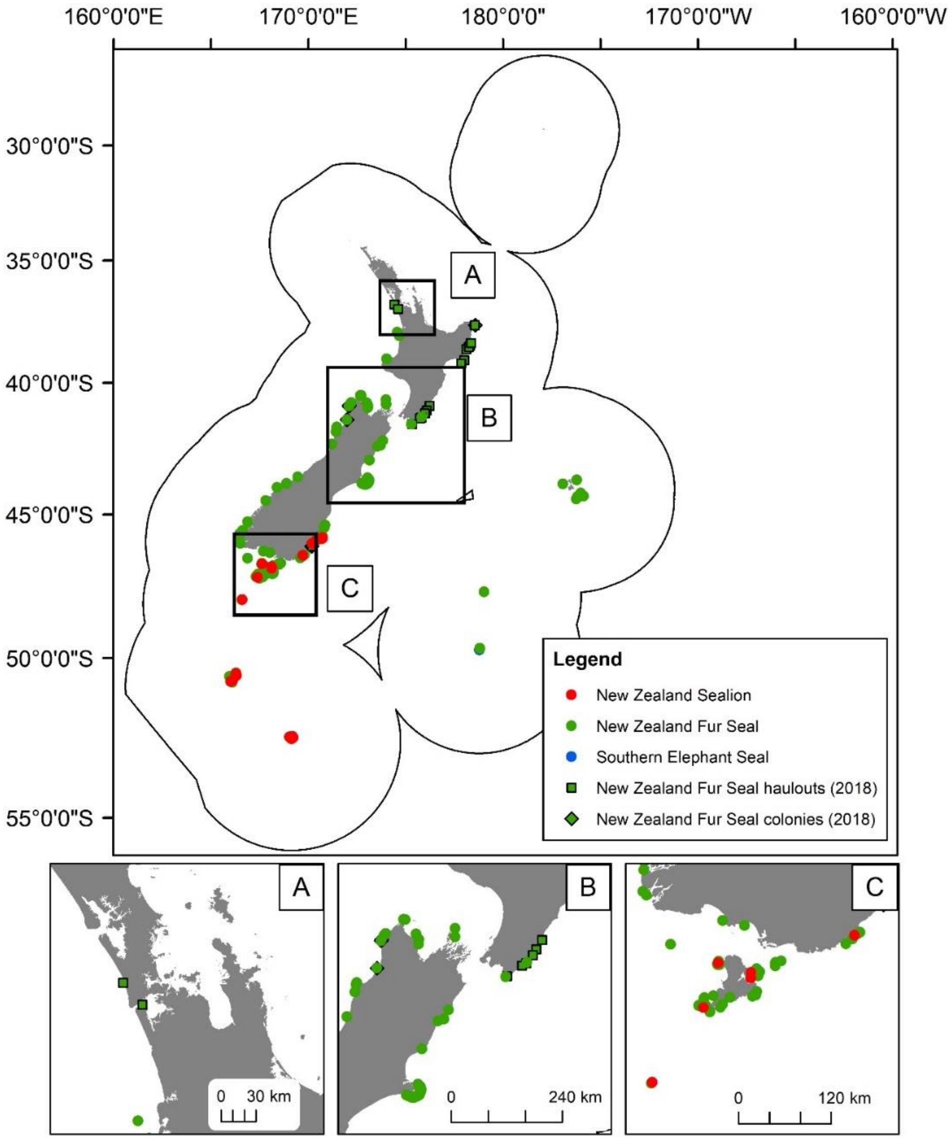

Figure 3-14: New Zealand Seal breeding and haul-out grounds. Circles show layers from NABIS. Recently updated data for New Zealand Fur Seal haul-outs and colonies are shown as green squares and diamonds respectively.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	Moderate	Breeding colonies and haul-outs (New Zealand fur seals, *Arctocephalus forsteri* and the southern elephant seal, *Mirounga leonine.*

Description of data:

Locations of seal breeding colonies and haul-outs (New Zealand fur seals, *Arctocephalus forsteri* and the southern elephant seal, *Mirounga leonina)* were obtained from NABIS (2012) and supplemented with recent work by DOC (unpublished). A breeding colony is defined as “any breeding location where at least 10 pups are born in at least three successive years and where offspring return each year to the same site” (NABIS, 2012). All colonies were mapped according to written/oral descriptions from Department of Conservation staff, University of Otago staff and students, and independent researchers (NABIS, 2012) (Figure 3-14).

Matching criteria: Special importance for life history stages.

All seal breeding grounds and nursery areas are by definition areas of special importance for specific life stages.

Limitations and consideration for future use

Temporal change in colonies (e.g., new colonies, loss of colonies) was not provided and it is unclear when individual seal breeding and haul out locations were collected. This limits the usefulness of this data on an ongoing basis, although recent additions of data (16 haul-outs and 8 colonies) provided by DOC were updated and are accurate as of 2018 (Figure 3-14).

3.4.4 Fish spawning grounds

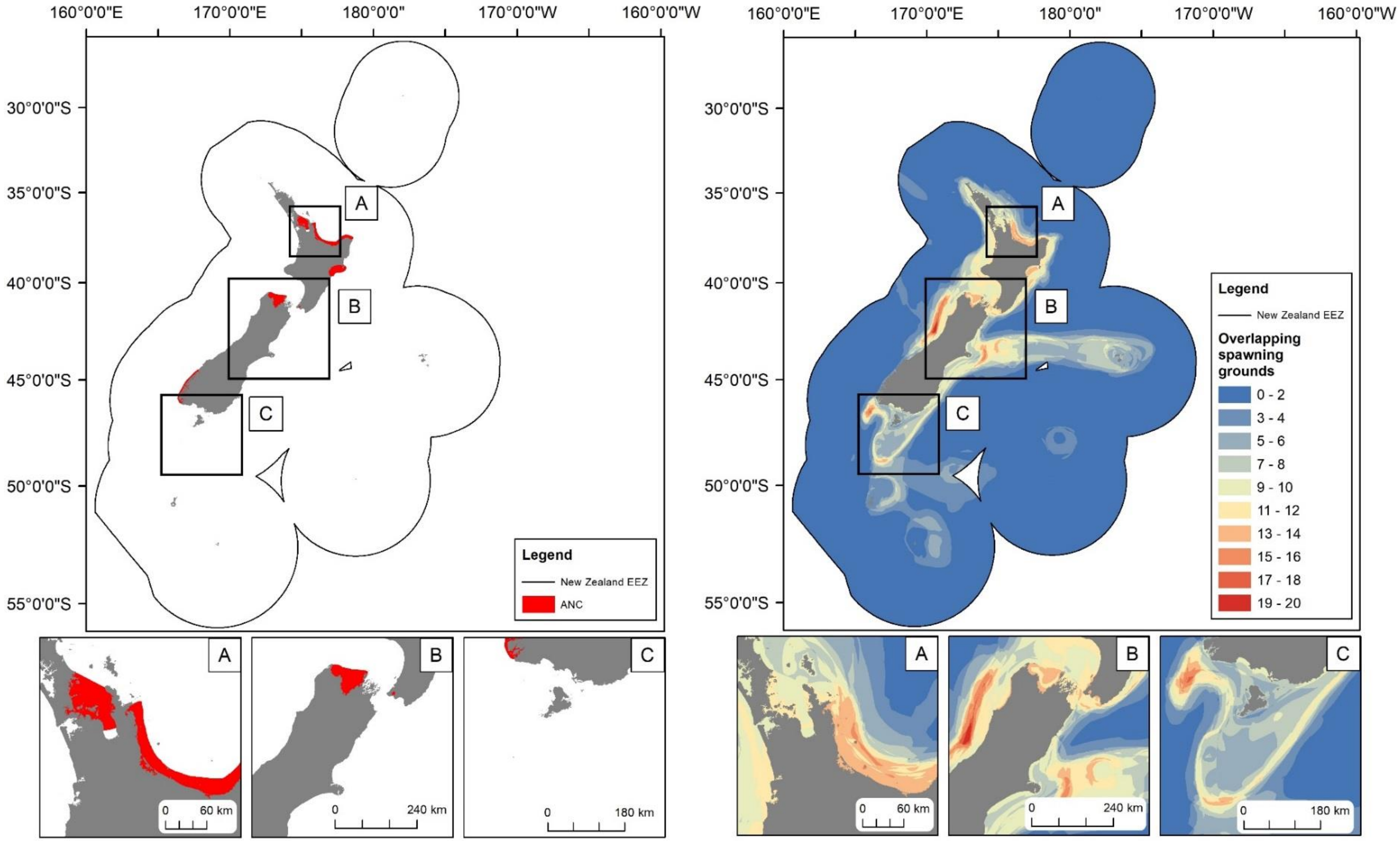

Figure 3-15: Example of annual spawning distribution of Anchovy (*Engraulis australis* – code: ANC) considered accurate to ± 15% (left) and hotspots of spawning grounds for commercially important species (the overlap of individual annual spawning distribution for 39 species) (right). Data layers from MPI (Nabis website). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (polygon data).	NZ EEZ	NA	High	See Appendix 1, section 7.2, for list of species.

Description of data

Annual spawning distribution for 39 species were obtained from NABIS (2012). Data inputs used to create these layers varied by species – further details on the methods used to generate estimates of spawning distributions for individual species are available from NABIS (2012). Broadly, spatial estimates of the mean annual catch (number of fish) of running ripe females, the proportion of running ripe females in the catch of the species, and proportion of tows that caught running ripe females for each species (if available) were extracted from electronic databases (TRAWL and COD databases from 1961 - 2009) which were provided to an expert scientist who integrated this information with other information from the literature, and expert opinion, and produced hand-drawn distributional zones on a template map containing depth contours at 250 m, 500 m, and 1000 m. These maps were then digitised and imported into a GIS software package as layers (e.g., annual spawning distribution of Anchovy (*Engraulis australis*) is shown on the left side of Figure 3-15). The layers are a scientific interpretation of data and are considered accurate to ±15%. Expert consideration of the accuracy of these data layers resulted in a high confidence score in these data.

Annual spawning distribution for 39 species were intersected in ArcGIS (v. 10.6) and summed to provide estimates of the spatial distribution of the number of spawning grounds. Hotspots of spawning grounds occur primarily close to shore and along the Chatham Rise. Notable hotspots occur in the Bay of Plenty, Hawkes Bay, West Coast, South of Fiordland and the west of the Chatham Rise.

Matching criteria: Special importance for life history stages.

Fish spawning is an essential part of the life history of all species, and most species of any appreciable body size in New Zealand coastal waters undertake seasonal migrations to key areas to spawn (Morrison et al. 2014a). Visual staging of fish reproductive state is a well-established method, validated by more intensive histological studies. These data are collected as a matter-of-course in most fisheries surveys for key Quota Management System (QMS) species; in a few studies, workers have used targeted collection over time and space to strongly infer seasonal migratory patterns. For example, (Francis, 1981) used several lines of evidence to convincingly argue for blue moki migration (locally known as ‘moki runs’) north to East Cape for spawning and then south again each year.

It should be noted that not all adults in a population spawn each year. Many do not; known as skipped spawning, a component will choose not to spawn, based on environmental factors and physiology interactions. Inter-related with this, most of New Zealand’s larger-bodied fish species also show evidence of partial migration (Morrison et al. 2014a), where one component of the population is migratory, and another more sedentary, with associated different life history consequences (Kerr et al. 2009).

Limitations and consideration for future use

The NABIS data was interpreted and hand-drawn as abundance/intensity polygons by experts into large scale maps at the regional to national scale. Many fish spawning aggregations occur at finer spatial scales, e.g., discrete and stable (over years) areas of snapper spawning aggregations are well known to commercial fishers in East Northland and the Hauraki Gulf. Some fish records will be of ripe fish migrating to the spawning grounds, moving along spawning migration corridors/pathways, rather than being at their spawning areas. Surveys are often also not aligned to spawning times, meaning that there is unknown spatial/temporal bias in the data; not all spawning areas may be detected/represented. Pelagic spawning species are also less likely to be sampled by the demersal fish trawl surveys which contribute most of the fish reproductive stage data; in addition, usually only key target (QMS) species are staged. Egg surveys are probably the most reliable way of mapping out areas important for spawning; such data as available have been incorporated into NABIS (e.g., blue warehou (Robertson, 1973); frostfish, (Robertson, 1980); red gurnard, (Crossland, 1982); tarakihi, (Vooren, 1975); and snapper, (Zeldis, 1993)).

The NABIS coverages are updated over time as appropriate, as new data becomes available.

3.4.5 New Zealand fish records

For an example map and detailed description of the data see section 3.3.1.

Description of data

The databases containing records of fish species in the New Zealand region were not ultimately used for the assessment of areas of special importance for life history stages. Although data on size and maturity are available in various tables within the TRAWL database, it was impractical with the time available in this project to carry out an extract and analysis of data to indicate where areas might be of special importance.

Matching criteria: Special importance for life history stages.

Fish record and biological data could be used to inform identification of nursery areas (small fish) or feeding grounds.

Data limitations and consideration for future use:

The data in these databases is not in a form where analyses can be readily carried out to inform identification of areas of importance for early life history stages. There is information on the distribution of juvenile/immature/adult fish for many species from the TRAWL database (O'Driscoll et al. 2003) with comments in the text about areas of known importance for pupping or nursery functions. However, the latter are limited, and for many commercial species is captured by the Spawning layer in NABIS (see section 1.1.1).

NABIS layers also contain some juvenile distributional data, but this was very patchy, and was not regarded as adequate for inclusion here.

3.4.6 Seabird breeding and feeding grounds

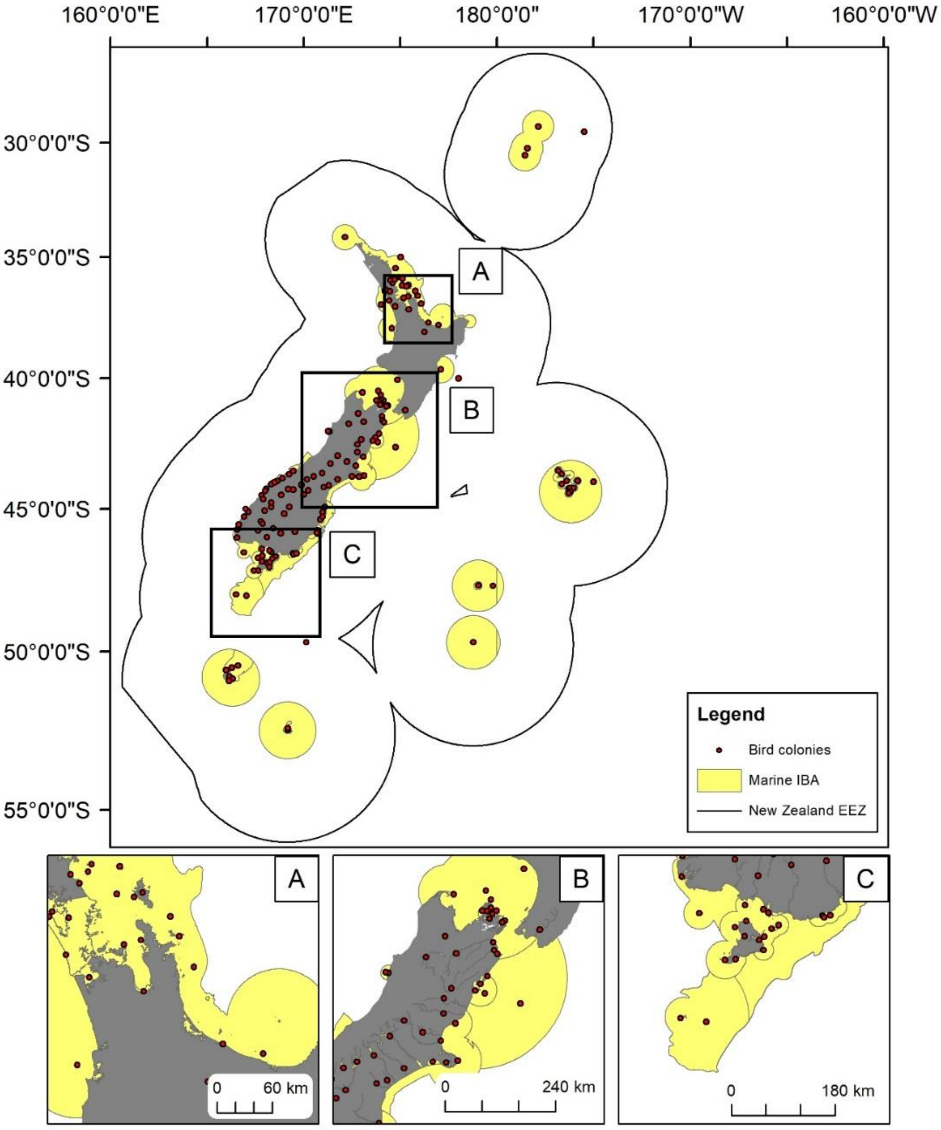

Figure 3-16: Bird colonies (terrestrial and marine species; red dots) with their associated seaward extensions used to identify marine Important Bird Areas (IBA – yellow polygons) (Forest and Bird, 2014). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	High	Single layer

Description of data:

Location of bird colonies and proposed important bird areas (IBA) for New Zealand seabirds were provided by Forest & Bird (2014) (Figure 3-16) based on global analyses developed by BirdLife International. Criteria applied in the marine environment for identification of IBAs are: Regular presence of threatened species; More than 1% of global population regularly occurring (Forest & Bird, 2014). Seaward extensions to breeding colonies provide one method for marine IBA identification.

The boundaries of breeding colony sites can be extended to include those parts of the marine environment which are used for feeding, maintenance behaviours and social interactions. Expert opinion and information from various sources (GPS tracking data and existing literature, published and unpublished data including foraging ranges, dive depth limits for some species, and bathymetry) were used to estimate foraging range, depth and/or habitat preferences of the species concerned. The seaward boundary was colony and/or species-specific, based on known or estimated foraging and maintenance behaviour (Forest & Bird, 2014).

Information for year of the assessment, IBA trigger species, source of GPS tracking and supporting information and the IBA criteria met for each proposed IBA is provided in the metadata (Appendix 1, section 7.1) and in Forest & Bird (2014).

Matching criteria: Special importance for life history stages.

The high endemicity, rarity and threatened status of many New Zealand seabirds, and known interactions and capture as bycatch in fishing fleets highlights the importance of recognising key locations important for their life history stages to minimise threats to their persistence.

Limitations and consideration for future use

These particular analyses, based on Birdlife International IBA analyses, are reasonably simplistic distance-based metrics of foraging, and show no temporal variability (i.e., potential differences in foraging distance depending on seasonal/intra-annual and inter-annual differences in productivity), and also have not been based on productivity of different ocean masses that are likely linked to foraging hotspots. They are primarily useful as generic indicators of locations in which breeding colonies may be found, but are unlikely to protect seabirds during migratory/non-breeding periods.

3.4.7 Seabird distributions

For an example map and detailed description of the data see section 3.3.9.

Matching criteria: Special importance for life history stages.

These seabird distribution models include positions of breeding colonies, and significant portions of foraging required while colonies are occupied, important for seabird life histories, particularly with the high proportion of the global seabird population which breeds in New Zealand's EEZ.

Limitations and consideration for future use:

These models are potentially biased toward the protection of breeding colonies at a particular life history stage. To better describe other life history stages of seabirds, new improvements in methodology that reduce uncertainty and improve our ability to develop distribution and habitat suitability models based on environmental data can be trialled when these models are updated.

Further, many of the individual species modelled had limited data records contributing to model derivation, and additional data, particularly if collected in areas with limited numbers of prior sightings, which could improve model predictions. Finally, seabird distribution models were created primarily based on bycatch observer records, thus showing bias with respect to reporting within proximity of fishing vessels, but limited understanding of the distribution of seabirds when not associated with fishing vessels.

3.4.8 Regional Council identified important marine areas

For an example map and detailed description of the data and how these meet this criteria see section 3.2.1

3.5 Criteria: Importance for threatened and/or declining species and habitats

3.5.1 Sensitive Environments / Biogenic Habitats (marine)

For an example map and detailed description of the data see section 3.2.3.

Matching criteria: Importance for threatened and/or declining species and habitats.

Biogenic habitats are represented by a wide range of plant and animal species, some of which are very common (e.g., brown kelp forests as a collective group), and others much rarer (e.g., red corals). The available data on biogenic habitat distributions has been broadly summarised for 15 key groups by Anderson et al. (2018), which unsurprisingly, revealed a general paucity of quantitative data, and many species/spatial gaps. Unlike the terrestrial environment, the status of many biogenic habitat forming species is very poorly known, meaning that most categorisations of species as threatened, or declining is based on expert opinion rather than empirical data. (Freeman et al. 2014) used expert opinion to determine the conservation status of New Zealand marine invertebrates. They classified the brachiopod *Pumilus antiquatus* (a monotypic, endemic genus) as Nationally Critical, to reflect an apparent decline in abundance at the sites they were previously recorded from (Otago Harbour and Lyttleton). The giant seep mussel *Bathymodiolus tangaroa* was also listed as Nationally Critical. At Risk habitat-forming species included one bryozoan and five coral species. Data Deficient species included 22 coral species (bamboo, sea-fan, bubble-gum, red,) and 13 species of glass sponges. Naturally Uncommon species included 24 coral species (bamboo, sea-fan, bubble-gum, red, black, stony, hydrozoan) and seven species of glass sponges.

Other more common species that are anecdotally in decline from land-based impacts and fishing, as well as other pressures, include horse mussels, the giant kelp *Macrocystis pyrifera*, and various species of reef-building bryozoans (Morrison et al. 2014b).

Data limitations and consideration for future use:

The data available is patchy in its spatial and temporal coverage, and is largely 'point' based, meaning that inferring trajectories of change, and the causes of such change, remains problematic. A key exception is seagrass, which is limited to the intertidal and very shallow sub-tidal. Even for this species, many gaps are present, the data is of varying quality and spatial resolution, and the underlying causes of seagrass decline, through broadly understood, remain an area of active research for the New Zealand situation.

3.5.2 New Zealand fish records

For an example map and detailed description of the data see section 3.3.1.

The OBIS, TRAWL and NIWAinvert databases were searched for distributional records of species listed as protected (basking shark, white pointer shark, deepwater nurse shark) or sharks and rays listed as Threatened or Declining in the NZ Threat Classification system. This included 49 species, many of them deep-sea species which are taken in trawl fisheries, and have low productivity.

Matching criteria: Importance for threatened and/or declining species and habitats.

These shark and ray species are all listed as threatened/declining species. These data are also linked with species that meet criteria for vulnerability, fragility, sensitivity, or slow recovery (section 3.2.4).

Data limitations and consideration for future use:

In common with data limitations presented for vulnerability, fragility etc., in section 3.2.4, productivity information is limited for many chondrichthyan species, especially deep-sea species where for a number of species age and growth, and maturity estimates are poorly known. As further research is carried out on the biology and ecology of deep-sea species, our confidence in this layer will improve. A further limitation of the data is the lack of robust time series of abundance data, from research trawl surveys. The latter are usually focussed on the target commercial species, and are not optimised for species that have different distributions, abundance patterns, or depth ranges. Nevertheless, as these survey series develop, some relative trends can be analysed – as several species have been from Chatham Rise and Southern Plateau middle-depth trawl surveys. However, these have not been included here, but were considered in the risk assessment by Ford et al. (2018).

3.5.3 New Zealand benthic invertebrate records

For an example map and detailed description of the data see section 3.3.2.

Matching criteria: Importance for threatened and/or declining species and habitats.

All New Zealand marine mammals, seabirds and reptiles have been assessed (see Lundquist et al. (2015b)), but the few marine invertebrates which were reviewed by Freeman et al. (2010);Freeman et al. (2014) is only estimated to be 2.7% of the possible total. Of those reviewed most (79%) were classified as naturally uncommon. Only 3.5% were listed as not threatened, with 4% “data deficient” and the rest being either “critical”, “endangered”, “vulnerable” or “declining”.

Data limitations and consideration for future use

The data is limited in terms of distributional and temporal information. In order for it to be useful in the future, more sampling is required at both previously visited sites and also new sites. However, in order for the extra data to be of use, more of the marine invertebrates need to be assessed. A repeat of those taxa previously assessed as “naturally uncommon” would also be required because having such a high proportion of naturally uncommon species is unusual. For example the percentage of fish species assessed as “naturally uncommon” was less than 25%, and other large scale surveys have suggested that usually 30 to 60% of marine invertebrates are rare in occurrence (Ellingsen et al. 2007).

3.5.4 New Zealand reptile and cetacean sightings

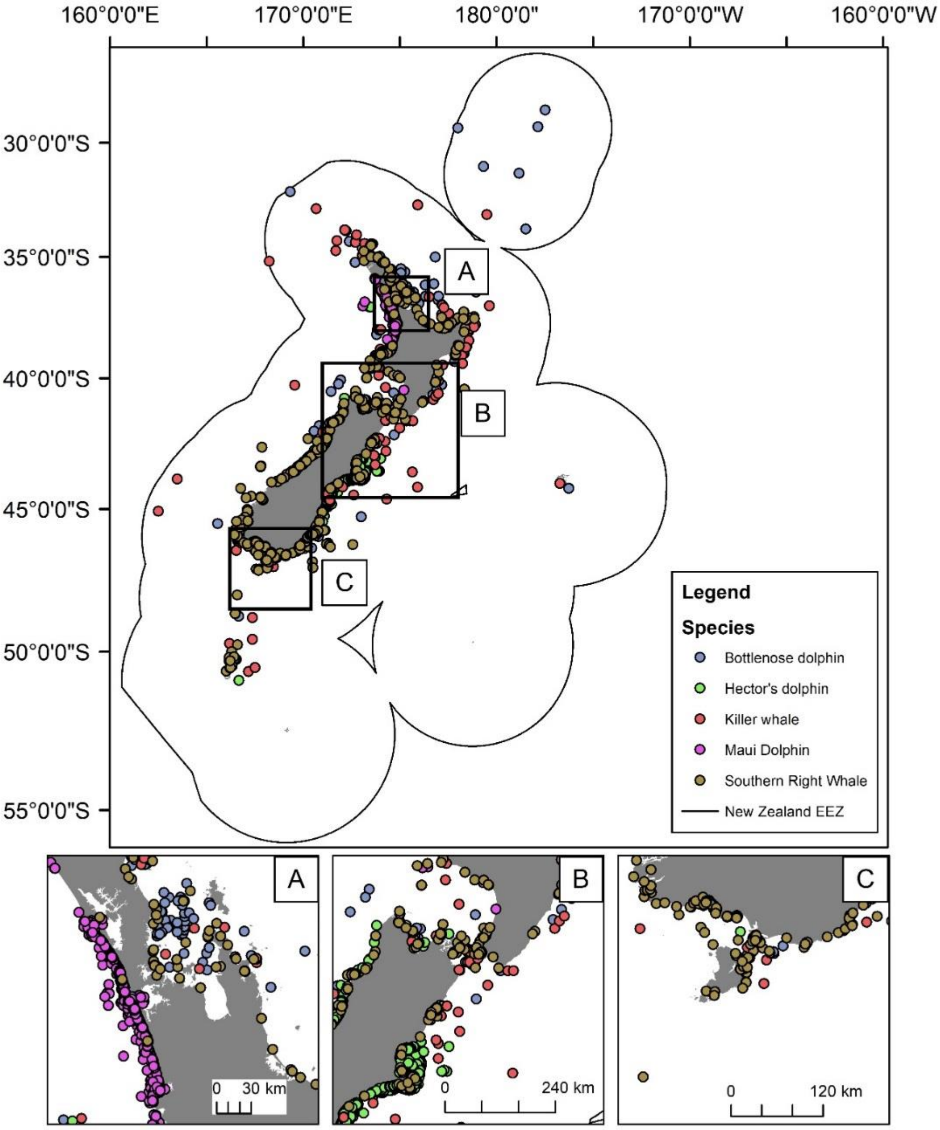

Figure 3-17: Cetacean species listed as Threatened or Declining in the NZ Threat Classification system. Example shows Bottlenose Dolphins (*Tursiops spp*; blue dots); Hector's Dolphin (*Cephalorhynchus hectori*; Green dots); Killer Whale (*Orcinus orca*; Red dots); Maui Dolphin (*Cephalorhynchus hectori maui*; Pink dots); Southern Right Whale (*Eubalaena australis*; Orange dots). Records made available from MPI. Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	High	'Threatened' and 'Declining' marine mammals : Bottlenose dolphins; Hector's dolphin; Māui's dolphin; Killer whale; Southern right whale. Threatened' and 'Declining' reptiles: loggerhead sea turtle; green sea turtle; leatherback sea turtle; hawksbill sea turtle; yellow-lipped sea krait; yellow-bellied sea snake.

Description of data:

Marine reptile records (locations) were extracted from OBIS, TRAWL & NIWA invert (2015 extract for project: Lundquist et al. 2015). Records were groomed and quality controlled. Cetacean records (locations) were obtained from MPI database (collated from multiple sources including NIWA, DOC, other researchers and COD, records range from 1970 – 2015) (Stephenson et al. unpublished).

Records for species listed as "Threatened" (including categories Nationally Critical, Nationally Endangered and Nationally Vulnerable) or "Declining" in the NZ Threat Classification system (Townsend et al. 2008) were imported to ArcGIS as a feature class (point data – the five cetacean species meeting these criteria are shown in Figure 3-17). Further information on criteria used to define 'Threatened' and 'Declining' cetacean and reptile species can be found in Baker et al. (2016) and Hitchmough et al. (2013) respectively.

- 4951 cetacean records from five cetacean species were classified as 'Threatened' and 'Declining': Bottlenose dolphins (*Tursiops truncatus*); Hector's dolphin (*Cephalorhynchus hectori*); Māui's dolphin (*Cephalorhynchus hectori maui*); Killer whale (*Orcinus orca*); Southern right whale (*Eubalaena australis*).
- 48 records from six marine reptile species were classified as 'Threatened' and 'Declining': loggerhead sea turtle (*Caretta caretta*); green sea turtle (*Chelonia mydas*); leatherback sea turtle *(Dermochelys coriacea*); hawksbill sea turtle (*Eretmochelys imbricata*); yellow-lipped sea krait (*Laticauda colubrina*); yellow-bellied sea snake (*Pelamis platurus*).

Matching criteria: Importance for threatened and/or declining species and habitats.

Lundquist et al. (2015b) notes that all New Zealand reptiles and mammals (which include cetaceans) have been assessed for conservation status. No reptiles were categorised as data deficient but around 20% of mammals were assigned to this category.

Limitations and consideration for future use:

The usefulness of this data is assessed in section 1.1.1 for cetaceans.

3.5.5 New Zealand cetacean distributions

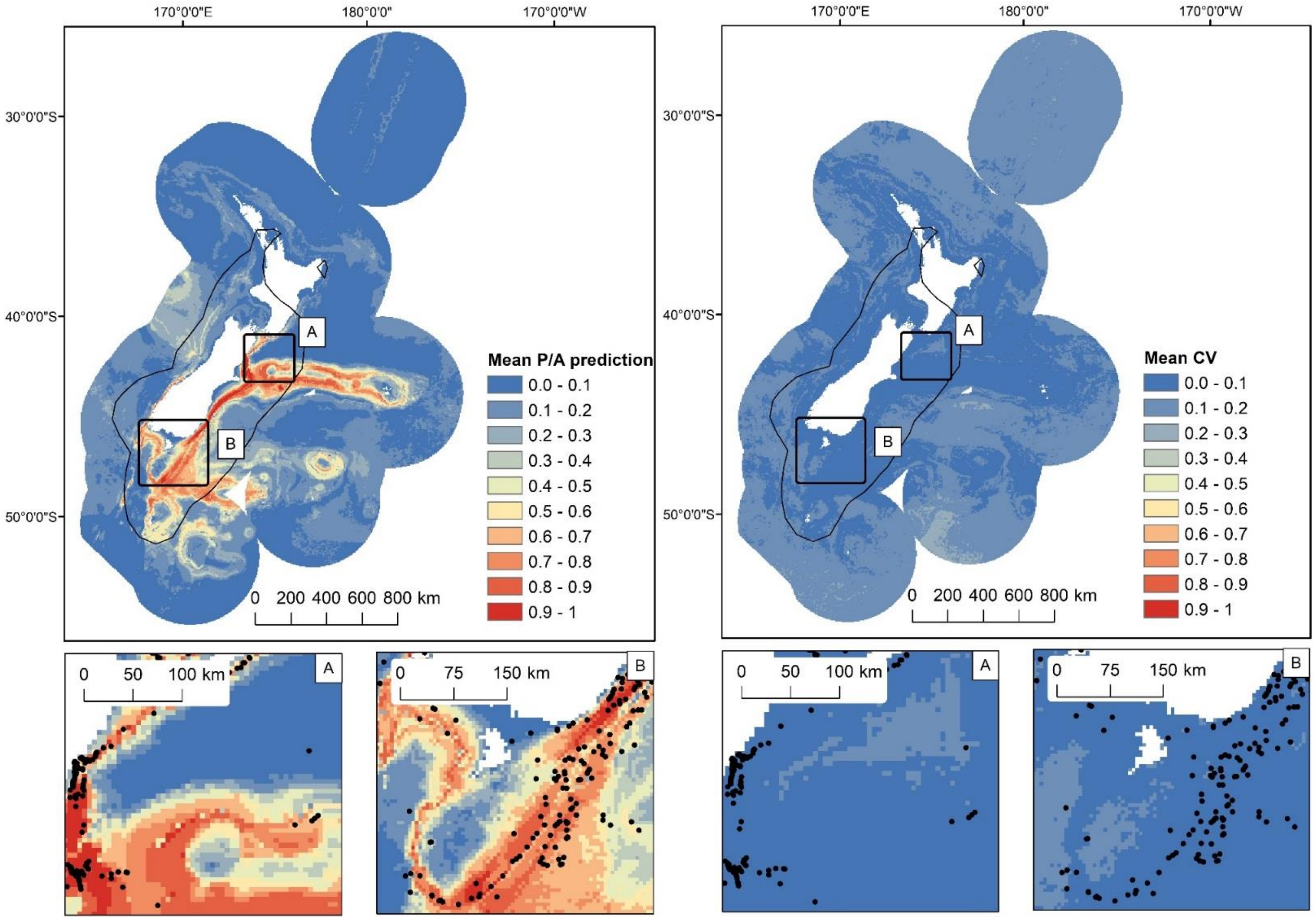

Figure 3-18: Annual predicted distribution (occurrence) of Dusky Dolphin (left, scale: absence (0) – presence(1)) and associated spatial uncertainty measured as coefficient of variation (right, scale: low (0) – high uncertainty (1)). Dusky Dolphin records made available from MPI, a subset of which are shown as black dots (Stephenson, et al. unpublished). Black line shows the 95% Utilisation Distribution. Inset maps: A) north-western Chatham Rise; B) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	NZ EEZ at a 1km grid resolution.	Not validated but bootstrapped mean and uncertainty layers created.	High	See Appendix 1, section 7.2, for list of species.

Description of data:

Predicted annual and seasonal (data permitting) distribution occurrence of 33 cetacean species are currently being prepared for an MPI project (project code: PRO201401) (Stephenson et al. unpublished). Cetacean records (locations) obtained from MPI (collated from multiple sources including NIWA, DOC, other researchers and COD, records range from 1970 – 2015) were used to predict distribution occurrence maps using two methods:

- Relative environmental suitability (RES) models were used for 21 species with low numbers of records (< 50 locations) following methods by Kaschner et al. (2006).
- Bootstrapped BRTs of presence/relative absence were fitted using 14 environmental variables for 17 species (for more information on bootstrapped BRTs see section 3.2.2.). Example mapped outputs for the Dusky Dolphin (*Lagenorhynchus obscurus*) with associated uncertainty is shown in Figure 3-18). 11 species which had records for > 300 were split into summer (November – April) and winter (May – October) and 'seasonal' bootstrapped BRT models (summer and winter) were fitted.

Matching criteria: Importance for threatened and/or declining species and habitats.

Once this project is finished, comparison between the categorisation of individual cetacean based on the predicted distribution data with that reported by Baker et al. (2010);Baker et al. (2016) could be used to determine whether the data can be used for this criterion.

Limitations and consideration for future use:

Cetacean sightings records were spatially biased with higher effort closer to shore. Model outputs should only be interpreted as accurate within the 95% Utilization distribution calculated for each species (e.g., the black line in Figure 3-18). In addition, to further account for the uncertainty introduced by the sampling bias, coverage of the environmental space was also predicted as an added measure to assess the uncertainty of the predicted distribution layers (see further details for the methods and interpretation of this layer in section 3.3.3).

Not all data were available at the time of writing this report, but preliminary results suggest that, for those species with adequate sample number, model outputs were robust: AUC scores > 0.75, and deviance explained for models ranged from acceptable (0.2) – high (0.7) for both training and evaluation datasets. For example, the model fitted to dusky dolphin (Figure 3-18) data, the deviance explained was 0.6 and had an AUC of 0.94. Datasets will be available once the report to MPI has been approved and finalised (expected release data Jan 2019).

3.5.6 New Zealand naturally uncommon habitats in coastal environment

For an example map and detailed description of the data see section 3.3.8.

Matching criteria: Importance for threatened and/or declining species and habitats.

By their definition, those naturally uncommon habitats defined as threatened or critically endangered will match this criterion (including those coastal habitats listed in section 3.3.8). In addition, naturally uncommon habitats are likely to host threatened or decline species (Wiser et al. 2013).

Data limitations and consideration for future use:

The usefulness of this data is assessed in section 3.3.8.

3.5.7 Regional Council identified important marine areas

For an example map and detailed description of the data and how these meet this criteria see section 3.2.1

3.6 Criteria: Biological productivity

3.6.1 Sensitive Environments / Biogenic Habitats (marine)

For an example map and detailed description of the data see section 3.2.3.

Matching criteria: Biological productivity.

Marine plants such as seagrass and macroalgae (especially Kelp forest species, e.g., *Macrocystis* and *Ecklonia* species) are important primary producers in the nearshore coastal environments around New Zealand (described in Anderson et al. 2018) and are some of the most productive habitats on Earth (Costanza et al. 2014;Krumhansl et al. 2016).

Data limitations and consideration for future use

DOC's national seagrass dataset (described in Anderson et al. (2018)) is one of the best available datasets for biogenic habitats in New Zealand. Data are available as spatial data layers that provide spatial coverage (although not complete for all estuaries where seagrass are known to occur) and may include seagrass density for some estuaries.

Macroalgae data are represented by presence-only data (i.e., no abundance or absence data), with most data records from intertidal areas (~>80% of the data available), with markedly fewer records from subtidal areas that comprise more area (Anderson et al. 2018). While these data provide good information of the geographic distributions of key habitat-forming species, they also include notable data gaps, reflecting a bias in Collections databases towards rare or unusual species. For example, easily identifiable and commonly occurring kelp species (e.g., *Ecklonia radiata*) were missing data distributions from many locations where they are known to occur. Unlike seagrass data, little to no information is available on the spatial extent of macroalgal habitats.

3.6.2 New Zealand marine reef fish records

For an example map and detailed description of the data see section 3.3.3.

Matching criteria: Biological productivity.

Shallow rocky reefs often support diverse rocky reef communities based on high primary productivity of reef-associated macroalgal species (Andrew and O'Neill, 2000). While the individual reef fish species distributions themselves are not indicators of this particular ecological significance criteria, these layers in combination showcase the high productivity of these habitats through their association with diverse and abundant fish communities. Reef fish layers (through combined layers to generate species richness) may give indications of differences in quality and productivity between different reefs, as these models incorporate environmental drivers linked to primary and secondary productivity. Elsewhere, using the Ecosystem Principles Approach, these environmental drivers suggest high value of these reefs for productivity (Townsend et al. 2014a) (see section 3.10.2 for spatial predictions of biogenic habitat provision).

Data limitations and consideration for future use

Limitations due to model uncertainty and underpinning environmental layers (e.g., rocky reef habitats) are discussed in section 3.3.3. Another key limitation for these layers is their correlation with productivity itself, as the reef fish models may better reflect environmental drivers of species distributions that are poorly correlated with productivity (e.g., depth, temperature) (Hewitt et al. 2015).

3.6.3 Hydrothermal vents

For an example map and detailed description of the data see section 3.3.4.

Matching criteria: Biological productivity.

Hydrothermal vents occur where geothermally heated water emanates through and from fissures in the seafloor. The temperature of the venting fluid and its flow rate varies depending on a number of factors. Chemical compounds in the vent fluid (principally hydrogen sulphide) support special ecosystems, at the base of which are chemosynthetic bacteria and archaea that directly or indirectly support a range of other mostly vent-dependent larger organisms. Hydrothermal vent ecosystems are among the most productive deep-sea ecosystems known in the ocean (Van Dover, 2000). Vent ecosystems are highly productive because of the amount of energy that is supplied to the base of the food chain by the chemosynthetic microorganisms. Some species of the vent dependent macrofauna can grow to be relatively large, and a single vent site can support very large densities of such organisms. Communities dominated by such organisms can represent very large biomasses concentrated in a relatively small area (e.g., vent mussels and clams at New Zealand vents, (Von Cosel and Marshall, 2003;Glover et al. 2004)).

Vent sites are also areas where densities of non-vent-dependent species can also exist in high abundances and biomasses, due to the benefits gained from feeding on vent organisms or their degraded products (e.g., seastars and crabs at New Zealand vents, (McKnight, 2006).

Data limitations and consideration for future use:

Data limitations and considerations are described in section 3.3.5.

3.6.4 Cold seeps

For an example map and detailed description of the data see section 3.3.5.

Matching criteria: Biological productivity.

Seeps occur where hydrocarbon-rich fluid emanates through and from the seafloor, forming via a number of mechanisms that generate different types of seeps. Chemical compounds in the seep fluid (principally methane) support special ecosystems, at the base of which are chemosynthetic bacteria and archaea that directly or indirectly support a range of other mostly seep-dependent larger organisms. Cold seep ecosystems are among the most productive deep-sea ecosystems known in the ocean (Levin, 2005). Seep ecosystems are highly productive because of the amount of energy that is supplied to the base of the food chain by the chemosynthetic microorganisms. Some species of the seep dependent macrofauna can grow to be relatively large, and a single seep site can support very large densities of such organisms. Communities dominated by these organisms can represent very large biomasses concentrated in a relatively small area (e.g., seep clams at New Zealand seeps, (Baco et al. 2010;Bowden et al. 2013)).

In some instances, the reaction between the chemicals in the seep fluid and bacteria can lead to the formation of hard substrates, calcium carbonates, which can form isolated rocks or reefs. These reefs can form attachment sites for non-chemosynthetic sessile organisms, which can occur in relatively high densities and biomasses by benefiting from feeding on seep organisms or their degraded products (e.g., sponges and corals at New Zealand seeps, (Baco et al. 2010;Thurber et al. 2010;Bowden et al. 2013)).

Data limitations and consideration for future use:

Data limitations and considerations are described in section 3.3.5.

3.6.5 Inshore and offshore primary productivity

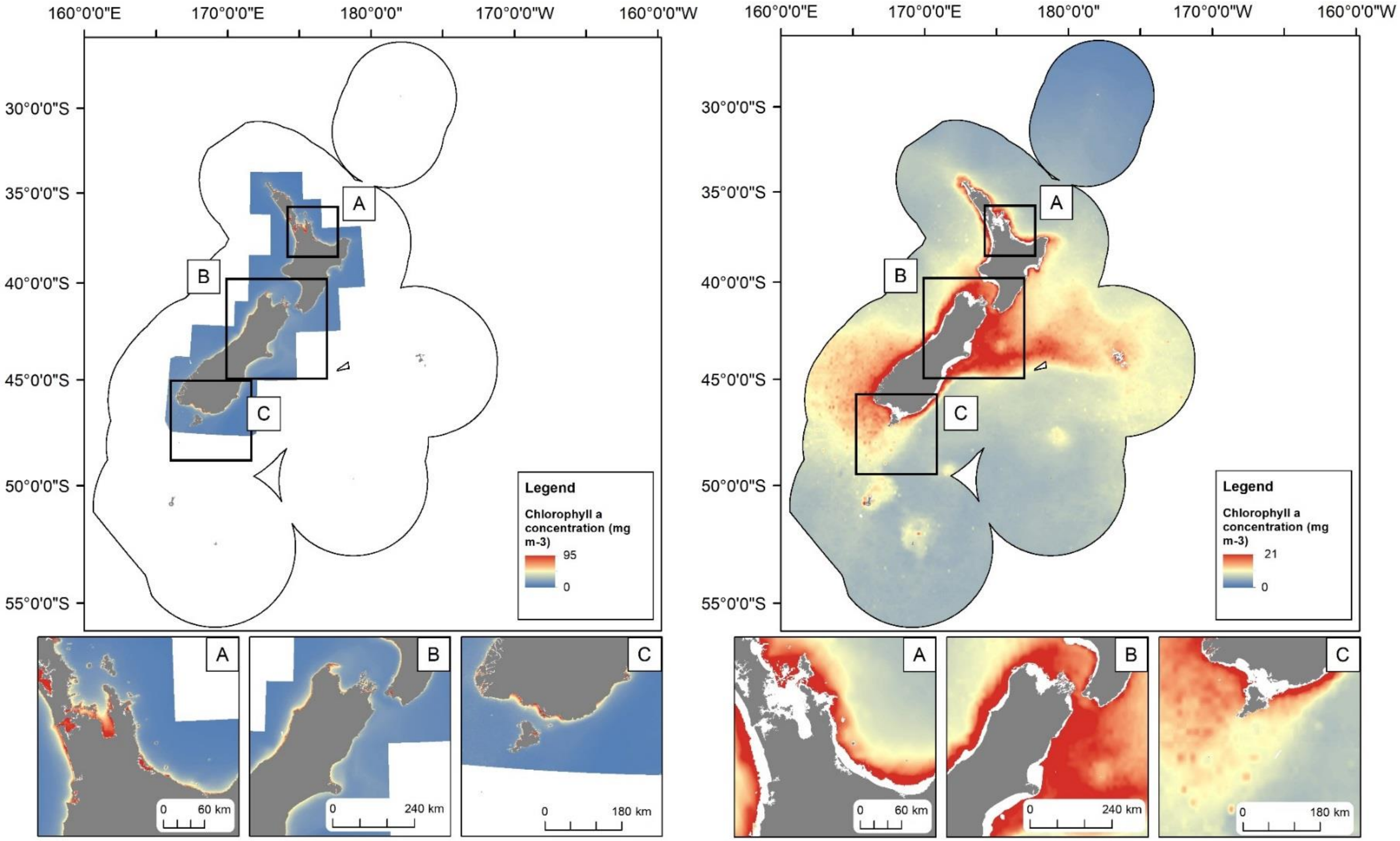

Figure 3-19: Near-surface chlorophyll-a concentration (mg/m^3, proxy for water column primary productivity) measured estimated from satellite ocean colour observations (Pinkerton 2016; Pinkerton et al. 2018). Inshore estimates (left) are average values 2002–2017 at 500 m resolution (MODIS-Aqua; Pinkerton et al. 2018). Offshore estimates (right) are average values 1997–2017 at 4 km resolution (SeaWiFS, MODIS-Aqua merged; Pinkerton 2016) with values in depths shallower than 50 m removed (see below for further details). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	Inshore, shallower than 50 m. 500 m grid resolution.	Comparison with matched in situ, inshore measurements (Hauraki Gulf, Pinkerton et al. 2018; Manukau Harbour, Pinkerton 2017).	Moderate	Single layer
Raster	Offshore/oceanic, EEZ, deeper than 50 m 4 km grid resolution.	Biogeographic (EEZ: Murphy et al. 2001). Comparison with matched in situ, offshore measurements (Subtropical Front Pinkerton et al. 2005). Discussion of data quality in Pinkerton, 2016.	High	Single layer

Description of data

Water column phytoplankton biomass proxied by chlorophyll a concentration ("chl-a", mg m^{-3}) were collated for offshore areas (NZ EEZ wide excluding depths < 50 m) and inshore areas (limited to the inshore for all depths). Offshore chl-a was estimated from merged satellite dataset, including SeaWiFS (NASA/OrbImage: Sea-Viewing Wide-Field-of-view Sensor) and NASA MODIS-Aqua (Moderate Resolution Imaging Spectroradiometer) to a ca 4 km grid resolution (left, Figure 3-19). See Murphy et al. (2001);Pinkerton et al. (2005);Pinkerton (2016) for details. Inshore water column productivity was estimated from MODIS-Aqua data from 2002–2017 at 500 m grid resolution using the near infra-red/short-wave infra-red (NIR-SWIR) switching atmospheric correction (Wang and Shi, 2007) and quasi-analytic algorithm (QAA: Lee et al. (2009)), appropriate for optical Case-2 (coastal) conditions (right, Figure 3-19; Pinkerton (2017);Pinkerton et al. (2018)). Surface chl-a concentration is a good proxy for water-column integrated primary productivity (Murphy et al. 2001;Campbell et al. 2002).

Matching criteria: Biological productivity.

Surface productivity gathered from water colour information gives an aerial estimate of algal biomass that is indicative of large-scale water-column primary productivity.

Limitations and consideration for future use

Oceanic: Virtually all primary production in offshore waters (deeper than ~50 m) is from phytoplankton in the water column. The concentration of chl-a near the ocean surface as seen by satellites is not the same thing as ocean primary productivity, although it is related to it. Net primary productivity (NPP) is the vertically-integrated rate of growth of phytoplankton after allowing for respiration, and considering the depth distribution of phytoplankton through the water column. NPP is the amount of organic material potentially available to higher trophic levels (consumers) and so directly relevant to mapping key ecological areas. Although there are many ways of estimating phytoplankton NPP from satellite data, none has yet been validated in the New Zealand region, and national scale “state of the environment” reporting in New Zealand presently uses chl-a as a proxy for ocean productivity (Pinkerton et al. 2018).

Coastal: Primary production in shallow waters is from two major sources: phytoplankton in the water column (as above), and benthic primary producers (including macroalgae, seagrass, and benthic microalgal and periphytes). As water depths become shallower, and water becomes clearer (lower turbidity) the role of benthic productivity increases in importance over water column productivity.

Coastal, water column NPP: Primary production by coastal phytoplankton can be proxied using satellite observations of near-surface chl-a concentration as for oceanic waters. The method of estimating chl-a in coastal waters is substantially more complex than for oceanic waters because of the intermittent presence of coloured material (sediment and dissolved yellow substance) from land-run off and local benthic resuspension. Processing methods dealing with this optical complexity have been used here (Pinkerton et al. 2018) to estimate long-term chl-a distributions at the national scale and moderate spatial resolution (500 m). Methods to assess the quality of these satellite-based estimates of chl-a in the coastal zone are limited (Pinkerton et al. 2005;Pinkerton et al. 2018). Similar data will be included in the 2019 State of the Environment reporting for the New Zealand coastal zone to track long-term change in coastal primary productivity in the water column.

Coastal, benthic NPP: Estimating relative benthic primary production can potentially be achieved using estimates of the amount of light reaching the seabed, although this measure does not take into account the influence of benthic substrate on the type of benthic primary producers (e.g., soft sediment versus rock outcrop). The approach used to estimate the amount of light reaching the seabed is relatively well advanced but has not yet been used extensively or validated across New Zealand. Although light reaching the seafloor is likely to be one of the main drivers of primary productivity, the unknown and as of yet untested relationship of resulting productivity for different seabed habitats means further testing is required to ascertain this layers value as a proxy for seabed productivity. For this reason, this layer was not included here, but further work is on-going and may be of use for future assessments.

3.7 Criteria: Biological diversity

3.7.1 New Zealand demersal fish species turnover and classification

For an example map and detailed description of the data see section 3.3.6.

Matching criteria: Biological diversity.

Characterization of biodiversity patterns required for conservation planning should ideally be based on quantitative information describing different components of diversity, including not only the distributions of individual species and/or communities, but also of emergent properties such as alpha diversity (local richness – see section 3.7.3 and 3,7,4) and beta diversity (species turnover along spatial or environmental gradients) (Harrison et al. 1992;Nekola and White, 2002;Legendre et al. 2005). While the former (alpha diversity) contributes to the relative importance of an area for conservation, it is the rate of species turnover between sites that largely determines the optimal spatial arrangement of conservation areas (McKnight et al. 2007;Arponen et al. 2008;Bush et al. 2016). The spatial scale at which species turnover is high relative to alpha diversity is crucial for determining whether it is advantageous to incorporate areas where there is high species turnover to maximise both the richness across the site as whole, but also ensure diversity in assemblages. The datasets presented here, can help with both the optimal spatial arrangement (i.e., selecting areas which maximise species turnover) but can also be used in a target-based analysis, i.e., where the aim is to protect a given percentage (e.g., 10%) of each assemblage (with the assumption that these assemblages act as surrogates for biodiversity (Ferrari et al. 2018).

Data limitations and consideration for future use

The dataset limitations are already described in section 3.3.6. Future work could consider using the species records to generate layers of the individual SDMs (which are produced as part of the first step in the GF analysis using Random Forests); this would provide a more complete assessment of demersal fish diversity as well as associated uncertainty – this work is currently in progress with these layers expected to be available in 2019.

3.7.2 New Zealand benthic invertebrate species turnover and classification

For an example map and detailed description of the data see section 3.3.7.

Matching criteria: Biological diversity.

The benthic invertebrate species classification match the “Biological diversity” criteria in the same way as the demersal fish species classification discussed in section 3.7.1.

Data limitations and consideration for future use:

The dataset limitations are already described in section 3.3.7. Future work could consider using the species records to generate layers of the individual SDMs (which are produced as part of the first step in the GF analysis using Random Forests); However, with the relatively low number of records available, this might only be of use for those species with adequate sample number (e.g., n ≥ 50).

3.7.3 New Zealand demersal fish species richness

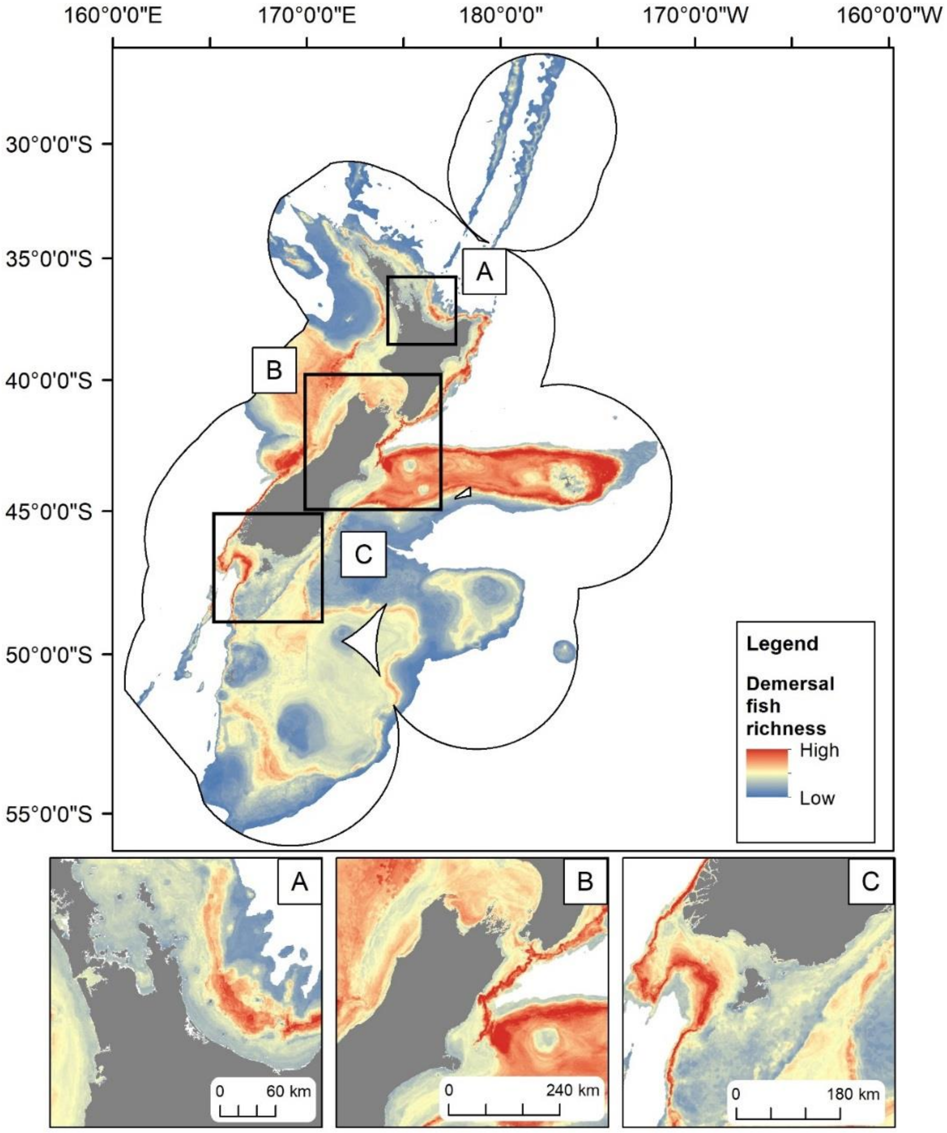

Figure 3-20: Predicted demersal fish species richness to depths of 2500m (adapted from Leathwick et al. 2006). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	NZ EEZ (only to depths of 2500m) with a 1km grid resolution.	Not validated but bootstrapped mean and uncertainty layers created.	High	Single layer

Description of data:

Demersal fish species richness, and the associated uncertainty (5-95% confidence interval) were predicted using bootstrapped BRTs fitted using 16 946 demersal fish records (from 1979 to 1997 from TRAWL database), eight environment predictors and trawl characteristics (e.g., cod-end mesh size, tow length and tow speed) (Leathwick et al. 2006). Further details on the methods used are available in Leathwick et al. (2006).

Matching criteria: Biological diversity

Demersal fish richness is one measure of biological diversity. Demersal fish richness has been tested for its use as a surrogate for epibenthic richness (another measure of diversity). However, this was not a useful surrogate except as very small scales (< 2km, (Hewitt et al. 2015)). The congruence of fish assemblages and turnover patterns, to that of epibenthos and macroalgae is limited although these could be used if no further information is available (Thomson et al. 2014).

Limitations and consideration for future use:

As noted in previous sections (see section 3.3.6; 3.3.7 and 3.7.4 for further detail), while this data is spatially extensive, there is still a relatively high proportion of the EEZ that has not been sampled. In particular, there are areas of the environmental space which remain unsampled (e.g., > 2000 m depth). Moreover, the sampling has taken place over an extended period of time suggesting that analysis of change over time should be conducted (see Appendix 2, section 7.2 for examples of the consideration of change in sampling and species richness over time).

Demersal fish richness has been tested for its use as a surrogate for epibenthic richness. However, this was not a useful surrogate except as very small scales (< 2km, Hewitt et al. (2015)).

3.7.4 New Zealand benthic invertebrate species richness

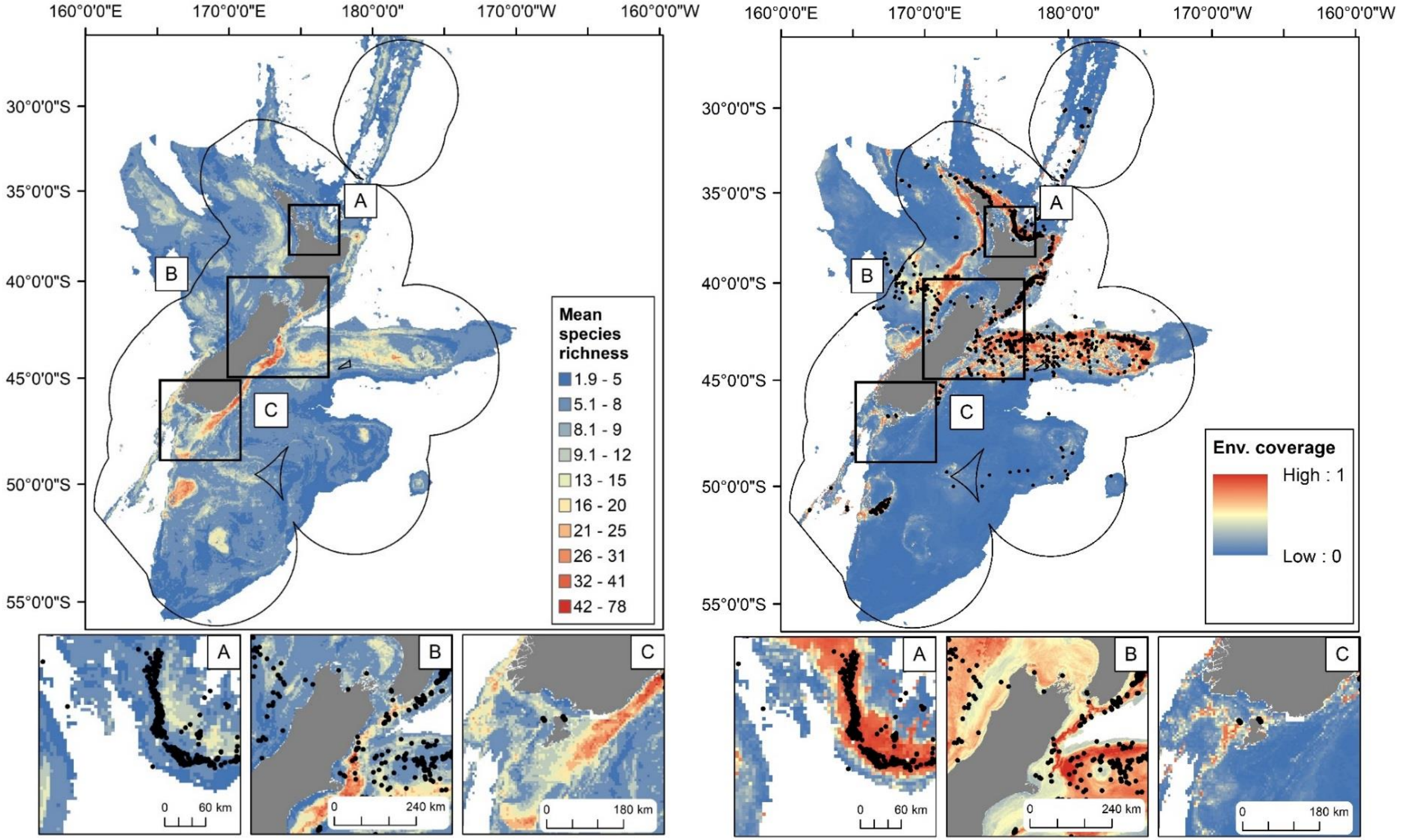

Figure 3-21: Mean predicted benthic invertebrate species richness to depths of 2500 m (left) and location of benthic invertebrate record overlaid on the predicted environmental coverage. Inset maps, with location of records (black dots): A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	NZ EEZ (only to depths of 2500m) with a 1km grid resolution.	Not validated but bootstrapped mean and uncertainty layers created.	High	Single layer

Description of data:

Benthic invertebrate species richness, and the associated uncertainty (5-95% confidence interval) was predicted using bootstrapped BRTs (methods based on Leathwick et al. (2006)). BRT models were fitted using benthic invertebrate records from 2449 locations (extracted from multiple database – see section 3.3.7 for details), across 4 gear categories in combination with fifteen environment predictors (see appendix 0 for further detail on methods used).

The mean deviance explained by the model was relatively high at 0.45 (although this is lower than the deviance explained by Leathwick et al. (2006) which was 0.6, most likely due to the much lower number of records). The mean explained deviance of the withheld dataset used during the bootstrap was similar (0.45) providing evidence that the models were not overfitted. There was a reasonable correlation between observed and expected species richness when comparing the predicted values of the evaluation dataset with observed values (mean correlation 0.58).

Gear category made a substantial contribution to analysis outcomes (see appendix 0 for further information). In order to incorporate the (non-spatial) differences in gear category, benthic invertebrate richness models were predicted separately for the two gear categories with the largest number of samples (859 unique locations from large gear types with moderate sample areas; 1264 unique locations from medium sized gear types with moderate sample areas) with resulting predictions averaged (Figure 3-21). This process was repeated for the associated spatial uncertainty predictions.

As an added measure to assess the uncertainty of the predicted species richness layer the environment coverage was also modelled. This layer highlighted that the relationships between the environment and the biological samples were well understood for a relatively small proportion of the study area (deeper waters close to the coasts and the Chatham Rise, red areas on the map on the right of Figure 3-21). Prediction of benthic invertebrate richness from areas offshore and very close to shore (e.g., the Hauraki Gulf) should be treated with more caution (blue areas on the map on the right of Figure 3-21).

Matching criteria: Biological diversity

Benthic invertebrate richness is one possible measure of biological diversity. See section 3.7.3 for a brief overview of how this may reflect other taxa.

Limitations and consideration for future use:

The same limitations will apply to this dataset, as described in section 3.7.3 (above). In addition, as discussed in previous sections, benthic invertebrate samples are further limited by the smaller sample number, covering a more restrictive environmental space. Of note, the integration of video or image data would greatly increase the number of samples within the dataset (with the caveat that species identification may be limited for certain taxa, (Stephenson et al. 2017)), however, difficulties may arise when considering the differences in spatial scale used by different methods.

3.7.5 Seabird distributions

For an example map and detailed description of the data see section 3.4.6.

Matching criteria: Biological diversity.

New Zealand is internationally recognised for its diversity of seabirds, and the large proportion of the global seabird population that utilises New Zealand waters within its foraging migrations or for breeding colonies, often on offshore islands (Gordon, 2009).

Data limitations and consideration for future use:

Data limitations are discussed in sections 3.3.3 and 3.4.6.

3.7.6 Regional Council identified important marine areas

For an example map and detailed description of the data and how these meet this criteria see section 3.2.1

3.8 Criteria: Naturalness

3.8.1 Bottom fishing footprint

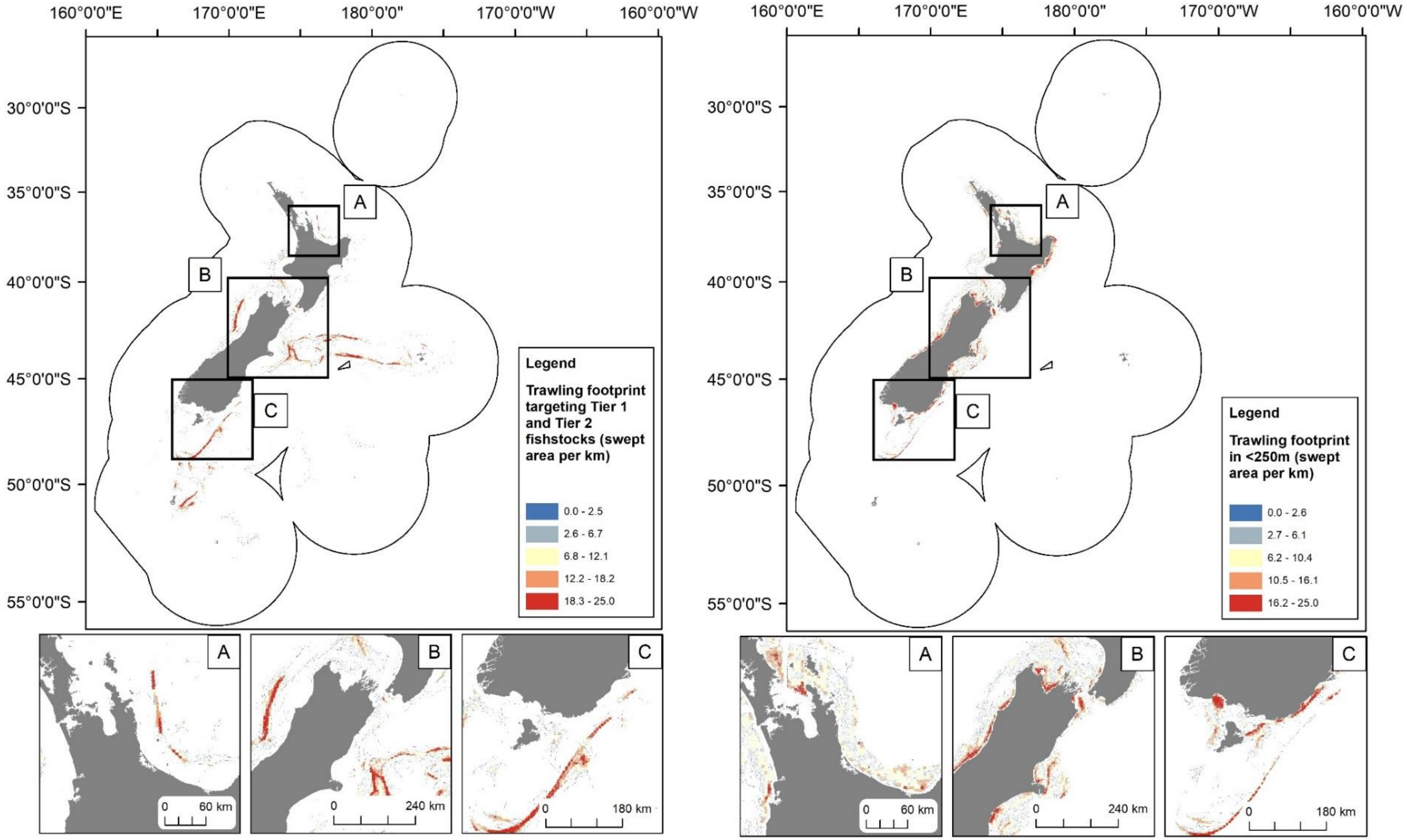

Figure 3-22: The swept area (footprint) of trawling (tows per km) for Offshore/deepwater bottom trawl fisheries (left, data from fishers targeting Tier 1 and Tier 2 fishstocks from 2008) and for Inshore/shallow water bottom trawl fisheries (right, data from waters shallower than 250m from 2008). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (polygon).	Offshore: NZ EEZ. Inshore: NZ EEZ to depths of 250m.	NA	High	Single layer for each year: Offshore fishing: 1990 – 1991 to 2015 – 2016. Inshore fishing: 2008 – 2009 to 2011 – 2012.

Description of data:

The trawl footprint (total swept area in km^2) was estimated from tow by tow data for fisheries targeting deepwater Tier 1 and Tier 2 fishstocks, over the period of 1990 to 2016 (termed 'offshore' although this extends from the close to the coast to 200 nmi EEZ boundary) (Baird and Wood, 2018). Similar estimates were made for fisheries in New Zealand waters shallower than 250 m for the years 2008 – 2012 (referred to here as 'inshore' although this is not limited by distance to shore but rather by depth) (Baird et al. 2015). These data were sourced from a combination of reporting forms by the commercial fleet: Trawl Catch Effort Processing Returns (TCEPRs), Trawl catch Effort Returns (TCERs), and Catch Effort landing Returns (CELRs). Spatial layers of fishing effort were available separately for each fishing year: 1990 – 1991 to 2015 – 2016 for offshore fishing effort, and 2008 – 2009 to 2011 – 2012 for inshore fishing effort. Offshore and inshore maps of fishing effort are presented for fishing year 2008 – 2009 (left and right respectively) in Figure 3-22. Yearly maps of fishing effort can be combined to investigate changes over various combinations and periods of time to identify general areas which may be particularly under pressure from fishing; these areas are discussed in more detail in Baird et al. (2015) and Baird and Wood (2016).

The total footprint for Tier 1 and Tier 2 target fishstock over the period 1990–2016 was estimated at 335 812 km^2, representing 8.2% of the area within the EEZ and 24% of the seafloor down to 1600 m that is open to fishing (Baird and Wood, 2018).

Matching criteria: Naturalness

The relative swept-area estimates enable an evaluation of how heavily fished, and hence potentially modified, a site might be. The data enable estimates that can be separated by trawl gear type (bottom and midwater in particular), by area, by time period, and by seafloor depth.

Limitations and consideration for future use:

Data cover both bottom and midwater trawl gear. Hence the degree of naturalness will vary depending on the habitat of interest. Bottom trawl gear will have a direct impact on seafloor communities, whereas midwater trawls off the seafloor could have little impact on the seabed but affect pelagic communities.

The inshore data have only recently converted to start and finish positions, rather than reporting as a tow duration within a statistical fishing area. In the past, the use of CELRs by most small vessels in the New Zealand fleet has limited an overall effort assessment. The data reported across the entire commercial fishing fleet is now much better. Over time, these data will give a better indication of the spatial nature and extent of inshore fishing, and hence a better understanding of the location of unfished or lightly fished areas.

Positional accuracy of location data is to the nearest minute of latitude-longitude, and is based on vessel position, not fishing gear position. For bottom trawling on small features such as knolls and hills, the gear may be many hundreds of metres behind the vessel, and where tow duration is short, the direction of tow cannot be determined. This is not an issue for larger-scale analyses, but can misrepresent small-spatial scale interpretation. Further improvements to the swept-area analysis are suggested by Baird & Wood (2018).

A key issue in application of these data is what level of effort/footprint constitutes a significant impact. There are no accepted threshold values, although an increasing number of studies quantify changes in community structure related to trawling effort. In New Zealand, as an example, an effort level of 10 trawls (equivalent to about 30 trawls km^{-2}) was estimated by experts to effectively remove benthic stony coral densities (Rowden et al. in press).

3.8.2 Commercial fishing (all methods); dredging and recreational fishing footprints

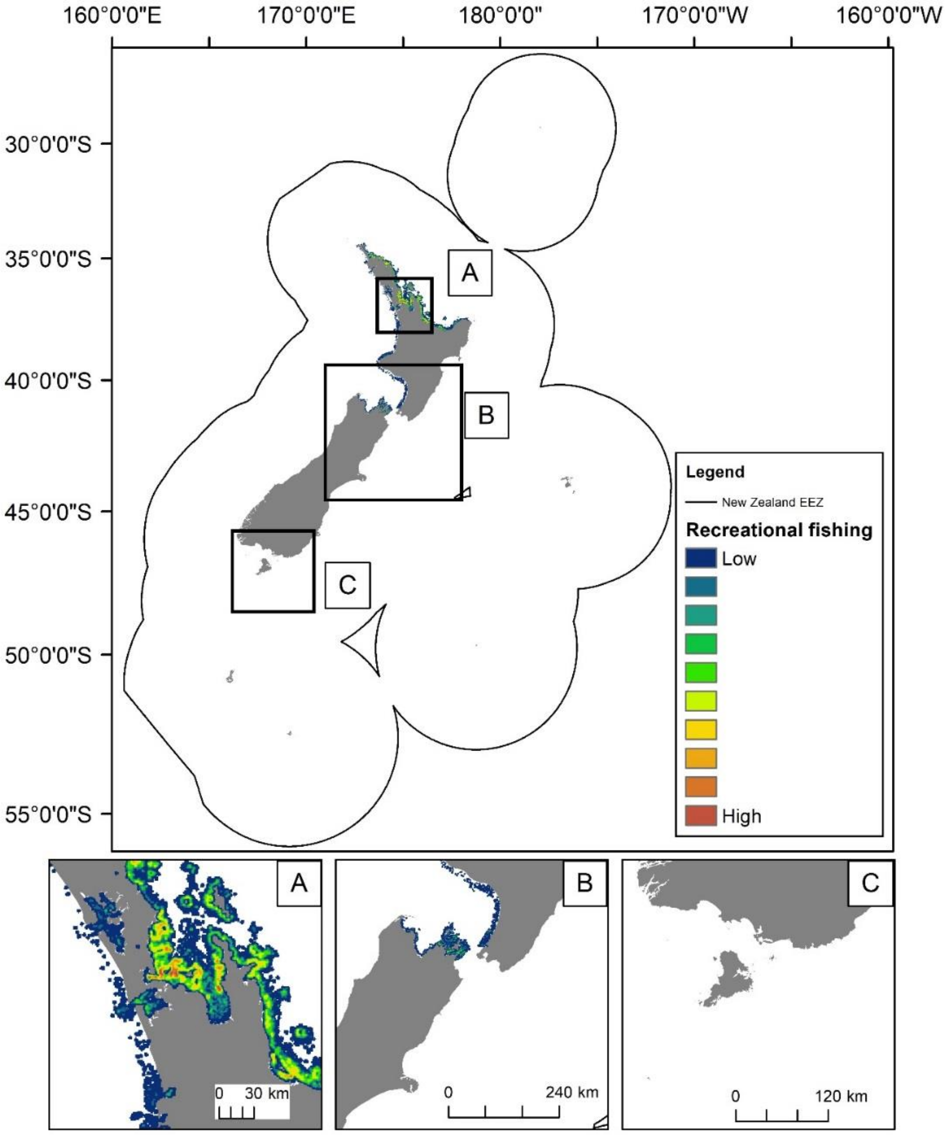

Figure 3-23: Heat maps and spatial estimates of recreational fishing (low – high). Mean annual estimate for data from 2007 - 2016)(MPI, CatchMapper). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	NZ EEZ at a 1km grid resolution.	NA	High	Commercial fishing (all trawl, line and potting methods); dredging effort; and recreational fishing.

Description of data:

Heat maps and spatial estimates of commercial fishing (all trawl, line and potting methods); dredging effort; and recreational fishing (annual estimates provided here for a subset of the data by fishing year (October to September) from 2007 - 2016) were obtained from the MPI project 'CatchMapper' (Osborne, 2018). Estimates of fishing are given as annual averages (e.g., spatial estimates of recreational fishing (low – high) for fishing years 2007/8 – 2015/16 is shown in Figure 3-23) but can also be provided as monthly or annual time series (Osborne, 2018). CatchMapper includes all commercially fished species and all fishing methods, although the underlying data used for each fishing method varies and thus the quality of the data also varies. Only average values of estimates are provided without statistical confidence intervals. Qualitative ranking of the quality of the underlying data and therefore the confidence in the estimate is provided for guidance for each fishing method in Osborne (2018).

Fishing events in the EEZ since October 2007 were reproduced as a polygon defining the location of the fishing event recorded by fishers and other information available to MPI fishery analysts. To map and visualise fishing intensity patterns, each polygon was pixelated to a 1 km^2 resolution and pixels given values of catch per unit area, or effort per unit area, or catch per unit effort (CPUE) reported for the fishing event. The resulting images can be grouped, summed and averaged in a multitude of ways. Here we present three annual means for recreational fisheries effort, dredge landings for fisheries statistics areas and commercial fishing effort for all gear types. For further detail on the assumptions made and the quality of the data see Osborne et al. (2018).

Matching criteria: Naturalness

In a similar way to the analysis of the fishing footprint in section 3.8.1, the relative density of fishing effort or catch or CPUE can indicate the extent of impact in a certain area, and hence support an evaluation of how modified the environment or species composition might be. However, the spatial layers presented here indicate fishing intensity on a relative scale, depending on how these data may be used in future analyses it may be of use to have actual values.

Limitations and consideration for future use:

The spatial scale at 1 km^2 is not as precise as the trawl footprint analysis, and the data are combined across a multitude of fishery and gear types, as well as variable data quality.

Most of the limitations, and comments on future use, are the same as described in section 3.8.1.

3.8.3 Area-based marine protection

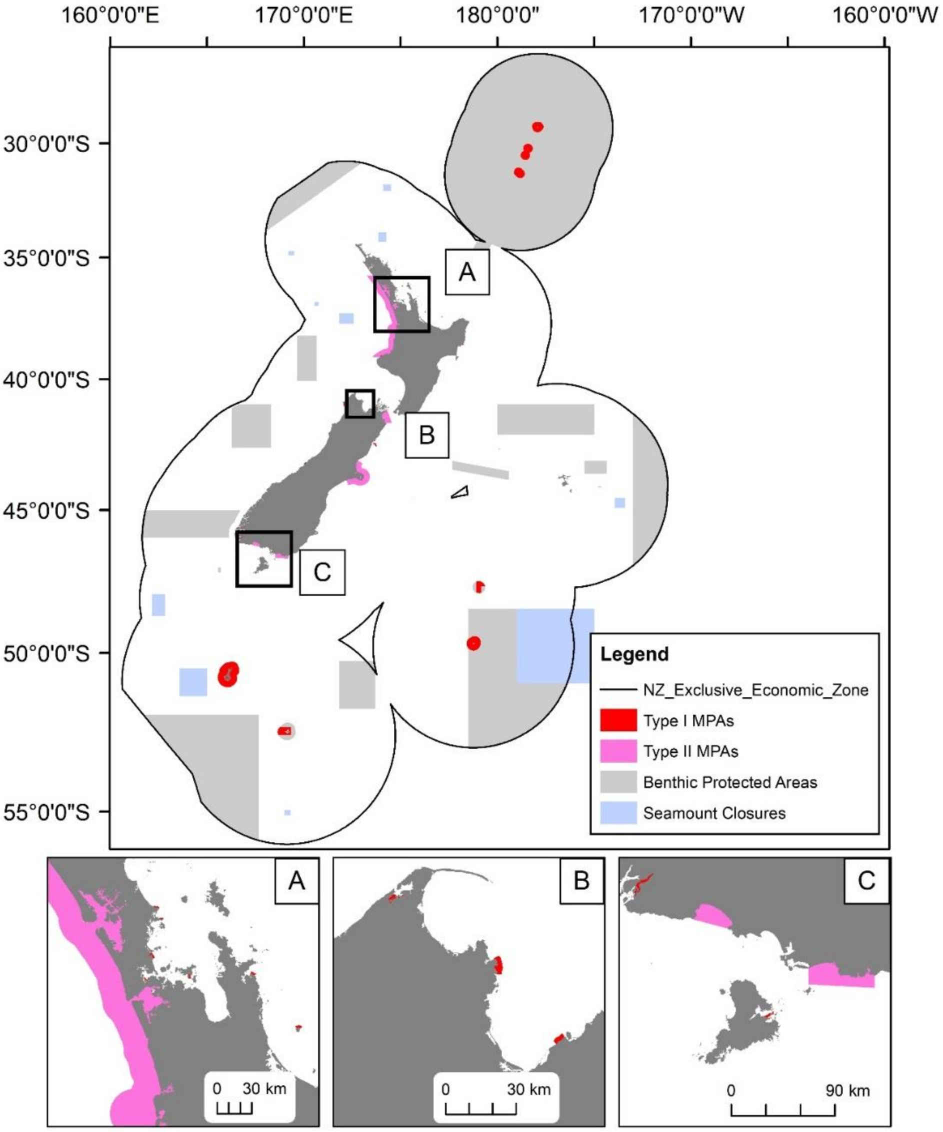

Figure 3-24: Location of Benthic Protection Areas, Seamount Closures, Type I Marine protected areas, and marine mammal sanctuaries.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (polygon).	NZ EEZ	NA	High	Benthic Protection Areas, Seamount Closures, Type I and Type II Marine protected areas, and marine mammal sanctuaries.

Description of data:

The location of area-based marine protection in New Zealand waters are provided, including: Benthic Protection Areas; Seamount in New Zealand waters including: Benthic Protected Areas; Seamount Closures; Type II MPAs; Marine Mammal Sanctuaries; Marine reserves (Figure 3-24).

The Marine Protected Area: Policy and Implementation Plan (Department of Conservation and Ministry of Fisheries, 2005) defines an MPA as:

"An area of the marine environment especially dedicated to, or achieving, through adequate protection, the maintenance and/or recovery of biological diversity at the habitat and ecosystem level in a healthy functioning state."

The MPA Policy defines three categories of MPAs: no-take reserves (Type 1 MPAs), Cable Zones and other conservation areas that meet the protection standard described in the MPA Policy (Type 2 MPAs); and other forms of protection that do not achieve the protection standard, but do provide some benefits for biodiversity.

Type 1 Marine reserves

Marine reserves are statutory tools established under the Marine Reserves Act 1971 for the purpose of preserving marine life for scientific study (Figure 3-24). A wide range of activities including marine farming, fishing, other extraction, anchoring, point discharges, research, and bio-prospecting can be managed, controlled, or excluded from marine reserves.

Type 2 Marine Protected Areas (MPAs)

Type 2 MPAs defined in the MPA Policy include Fisheries Act 1996 statutory tools to establish prohibitions (i.e., those rules imposed primarily for the purpose of sustaining fisheries resources and for avoiding, remedying or mitigating the adverse effects of fishing on the environment) (Figure XX). A total of 18 Type 2 MPAs exist in New Zealand, covering 2.5% of the Territorial Sea.

Type 2 MPAs may also include cable protection zones and protection provided by provisions in the Resource Management Act, the Crown Minerals Act, the Maritime Transport Act, and/or the Biosecurity Act, provided the protection standard is met. Some Marine Parks (Mimiwhangata, the Sugar Loaf Islands), and parts of the Fiordland (Te Moana o Atawhenua) Marine Area are categorised as Type 2 MPAs, and satisfy the protection standard. Other Marine Parks (e.g., the Hauraki Gulf Marine Park) are not classified as Type 2 MPAs as they do not meet the protection standard. Two fisheries closures are categorised as Type 2 MPAs: Te Whaka a te Wera Mataitai Reserve (Paterson Inlet, Stewart Island) which prohibits set nets, cod pots, drag nets and shellfish dredging, and the Pukerua Bay Fisheries closure, a s186 temporary closure administered under the Fisheries Act.

Cable and pipeline zones were generally included as Type 2 MPAs, with one exception for the sand mining pipeline at Taharoa due to disturbance from pipeline operations. Marine mammal sanctuaries, established under the Marine Mammal Protection Act (1978), do not directly regulate fishing activities, and thus do not qualify as Type 2 MPAs (Department of Conservation and Ministry of Fisheries, 2011).

Other Marine Protection Tools

Other forms of marine protection are not categorised as marine reserves or Type 2 MPAs under MPA Policy but they may provide some biodiversity benefits. These tools include:

- Benthic Protection Areas (Fisheries Regulations 2007 – Schedule: Part 1) (Figure 3-24).
- Seamount Closures (Figure 3-24).
- Marine Parks (those that do not include sufficient protection to be categorised as a Type 2 MPA, e.g., Hauraki Gulf Marine Park) (Figure 3-24).
- Other Fisheries Act measures (taiapure, mataitai, rahui).

Seventeen Benthic Protection Areas (BPAs), established in November 2007, prohibit benthic trawling and dredging disturbance; these BPAs cover approximately 30% of the EEZ (though a majority of this area was too deep for trawling) (Leathwick et al. 2008a). Other resource uses (e.g., mining for mineral resources) are not prevented in these BPAs. For example, the Chatham Rise BPA has been investigated for potential for phosphorus mining, with a recent application to the Environmental Protection Authority (EPA) being unsuccessful (www.epa.govt.nz).

Matching criteria: Naturalness

Type 1 marine reserves and Type 2 MPAs are assessed under a protection standard to determine if they offer sufficient protection to habitats and ecosystems for areas to be considered as MPAs (Ministry of Fisheries and Department of Conservation, 2008). To meet this Protection Standard, the management tool(s) at a particular site must provide for the maintenance and recovery of:

- physical features and biogenic structures that support biodiversity
- ecological systems, natural species composition (including all life-history stages), and trophic linkages, and
- the potential for the biodiversity to adapt and recover in response to perturbation.

Most marine reserves were selected through either formal stakeholder processes which used biodiversity as one of many criteria in identifying areas suitable for marine protection, or through ad-hoc processes where an individual area was selected based on anecdotal evidence of its value for a particular aspect of biodiversity (Davies et al. 2018). Other locations of historical or recent protected area status reflect areas which have been protected from some forms of disturbance (typically seabed disturbance from trawls or dredges) and customary, recreational and/or commercial fishing activities. Some areas were selected through processes with either no (e.g., Cable Protection Zones) or only limited criteria for their biodiversity value.

Lundquist et al. (2015a) summarised the wide range of protected area tools and their relative contribution to protection from different impacts (Table 3-3). For example, marine mammal sanctuaries provide protection measures solely with respect to marine mammals. BPAs exclude bottom trawling and dredging, but do not prohibit mining or oil and gas exploration. Many no-take marine reserves are very small, and unlikely to provide protection for wide-ranging or migratory species such as fish.

Table 3-3: Benefits to biodiversity and mitigation of threats provided by a selection of Marine Protection Tools. * indicates limited benefits for wide-ranging or migratory species. ** indicates that some provisions could provide benefits. Based on Table 2-3 in Lundquist et al. (2015).

Biological feature protected / Threat mitigation	No-take MPA	BPA	Seamount reserve	Marine Park	Customary management tools	Marine mammal sanctuary	Cable and pipeline zones	Fisheries Act provisions	Shipping lane/Transport restrictions
Biodiversity (entire ecosystem)	Y*	N	N	N	N	N	Y*	N	N
Marine mammals	Y*	N	N	N	N	Y	Y*	N	Y
Seabirds and shorebirds	Y*	N	N	N	N	N	Y*	Y**	N
Benthic fishes	Y	Y	Y	N	Y**	N	Y	Y**	N
Pelagic fishes	Y*	N	N	N	Y**	N	Y*	N	N
Benthic invertebrates	Y	Y	Y	N	Y**	N	Y	N	N
Flora	Y	Y	Y	N	N	N	Y	N	N
Benthic habitats	Y	Y	Y	Y**	N	N	Y	Y**	N
Fishing – direct impacts	Y	Y**	Y	N	Y**	N	Y	Y**	N
Mining	Y	N	Y	Y**	N	N	Y	N	N
Oil and gas exploration	Y	N	Y	Y**	N	N	Y	N	N
Benthic impacts	Y	Y	Y	Y**	Y**	N	Y	Y**	N
Oil spills and other hazards	N	N	N	N	N	N	N	N	N
Land-based sediments, nutrients, and other pollutants	N	N	N	N	N	N	N	N	N
Climate change	N	N	N	N	N	N	N	N	N

Limitations and consideration for future use:

All maps are of high confidence and geospatial accuracy. Maps require updating as additional areas are set aside for marine protection. However, the relative value for biodiversity protection for many of these areas is disputed, for example Cable Protection Zones have shown little evidence of protection of fish biodiversity (Shears and Usmar, 2006). Some of these areas may be protected from one type of resource extraction but allow others, for example Benthic Protection Areas could, in theory, be subject to mineral extraction. Finally, most of these protected area designations provide no protection from disturbances other than resource extraction, such as land-based impacts (sedimentation, nutrients, pollutants from land-based sources), natural disasters (tsunamis), oil spills, or climate change. Here, location of Benthic Protection Areas; Seamount Closures; Type II MPAs; Marine Mammal Sanctuaries and Marine reserves are provided – for further fishery specific closures see discussion in (Baird and Wood, 2018).

3.8.4 Land-use layers

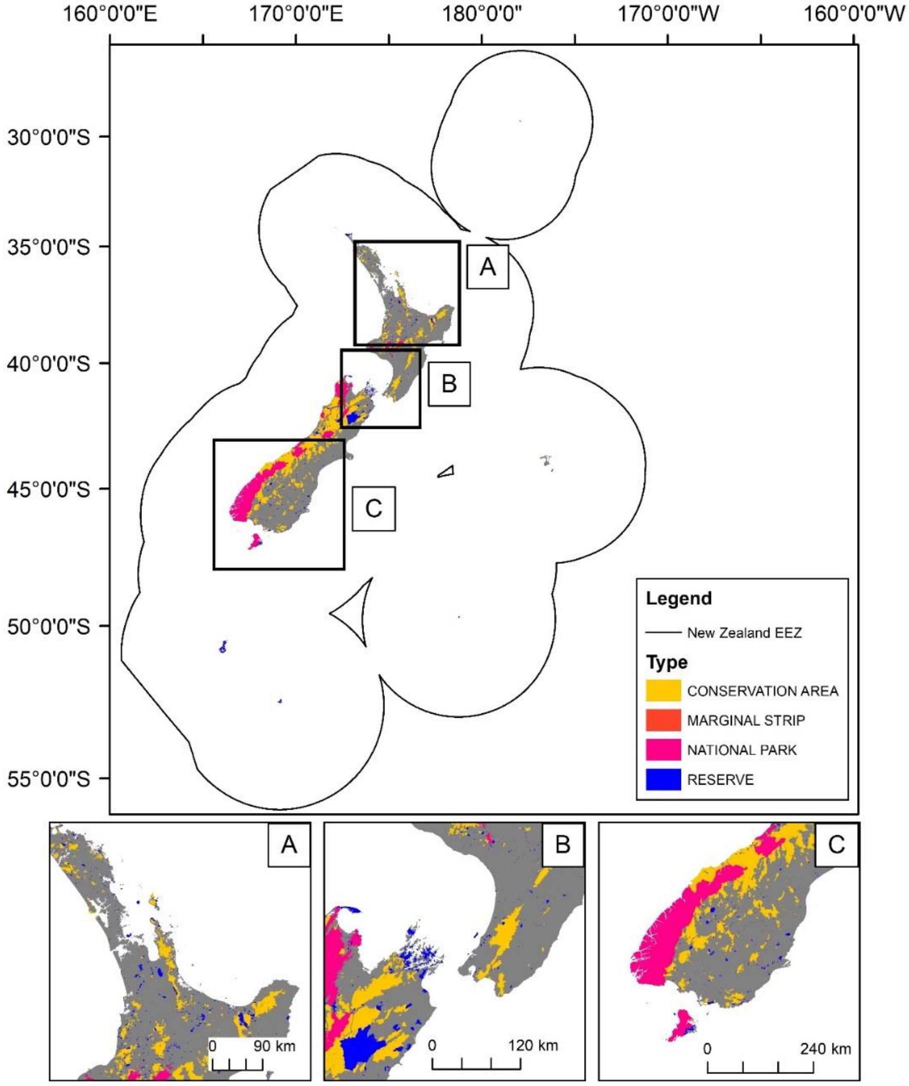

Figure 3-25: DOC Public conservation areas used as an indication of land-sea connectivity (Lundquist et al. unpublished). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	High	Landcover classes; DOC Public Conservation Areas; Soil erosion; Population.

Description of data

Land use layers used in Lundquist et al. (in submission) as indication of land-sea connectivity of stressors for individual Marine Reserves. These layers were calculated primarily for catchments affecting marine reserves, with catchments identified through the Rivers Environments Classification at the highest available catchment classification. Layers included: individual catchments associated with each marine reserve, land cover class within catchments, terrestrial protection within each catchment, sediment and nutrient loads, and population size both within catchments and within a number of set distances from the marine reserve. Land-use cover was calculated from LUCAS land-cover classes which is a subset of categories in the LCDB v4.1, summarised into 10 broader categories of land-use (shrub/grassland; non-plantation forest; barren/other; plantation forest; open water (e.g., lakes); vegetated wetlands; annual cropland; perennial cropland; high-producing grassland; urban).

Terrestrial protected areas in the layers include conservation areas, scenic reserves, national parks, and Queen Elizabeth II land covenants on private land.

Human population was calculated by extrapolated population mesh grid blocks based on NZ 5-year census data from 2012 obtained from StatsNZ. Geospatial population mesh grid blocks did not directly overlap on a standard grid or on the REC catchments, and were allocated proportionally based on overlap with distance-derived polygons (within 100 km) from marine reserve centroids, or with REC catchments.

Sediment and nutrient loading for individual marine reserves was estimated using the CLUES software, based on the REC catchments, and includes estimates of P, N and sediment loads to all riverine inputs to the coast within 10 km of a marine reserve. Sediment loads were also quantified based on Landcare Research sediment erosion maps, which were generally similar to the CLUES sediment maps with the exception of a few locations (e.g., Fiordland) where CLUES sediment estimates were very high, likely due to dependence of the CLUES model estimates on rainfall.

Matching criteria: Naturalness.

Land-use impacts on the coastal marine area are a strong driver of ecological health, and these layers provide estimates of relative pristineness or naturalness in the face of land-based impacts through estimates of sediment and nutrient loading, and estimates of impacts of human populations (through effects such as tourism, recreational fishing, beach use etc.,) on marine biodiversity.

Limitations and consideration for future use

These land-use impact layers to date have only been calculated for 44 New Zealand marine reserves. Impacts of sediments and nutrients are based on unrealistic assumptions of riverine input dispersal both north and southward to 10 km either side of the river mouth, in the absence of high resolution information of spatial and temporal variability in hydrodynamic influence on the dispersal of river plumes, though anecdotal information is available for a limited number of marine reserves that could be used to improve the accuracy of these predictions of contaminant dispersal. Land-use cover does not include quality, particularly for native (non-plantation) forests, which have a significant influence of sediment erosion. Similarly, plantation forest categorisation does not include age of stand for rotating harvest, which are correlated with sediment erosion when forestry stands are harvested.

3.8.5 Depth-related refuge areas

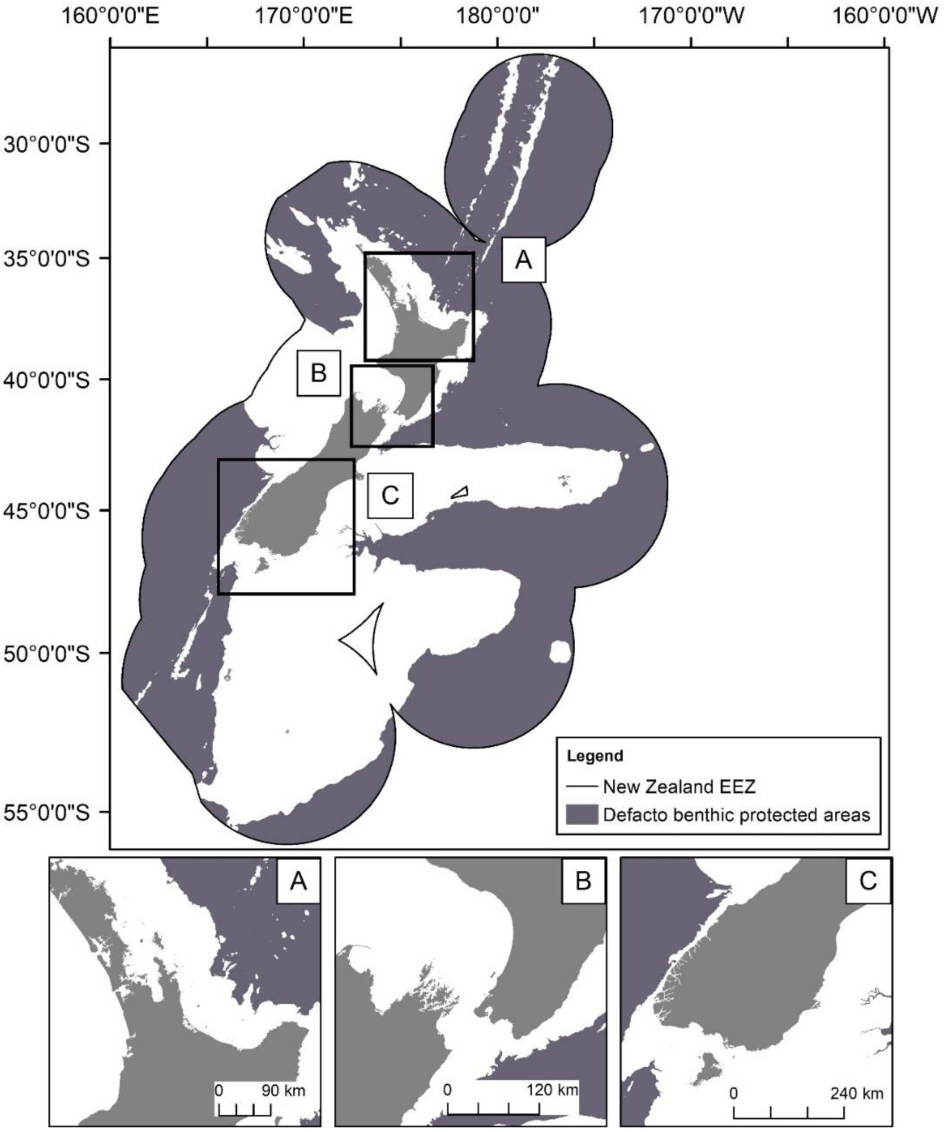

Figure 3-26: Unfished depths of the marine environment (areas deeper than 1600 m; dark grey polygon) were considered as de facto-benthic protection area (Black and Tilney, 2017). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Raster	NZ EEZ at a 1km grid resolution.	NA	High	Single layer

Description of data:

Seafloor depths beyond the range of current bottom fishing (used a proxy for de facto refuge areas) were defined as those areas deeper than 1600 m following the advice of MPI (Black and Tilney, 2017) and experts at the first stakeholder workshop meeting (Figure 3-26). Although longline fishing can extend deeper, most effort within New Zealand's deepest fisheries (e.g., orange roughy) is shallower than 1300 m, and rarely has extended beyond 1600 m - this is also the cut-off of trawl footprint analyses by Baird & Wood (2018). A bathymetry layer of New Zealand (NIWA, 2016) was classified into depth-refuge areas deeper than 1600 m. The bathymetry layer is compiled from the best available data, including multibeam and single-beam data sourced from surveys by NIWA and Land Information New Zealand (LINZ), as well as international surveys by vessels from United States of America, France, Germany, Australia and Japan, and is considered robust resulting in the high confidence score assigned.

Matching criteria: Naturalness

As described above, trawl fisheries do not currently extend below 1600 m, and hence depths greater than 1600 m can be regarded as unaffected directly by human activities (at least trawl fisheries).

Limitations and consideration for future use:

It is possible that fishing practices will change over time, and that the region that is considered fishable may extend to deeper waters (Black and Tilney, 2017). However, the recorded water depth of recent trawls for years 2003 – 2013 showed that in each of the fishing years only a handful of trawls have recorded a water depth of more than 1600 m, providing confidence that the cut off depth used here is still a conservative outer boundary for the fishable area (Black and Tilney, 2017). Patagonian toothfish is the only current commercial species in the New Zealand region that is known to inhabit these deeper waters. However, abundance is low, and there is no regular fishing (by longline) at these depths. At present, MPI is planning regular updates of the trawl footprint data, and this will indicate if future practices are trending deeper.

3.9 Criteria: Ecological function

3.9.1 Sensitive Environments / Biogenic Habitats (marine)

For an example map and detailed description of the data see section 3.2.3.

Matching criteria: Ecological Function.

Biogenic habitats are valuable for a range of ecological roles and functions, including enhanced primary and secondary production, provision of three-dimensional structure that provides shelter, protection and resources, bentho-pelagic coupling, habitat provision, enhanced biodiversity, and juvenile fish nursery functions (e.g., (Heck Jr and Wetstone, 1977;Connell, 1978;Luckhurst and Luckhurst, 1978;Dean and Connell, 1987;Cummings et al. 2001;Norkko et al. 2001;Buhl-Mortensen et al. 2010;Beazley et al. 2013;Morrison et al. 2014a;Anderson et al. 2016b;Anderson et al. 2018).

Data limitations and consideration for future use

The basic ecological functions provided by most biogenic habitats in New Zealand are very poorly known, and often inferred from overseas studies. Caution should be taken when using such approaches, e.g., New Zealand mangroves were once seen as being critical to many juvenile fish life histories, based on work in tropical mangroves, but more recent work in temperate mangroves in New Zealand and elsewhere has shown this to not be true (Morrisey et al. 2010). Functions will also vary with setting; e.g., subtidal seagrass in northern New Zealand provides a key fish nursery role for a number of species including snapper, but not in the south (Morrison et al. 2014b). Even in the north, fish nursery value is very low if only intertidal seagrass is present.

3.9.2 Regional Council identified important marine areas

For an example map and detailed description of the data and how these meet this criteria see section 3.2.1

3.10 Criteria: Ecosystem Services

3.10.1 Sensitive Environments / Biogenic Habitats (marine)

For an example map and detailed description of the data see section 3.2.3.

Matching criteria: Ecosystem Services.

Biogenic habitats provide a diverse range of ecosystem services that keep our marine environments healthy (Thrush et al. 2001;Morrison et al. 2014a;Anderson et al. 2018). They, by their definition, provide 3-dimensional structure that support and maintain diverse marine communities (Townsend et al. 2011). Many biogenic habitats are formed by suspension feeders (e.g., bryozoans, sponges, Calcareous and non-calcareous tubeworms, shellfish) that when present in large aggregations can act as marine vacuum cleaners, filtering large volumes of water and removing organic and inorganic particles from the water column, resulting in cleaner water. Biogenic habitats that grow in soft sediments (e.g., seagrass meadows, mangroves, algal meadows, rhodoliths, non-calcareous tubeworm fields [e.g., wireweed], bivalve beds) act to trap and stabilise bottom sediments, and where they occur nearshore are important in mitigating coastal erosion and inundation (Morrison et al. 2009;Townsend et al. 2011). Biogenic habitats formed by motile species (e.g., large bivalves) may act as bio-engineers that actively oxygenate sediments. Bivalve beds (e.g., *Tucetona*, scallops and/or green-lipped mussels) are also important food sources for crayfish, octopuses, large carnivorous fishes and humans, while macroalgae is eaten by a wide range of herbivorous invertebrates, fishes (e.g., odacids), birds (e.g., swans) and humans. Habitat-forming plants, such as seagrass, kelp forests, are known to be significant repositories for “blue carbon” (i.e., as a marine primary producer), the release of oxygen, and sequestration of organic carbon and long-term carbon storage.

Data limitations and consideration for future use

Ecosystem functions are well known for some biogenic habitats (e.g., seagrass meadows), with large gaps in knowledge for many (e.g., macroalgal meadows, tubeworm fields, rhodolith beds) and little if anything known for others (e.g., Xenophyophores). Ecosystem function is also likely to vary relative to the size, depth zone and health of a habitat in any location. Datasets currently available for biogenic habitats do not provide this level of information (with the exception of seagrasses and mangroves). However ongoing work within the Sustainable Seas Challenge is accumulating valuable information on the functional roles and service provision of benthic marine organisms, including those that form biogenic habitats. Although data on New Zealand mangroves is the most comprehensive of the biogenic habitat datasets, caution should be used when assigning simple ecosystem service measures to these data, as there is increasing scientific information to suggest that mangrove expansion out over intertidal flats may be an indicator of declining environmental quality in some areas, e.g., muddier sediments from terrigenous sources, (Morrisey et al. 2010), and may therefore reflect a loss of other ecosystem services in these areas.

3.10.2 Ecosystem Goods and Services

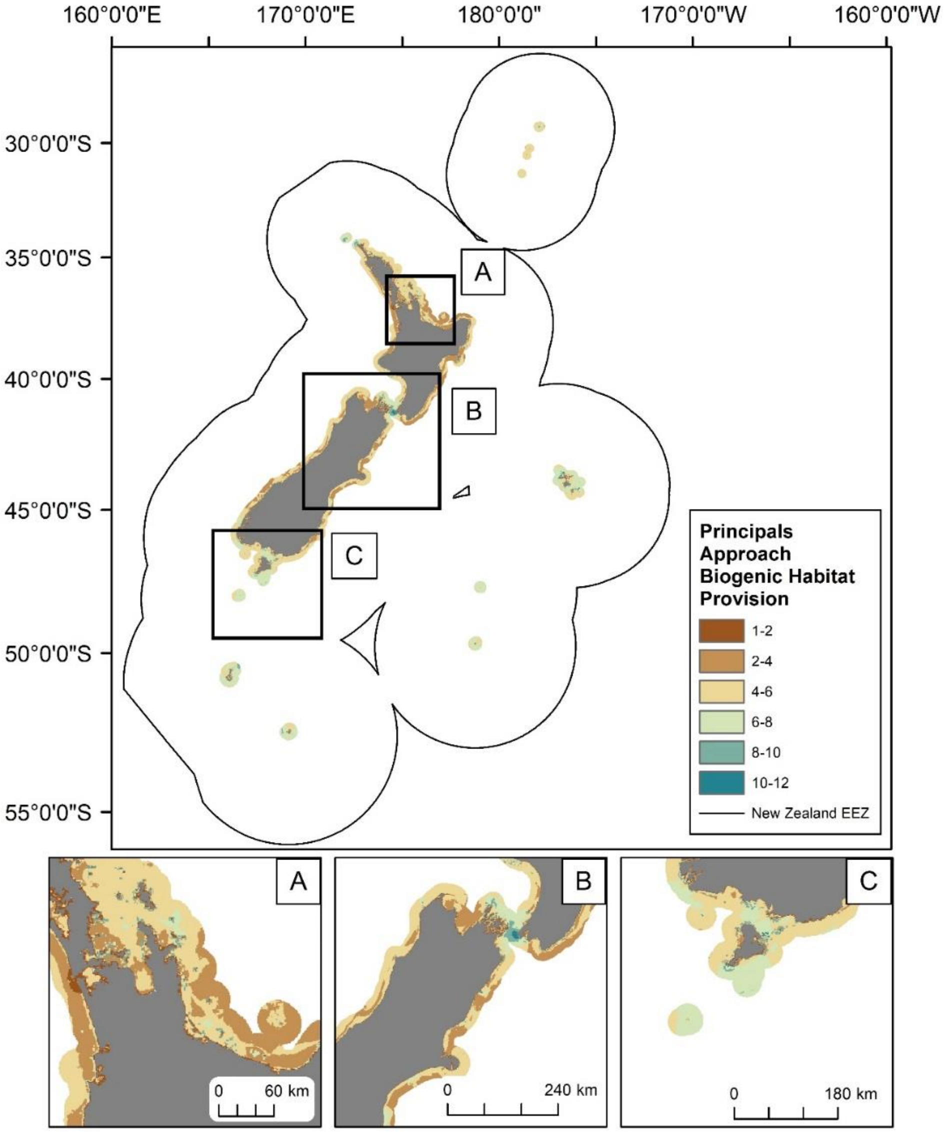

Figure 3-27: Predicted biogenic habitat provision (Unitless scale: 1 (low provision) – 12 high provision)) using rule-based mapping (methods based on Townsend et al. 2014). Inset maps: A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Overview

Data format	Extent and resolution	Validation	Confidence score	Overview of layers
Feature class (point data).	NZ EEZ	NA	High	Single layer

Description of data:

The application and mapping of Ecosystem Services is hindered by inadequate knowledge of the distribution of communities and habitats and the ecosystem functions that they provide. Townsend et al. (2014b) defined services from a series of 'principles' based on current ecological understanding and linking these to marine biophysical parameters for the Hauraki Gulf, New Zealand. Here, we expanded on this work by predicting biogenic habitat provision for the whole Territorial Sea surrounding New Zealand (coastline out to 12 nm - Figure 3-27) through the manipulation (normalisation or categorisation) and combination of several readily available GIS layers following the 'principles' articulated in Townsend et al. (2014b). Table 3-4 provides information on the 'principles', the GIS data layers used, manipulations of the data layers to provide normalised scores, and the weighting given to each layer. Maps of ecosystem service potential were then produced by combining all the appropriately weighted principles layers in a simple additive model (Townsend et al. 2014).

Table 3-4: 'Principles', rationale for their use and the GIS data layer used for predictive mapping of biogenic habitat provision (Townsend et al. 2014).

Principle	Rationale	GIS layer and source	GIS layer manipulation	Weighting
P12	Mollusc species and other organisms' carbonate shells and skeletons sequester carbon and create sediment through the production of shells; this can increase habitat complexity.	Carbonate sediment distribution (Bostock et al. 2018).	Values of calcium carbonate > 50% were given a score of 1, <50% was given a score of 0.	1
P20	Flora and Fauna that have a sedentary lifestyle provide habitat structure and are more common on firm sediments and larger grain sizes – rock > gravel > sand > mud.	Inshore rocky reefs polygon (Smith et al. 2013). Gravel – sand – mud distribution (Bostock et al. 2018).	Sediment maps were categorised and scored: Gravel 0.50 Gravel–mud 0.50 Gravel–sand 0.50 Mud 0.10 Mud–gravel 0.10 Mud–sand 0.10 Sand 0.25 Sand gravel 0.25 Sand–mud 0.25 Rock 1.00	5

Principle	Rationale	GIS layer and source	GIS layer manipulation	Weighting
P1	Benthic productivity is an important contributor to system productivity and is greater in shallow than deeper waters.	NIWA bathymetry layer (NIWA, 2016).	The Bathymetry layer was normalised: Intertidal habitats = 1 normalised score(ratio to maximum) 0-5 m depth = 0.78 5-20 m depth = 0.56 > 35 m depth = 0.0	1
P19	In deeper water instability driven down from surface water decreases and the stability of bottom waters increases.	NIWA bathymetry layer (NIWA, 2016).	Depth > 60 m were scored 0 Depth < 60 were scored 1	1
P7	Flora and fauna that filter food or nutrients from the water column and maintain a sedentary lifestyle have a stabilising effect on the sediment.	Maximum, depth averaged tidal current (ms^1) (Leathwick et al. 2012).	Tidal currents were normalised: highest flow scored 1, and lowest scored 0.	5

Matching criteria: Ecosystem Services

This data layer, matches one ecosystem service: provision of biogenic habitat. This service is largely described in section 3.10.1 (above) where greater detail is provided on the different types of biogenic habitats in New Zealand and their associated services. In the layer presented here, no assumptions are made on the organisms or taxa providing the biogenic habitat. In turn, this means that other associated ecosystem services associated with these biogenic habitats cannot be described (e.g., mussels beds provide biogenic habitat but also provide services such as filtering water, the latter service will not be the case for seagrasses for example). However, biogenic habitat provision shown here is predicted across a large spatial scale in a consistent manner (making comparisons between areas possible).

Limitations and consideration for future use:

This layer was generated as an example of one possible ecosystem service that could be mapped nationwide using the ‘principles approach’ described by Townsend et al. (2014). With increasingly available high resolution environmental data from across New Zealand, other layers could be created following this ‘principles approach’. Ecosystem services mapped and validated by Townsend et al. (2014) at a local scale (but not presented here) include: Nutrient recycling and Ecosystem Productivity. These other services could equally be mapped in future to help increase the representation of datasets for the ‘Ecosystem Services’ KEA criteria.

Although a principles approach to mapping ecosystem services has several key advantages (low cost, large-scale mapping for data poor areas, validated in several regions (see Townsend et al. in press; Clark et al. unpublished), the maps remain broad-scale relative indicators of ‘service potential’ rather than exact measures of services (i.e., there is no measure of grams of carbon sequestered per m^2 or tonnage of fish species production per km^2 seabed). The lack of quantification of services in real terms can be limiting for management decisions where trade-offs are required (e.g., a zonation analysis where closures of an area would result in a cost to other stakeholders).

3.10.3 Regional Council identified important marine areas

For an example map and detailed description of the data and how these meet this criteria see section 3.2.1.

4 Discussion

In this project we aimed to assess the availability of datasets that could be used to identify KEA in the New Zealand Territorial Sea (TS) and Exclusive Economic Zone (EEZ). This work involved collating candidate data sets, working with experts and stakeholders to identifying which datasets are relevant for each of the KEA criteria, and producing a series of maps showing these datasets, as well as making available the associated GIS files. These datasets would not only be of use to help inform the Marine Protected Area (MPA) reform work, and provide essential support for delivering on DOC's 2025 Stretch Goal to develop a representative network of marine protected areas, but may also be useful for broader marine spatial planning or management processes.

Clark et al. (2014) describe a sequential process for identifying candidate EBSAs consisting of four key steps. For the identification of KEA this framework can also be followed. Here we have addressed the first three aspects of the process: 1) the area to be examined was defined as the New Zealand TS and EEZ; 2) the appropriate datasets and (where available) thresholds to be examined in the evaluation were collated; 3) these datasets were evaluated against the criteria and critically appraised. The final step in the process described by Clark et al. (2014) was to combine the datasets to assess and identify candidate EBSAs (in this case this would be KEAs). This final step was outside the scope of the current work, but in the following section, we summarise our findings and reflect on the possible difficulties and caveats in identifying KEAs using the datasets described here, as well as providing some recommendations for potential methods for systematic conservation planning based on the available data.

4.1 Critical appraisal of the datasets collated

Twenty-seven datasets were collated for this project, most of these datasets had multiple data layers. For example, the New Zealand marine reef fish records dataset (described in section 3.3.3) included individual abundance distribution layers for 72 species of marine reef fish. The number of layers contained within each dataset is described in Appendix 1 (section 7.1) but detailed information and descriptions for each layer is not provided here (but see Smith et al. (2013) for the reef fish example).

In many cases the datasets match multiple criteria (see far right column in Table 4-1). For example, two of the datasets match seven of the criteria: 'Regional Council identified important areas (e.g., SEAs, SNAs, SCAs)' and 'Sensitive Environments / biogenic habitats' (Table 4-1). Both of these datasets are very large, composed of data collected from across New Zealand, and in many cases for differing purposes, as well as having a range of confidence scores which largely relates to individual layers (i.e., low – high confidence score). Although these datasets are clearly of importance for the identification of KEAs, care must be taken when using these in practice. For example, although described as matching the KEA criteria 'Importance for threatened and/or declining species and habitats' not all Sensitive Environments (section 3.2.3) will be of importance or relevant examples of this criteria. Additionally, the confidence score that is assigned to individual layers should be carefully considered so that any caveats or biases in the data are thoroughly understood on a layer by layer basis (i.e., is the layer from a regional source or national source? Is it presence only, or were absences or abundances also recorded?). The somewhat subjective confidence assessment presented here relates to the dataset as whole, rather than providing detailed confidence assessments of each individual layer. Although out of the scope of this report, the latter would be of value for any future analyses using these data layers. A summary of the caveats for each dataset is presented in sections 3.2 – 3.10, however, these should be revisited for individual layers as and when required for any practical application of the KEA criteria.

Some KEA criteria are better represented by the datasets than others (see the final row of Table 4-1 for the total number of datasets which match the nine KEA criteria). KEA criteria*,* 'Importance for threatened and/or declining species and habitats' and 'Biological diversity' are well represented with one third of the datasets potentially informing these criteria. This overlap is likely due to the correlation between these criteria, with several datasets informing two or three of these criteria (e.g., Sensitive Environments, Seabird distributions, Table 4-1). Similarly, in a summary of the results of efforts by the Convention on Biological Diversity to describe EBSAs, Bax et al. (2016) found that some of the criteria were correlated. For example, Bax et al. (2016) highlighted that naturalness was correlated with uniqueness, fragility, and biodiversity; productivity was correlated with life history, endangered and threatened species, fragility, and biodiversity criteria but not uniqueness or naturalness. Although not formally assessed here, this is also likely to be the case for KEA criteria since KEA criteria 1 – 7 were heavily based on EBSA criteria.

Table 4-1: Matching Key Ecological Area criteria with data layers collated.

KEA criteria Data layers	Vulnerability, fragility, sensitivity, or slow recovery	Uniqueness, rarity and/or endemism	Special importance for life history stages	Importance for threatened and/or declining species and habitats	Biological productivity	Biological diversity	Naturalness	Ecological function	Ecosystem services	Total criteria matched
Regional Council identified important areas (e.g., IBAs, ASCVs)	X	X	X	X		X		X	X	**7**
Sensitive Environments	X		X	X	X			X	X	**6**
Vulnerable Marine Ecosystems (VME)	X			X				X		**3**
Marine reef fish			X			X		X		**3**
Seabird distributions		X	X			X				**3**
Vulnerable fragile, sensitive, or slow to recover species.	X	X								**2**
Fish records		X		X						**2**
Benthic invertebrate records		X		X						**2**

KEA criteria / Data layers	Vulnerability, fragility, sensitivity, or slow recovery	Uniqueness, rarity and/or endemism	Special importance for life history stages	Importance for threatened and/or declining species and habitats	Biological productivity	Biological diversity	Naturalness	Ecological function	Ecosystem services	Total criteria matched
Marine mammal and reptiles sightings				X					X	**2**
Hydrothermal vents		X			X					**2**
Cold seeps		X			X					**2**
Marine mammal distributions				X		X				**2**
Demersal fish species turnover and classification		X				X				**2**
Invert species turnover and classification		X				X				**2**
Rare ecosystems		X		X						**2**
Fish spawning grounds			X							**1**
Seal breeding grounds			X							**1**
Bird feeding and breeding grounds			X							**1**

KEA criteria / Data layers	Vulnerability, fragility, sensitivity, or slow recovery	Uniqueness, rarity and/or endemism	Special importance for life history stages	Importance for threatened and/or declining species and habitats	Biological productivity	Biological diversity	Naturalness	Ecological function	Ecosystem services	Total criteria matched
Inshore and offshore Productivity					X					**1**
Ecosystem service: Biogenic habitat provision									X	**1**
Other trawl/dredge footprint/ long lining							X			**1**
Protected areas							X			**1**
Land use layers							X			**1**
De facto benthic protected areas							X			**1**
Demersal Fish richness						X				**1**
Benthic invertebrate richness						X				**1**
Bottom fishing footprint							X			**1**
TOTAL	**4**	**10**	**7**	**8**	**5**	**9**	**6**	**4**	**4**	**56**

Some KEA criteria are poorly represented, e.g., ‘Ecosystem services’ and ‘Ecological function′. These two additional criteria to the seven EBSA criteria were specifically included to recognise separately these important attributes of a KEA, despite the acknowledgement of the correlation with most of the EBSA criteria. Thus, not surprisingly, datasets for several criteria overlap with ‘Ecosystem services’ and ‘Ecological function’, but were not specifically included in the report sections for ‘Ecosystem services’ and ‘Ecological function′ since the links between the criteria have not been established specifically with the current data. For example, coral reefs and sponge gardens, are biologically productive and diverse, can provide habitat to support key life history stages of some species, and thus support ecosystem function and provide ecosystem services (Baillon et al. 2012;Cathalot et al. 2015). However, the relationships between the data layers for predicted occurrence of coral and sponge VME indicator taxa (see VME dataset for the criteria ‘Vulnerability, fragility, sensitivity, or slow recovery’), and the occurrence of coral reefs and sponge gardens, has not been established in the New Zealand EEZ. Similarly, linkages between datasets for other criteria that could potentially be used to assess ‘Ecosystem Services’ and ‘Ecosystem Function’ have not been defined or quantified for the study area. Describing these linkages in greater detail was outside of the scope of this work, but would be of use for any future work to identify KEAs.

Finally, criteria with several datasets might still not be adequately described (i.e., do not describe all aspects of the criteria). For example, none of the datasets matching the criteria ‘Biological productivity′ have any continuous estimates of productivity outside primary productivity of surface waters. The other data matching this criterion are either geographically restricted (e.g., cold seeps) or for specific parts of the ecosystem (e.g., fish, macroalgae). In addition, the ‘Naturalness’ criterion was largely described by data relating to the distribution of fishing (i.e., fishing effort distribution layers, location of BPAs, depth related refuge); data describing mining impacts and distribution, current and future distribution of invasive marine species and distribution of sedimentation were not available within the timeframe of this project but would be important to more fully inform the ‘Naturalness’ criterion. Assessing how well each criterion is represented by the data, and balancing the level of importance of each criterion (if any), will be an important (albeit difficult) next step in the identification of KEAs. The question of whether all criteria are equally important was raised by Clark et al. (2014) in the development of their method for identifying EBSAs. They assessed different ways to weight the relative importance of the data representing the criteria for identifying EBSAs for seamounts (using multi-criteria combinations options that included grouping criteria by theme, ranking, and non-additive combinations). The assessment produced a large range in the number of EBSAs identified by the 6 combination options examined. Clark et al. (2014) considered, whichever criteria combination method was finally used, it should identify a tractable number of sites that satisfied the EBSA criteria, and which could be incorporated into larger areas that represent meaningful ecological and practicable management units. However, they also stressed that any weighting may need to be different for different ecosystems (Clark et al. 2014). See the following section for further discussion on how to weight the value of different criteria using confidence/uncertainty information.

Bax et al. (2016) also noted that among the EBSA processes, there was a relative lack of data on endangered and threatened species compared with other species. Here, information on endangered and threatened species was present for many taxa spanning multiple datasets, e.g., threatened and uncommon benthic invertebrates from Freeman et al. (2014), uncommon ecosystems (Wiser et al. 2013) and VMEs (Anderson et al. 2016a). ‘Rarity and uniqueness’ information for certain datasets were described in a broad manner (e.g., “Sensitive environments / biogenic habitats are represented by a wide range of plant and animal species, some of which are rare, e.g., red corals”), whereas for others a quantitative (relatively simple and subjective) threshold was defined (e.g., Fish and invertebrate species with 2 - 10 records in the New Zealand EEZ were extracted to reflect ‘Rare species’). The latter provides an indication of possible rarity but is also likely to be biased by a paucity of quantitative data, and spatial gaps/biases in sampling, and as such, should be used with some caution. Clark et al. (in revision) used a more ecologically relevant method for determining one possible measure of rarity (Species with restricted distributions) for an analysis assessing the biodiversity of Benthic Protection Areas and Seamount Closure Areas. Species with restricted distributions were calculated using a neighbourhood analysis performed within Arc GIS with a 20 km range chosen to define “restricted”. This threshold distance was based on examining species distributions where there were five or more records in the database (so the analysis was not driven by singletons) and where distance separation between records was 500 km or less (Clark et al. in revision). This method could be used on the data collated for this report (e.g., benthic invertebrates, demersal fish, cetaceans and reptiles), however, it would require decisions on relevant spatial scales and search distances which was outside the scope of this work. It is also likely that the spatial degree of sampling would be insufficient for the analysis to take place for the majority of species. A number of the other data layers reported upon here should also be re-examined before future use, in order to make a more complete assessment of the relevant thresholds that should be applied to the datasets (as part of step 2 of Clark et al. (2014)). Clark et al. (2014) provide a demonstration on how to identify such thresholds using subjective data cut-offs, expert opinion or reference to the scientific literature, but also note that whenever possible such thresholds should be based on objective analysis of those data being used to represent the EBSA (or KEA) criteria.

Although out of the scope of this work, this report is lacking datasets or data layers that incorporate Maori perspectives or other LEK on KEAs (bar some LEK layers of biogenic habitat from Jones et al. (2016)). Future work would benefit from investigating whether Maori and stakeholder values align with the criteria and whether any further important information and datasets matching these values exist and could be incorporated. It may be an important and necessary step to undertake this engagement and data collation prior to the identification of candidate KEAs in order to gain wider acceptance of any possible management changes (see section 4.2 for further information).

The datasets collated here were collected for specific purposes. While many of them form the basis for high impact scientific articles, they suffer from the usual biases associated with large-scale ecological and biological datasets collected over time for a variety of purposes. Namely, some of the datasets have: relatively sparse sampling (e.g., benthic invertebrate records) and are spatially restricted – some locations are very well studied, in many cases because of their importance for industry (e.g., fishing) and their unusual and sometimes unique biota (e.g., the Chatham Rise); suffer from spatially biased sampling; lack estimates of uncertainty; and for the vast majority of the datasets, lack information on temporal change (natural or unnatural). The latter point is of particular concern for the designation of MPAs. Although changes over time are discussed for certain data layers (e.g., in the Sensitive environments / biogenic habitats dataset - see Anderson et al. (2018) for further detail) this issue was only accounted for explicitly in one of the datasets presented in this report (see the benthic invertebrate species richness modelling methods in Appendix 1 (section 7.2.) for a discussion on cut-off year for the inclusion of data). Changes over time (natural, anthropogenic or due to changes in sampling methods) are likely to have occurred in many of the datasets here since the raw data commonly spans 20 – 80 years (e.g., Demersal fish dataset, Stephenson et al. (2018)). In the face of climate change and ocean acidification, it is increasingly important to understand past changes in order to better predict or mitigate against future changes over time (Elith and Leathwick, 2009). For conservation planning and designation of MPAs, ideally areas should be selected that are both effective at protecting the most valuable areas in the present but will also maintain their effectiveness through time as the climate or environmental divers change (Carroll et al. 2010;Elith et al. 2010;Kujala et al. 2013). For example, with increasing ocean acidification, the aragonite saturation horizon will become shallower and coral species that rely on aragonite for building their skeletons will become more restricted in their depth distribution (Tittensor et al. 2010). Some coral species are vulnerable, threatened, rare, or provide ecosystem function and services (i.e., their distribution may be used to identify KEAs), and information on their predicted future distribution is needed to adequately design and implement MPAs for their protection (Anderson et al. 2015). A paucity in information on temporal dynamics of ecosystems (EBSA criterion 4) have also been noted but not resolved in studies applying EBSA criteria for MPA designation in Japan (Yamakita et al. 2015).

4.2 Frameworks and tools for identification of KEAs

Internationally, EBSA-type designations have been increasingly used to inform the selection of areas for MPA designation, with several examples of spatial planning frameworks and approaches for extracting and prioritizing EBSAs according to quantitative scientific information (Yamakita et al. 2015;Dunstan et al. 2016). However, due to the large number of datasets, of varying datatypes collected here (point data; feature data; gridded data), systematic conservation planning software may be a more appropriate tool to identify KEAs (e.g., Zonation (Lehtomäki and Moilanen, 2013) or Marxan (Ball et al. 2009)). These spatial conservation planning tools identify areas that are important for retaining habitat quality and connectivity simultaneously for multiple biodiversity features whilst accounting for costs (e.g., other stakeholder views), thereby allowing cost effective allocation of resources (Moilanen et al. 2009). The Zonation software in particular has been successfully used in a New Zealand marine context by decision makers (since it can easily incorporate all the above-mentioned data types). The software has been socialised with stakeholders as part of an engagement process aiming to identify and protect VMEs in the high seas (e.g., (Cryer et al. 2017)), used to investigate the effectiveness of Benthic Protection Areas and Seamount Closure Areas (Leathwick et al. 2008b;Clark et al. in revision) and to explore the practical considerations of integrating conservation and economic objectives in MPA network planning (Geange et al. 2017) – to name but a few examples of its applications in a New Zealand context.

The use of a systematic conservation planning tools require careful consideration of several aspects of data treatment. As with other studies using quantitative methods to integrate different categories of variables when identifying EBSAs or KEAs, or spatial management measures such as MPAs, the results will vary depending on how data for each criteria is weighted with respect to interrelatedness, and care must be taken to assess the statistical and practical accuracy of both the data inputs and the analyses used (Yamakita et al. 2015). This issue is particularly relevant here for identifying KEAs if used to inform establishment of spatial management measures in the New Zealand TS and EEZ, and decisions would be required on:

- **Weighting of features**: Some of the datasets are poorly understood (e.g., the source and pre-processing of the seabird data underpinning the distribution predictions) or have a weak, less evident link to the KEA criteria (e.g., uncommon ecosystems). This issue is somewhat reflected in the confidence scores assigned to each dataset (although further work to refine these estimates is recommended). The different levels of confidence in the data and usefulness in representing a KEA criterion could be incorporated in a systematic conservation planning analyses by having less influence in the analysis by down-weighting their importance. Additionally, if any criteria were deemed more important than others, datasets representing these could be weighted to reflect these differences in importance.

- **The use of naturalness layers**: These data layers can be used simply as another input (simplistically, these are just another data layer) however, depending on the goal of the analysis, these could also be used as a discounting layer in Zonation. That is, certain groups of species and types of habitats have specific responses following impacts (e.g., death, reduced abundance, habitat loss), and if following discounting using a naturalness data layer, data for these variables no longer meet the KEA criteria then these areas can be avoided for conservation. For example, the New Zealand and Australian bottom trawling effort footprint was taken into account when identifying potential conservation areas for VMEs in the high seas (Cryer et al. 2017).

- **Incorporation of uncertainty or confidence in the data layers**: Assigning uncertainty to the data layers can either be simplistically linked to the weighting of layers based on the confidence subjectively assigned to them here, or for those data which also include associated uncertainty predictions (primarily modelled data) these can be used to ensure that areas with high predicted value and low uncertainty are selected before those with high predicted value and high uncertainty (avoiding potential negative conservation results (Moilanen and Wintle, 2006)).

- **Trade-off analysis:** Zonation like other conservation planning software, can incorporate other stakeholder values as trade-offs (e.g., value to fishing, deep sea mining, aquaculture, sense of place, etc.,) in order to satisfy both conservation and stakeholder objectives resulting in a wider acceptance of the spatial planning measure (Lester et al. 2018). Stakeholder values were not collated in this report, and doing so may be outside of the remit for decision makers, rather stakeholders should be in a position to articulate their own values. This was successfully trailed via stakeholder engagement when identifying potential conservation areas for VMEs in the high seas (Cryer et al. 2017) – however, it was noted that this stakeholder process was successful due to early engagement allowing time for the data to be collated in the appropriate formats for use in the trade-off tool.

- **Additional elements:** KEA data could provide just one input into conservation or resource management planning process. For example, in relation to MPAs, data on habitat extent and distribution and other ecological data would also be required (including to achieve representativeness), and along with data on trade-offs or costs (see above) information such as constraints, and social, cultural and economic value would need to be incorporated.

4.3 Conclusions

The use of the EBSA concept, and by extension the concept of KEAs, provides a sound basis for developing the scientific advice and data to support national and international management of the world's oceans through identifying sites of particular significance for biodiversity conservation that could be considered in planning a representative MPA network (Yamakita et al. 2015). In this report, we collect and critically appraise the available datasets for identifying KEAs in the New Zealand TS and EEZ. The EBSA framework described by (Clark et al. 2014) and (Dunstan et al. 2016) supports the gradual progress to more complex and information rich structures as needed and appropriate. Critically the next step of identifying KEAs will require careful consideration of the weaknesses of the datasets in order to both assess whether the criteria are adequately described by the available datasets, and also to ensure that the weaknesses of the data are not overlooked and adequately addressed when combining these in any future analyses. With the large number of datasets collected, in various formats, the conservation planning software Zonation appears to be the most promising tool to help identify possible KEAs and/or input the component data layers into broader conservation planning processes. Additionally, Zonation and other spatial planning tools have a strong track record of success in New Zealand and have been socialised with stakeholders who have expressed appreciation for the iterative process that this tool facilitates for designing effective spatial planning measures.

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6 References

Anderson, O., Fletcher, S.M., and Bostock, H. (2015). "Development of models for predicting future distributions of protected coral species in the New Zealand Region. Prepared for Marine Species and Threats, Department of Conservation. NIWA CLIENT REPORT No: WLG2015-65".

Anderson, O., Tracey, D., Bostock, H., Williams, M., and Clark, M. (2014). "Refined habitat suitability modelling for protected coral species in the New Zealand EEZ". NIWA).

Anderson, O.F., Guinotte, J.M., Rowden, A.A., Clark, M.R., Mormede, S., Davies, A.J., and Bowden, D.A. (2016a). Field validation of habitat suitability models for vulnerable marine ecosystems in the South Pacific Ocean: Implications for the use of broad-scale models in fisheries management. *Ocean & Coastal Management* 120**,** 110-126.

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

Anderson, T.J., Morrison, M., Macdiarmid, A., Clark, M., D'archino, R., Nelson, W., Tracey, D., Gordon, D., Read, G., Kettles, H., Morrisey, D., Wood, A., Anderson, O., Smith, A.M., Page, M., Paul-Burke, K., Schnabel, K., and Wadhwa, S. (2018). "Review of New Zealand's Key Biogenic Habitats". Prepared for the Ministry for the Environment, NIWA client report No: 2018139WN.

Andrew, N., and O'neill, A. (2000). Large-scale patterns in habitat structure on subtidal rocky reefs in New South Wales. *Marine and Freshwater Research* 51**,** 255-263.

Arponen, A., Moilanen, A., and Ferrier, S. (2008). A successful community-level strategy for conservation prioritization. *Journal of Applied Ecology* 45**,** 1436-1445.

Asaad, I., Lundquist, C.J., Erdmann, M.V., and Costello, M.J. (2017). Ecological criteria to identify areas for biodiversity conservation. *Biological Conservation* 213**,** 309-316.

Auckland Council (2011). Auckland Council's Indigenous Biodiversity Strategy. Auckland Council, Auckland, New Zealand.

Baco, A.R., Rowden, A.A., Levin, L.A., Smith, C.R., and Bowden, D.A. (2010). Initial characterization of cold seep faunal communities on the New Zealand Hikurangi margin. *Marine Geology* 272**,** 251-259.

Baillon, S., Hamel, J.-F., Wareham, V.E., and Mercier, A. (2012). Deep cold-water corals as nurseries for fish larvae. *Frontiers in Ecology and the Environment* 10**,** 351-356.

Baird, S., Hewitt, J.E., and Wood, B.A. (2015). *Benthic Habitat Classes and Trawl Fishing Disturbance in New Zealand Waters Shallower Then 250 M.* Ministry for Primary Industries.

Baird, S.J., and Wood, B.A. (2018). Extent of bottom contact by New Zealand commercial trawl fishing for deepwater Tier 1 and Tier 2 target fishstocks, 1989–90 to 2015–16. *New Zealand Aquatic Environment and Biodiversity Report No. 193.***,** 102.

Baker, C., Chilvers, B., Constantine, R., Dufresne, S., Mattlin, R., Van Helden, A., and Hitchmough, R. (2010). Conservation status of New Zealand marine mammals (suborders Cetacea and Pinnipedia), 2009. *New Zealand Journal of Marine and Freshwater Research* 44**,** 101-115.

Baker, C.S., Chilvers, B., Childerhouse, S., Constantine, R., Currey, R., Mattlin, R.H., Van Helden, A., Hitchmough, R., and Rolfe, J.R. (2016). *Conservation status of New Zealand marine mammals, 2013.* Publishing Team, Department of Conservation.

Ball, I.R., Possingham, H.P., and Watts, M. (2009). Marxan and relatives: software for spatial conservation prioritisation. *Spatial conservation prioritisation: quantitative methods and computational tools. Oxford University Press, Oxford***,** 185-195.

Batson, P.B., and Probert, P.K. (2000). Bryozoan thickets off otago peninsula. New Zealand fisheries assessment report 2000/46 wellington, Ministry of Fisheries.

Bax, N.J., Cleary, J., Donnelly, B., Dunn, D.C., Dunstan, P.K., Fuller, M., and Halpin, P.N. (2016). Results of efforts by the Convention on Biological Diversity to describe ecologically or biologically significant marine areas. *Conservation Biology*.

Beazley, L.I., Kenchington, E.L., Murillo, F.J., and Sacau, M.D.M. (2013). Deep-sea sponge grounds enhance diversity and abundance of epibenthic megafauna in the Northwest Atlantic. *ICES Journal of Marine Science* 70**,** 1471-1490.

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., and Minello, T.J. (2001). The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: a better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. *AIBS Bulletin* 51**,** 633-641.

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

Bellingham, M., Lloyd, K., Lundquist, C., Quinn, J., Roper-Lindsay, J., Davis, A., and Fuller, S. (2017). Assessing significant ecological values. Technical report prepared for environment institute of Australia and New Zealand inc. New Zealand chapter. 19pp.

Birdlife International and Natureserve (2015). Bird Species Distribution Maps of the World.

Black, J., and Tilney, R. (2017). Monitoring New Zealand’s trawl footprint for deepwater fisheries: 1989–90 to 2011-2012 and 2012–13 (New Zealand Aquatic Environment and Biodiversity Report No. 176). *Wellington, New Zealand: Ministry for Primary Industries*.

Bostock, H., Jenkins, C., Mackay, K., Carter, L., Nodder, S., Orpin, A., Pallentin, A., and Wysoczanski, R. (2018). Distribution of surficial sediments in the ocean around New Zealand/Aotearoa. Part B: continental shelf. *New Zealand Journal of Geology and Geophysics***,** 1-22.

Bowden, D.A., Rowden, A.A., Thurber, A.R., Baco, A.R., Levin, L.A., and Smith, C.R. (2013). Cold seep epifaunal communities on the Hikurangi Margin, New Zealand: composition, succession, and vulnerability to human activities. *PLoS One* 8**,** e76869.

Buhl-Mortensen, L., Vanreusel, A., Gooday, A.J., Levin, L.A., Priede, I.G., Buhl-Mortensen, P., Gheerardyn, H., King, N.J., and Raes, M. (2010). Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. *Marine Ecology* 31**,** 21-50.

Bush, A., Harwood, T., Hoskins, A.J., Mokany, K., and Ferrier, S. (2016). Current Uses of Beta-Diversity in Biodiversity Conservation: A response to. *Trends in ecology & evolution* 31**,** 337.

Butler, A.J., and Jernakoff, P. (1999). *Seagrass in Australia: strategic review and development of an R & D plan.* Melbourne, Vic., CSIRO Publishing.

Campbell, J., Antoine, D., Armstrong, R., Arrigo, K., Balch, W., Barber, R., Behrenfeld, M., Bidigare, R., Bishop, J., and Carr, M.E. (2002). Comparison of algorithms for estimating ocean primary production from surface chlorophyll, temperature, and irradiance. *Global biogeochemical cycles* 16**,** 9-1-9-15.

Canz (2008). *New Zealand Regional Bathymetry.* NIWA Chart,.

Carbines, G., and Cole, R.G. (2009). Using a remote drift underwater video (DUV) to examine dredge impacts on demersal fishes and benthic habitat complexity in Foveaux Strait, Southern New Zealand. *Fisheries Research* 96**,** 230-237.

Carroll, C., Dunk, J.R., and Moilanen, A. (2010). Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest, USA. *Global Change Biology* 16**,** 891-904.

Cars2009 (2009). *CSIRO Atlas of Regional Seas* [Online]. CSIRO. Available: www.cmar.csiro.au/cars [Accessed 14/12/2017 2017].

Cathalot, C., Van Oevelen, D., Cox, T.J., Kutti, T., Lavaleye, M., Duineveld, G., and Meysman, F.J. (2015). Cold-water coral reefs and adjacent sponge grounds: Hotspots of benthic respiration and organic carbon cycling in the deep sea. *Frontiers in Marine Science* 2**,** 37.

Clark, M.R. (2015). *Vulnerable Marine Ecosystems of the Louisville Seamount Chain: voyage report of a survey to evaluate the efficacy of preliminary habitat suitability models.* Ministry for Primary Industries.

Clark, M.R., Mills, S., Leduc, D., Anderson, O.F., and Rowden, A.A. (in revision). Biodiversity of Benthic Protection Areas and Seamount Closure Areas: a description of available benthic invertebrate data, and a preliminary evaluation of the effectiveness of biodiversity protection. *New Zealand Aquatic Environment and Biodiversity Report*.

Clark, M.R., Rowden, A.A., Schlacher, T.A., Guinotte, J., Dunstan, P.K., Williams, A., O'hara, T.D., Watling, L., Niklitschek, E., and Tsuchida, S. (2014). Identifying ecologically or biologically significant areas (EBSA): a systematic method and its application to seamounts in the South Pacific Ocean. *Ocean & Coastal Management* 91**,** 65-79.

Connell, J.H. (1978). Diversity in tropical rain forests and coral reefs. *Science* 199**,** 1302-1310.

Cordes, E.E., Bergquist, D.C., Predmore, B.L., Jones, C., Deines, P., Telesnicki, G., and Fisher, C.R. (2006). Alternate unstable states: convergent paths of succession in hydrocarbon-seep tubeworm-associated communities. *Journal of Experimental Marine Biology and Ecology* 339**,** 159-176.

Costanza, R., De Groot, R., Sutton, P., Van Der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., and Turner, R.K. (2014). Changes in the global value of ecosystem services. *Global environmental change* 26**,** 152-158.

Costello, M.J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H., and Miloslavich, P. (2010). A Census of Marine Biodiversity Knowledge, Resources, and Future Challenges. *PLoS ONE* 5**,** e12110.

Crossland, J. (1982). Distribution and abundance of fish eggs and larvae from the spring and summer plankton of north-east New Zealand, 1976-78. *Fish. Res. Bull. New Zealand* 24**,** 11-57.

Cryer, M., Nicol, S., Geange, S., Rowden, A., Lundquist, C., and Stephenson, F. (2017). Report from a series of stakeholder workshops to gather and document stakeholder views on the nature and content of a revised conservation and management measure for bottom fisheries in the SPRFMO Area. *Report to the SPRFMO Scientific Committee, Shanghai*.

Cummings, V., Thrush, S., Hewitt, J., and Funnell, G. (2001). Variable effect of a large suspension-feeding bivalve on infauna: experimenting in a complex system. *Marine Ecology Progress Series* 209**,** 159-175.

Dahlgren, C.P., Kellison, G.T., Adams, A.J., Gillanders, B.M., Kendall, M.S., Layman, C.A., Ley, J.A., Nagelkerken, I., and Serafy, J.E. (2006). Marine nurseries and effective juvenile habitats: concepts and applications. *Marine Ecology Progress Series* 312**,** 291-295.

Davies, K., Murchie, A.A., Kerr, V., and Lundquist, C. (2018). The evolution of marine protected area planning in Aotearoa New Zealand: Reflections on participation and process. *Marine Policy* 93**,** 113-127.

Dean, R.L., and Connell, J.H. (1987). Marine invertebrates in an algal succession. III. Mechanisms linking habitat complexity with diversity. *Journal of Experimental Marine Biology and Ecology* 109**,** 249-273.

Department of Conservation, and Ministry of Fisheries (2005). "Marine Protected Areas: Policy and Implementation Plan". Wellington, New Zealand: Department of Conservation and Ministry of Fisheries.

Department of Conservation, and Ministry of Fisheries (2011). "Coastal marine habitats and marine protected areas in the New Zealand Territorial Sea: a broad scale gap analysis". (Wellington, New Zealand).

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J.R.G., Gruber, B., Lafourcade, B., and Leitão, P.J. (2013). Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36**,** 27-46.

Dunn, D.C., Ardron, J., Bax, N., Bernal, P., Cleary, J., Cresswell, I., Donnelly, B., Dunstan, P., Gjerde, K., and Johnson, D. (2014). The convention on biological diversity's ecologically or biologically significant areas: origins, development, and current status. *Marine Policy* 49**,** 137-145.

Dunstan, P.K., Bax, N.J., Dambacher, J.M., Hayes, K.R., Hedge, P.T., Smith, D.C., and Smith, A.D. (2016). Using ecologically or biologically significant marine areas (EBSAs) to implement marine spatial planning. *Ocean & Coastal Management* 121**,** 116-127.

Dunstan, P.K., Clark, M.R., Guinotte, J., O'hara, T., Niklitschek, E., Rowden, A.A., Schlacher, T., Tsuchida, S., Watling, L., and Williams, A. (2011). "Identifying Ecologically and Biologically Significant Areas on Seamounts". (Gland, Switzerland: IUCN).

Edgar, G.J., Stuart-Smith, R.D., Willis, T.J., Kininmonth, S., Baker, S.C., Banks, S., Barrett, N.S., Becerro, M.A., Bernard, A.T., and Berkhout, J. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506**,** 216.

Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, R., Huettmann, F., R. Leathwick, J., Lehmann, A., Li, J., G. Lohmann, L., A. Loiselle, B., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Mcc. M. Overton, J., Townsend Peterson, A., J. Phillips, S., Richardson, K., Scachetti-Pereira, R., E. Schapire, R., Soberón, J., Williams, S., S. Wisz, M., and E. Zimmermann, N. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29**,** 129-151.

Elith, J., Kearney, M., and Phillips, S. (2010). The art of modelling range-shifting species. *Methods in ecology and evolution* 1**,** 330-342.

Elith, J., and Leathwick, J.R. (2009). Species distribution models: ecological explanation and prediction across space and time. *Annual review of ecology, evolution, and systematics* 40**,** 677-697.

Ellingsen, K.E., Hewitt, J.E., and Thrush, S.F. (2007). Rare species, habitat diversity and functional redundancy in marine benthos. *Journal of Sea Research* 58**,** 291-301.

Ellis, N., Smith, S.J., and Pitcher, C.R. (2012). Gradient forests: calculating importance gradients on physical predictors. *Ecology* 93**,** 156-168.

Fao (2009). "International Guidelines for the Management of Deep-Sea Fisheries in the High-Seas". (Food and Agriculture Organisation of the United Nations, Rome, Italy, 73 p.).

Fenwick, G. (2018). Significant indigenous coastal biodiversity Criteria for its identification. NIWA Client Report prepared for West Coast Regional Council NIWA CLIENT REPORT No: 018088CH. NIWA Project: ELF18503.

Ferrari, R., Malcolm, H., Neilson, J., Lucieer, V., Jordan, A., Ingleton, T., Figueira, W., Johnstone, N., and Hill, N. (2018). Integrating distribution models and habitat classification maps into marine protected area planning. *Estuarine, Coastal and Shelf Science* 212**,** 40-50.

Ferrier, S., Manion, G., Elith, J., and Richardson, K. (2007). Using generalized dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment. *Diversity and distributions* 13**,** 252-264.

Ford, R.B., Francis, M.P., Holland, L., Clark, M.R., Duffy, C.a.J., Dunn, M.R., Jones, E., and Wells, R. (2018). *Qualitative (Level 1) Risk Assessment of the impact of commercial fishing on New Zealand Chondrichthyans: an update for 2017.* Ministry for Primary Industries.

Ford, R.B., Galland, A., Clark, M.R., Crozier, P., Duffy, C.a.J., Dunn, A., Francis, M., and Wells, R. (2015). *Qualitative (Level 1) risk assessment of the impact of commercial fishing on New Zealand chondrichthyans.* Ministry for Primary Industries.

Forest & Bird (2014). "New Zealand Seabirds: Important Bird Areas and Conservation". The Royal Forest & Bird Protection Society of New Zealand, Wellington, New Zealand. 72 pp.

Foster, S., Givens, G., Dornan, G., Dunstan, P., and Darnell, R. (2013). Modelling biological regions from multi-species and environmental data. *Environmetrics* 24**,** 489-499.

Francis, M. (1988). *Coastal fishes of New Zealand: a diver's [skindiver's] identification guide.* Heinmann Reed.

Francis, M.P. (1981). Spawning migration of moki (Latridopsis ciliaris) off eastern New Zealand. *New Zealand journal of marine and freshwater research* 15**,** 267-273.

Freeman, D., Ford, R., Funnell, G., Geange, S., Sharp, B., and Tellier, P. (2017). "Key Ecological Areas for Marine Protected Area Planning in New Zealand", in: *Note defining Key Ecological Areas.* Interim Marine Protected Areas Science Advisory Group.

Freeman, D., Marshall, B., Ahyong, S., Wing, S., and Hitchmough, R. (2010). Conservation status of New Zealand marine invertebrates, 2009. *New Zealand Journal of Marine and Freshwater Research* 44**,** 129-148.

Freeman, D., Schnabel, K.E., Marshall, B., Gordon, D.P., Wing, S., Tracey, D.M., and Hitchmough, R. (2014). *Conservation status of New Zealand marine invertebrates, 2013.* Department of Conservation Wellington, New Zealand.

Geange, S.W., Leathwick, J., Linwood, M., Curtis, H., Duffy, C., Funnell, G., and Cooper, S. (2017). Integrating conservation and economic objectives in MPA network planning: A case study from New Zealand. *Biological Conservation* 210**,** 136-144.

Glover, E.A., Taylor, J.D., and Rowden, A.A. (2004). Bathyaustriella thionipta, a new lucinid bivalve from a hydrothermal vent on the Kermadec Ridge, New Zealand and its relationship to shallow-water taxa (Bivalvia: Lucinidae). *Journal of Molluscan Studies* 70**,** 283-295.

Gordon, D.P. (2009). *New Zealand inventory of biodiversity.* Canterbury University Press.

Gordon, D.P. (2013). "Life on the Edge: Parachnoidea (Ctenostomata) and Barentsia (Kamptozoa) on Bathymodiolin Mussels from an active submarine volcano in the Kermadec Volcanic Arc," in *Bryozoan Studies 2010*. Springer), 75-89.

Gordon, D.P., Beaumont, J., Macdiarmid, A., Robertson, D.A., and Ahyong, S.T. (2010). Marine Biodiversity of Aotearoa New Zealand. *PLoS ONE* 5**,** e10905.

Gorman, R.M., Bryan, K.R., and Laing, A.K. (2003). Wave hindcast for the New Zealand region: Deep-water wave climate. *New Zealand Journal of Marine and Freshwater Research* 37**,** 589-612.

Greinert, J., Lewis, K., Bialas, J., Pecher, I.A., Rowden, A., Bowden, D., De Batist, M., and Linke, P. (2010). Methane seepage along the Hikurangi Margin, New Zealand: Overview of studies in 2006 and 2007 and new evidence from visual, bathymetric and hydroacoustic investigations. *Marine Geology* 272**,** 6-25.

Halpern, B.S., Lester, S.E., and Mcleod, K.L. (2010). Placing marine protected areas onto the ecosystem-based management seascape. *Proceedings of the National Academy of Sciences* 107**,** 18312-18317.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., and Fox, H.E. (2008). A global map of human impact on marine ecosystems. *Science* 319**,** 948-952.

Harrison, S., Ross, S.J., and Lawton, J.H. (1992). Beta diversity on geographic gradients in Britain. *Journal of Animal ecology***,** 151-158.

Heck Jr, K.L., and Wetstone, G.S. (1977). Habitat complexity and invertebrate species richness and abundance in tropical seagrass meadows. *Journal of Biogeography***,** 135-142.

Henry, L.-A., and Roberts, J.M. (2007). Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. *Deep Sea Research Part I: Oceanographic Research Papers* 54**,** 654-672.

Hewitt, J.E., Lundquist, C.J., and Ellis, J. (2018). Assessing sensitivities of marine areas to stressors based on biological traits. *Conservation Biology*.

Hewitt, J.E., Wang, D., Francis, M., Lundquist, C., and Duffy, C. (2015). Evaluating demersal fish richness as a surrogate for epibenthic richness in management and conservation. *Diversity and Distributions* 21**,** 901-912.

Hijmans, R.J., Phillips, S., Leathwick, J., and Elith, J. (2017). dismo: Species Distribution Modeling R package version 1.1-4. https://CRAN.R-project.org/package=dismo.

Hill, N.A., Foster, S.D., Duhamel, G., Welsford, D., Koubbi, P., and Johnson, C.R. (2017). Model-based mapping of assemblages for ecology and conservation management: A case study of demersal fish on the Kerguelen Plateau. *Diversity and Distributions* 23**,** 1216-1230.

Hitchmough, R., Anderson, P., Barr, B.P., Monks, J.M., Lettink, M., Reardon, J.T., Tocher, M., and Whitaker, A.H. (2013). *Conservation status of New Zealand reptiles, 2012.* Publishing Team, Department of Conversation.

Hobday, A., Smith, A., Stobutzki, I., Bulman, C., Daley, R., Dambacher, J., Deng, R., Dowdney, J., Fuller, M., and Furlani, D. (2011). Ecological risk assessment for the effects of fishing. *Fisheries Research* 108**,** 372-384.

Hurst, R., Stevenson, M., Bagley, N., Griggs, L., Morrison, M., Francis, M., and Duffy, C. (2000). Areas of importance for spawning, pupping or egg-laying, and juveniles of New Zealand coastal fish. *National Institute of Water and Atmospheric Research, Wellington*.

Interridge (2016). *InterRidge Global Database of Active Submarine Hydrothermal Vent Fields* [Online]. Available: https://vents-data.interridge.org/about_the_database [Accessed 22/10/2018 2018].

Iucn-Wcpa (2008). "Establishing Marine Protected Area Networks—Making It Happen". (Washington, D.C.: IUCN-WCPA, National Oceanic and Atmospheric Administration, The Nature Conservancy).

Iucn (2012). "Guidelines for Applying the IUCN Protected Area Management Categories to Marine Protected Areas".).

Iucn (2016). "A global standard for the identification of key biodiversity areas". Gland, Switzerland: IUCN.

Jones, E., Morrison, M., Davey, N., Hartill, B., and Sutton, C. (2016). Biogenic habitats on New Zealand's continental shelf. Part I: Local Ecological Knowledge.

Jones, E.G., Morrison, M.A., Davey, N., Mills, S., Pallentin, A., George, S., Kelly, M., and Tuck, I. (2018). Biogenic habitats on New Zealand's continental shelf. part ii: National field survey and analysis. New Zealand aquatic environment and biodiversity report no. 202.

Jones, G. (2013). Ecology of rocky reef fish of northeastern New Zealand: 50 years on. *New Zealand Journal of Marine and Freshwater Research* 47**,** 334-359.

Kaschner, K., Watson, R., Trites, A., and Pauly, D. (2006). Mapping world-wide distributions of marine mammal species using a relative environmental suitability (RES) model. *Marine Ecology Progress Series* 316**,** 285-310.

Kerr, L.A., Secor, D.H., and Piccoli, P.M. (2009). Partial migration of fishes as exemplified by the estuarine-dependent white perch. *Fisheries* 34**,** 114-123.

Krumhansl, K.A., Okamoto, D.K., Rassweiler, A., Novak, M., Bolton, J.J., Cavanaugh, K.C., Connell, S.D., Johnson, C.R., Konar, B., and Ling, S.D. (2016). Global patterns of kelp forest change over the past half-century. *Proceedings of the National Academy of Sciences* 113**,** 13785-13790.

Kujala, H., Moilanen, A., Araújo, M.B., and Cabeza, M. (2013). Conservation planning with uncertain climate change projections. *PloS one* 8**,** e53315.

Leaper, R., Hill, N.A., Edgar, G.J., Ellis, N., Lawrence, E., Pitcher, C.R., Barrett, N.S., and Thomson, R. (2011). Predictions of beta diversity for reef macroalgae across southeastern Australia. *Ecosphere* 2**,** 1-18.

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

Leathwick, J., Moilanen, A., Francis, M., Elith, J., Taylor, P., Julian, K., Hastie, T., and Duffy, C. (2008a). Novel methods for the design and evaluation of marine protected areas in offshore waters. *Conservation Letters* 1**,** 91-102.

Leathwick, J., Moilanen, A., Francis, M., Elith, J., Taylor, P., Julian, K., Hastie, T., and Duffy, C. (2008b). Novel methods for the design and evaluation of marine protected areas in offshore waters. *Conservation Letters* 1**,** 91-102.

Leathwick, J., Rowden, A., Nodder, S., Gorman, R., Bardsley, S., Pinkerton, M., Baird, S., Hadfield, M., Currie, K., and Goh, A. (2012). "A Benthic-optimised marine environment classification (BOMEC) for New Zealand waters", in: *New Zealand Aquatic Environment and Biodiversity Report; ISSN 1176-9440.* (Wellington: Ministry of Fisheries.

Lee, Z., Lubac, B., Werdell, J., and Arnone, R. (2009). An update of the quasi-analytical algorithm (QAA_v5). *International Ocean Color Group Software Report*, 1-9.

Legendre, P., Borcard, D., and Peres-Neto, P.R. (2005). Analyzing beta diversity: partitioning the spatial variation of community composition data. *Ecological Monographs* 75**,** 435-450.

Lehtomäki, J., and Moilanen, A. (2013). Methods and workflow for spatial conservation prioritization using Zonation. *Environmental Modelling & Software* 47**,** 128-137.

Lester, S., Stevens, J., Gentry, R., Kappel, C., Bell, T., Costello, C., Gaines, S., Kiefer, D., Maue, C., and Rensel, J. (2018). Marine spatial planning makes room for offshore aquaculture in crowded coastal waters. *Nature communications* 9**,** 945.

Levin, L.A. (2005). "Ecology of cold seep sediments: interactions of fauna with flow, chemistry and microbes," in *Oceanography and Marine Biology*. CRC Press), 11-56.

Lewis, K.B., and Marshall, B.A. (1996). Seep faunas and other indicators of methane-rich dewatering on New Zealand convergent margins. *New Zealand Journal of Geology and Geophysics* 39**,** 181-200.

Lipcius, R., Stockhausen, W., Eggleston, D., Marshall Jr, L., and Hickey, B. (1997). Hydrodynamic decoupling of recruitment, habitat quality and adult abundance in the Caribbean spiny lobster: source–sink dynamics? *Marine and Freshwater Research* 48**,** 807-816.

Luckhurst, B., and Luckhurst, K. (1978). Analysis of the influence of substrate variables on coral reef fish communities. *Marine Biology* 49**,** 317-323.

Lundquist, C., Davies, K., and Mccartain, L. (2015a). Best practice guidelines for marine protected area network design and evaluation. NIWA Client report #HAM2015-051 prepared for Ministry for the Environment, project #MFE15206. 87 p.

Lundquist, C.J., Julian, K.A., Costello, M., Gordon, D.P., Mackay, K., Neill, K., Mills, S., Nelson, W.A., and Thompson, D. (2015b). *Development of a Tier 1 National Reporting Statistic for New Zealand's Marine Biodiversity.* Ministry for Primary Industries.

Lundquist, C.J., and Smith, B. (2014). " Review of ecological significance criteria for the Auckland marine region. Prepared by the National Institute of Water & Atmospheric Research for Auckland Council. Auckland Council Working Report 2015/001.

Macdiarmid, A., Bowden, D., Cummings, V., Morrison, M., Jones, E., Kelly, M., Neil, H., Nelson, W., and Rowden, A. (2013). Sensitive marine benthic habitats defined. *NIWA client report number WLG2013-18. National Institute of Water and Atmospheric Research, Wellington, New Zealand*.

Mcknight, D.G. (2006). Marine fauna of New Zealand: Echinodermata: Asteroidea (sea-stars). 3. Orders Velatida, Spinulosida, Forcipulatida, Brisingida with addenda to Paxillosida, Valvatida. *NIWA Biodiversity memoir* 120**,** 1-187.

Mcknight, M.W., White, P.S., Mcdonald, R.I., Lamoreux, J.F., Sechrest, W., Ridgely, R.S., and Stuart, S.N. (2007). Putting beta-diversity on the map: broad-scale congruence and coincidence in the extremes. *PLoS Biol* 5**,** e272.

Mfe (Ministry for the Environment) (2016). " A new Marine Protected Areas Act: Consultation document. Ministry for the Environment, Wellington. 48p.

Ministry of Fisheries, and Department of Conservation (2008). "Marine protected areas: Classification, protection standard and implementation guidelines". Wellington, New Zealand: Ministry of Fisheries Department of Conservation.

Miskelly, C.M., Dowding, J.E., Elliott, G.P., Hitchmough, R.A., Powlesland, R.G., Robertson, H.A., Sagar, P.M., Scofield, R.P., and Taylor, G.A. (2008). Conservation status of New Zealand birds, 2008. *Notornis* 55**,** 117-135.

Mitchell, J.S., Mackay, K.A., Neil, H.L., Mackay, E.J., Pallentin, A., and Notman, P. (2012). Undersea New Zealand, 1:5,000,000. . *NIWA Chart, Miscellaneous Series No. 92*.

Moilanen, A., Kujala, H., and Leathwick, J. (2009). The Zonation framework and software for conservation prioritization. *Spatial conservation prioritization***,** 196-210.

Moilanen, A., and Wintle, B.A. (2006). Uncertainty analysis favours selection of spatially aggregated reserve networks. *Biological Conservation* 129**,** 427-434.

Morrisey, D.J., Swales, A., Dittmann, S., Morrison, M.A., Lovelock, C.E., and Beard, C.M. (2010). "The ecology and management of temperate mangroves". CRC Press, Boca Raton(USA).

Morrison, M., Jones, E.G., Parsons, D.M., and Grant, C. (2014a). *Habitats and areas of particular significance for coastal finfish fisheries management in New Zealand: A review of concepts and life history knowledge, and suggestions for future research.* Ministry for Primary Industries.

Morrison, M.A., Lowe, M., Parsons, D., Usmar, N., and Mcleod, I. (2009). A review of land-based effects on coastal fisheries and supporting biodiversity in New Zealand. *New Zealand Aquatic Environment and Biodiversity Report* 37**,** 100.

Morrison, M.A., Lowe, M.L., Grant, C.G., Smith, P.J., Carbines, G., Reed, J., Bury, S.J., and Brown, J. (2014b). Seagrass meadows as biodiversity and productivity hotspots. New Zealand aquatic environment and biodiversity report no. 137.

Murphy, R., Pinkerton, M., Richardson, K., Bradford-Grieve, J., and Boyd, P. (2001). Phytoplankton distributions around New Zealand derived from SeaWiFS remotely-sensed ocean colour data. *New Zealand Journal of marine and freshwater research* 35**,** 343-362.

Nabis (2012). *New Zealand's National Aquatic Biodiversity Information System (NABIS)* [Online]. Available: http://www.nabis.govt.nz/ [Accessed 22/10/2018 2018].

Nekola, J.C., and White, P.S. (2002). Conservation, the two pillars of ecological explanation, and the paradigm of distance. *Natural Areas Journal* 22**,** 305-310.

Nelson, W., Neill, K., Farr, T., Barr, N., D'archino, R., Miller, S., and Stewart, R. (2012). Rhodolith beds in northern New Zealand: characterisation of associated biodiversity and vulnerability to environmental stressors. *New Zealand aquatic environment and biodiversity report* 99**,** 106.

Niwa (2016). *New Zealand Regional Bathymetry (2016)* [Online]. Available: https://www.niwa.co.nz/our-science/oceans/bathymetry/download-the-data [Accessed 22/10/2018 2018].

Norkko, A., Hewitt, J.E., Thrush, S.F., and Funnell, T. (2001). Benthic-pelagic coupling and suspension-feeding bivalves: Linking site-specific sediment flux and biodeposition to benthic community structure. *Limnology and Oceanography* 46**,** 2067-2072.

O'driscoll, R., Booth, J., Bagley, N., Anderson, O., Griggs, L., Stevenson, M., and Francis, M. (2003). Areas of importance for spawning, pupping or egg-laying, and juveniles of New Zealand deepwater fish, pelagic fish, and invertebrates. *National Institute of Water and Atmospheric Research Technical Report* 119**,** 1-377.

Osborne, T.A. (2018). "Forecasting quantity of displaced fishing Part 2: CatchMapper - Mapping EEZ catch and effort.". New Zealand Aquatic Environment and Biodiversity Report No. 200. 168 p.).

Parker, S.J., Penney, A.J., and Clark, M.R. (2009). Detection criteria for managing trawl impacts on vulnerable marine ecosystems in high seas fisheries of the South Pacific Ocean. *Marine Ecology Progress Series* 397**,** 309-317.

Phillips, S.J., Anderson, R.P., and Schapire, R.E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological modelling* 190**,** 231-259.

Pinkerton, M. (2016). "Ocean colour satellite observations of phytoplankton in the New Zealand EEZ, 1997–2016". (Prepared for the Ministry for the Environment. Wellington: NIWA).

Pinkerton, M.H. (2017). Satellite remote sensing of water quality and temperature in Manukau Harbour.NIWA report 2017092WN produced for Watercare Services Ltd, p 76.

Pinkerton, M.H., Gall, M., Wood S, and Zeldis J (2018). Measuring the effects of bivalve mariculture on water quality in northern New Zealand using MODIS-Aqua satellite observations. *Aquaculture Environment Interactions* in press.

Pinkerton, M.H., Richardson, K.M., Boyd, P.W., Gall, M.P., Zeldis, J., Oliver, M.D., and Murphy, R.J. (2005). Intercomparison of ocean colour band-ratio algorithms for chlorophyll concentration in the Subtropical Front east of New Zealand. *Remote Sensing of Environment* 97**,** 382-402.

Pitcher, C., Ellis, N., and Smith, S. (2011). "Example analysis of biodiversity survey data with R package gradientForest".

Pitcher, C.R., Doherty, P., Arnold, P., Hooper, J., Gribble, N., Bartlett, C., Browne, M., Campbell, N., Cannard, T., Cappo, M., Carini, G., Chalmers, S., Cheers, S., Chetwynd, D., Colefax, A., Coles, R., Cook, S., Davie, P., De'ath, G., Devereux, D., Done, B., Donovan, T., Ehrke, B., Ellis, N., Ericson, G., Fellegara, I., Forcey, K., Furey, M., Gledhill, D., Good, N., Gordon, S., Haywood, M., Hendriks, P., Jacobsen, I., Johnson, J., Jones, M., Kinninmoth, S., Kistle, S., Last, P., Leite, A., Marks, S., Mcleod, I., Oczkowicz, S., Robinson, M., Rose, C., Seabright, D., Sheils, J., Sherlock, M., Skelton, P., Smith, D., Smith, G., Speare, P., Stowar, M., Strickland, C., Van Der Geest, C., Venables, W., Walsh, C., Wassenberg, T., Welna, A., Yearsley, G. (2007). Seabed Biodiversity on the Continental Shelf of the Great Barrier Reef World Heritage Area. *AIMS/CSIRO/QM/QDPI CRC Reef Research Task Final Report.* **,** 320.

Pitcher, R.C., Lawton, P., Ellis, N., Smith, S.J., Incze, L.S., Wei, C.L., Greenlaw, M.E., Wolff, N.H., Sameoto, J.A., and Snelgrove, P.V. (2012). Exploring the role of environmental variables in shaping patterns of seabed biodiversity composition in regional-scale ecosystems. *Journal of Applied Ecology* 49**,** 670-679.

Ramirez-Llodra, E., Tyler, P.A., Baker, M.C., Bergstad, O.A., Clark, M.R., Escobar, E., Levin, L.A., Menot, L., Rowden, A.A., and Smith, C.R. (2011). Man and the last great wilderness: human impact on the deep sea. *PLoS one* 6**,** e22588.

Richard, Y., and Abraham, E.R. (2013). *Risk of commercial fisheries to New Zealand seabird populations.* Ministry for Primary Industries.

Ridgway, K., Dunn, J., and Wilkin, J. (2002). Ocean interpolation by four-dimensional weighted least squares—Application to the waters around Australasia. *Journal of atmospheric and oceanic technology* 19**,** 1357-1375.

Roberts, C.D., Stewart, A.L., and Struthers, C.D. (2015). *The fishes of New Zealand (4 volumes).* Wellington.: Te Papa Press.

Roberts, C.M., Branch, G., Bustamante, R.H., Castilla, J.C., Dugan, J., Halpern, B.S., Lafferty, K.D., Leslie, H., Lubchenco, J., Mcardle, D., Ruckelshaus, M., and Warner, R.R. (2003). Application of ecological criteria in selecting marine reserves and developing reserve networks. *Ecological Applications* 13**,** S215-S228.

Robertson, D. (1980). Spawning of the frostfish, Lepidopus caudatus (Pisces: Trichiuridae), in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research* 14**,** 129-136.

Robertson, D.A. (1973). *Planktonic eggs and larvae of some New Zealand marine teleosts.* University of Otago.

Robertson, H.A., Baird, K., Dowding, J.E., Elliott, G.P., Hitchmough, R.A., Miskelly, C.M., Mcarthur, N., O’donnell, C.J., Sagar, P.M., Scofield, R.P., and Taylor, G.A. (2017). "Conservation status of New Zealand birds, 2016", in: *New Zealand Threat Classification Series 19.* Wellington: Department of Conservation.

Rowden, A.A., Anderson, O.F., Georgian, S.E., Bowden, D.A., Clark, M.R., Pallentin, A., and Miller, A. (2017). High-Resolution Habitat Suitability Models for the Conservation and Management of Vulnerable Marine Ecosystems on the Louisville Seamount Chain, South Pacific Ocean. *Frontiers in Marine Science* 4**,** 335.

Rowden, A.A., Lundquist, C.J., Hewitt, J.E., Stephenson, F., and Morrison, M.A. (2018). "Review of New Zealand’s coastal and marine habitat and ecosystem classification". NIWA Client Report 2018115WN, prepared for Department of Conservation.

Rowden, A.A., Schlacher, T.A., Williams, A., Clark, M.R., Stewart, R., Althaus, F., Bowden, D.A., Consalvey, M., Robinson, W., and Dowdney, J. (2010). A test of the seamount oasis hypothesis: seamounts support higher epibenthic megafaunal biomass than adjacent slopes. *Marine Ecology* 31**,** 95-106.

Shears, N.T., and Usmar, N.R. (2006). "The role of the Hauraki Gulf Cable Protection Zone in protecting exploited fish species: d*e facto* marine reserve? DOC Research & Development Series 253". Wellington, New Zealand: Department of Conservation.

Smith, A.N., Duffy, C.a.J., and Leathwick, J.R. (2013). *Predicting the distribution and relative abundance of fishes on shallow subtidal reefs around New Zealand.* Publishing Team, Department of Conservation.

Snelder, T.H., Leathwick, J.R., Dey, K.L., Rowden, A.A., Weatherhead, M.A., Fenwick, G.D., Francis, M.P., Gorman, R.M., Grieve, J.M., and Hadfield, M.G. (2007). Development of an ecologic marine classification in the New Zealand region. *Environmental Management* 39**,** 12-29.

Stephenson, F., Leathwick, J.R., Geange, S.W., Bulmer, R.H., Hewitt, J.E., Anderson, O.F., Rowden, A.A., and Lundquist, C.J. (2018). Using Gradient Forests to summarize patterns in species turnover across large spatial scales and inform conservation planning. *Diversity and Distributions* 0.

Stephenson, F., Mill, A.C., Scott, C.L., Polunin, N.V., and Fitzsimmons, C. (2017). Experimental potting impacts on common UK reef habitats in areas of high and low fishing pressure. *ICES Journal of Marine Science*.

Thomson, R.J., Hill, N.A., Leaper, R., Ellis, N., Pitcher, C.R., Barrett, N.S., and J Edgar, G. (2014). Congruence in demersal fish, macroinvertebrate, and macroalgal community turnover on shallow temperate reefs. *Ecological Applications* 24**,** 287-299.

Thrush, S.F., Hewitt, J.E., Funnell, G.A., Cummings, V.J., Ellis, J., Schultz, D., Talley, D., and Norkko, A. (2001). Fishing disturbance and marine biodiversity: the role of habitat structure in simple soft-sediment systems. *Marine Ecology Progress Series* 223**,** 277-286.

Thurber, A.R., Kröger, K., Neira, C., Wiklund, H., and Levin, L.A. (2010). Stable isotope signatures and methane use by New Zealand cold seep benthos. *Marine Geology* 272**,** 260-269.

Tittensor, D.P., Baco, A.R., Hall-Spencer, J.M., Orr, J.C., and Rogers, A.D. (2010). Seamounts as refugia from ocean acidification for cold-water stony corals. *Marine Ecology* 31**,** 212-225.

Townsend, A., De Lange, P., Duffy, C., Miskelly, C., Molloy, J., and Norton, D. (2008). New Zealand threat classification system manual. *Wellington, Department of Conservation* 30.

Townsend, M., Clark, D., Lohrer, D., Ellis, J., Lundquist, C., Hewitt, J.E., and Thrush, S. (2014a). An Ecosystem Services Matrix for New Zealand's coastal marine environment. *Report Prepared for the Department of Conservation* HAM2014-074**,** 56.

Townsend, M., Thrush, S., and Carbines, M. (2011). Simplifying the complex: an 'Ecosystem Principles Approach'to goods and services management in marine coastal ecosystems. *Marine Ecology Progress Series* 434**,** 291-301.

Townsend, M., Thrush, S.F., Lohrer, A.M., Hewitt, J.E., Lundquist, C.J., Carbines, M., and Felsing, M. (2014b). Overcoming the challenges of data scarcity in mapping marine ecosystem service potential. *Ecosystem Services* 8**,** 44-55.

Van Dover, C. (2000). *The ecology of deep-sea hydrothermal vents.* Princeton University Press.

Von Cosel, R., and Marshall, B.A. (2003). Two new species of large mussels (Bivalvia: Mytilidae) from active submarine volcanoes and a cold seep off the eastern North Island of New Zealand, with description of a new genus. *Nautilus* 117**,** 31-46.

Vooren, C.M. (1975). Nursery grounds of tarakihi (Teleostei: Cheilodactylidae) around New Zealand. *New Zealand journal of marine and freshwater research* 9**,** 121-158.

Walters, R.A., Goring, D.G., and Bell, R.G. (2001). Ocean tides around New Zealand. *New Zealand Journal of Marine and Freshwater Research* 35**,** 567-579.

Wang, M., and Shi, W. (2007). The NIR-SWIR combined atmospheric correction approach for MODIS ocean color data processing. *Optics Express* 15**,** 15722-15733.

Williams, A., Bax, N.J., Kloser, R.J., Althaus, F., Barker, B., and Keith, G. (2008). Australia's deep-water reserve network: implications of false homogeneity for classifying abiotic surrogates of biodiversity. *ICES Journal of Marine Science* 66**,** 214-224.

Wiser, S.K., Buxton, R.P., Clarkson, B.R., Hoare, R.J., Holdaway, R.J., Richardson, S.J., Smale, M.C., West, C., and Williams, P.A. (2013). New Zealand's naturally uncommon ecosystems. *Ecosystem services in New Zealand: conditions and trends. Manaaki Whenua Press, Lincoln***,** 49-61.

Wood, A.C., Rowden, A.A., Compton, T.J., Gordon, D.P., and Probert, P.K. (2013). Habitat-forming bryozoans in New Zealand: their known and predicted distribution in relation to broad-scale environmental variables and fishing effort. *PloS one* 8**,** e75160.

Yamakita, T., Yamamoto, H., Nakaoka, M., Yamano, H., Fujikura, K., Hidaka, K., Hirota, Y., Ichikawa, T., Kakehi, S., and Kameda, T. (2015). Identification of important marine areas around the Japanese Archipelago: Establishment of a protocol for evaluating a broad area using ecologically and biologically significant areas selection criteria. *Marine Policy* 51**,** 136-147.

Zeldis, J. (1993). Applicability of egg surveys for spawning-stock biomass estimation of snapper, orange roughy, and hoki in New Zealand. *Bulletin of marine science* 53**,** 864-890.

7 Appendices

7.1 File location paths and metadata

For those datasets that contain multiple layers, metadata is described at a geodatabase level. For those datasets where metadata already exists, a brief summary is provided, along with the location of the file where the original metadata is provided.

All folders, files and datasets described here are provided in the "GIS_deliverables_for_DOC" folder.

All figures and map templates from the report are available in the "Figures" folder.

Data Name	**Data format**	**Extent and resolution**	**Geodatabase**	**Summary**	**Filename (s) and Description (s)**	**Credits**
Vulnerable Marine Ecosystems (VME).	Raster	NZ EEZ in depths 200-3000m at 1km grid resolution.	VME.gdb	Predicted distribution of occurrence and associated uncertainty layers of 10 indicator taxa for Vulnerable Marine Ecosystems (VME).	Raster files: Order Antipatharia (cob_cmb); Family Stylasteridae (cor_cmb); Class Demospongiae (dem_cmb); *Enallopsammia rostrata* (ero_cmb); *Goniocorella dumosa* (gdu_cmb); Class Hexactinellida (hex_cmb); *Madrepora oculate* (moc_cmb); Order Pennatulacea (ptu_cmb); Order Alcyonacea (soc_cmb); *Solenosmilia variabilis* (sva_cmb): VME probability occurrence from ensemble models (scale = 0-1) within the NZ EEZ. cob_cv; cor_cv… etc… sva_cv: Associated uncertainty layers (measured as the coefficient of variation, CV) for the VME distribution data from ensemble models within the NZ EEZ. Scale 0-1. Commonly used abbreviations for VMEs:	Anderson et al. (2016)

Name	**FNZ code**	**FAO code**
Antipatharia	COB	AQZ
Stylasteridae	COR	AXT
Demospongia	DEM	DMO
Enallopsammia rostrata	ERO	FEY
Goniocorella dumosa	GDU	GDV
Hexactinellida	HEX	HXY
Madrepora oculata	MOC	MVI
Pennatulacea	PTU	NTW
Alcyonacea	SOC	AJZ
Solenosmilia variabilis	SVA	RZT

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
Sensitive Environments	Mainly presence only point data Some polygon Some raster	NZ EEZ Varying resolution depending on data format.	KeyBiologicalHabitats.gdb Bryozoan.gdb VME.gdb	15 biogenic habitats defined, and mapped (from a number of sources): • Seagrass • Mangroves • Kelp Forest (incl. Macrocystis as a significant species) • Algal Meadows (e.g., Caulerpa and Adamsiella) • Rhodoliths • Bryozoan Thickets (Wood et al. 2013) • Sponge Gardens • Large habitat-forming shellfish • Calcareous Tubeworms • Non-Calcareous Tubeworms • Stony Corals (reefs and thickets) and other 3D Corals (Trees, Bushy, Fans) • Seapens – Whips • Xenophyophores	All metadata and file structures the KeyBiologicalHaitats.gddb can be found in the "Metadata" folder under "Sensitive_Environments_Metadata.docx" Bryozoan.gdb: Bryozoan thickets described in (Wood et al. 2013) for 8 species of bryozoan	KeyBiologicalHabitats.gdb consists of data from various sources which were collated by Anderson et al. 2018 (including: Individual data from: OBIS; Te Papa; niwainverts; AVH The Australasian Virtual Herbarium Seasketch; Jones et al. 2018; local regional councils) Bryozoan.gdb: Wood et al. 2013 VME.gdb: Anderson et al. (2016)
Vulnerable fragile, sensitive, or slow to recover species.	Point data	NZ EEZ	NZ_fish_records.gdb	Chondrichthyans records (locations) deemed to be deemed to be vulnerable, fragile, sensitive, or slow to recover extracted from the New Zealand fish records described below), for both Quota Management system (QMS) and non QMS species, were extracted for all species with consequences scores of 4 or greater since this was deemed to be a biologically useful breakpoint.	sharks_at_risk_EEZ: Chondrichthyans records (locations extracted from the New Zealand fish records described below), for both Quota Management system (QMS) and non QMS species, with consequences scores of 4 or greater defined in the risk assessment by Ford et al. (2018). Species: *Amblyraja hyperborea* *Arhynchobatis asperrimus* *Bathyraja shuntovi* *Bythaelurus dawsoni* *Carcharhinus brachyurus* *Carcharodon carcharias* *Centrophorus squamosus* *Centroscymnus coelolepis* *Centroscymnus crepidater*	Data modified from Lundquist et al. (2015)

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
					Centroscymnus owstoni *Cetorhinus maximus* *Chimaera* *Chimaera lignaria* *Chlamydoselachus anguineus* *Dalatias licha* *Deania calcea* *Etmopterus baxteri* *Etmopterus lucifer* *Gollum attenuatus* *Hydrolagus trolli* *Odontaspis ferox* *Oxynotus bruniensis* *Proscymnodon plunketi* *Rhinochimaera pacifica*	
New Zealand fish records.	Point data	NZ EEZ	NZ_fish_records.gdb	Fish species records (locations) from OBIS, TRAWL & NIWA inverts, which were groomed, and quality controlled for a report by Lundquist et al. (2015).	Fish species records were split into several datasets in order to more accurately match the different aspects of the 'Uniqueness, rarity and/or endemism' criteria: Fish_unique_EEZ: Fish species with a single recording in the New Zealand EEZ were extracted to reflect 'Unique species' Fish_rare_EEZ: Fish species with 2 - 10 records in the New Zealand EEZ were extracted to reflect 'Rare species'. The values used to reflect rarity were subjectively selected by a group of experts during the first mapping KEA stakeholder meeting. Fish_Endemic_EEZ: Fish species records were cross-referenced to the endemic species listed in Gordon (2009) (information available online at the New Zealand Organisms Register - http://www.nzor.org.nz/) to reflect 'endemic species'. Fish_at_risk_threaten_shark_rays_EEZ: Fish species listed as Threatened or Declining in the NZ Threat Classification system – only available for sharks and rays.	Data modified from Lundquist et al. (2015)
New Zealand benthic	Point data	NZ EEZ	NZ_benthic_invert_records.gdb	Benthic invertebrate species records (locations) from OBIS, TRAWL & NIWA inverts, which were	Benthic invertebrate species records were split into several datasets in order to more accurately match the different aspects of the 'Uniqueness, rarity and/or endemism' criteria:	Data modified from Lundquist et al. (2015)

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
invertebrate records				groomed, and quality controlled for a report by Lundquist et al. (2015).	Invertebrates_Unique_EEZ: Benthic invertebrate species with a single recording in the New Zealand EEZ were extracted to reflect 'Unique species'. Invertebrates_rare_EEZ: Benthic invertebrate species with 2 - 10 records in the New Zealand EEZ were extracted to reflect 'Rare species'. The Marine values used to reflect rarity were subjectively selected by a group of experts during the first mapping KEA stakeholder meeting. Invertebrates_Endemic_EEZ: Benthic invertebrate species records were cross-referenced to the endemic species listed in Gordon (2009) (information available online at the New Zealand Organisms Register - http://www.nzor.org.nz/) to reflect 'endemic species'. Invertebrates_uncommon_EEZ: Benthic invertebrate species listed as Declining in the NZ Threat Classification system. Invertebrates_threatened_EEZ: Benthic invertebrate species listed as Threatened in the NZ Threat Classification system.	
Marine reef fish	Raster	NZ EEZ – limited to inshore reefs at 1km resolution	Folder: Marine_reef_fish Geodatabase: Rocky_reef_fish.gdb LowerCI.gdb upperCI.gdb	The predicted distributions and abundances and associated uncertainty layers of 72 species of rocky reef fishes.	Table of abbreviations, with full species name and number of samples and metadata are available in the appendices of Smith et al. 2013 (in the "Metadata" folder under "Smith et al 2013"). Abundance distributions (Rocky_reef_fish.gdb) and lower and upper confidence layers (LowerCI.gdb and upperCI.gdb respectively) are available for 72 fish species. *Species:* *Aplodactylus arctidens* — *Pempheris adspersa* *Aplodactylus etheridgii* — *Zanclistius elevatus* *Centroberyx affinis* — *Parapercis colias* *Parablennius laticlavius* — *Chromis dispilus* *Plagiotremus tapeinosoma* — *Parma alboscapularis* *Decapterus koheru* — *Helicolenus percoides* *Pseudocaranx dentex* — *Scorpaena cardinalis* *Seriola lalandi* — *Scorpaena papillosus*	Smith et al. (2013)

<table>
<tr><th>Data Name</th><th>Data format</th><th>Extent and resolution</th><th>Geodatabase</th><th>Summary</th><th>Filename (s) and Description (s)</th><th>Credits</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>
<table>
<tr><td>Trachurus novaezelandiae</td><td>Caesioperca lepidoptera</td></tr>
<tr><td>Amphichaetodon howensis</td><td>Caprodon longimanus</td></tr>
<tr><td>Cheilodactylus spectabilis</td><td>Epinephelus daemelii</td></tr>
<tr><td>Nemadactylus douglasii</td><td>Hypoplectrodes huntii</td></tr>
<tr><td>Nemadactylus macropterus</td><td>Hypoplectrodes sp.B</td></tr>
<tr><td>Chironemus marmoratus</td><td>Trachypoma macracanthus</td></tr>
<tr><td>Conger verreauxi</td><td>Pagrus auratus</td></tr>
<tr><td>Atypichthys latus</td><td>Canthigaster callisterna</td></tr>
<tr><td>Girella cyanea</td><td>Optivus elongatus</td></tr>
<tr><td>Girella tricuspidata</td><td>Paratrachichthys trailli</td></tr>
<tr><td>Kyphosus sydneyanus</td><td>Forsterygion lapillum</td></tr>
<tr><td>Scorpis lineolatus</td><td>Forsterygion malcolmi</td></tr>
<tr><td>Scorpis violaceus</td><td>Forsterygion varium</td></tr>
<tr><td>Anampses elegans</td><td>Forsterygion flavonigrum</td></tr>
<tr><td>Bodianus unimaculatus</td><td>Grahamina gymnota</td></tr>
<tr><td>Coris sandageri</td><td>Karalepis stewarti</td></tr>
<tr><td>Notolabrus celidotus</td><td>Notoclinops caerulepunctus</td></tr>
<tr><td>Notolabrus cinctus</td><td>Notoclinops segmentatus</td></tr>
<tr><td>Notolabrus fucicola</td><td>Notoclinops yaldwyni</td></tr>
<tr><td>Notolabrus inscriptus</td><td>Obliquichthys maryannae</td></tr>
<tr><td>Pseudolabrus luculentus</td><td>Ruanoho whero</td></tr>
<tr><td>Pseudolabrus miles</td><td>Zeus faber</td></tr>
<tr><td>Suezichthys aylingi</td><td>Pseudophycis barbata</td></tr>
<tr><td>Latridopsis ciliaris</td><td>Aldrichetta forsteri</td></tr>
<tr><td>Latris lineata</td><td>Upeneichthys lineatus</td></tr>
<tr><td>Mendosoma lineatum</td><td>Gymnothorax prasinus</td></tr>
<tr><td>Parika scaber</td><td>Odax cyanoallix</td></tr>
<tr><td>Lotella rhacina</td><td>Odax pullus</td></tr>
</table>
</td><td></td></tr>
<tr><td>Marine mammal; seabirds and reptiles sightings (2015 – sightings from Tier 1 biodiversity assessment).</td><td>Point data</td><td>NZ EEZ</td><td>marine_mammal_seabird_reptile.gdb</td><td>Marine reptile records (locations) extracted from OBIS, TRAWL & NIWA invert, which were groomed, and quality controlled for a report by Lundquist et al. (2015). Marine cetacean records (locations) from MPI database (collated from multiple sources - 2014) (Stephenson et al. unpublished).</td><td>Cetaceans_EEZ: Cetacean species listed as Threatened in the NZ Threat Classification system.
reptiles_EEZ: Marine reptile species listed as Threatened in the NZ Threat Classification system.
Species: TBC</td><td>Data modified from Lundquist et al. (2015)
And Stephenson et al. unpublished</td></tr>
</table>

<table>
<tr><th>Data Name</th><th>Data format</th><th>Extent and resolution</th><th>Geodatabase</th><th>Summary</th><th>Filename (s) and Description (s)</th><th>Credits</th></tr>
<tr><td>Ecosystem service: Biogenic habitat provision.</td><td>Raster</td><td>NZ – 12nmi limit at 1km resolution</td><td>Key_ecological_areas.gdb</td><td>Predicted biogenic habitat provision using ecosystem service rule-based mapping following methods described in Townsend et al. (2014).</td><td>Biogenic_Habitat_Provision_12nmi: Predicted biogenic habitat on relative scale from 0 to 14, where 0 is no biogenic habitat provision, and 14 is maximum biogenic habitat provision.</td><td>Stephenson et al. unpublished</td></tr>
<tr><td>Hydrothermal vents.</td><td>Point data</td><td>NZ EEZ</td><td>Vents_data.gdb</td><td>Locations of know hydrothermal vents.</td><td>Vent_InterRidge_in_EEZ: Locations of know hydrothermal vents from the Global Database of Active Submarine Hydrothermal Vent Fields (InterRidge, 2016).</td><td>InterRidge (2016)</td></tr>
<tr><td>Cold seeps.</td><td>Point data</td><td>NZ EEZ</td><td>Key_ecological_areas.gdb</td><td>Locations of methane.</td><td>Cold_Seeps_in_EEZ: Locations of methane seeps resulting from three cruises in 2006-2007 using multibeam backscatter data, water column hydroacoustic and visual data (Greinert et al. 2010).</td><td>Greinert et al. (2010)</td></tr>
<tr><td>Fish spawning grounds.</td><td>Polygons</td><td>NZ EEZ</td><td>FinFishSpawning.gdb</td><td>Annual spawning distribution for 39 species (NABIS, 2012). Annual spawning distribution count (Stephenson et al. unpublished).</td><td>Polygon files: ANC, BAR, BAS… etc: Individual annual spawning distribution for 39 species (see table “” for species in folder “TABLES_and_INFO_GISfiles” for information on the 3 letter codes, e.g., ANC = *Engraulis australis* (White 1790) (Anchovy) – the layers are a scientific interpretation of data and are considered accurate to ±15%.

FINAL SPAWNING_OVERLAP: Annual spawning distribution count

Species:
<table>
<tr><td>Anchovy</td><td>John Dory</td></tr>
<tr><td>Banded Giant Stargazer</td><td>Kahawai</td></tr>
<tr><td>Barracouta</td><td>Ling</td></tr>
<tr><td>Bass</td><td>Murphy's Mackerel</td></tr>
<tr><td>Black Cardinal Fish</td><td>Orange Roughy</td></tr>
<tr><td>Blue Mackerel</td><td>Porbeagle Shark</td></tr>
<tr><td>Blue Moki</td><td>Red Cod</td></tr>
<tr><td>Blue Shark</td><td>Red Gurnard</td></tr>
<tr><td>Blue Warehou</td><td>Ribaldo</td></tr>
<tr><td>Butterfish</td><td>Rig</td></tr>
<tr><td>Elephant Fish</td><td>Sea Perch</td></tr>
<tr><td>Frostfish</td><td>Silver Warehou</td></tr>
<tr><td>Gemfish</td><td>Snapper</td></tr>
<tr><td>Giant Stargazer</td><td>Southern Blue Whiting</td></tr>
<tr><td>Golden Mackerel</td><td>Spotted Black Grouper</td></tr>
<tr><td>Hake</td><td>Sprats</td></tr>
</table></td><td>NABIS (2012)

Stephenson et al. (unpublished)</td></tr>
</table>

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
					Hapuku Hoki Horse Mackerel Tarakihi Trevally White Warehou Yellow Belly Flounder	
Seal colonies and haul outs.	Polygons	NZ EEZ	Seal_colonies_ haulouts.gdb	Location of seal colonies and haul-outs.	MarineMammalBreedingSites: Locations of seal breeding colonies and haul-outs (New Zealand fur seals, *Arctocephalus forsteri*, New Zealand Hookers sealion, *Phocarctos hookeri* and the southern elephant seal, *Mirounga leonina*) from NABIS (2012) . Metadata for the NABIS layers are available at: https://mpi.maps.arcgis.com/home/item.html?id=3c2d8f9b44ad42f7883371394750de4a https://mpi.maps.arcgis.com/home/item.html?id=9d9dc5243834425c9ad2aa249b06e1f7 https://mpi.maps.arcgis.com/home/item.html?id=ddd6adcc2d144a588e8f33a82ee1cfaf New_Seal_haulouts: name and GPS location of recently confirmed seal haulouts (DOC unpublished, 2018). New_Seal_Colonies: name and GPS location of recently confirmed seal Colonies (DOC unpublished, 2018).	NABIS (2012) DOC (unpublished)
Bird feeding and breeding grounds.	Polygons	NZ EEZ	NZ_IBA.gdb	Location of Important Bird Areas (IBA) (Forest & Bird, 2014).	NZ_BC: Bird colony locations (point data). NZ_IBAs: Proposed seaward extension IBA. **Forest and Bird recommended to only use the shapefiles for spatial representation** - the tabular data in the attribute table is not necessarily up-to-date. The 'SitRecID' field in the shapefiles should be used to match up individual IBA records between the shapefile and the spreadsheets (in the folder TABLES_and_INFO_GISfiles). Details of each IBA are in 'NZ_IBAs_sites_details.csv' (folder TABLES_and_INFO_GISfiles). Details of the population numbers within each IBA have been split into two files: - Confirmed: These are population numbers for the IBA trigger species that have been confirmed by the BirdLife	Forest & Bird (2014)

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
					Secretariat as triggering the IBA. These details are in 'NZ_IBAs_species_criteria_confirmed.csv'. - Unconfirmed: These are population numbers that were also supplied with the IBA, but have not been confirmed. This may be because they do not meet global IBA criteria, or because more data are required to confirm them. These population numbers are supplied for completeness, but with the proviso that they are not confirmed as IBA trigger species. These details are in 'NZ_IBAs_species_criteria_unconfirmed.csv'.	
Inshore and offshore Productivity.	Raster data	NZ EEZ at 500m^2 - 4km^2 resolution	Primary_productivity.gdb	Water column productivity measured by Chlorophyll a concentrations (mg/m^3) estimated from remotely sensed Sea-Viewing Wide-Field-of-view Sensor (SeaWIFS) satellite imagery (M. Pinkerton, NIWA, pers. Comm.)	CHL_4km: Water column productivity measured by Chlorophyll a concentrations (mg m^{-3}) for offshore areas (NZ EEZ wide excluding depths < 50m) estimated from remotely sensed Sea-Viewing Wide-Field-of-view Sensor (SeaWIFS) satellite imagery (M. Pinkerton, NIWA, pers. Comm.) CHL_500m: Water column productivity measured by Chlorophyll a concentrations (mg m^{-3}) for inshore areas (limited to inshore water depths) estimated from long-term (2002 – 2007) MODIS-Aqua average values at 500 m resolution.	M. Pinkerton, NIWA, unpublished
Bottom fishing footprint.	Polygons	NZ EEZ	Fishing_footprint.gdb	Trawl footprint (swept area), targeting deepwater Tier 1 and Tier 2 fishstocks from the 1990 to 2016 (offshore) (Baird and Wood, 2018) and area swept by the trawl gear in New Zealand waters shallower than 250 m (inshore) (Baird et al. 2015).	**Offshore/deepwater bottom trawl fishing effort**: all files labelled "t12_xxxx" where xxxx represents the corresponding fishing year (1990 – 2016). The swept area (footprint) of trawling is shown as number of tows per km in the attribute table field "sqkm". **Inshore/shallow water bottom trawl fishing effort:** all files labelled "All_xxxx" where xxxx represents the corresponding fishing year (2008 - 2012). The swept area (footprint) of trawling is shown as number of tows per km in the attribute table field "sqkm". There is some overlap between these fishgig footprints, but it would difficult to account for this without the raw data.	Baird and Wood, 2018 Baird et al. 2015
Other trawl/dredge/ recreational footprint.	Raster Polygons	NZ EEZ at 1km^2 resolution	Fishing_footprint.gdb	Heat maps and spatial estimates of commercial fishing (all methods); dredging effort; and recreational fishing (annual estimates provided here for a subset of the data from 2007 - 2016) (Osborne, 2018).	CommercialCatchIntensity_20072016: The relative intensity (low – high) of all commercial fishing intensity. Colour scheme can be found in "Tables_and_INFO_GISFiles" folder in the layer file "CommercialCatchIntensity.lyr"	Osborne, 2018

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
			DredgeEventsByYeatAndStatArea.gdb		AnAvRecVessels: The relative mean fishing intensity (low – high) of all recreational fishing intensity. Colour scheme can be found in “Tables_and_INFO_GISFiles” folder in the layer file “AnAvRecVessels.lyr”. GeneralStatAreas_XXXX_XXXX: Polygons showing the number of fishing events for all dredging activity reported by statistical area for fishing years (2007 – 20019) as indicated by xxxx OysterStatAreas_XXXX_XXXX: Polygons showing the number of fishing events for oyster dredging activity reported by statistical area for fishing years (2007 – 20019) as indicated by xxxx ScallopStatAreas_XXXX_XXXX: Polygons showing the number of fishing events for scallop dredging activity reported by statistical area for fishing years (2007 – 20019) as indicated by xxxx	
Area-based marine protection	Polygons	NZ EEZ	Protected_areas.gdb	Location of protected areas including: Benthic Protected Areas; Seamount Closures; Type II MPAs; Marine Mammal Sanctuaries; Marine reserves.	Benthic_Protected_Areas: The location and extent of Benthic protection areas designated in the TS and EEZ. DOC_Marine_Reserves: location of Type I MPAs (Marine reserves. Seamount_Closures: location of Seamount Closures. DOC_MPAs_TypeII: location of Type II MPAs plus marine mammal sanctuaries.	DOC
Land use layers	Shapefile - raster	NZ land	Land_use_layers.gdb	Land use layers as indication of land-sea connectivity of stressors: includes, Land cover class, protected areas, population mesh grid, river catchments (Lundquist et al. unpublished).	LCBD_v41_LandCoverDatabase: Polygon of landcover classes, (information on classification at https://lris.scinfo.org.nz/layer/48423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/) DOC_Public_conservation_Areas: showing areas (km2) of “ conservation area”, “ Marginal strips”, “National park” and “Reserve” Soil_erosion: raster (1km grid) showing estimated kilotons per year of sediment erosion (kt y^{-1}) https://data.mfe.govt.nz/layer/52832-long-term-soil-erosion-north-island-2012/) Meshblocks_and_pop_2013: showing population from census by polygon blocks.	MfE DOC Stats NZ

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
Depth-related refuge areas	raster	Raster 1km^2 resolution	Key_ecological_areas.gdb	Unfishable depths of the marine environment were defined as deeper than 1600m (NIWA, 2016)	Unfishable_depths: Bathy layer clipped to those areas < 1600m depth, 1km grid resolution bathymetry layer (NIWA, 2016)(available at: https://www.niwa.co.nz/our-science/oceans/bathymetry)	Stephenson et al. (unpublished)
Marine mammal distributions	raster	NZ EEZ	Cetacean_distribution.gdb	Predicted distribution (occurrence) of 33 cetacean species (Stephenson et al. in prep). **FOLDERS AND FILES NOT YET AVAILABLE – EXPECTED RELEASE JAN 2019**	Species_sightings: Species sightings recores for summer, winter, and in total (Breaksown_of_species_models.xslx, in folder TABLES_and_INFO_GISfiles) Presence Relative Absence for 17 species with associated uncertainty for 12 of those. RES for 21 species – data to be provided after submission of the report – example images provided. Environmental coverage.	Stephenson et al. (unpublished) MPI
Demersal fish species turnover and classification	Raster	NZ EEZ to depths of 2500m at 1km^2 resolution.	Demersal_Fish.gdb	Predicted demersal fish species turnover and community assemblages (30; 50; 100 groups) (Stephenson et al. 2018).	Fishgf30: 30 class demersal fish assemblage prediction as described in Stephenson et al. 2018 Fishgf50: 50 class demersal fish assemblage prediction Fishgf100: 100 class demersal fish assemblage Env_coverage: A Bernoulli BRT on the presence/absence of fish records used to investigate the coverage of the environmental space as a measure of spatial uncertainty (i.e., location of where we have good understanding of environmental space and areas with poor coverage). Folder: TABLES_and_INFO_GISfiles FishGF30.lyr: colours used for classification and matching the PCA in Stephenson et al. 2018 FishGF50.lyr: colours used for classification – colours broadly indicate similarity in species assemblages GF30_MEAN.csv: Mean environmental predictor values and species presence (from records within each class) for 30 classes GF30_samp.csv: demersal fish trawl ID number (TRAWL database), environmental predictor value, species presence/absence and GF class for each record overlaid on the 30 class prediction GF50_MEAN.csv: As above but for the 50 class model GF50_samp.csv: As above but for the 50 class model GF100_MEAN.csv: As above but for the 100 class model GF100_samp.csv: As above but for the 100 class model	Stephenson et al. (2018)

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
Demersal fish species richness.	Raster	NZ EEZ to depths of 2500m at 1km^2 resolution	Demersal_Fish.gdb	Predicted demersal fish species richness (Leathwick et al. 2006).	Richness: Prediction of species richness for demersal fish, (resolution 1km) – further details of methods in Leathwick et al. (2006).	Leathwick et al. (2006)
Benthic invertebrate species richness.	Raster	NZ EEZ to depths of 2500m at 1km^2 resolution	Invert.gdb	Predicted benthic invertebrate species richness (Stephenson et al. unpublished – see appendix 7.2 for further details on results and methodology).	Richness_LMG: Invertebrate species richness for gear types LMG Richness_MMG: Invertebrate species richness for gear types MMG Richness_Ensemble: Ensemble species richness for gear types LMG and MMG Richness_95CI_LMG: associated 95% confidence interval for LMG predictions Richness_95CI_MMG: associated 95% confidence interval for MMG predictions Richness_95CI_Ensemble: associated 95% confidence interval for ensemble (LMG & MMG) predictions Invert_EC: Coverage of the environmental space of benthic invertebrate samples	Stephenson et al. (unpublished)
Benthic invertebrate species turnover and classification.	Raster	NZ EEZ to depths of 2500m at 1km^2 resolution	Invert.gdb	Predicted benthic invertebrate species turnover and community assemblages (30; 50; 100 groups) (Stephenson et al. unpublished – see appendix 7.2 for further details on results and methodology).	InvertGF30: 30 class benthic invertebrate assemblage prediction using methods from Stephenson et al. 2018 InvertGF50: 50 class benthic invertebrate assemblage InvertGF100: 100 class benthic invertebrate assemblage InvertGF5: 5 class benthic invertebrate assemblage prediction (indicative of bioregions) Folder: TABLES_and_INFO_GISfiles InvertGF30.lyr: colours used for classification and matching the PCA from the classification analysis InvertGF50.lyr: colours used for classification – colours broadly indicate similarity in species assemblages Invert_GF30_MEAN.csv: Mean environmental predictor values and species presence (from records within each class) for 30 classes Invert_GF30_samp.csv: sample ID number (TRAWL and Specify database), environmental predictor value, species presence/absence and GF class for each record overlaid on the 30 class prediction Invert_GF50_MEAN.csv: As above but for the 50 class model Invert_GF50_samp.csv: As above but for the 50 class model	Stephenson et al. (unpublished)

Data Name	Data format	Extent and resolution	Geodatabase	Summary	Filename (s) and Description (s)	Credits
					Invert_GF100_MEAN.csv: As above but for the 100 class model Invert_GF100_samp.csv: As above but for the 100 class model	
Regional Council identified important areas (e.g., IBAs, ASCVs).	Polygons	Regional	Regional_council_imp_Areas.gdb	Various layers representing important areas identified in regional council plans: Significant Conservation Areas (Canterbury RC); Indigenous Biodiversity (Greater Wellington RC); Significant Conservation Areas (Hawkes Bay RC); Natural Character (Waikato RC & Northland RC); Outstanding Natural Features and Landscapes (Northland RC & Otago RC); Marine Areas of Conservation (Gisborne DC & Northland RC); Coastal Natural Character Rating (Marlborough RC); Threatened Environments (Marlborough RC); Marine Mammal Bird Sites (Otago RC) (REF).	Metadata available for each council layer (in folder: "Metadata): - Regional_Imp_Areas_Metadata - Regional_Imp_Areas_Metadata_table	Regional councils (Canterbury RC, Greater Wellington RC, Hawkes Bay RC, Waikato RC, Northland RC, Otago RC, Gisborne DC, Marlborough RC)
New Zealand naturally uncommon habitats in coastal environment.	Polygons	NZ coast	NaturallyUncommonEcosystems.gdb	Identification and mapping of naturally uncommon habitats in NZ coastal environment (Wiser et al. 2013).	Geophysical_NaturallyUncommonEcosystems: polygon with description of naturally uncommon ecosystems as defined in Wiser et al. 2013.	Wiser et al. (2013)
Seabird Bird distributions.	Raster	NZ EEZ	Folder: SeabirdDistribution	Population and at-sea distributional data for 70 species of seabird (separate maps for the non-breeding and breeding distributions) (REF).	8 Geodatabases are contained within the folder "SeabirdDistribution". Each geodatabase contains annual, breeding and/or nonbreeding at-sea distribution layers for several Seabird species - Albatrosses.gdb - Diving_petrels.gdb - Gulls_terns_skuas_noddies.gdb - Other_seabirds.gdb - Penguins.gdb - Precellariidae_petrels.gdb - Shags.gdb - Storm_petrels.gdb More detailed metadata is provided in the "Seabirds" folder in the "metadata" folder.	BirdLife International and NatureServe (2015)

7.2 Methods: Benthic invertebrate species richness and turnover

7.2.1 Overview

Benthic invertebrate species richness, and the associated uncertainty (5-95% confidence interval) was predicted using bootstrapped Boosted Regression Trees (BRTs) (based on methods by Leathwick et. (2006)). Gradient Forest (GF) models were used to analyse and predict spatial patterns of benthic invertebrate species turnover (beta diversity) and assemblages (5;30;50;100 class groups) (based on methods by Pitcher et al. (2012);Stephenson et al. (2018)).

7.2.2 Biological data

Benthic invertebrate records (including GPS location, species name, collection date, and sampling gear used) were extracted from NIWA invertebrates (sample years: 1919 – 2015) and TRAWL databases (sample years: 1961 – 2015). Only records identified to species level were retained resulting in 28,017 NIWA invertebrates records and 44,002 TRAWL records.

Sampling of benthic invertebrates is highly dependent on gear selectivity. 123 different gear types were listed across all records. Many of these gear types were name variants of commonly used sampling gear types, however, for many records, the specific sampling parameters (e.g., mesh size, tow length, etc.,) were not recorded. In order to account for both the large number of gear types recorded and the differences in sampling parameters, gear types were grouped into categories to reflect 'catchability' of benthic invertebrates. Catchability was assumed to be influenced by gear size, deployment area and selectivity (Table 7-1).

Table 7-1: Categories used to reflect catchability of sampling gear types.

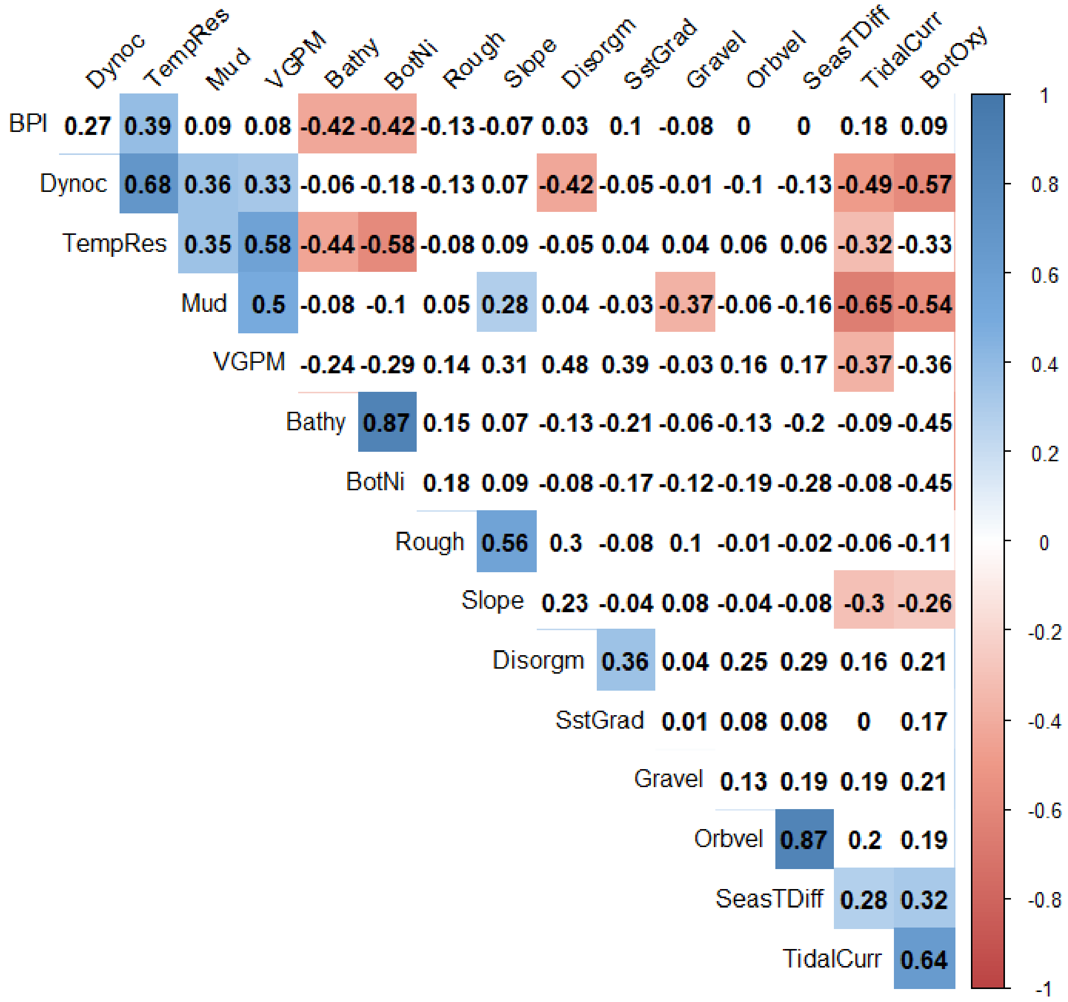
Type	Category	Description	Example
Gear size	Small	< 1m	Devonport dredge
	Medium	1-3m	Benthic sled
	Large	> 3m	Otter trawls
Deployment area	Small	< 1m	Box corer
	Medium	10 s – 100 s m	Beam trawls
	Large	> 1 km	Otter trawls
Selectivity	HS	Highly selective	Collected by hand
	G	General	Benthic sled

Sampling gear types were assigned codes for each of the three catchability types described in Table 7-1. Out of a possible 18 'catchability' groups, six 'catchability' groups were found in the samples used here: Large gear types, deployed over large areas, which were not selective (e.g., otter trawls, code: LLG); Large gear types, deployed over medium-sized areas, which were not selective (e.g., beam trawls, LMG); Medium sized gear types, deployed over medium sized areas, which were not selective (e.g., benthic sled, MMG); Small gear types, deployed over medium sized areas, which were not selective (e.g., Devonport dredge, SMG); Small gear types, deployed over medium sized areas, which were highly selective (e.g., collected by hand, bottom longline, SMHS); Small gear types, deployed over small areas, which were not selective (e.g., box corer, SSG).

Records, grouped by catchability, were imported to Esri ArcGIS (v10.6) where duplicate samples were removed and aggregated to a 1km^2 grid resolution (e.g., several records, from different sampling events could be grouped to better reflect the total benthic invertebrate diversity for a given 1km^2 cell). Finally, samples were clipped to the New Zealand EEZ and any clearly erroneous locations removed (e.g., points on land).

7.2.3 Environmental data

To capture variability in the marine environments surrounding New Zealand, fifteen high resolution gridded environmental predictors, were collated and imported into ArcGIS (v 10.6). Variables were selected based on their known influence on benthic invertebrate settlement, growth, survival and distribution, and therefore their likely influence on benthic invertebrate species richness, assemblage composition and turnover (Table 7-2). Several predictors showed some co-linearity (Figure), e.g., between depth and sea floor Nitrogen saturation (Pearson correlation of 0.87), however, these levels of co-linearity were considered acceptable for BRT modelling (Elith et al. 2010;Dormann et al. 2013) and GF modelling (Ellis et al. 2012).



	Dynoc	TempRes	Mud	VGPM	Bathy	BotNi	Rough	Slope	Disorgm	SstGrad	Gravel	Orbvel	SeasTDiff	TidalCurr	BotOxy
BPI	0.27	0.39	0.09	0.08	-0.42	-0.42	-0.13	-0.07	0.03	0.1	-0.08	0	0	0.18	0.09
Dynoc		0.68	0.36	0.33	-0.06	-0.18	-0.13	0.07	-0.42	-0.05	-0.01	-0.1	-0.13	-0.49	-0.57
TempRes			0.35	0.58	-0.44	-0.58	-0.08	0.09	-0.05	0.04	0.04	0.06	0.06	-0.32	-0.33
Mud				0.5	-0.08	-0.1	0.05	0.28	0.04	-0.03	-0.37	-0.06	-0.16	-0.65	-0.54
VGPM					-0.24	-0.29	0.14	0.31	0.48	0.39	-0.03	0.16	0.17	-0.37	-0.36
Bathy						0.87	0.15	0.07	-0.13	-0.21	-0.06	-0.13	-0.2	-0.09	-0.45
BotNi							0.18	0.09	-0.08	-0.17	-0.12	-0.19	-0.28	-0.08	-0.45
Rough								0.56	0.3	-0.08	0.1	-0.01	-0.02	-0.06	-0.11
Slope									0.23	-0.04	0.08	-0.04	-0.08	-0.3	-0.26
Disorgm										0.36	0.04	0.25	0.29	0.16	0.21
SstGrad											0.01	0.08	0.08	0	0.17
Gravel												0.13	0.19	0.19	0.21
Orbvel													0.87	0.2	0.19
SeasTDiff														0.28	0.32
TidalCurr															0.64

Figure 7-1: Correlation matrix of environmental predictors (Pearson correlation). Non-significant correlations are 5 shown in white.

Table 7-2: Environmental variables used as predictors in the Boosted Regression Tree and Gradient Forest analyses.

Abbreviation	Full name	Description	Original Resolution	Units	Source
Bathy	Bathymetry	Depth at the seafloor was interpolated from contours generated from various sources, including multi-beam and single-beam echo sounders, satellite gravimetric inversion, and others (Mitchell et al. 2012).	250m	m	CANZ (2008)
Beddist	Benthic sediment disturbance	Combination of seabed orbital velocities (estimates the average mixing at the seafloor as a consequence of orbital wave action, calculated from a wave climatology derived hindcast (1979 to 1998) of swell-wave conditions in the New Zealand (NZ) region (Gorman et al. 2003)) and friction velocity for seabed types (based on grain size). Benthic sediment disturbance from wave action was assumed to be zero where depth ≥ 200m.	1km	unitless	NIWA, unpublished
BotNi	Bottom nitrate	Annual average water nitrate concentration at the seafloor (using NZ bathymetry layer) based on methods from Ridgway et al. (2002). Oceanographic data from CARS2009 (2009).	250m	umol l^{-1}	NIWA, unpublished
BotOxy	Dissolved oxygen at depth	Annual average water dissolved oxygen concentration at the seafloor (using NZ bathymetry layer) based on methods from Ridgway et al. (2002). Oceanographic data from CARS2009 (2009).	250m	ml l^{-1}	NIWA, unpublished
Disorgm	Coloured dissolved organic matter (CDOM)	Indicative of Coloured dissolved organic matter (CDOM) absorption at 440 nm. Based on SeaWiFS ocean colour remote sensing data; modified Case 2 atmospheric correction; modified Case 2 inherent optical property algorithm(Pinkerton et al. 2005).	4 km	Indicative of CDOM absorption at 440 nm $a_g(440)$ (m^{-1})	Pinkerton (2016)
Dynoc	Dynamic oceanography	Mean of the 1993-1999 period sea surface above geoid, corrected from geophysical effects taken for the NZ region. This broadly corresponds to mean surface velocity recorded from drifters in the NZ region (Hadfield pers comm).	0.25 deg	na	AVISO
Roughness	Roughness	Roughness of the seafloor calculated as the standard deviation of depths in a surrounding 3 x 3 km neighbourhood (Leathwick et al. 2012).	250m	unitless	Leathwick et al. (2012) NIWA, unpublished data

Abbreviation	**Full name**	**Description**	**Original Resolution**	**Units**	**Source**
SeasTDiff	Annual amplitude of sea floor temperature	Smoothed difference in seafloor temperature between the three warmest and coldest months. Providing a measure of temperature amplitude through the year.	250m	°C km^{-1}	NIWA, unpublished data
SstGrad	Sea surface temperature gradient	Smoothed magnitude of the spatial gradient of annual mean SST. This indicates locations in which frontal mixing of different water bodies is occurring (Leathwick et al. 2006). Derived from Sea-Viewing Wide-Field-of-view Sensor (SeaWIFS) satellite imagery (Pinkerton et al. 2005).	1km	°C km^{-1}	Pinkerton et al. (2005)
TidalCurr	Tidal current speed	Maximum depth-averaged (NZ bathymetry) flows from tidal currents calculated from a tidal model for New Zealand waters (Walters et al. 2001)	250m	$m\ s^{-1}$	NIWA, unpublished data
VGPM	Productivity Model	Provides estimates of surface water primary productivity based on the Vertically generalized productivity model of Behrenfeld and Falkowski (1997). Net primary productivity by phytoplankton (mean daily rate of water column carbon fixation) is estimated as a function of remotely sensed chlorophyll concentration, irradiance, and photosynthetic efficiency estimated from remotely sensed Sea-Viewing Wide-Field-of-view Sensor (SeaWIFS) satellite imagery (M. Pinkerton, NIWA, pers. Comm.)	9km	$mgC\ m^{-2}\ d^{-1}$	NIWA, unpublished
Slope	Slope	Terrain metrics were calculated using a 5-cell window size (5km) using the NIWA bathymetry layer in the Benthic Terrain Modeler in ArcGIS 10.3.1.1 (Wright et al. 2012)	1km	Degrees	NIWA, unpublished
BPI	Bathymetric Position Index – Broad	Terrain metrics were calculated using a 5-cell window size (5km) using the NIWA bathymetry layer in the Benthic Terrain Modeler in ArcGIS 10.3.1.1 (Wright et al. 2012)	1km	Na	NIWA, unpublished
Mud	Percent mud	The percent mud layers for the region were developed from >30,000 raw sediment sample data compiled in dbseabed (Jenkins et al. 1997), which were then imported into ArcGIS and interpolated using Inverse Distance Weighting (Bostock, pers comm)	1km	%	NIWA, unpublished

Abbreviation	Full name	Description	Original Resolution	Units	Source
Gravel	Percent gravel	The percent gravel layers for the region were developed from >30,000 raw sediment sample data compiled in dbseabed (Jenkins et al. 1997), which were then imported into ArcGIS and interpolated using Inverse Distance Weighting (Bostock, pers comm)	1km	%	NIWA, unpublished

7.2.4 Model fitting and evaluation

Species richness

Species richness (number of species per 1km^2 gird cell) was calculated in R. Changes in species richness over time was investigated to ensure that temporal change was not a confounding variable in the species richness distribution mapping.

Large changes in species richness were found over time and gear categories, in particular for L_M_G and M_M_G gear categories (Figure 7-2). Various years were investigated as a cut-off point (1960; 1980; 1995;2000;2005) which aimed to minimise the changes in species richness over time, whilst still retaining adequate sample number to run robust models.

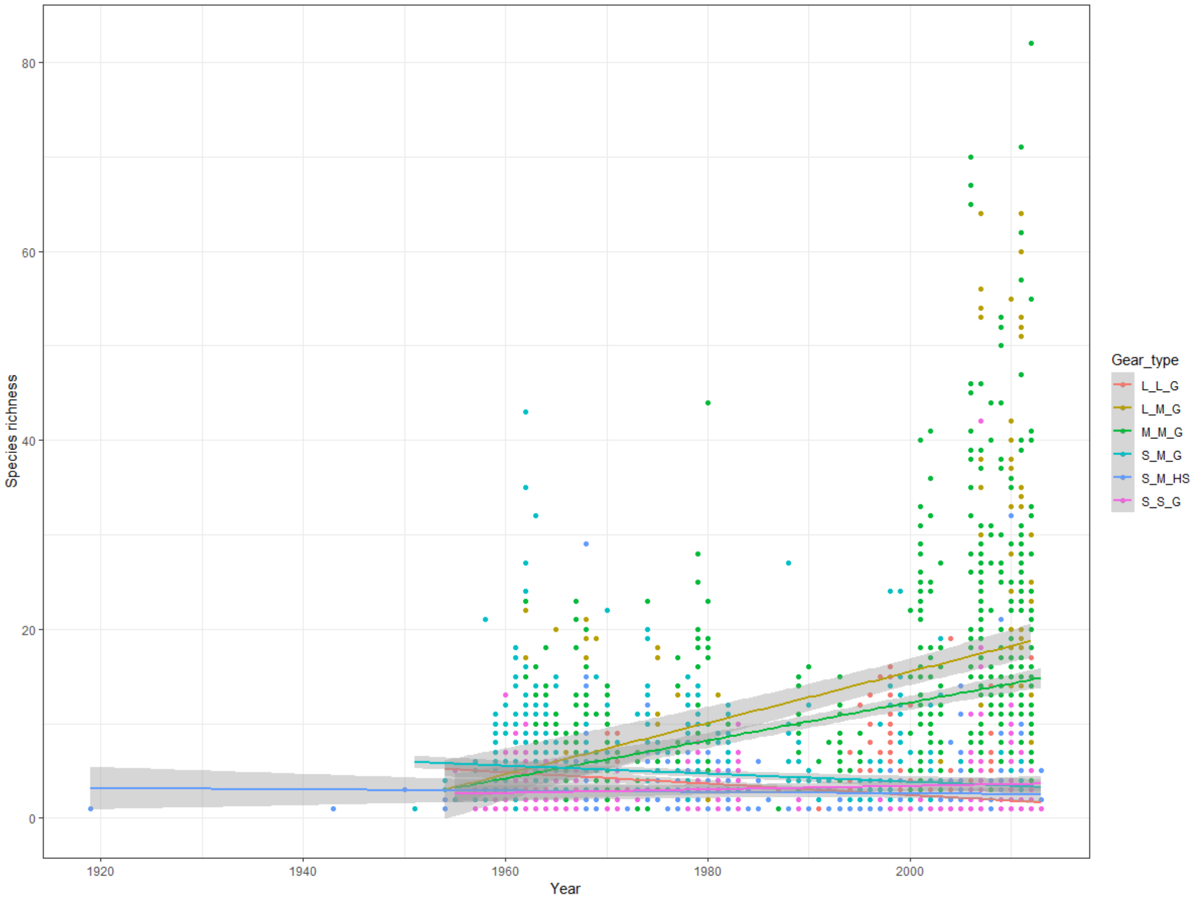


Figure 7-2: Species richness over time (years 1919 – 2015) for 6 gear categories.

Records from 1980-2015 provided the best compromise with relatively flat trends in species richness over time and adequate sample number: 3760 species from 21457 locations. Some gears were excluded (large gear types, deployed over large areas, which were not selective, e.g., otter trawls, and small gear types, deployed over medium sized areas, which were highly selective, e.g., bottom longline) as species would have been caught by chance and did not accurately represent invertebrate benthic diversity. Records > 20 samples across the study area from 1980 – 2015 from 4 categories of gear types were retained for the final analyses (2449 records across 2023 locations) (Figure 7-3).

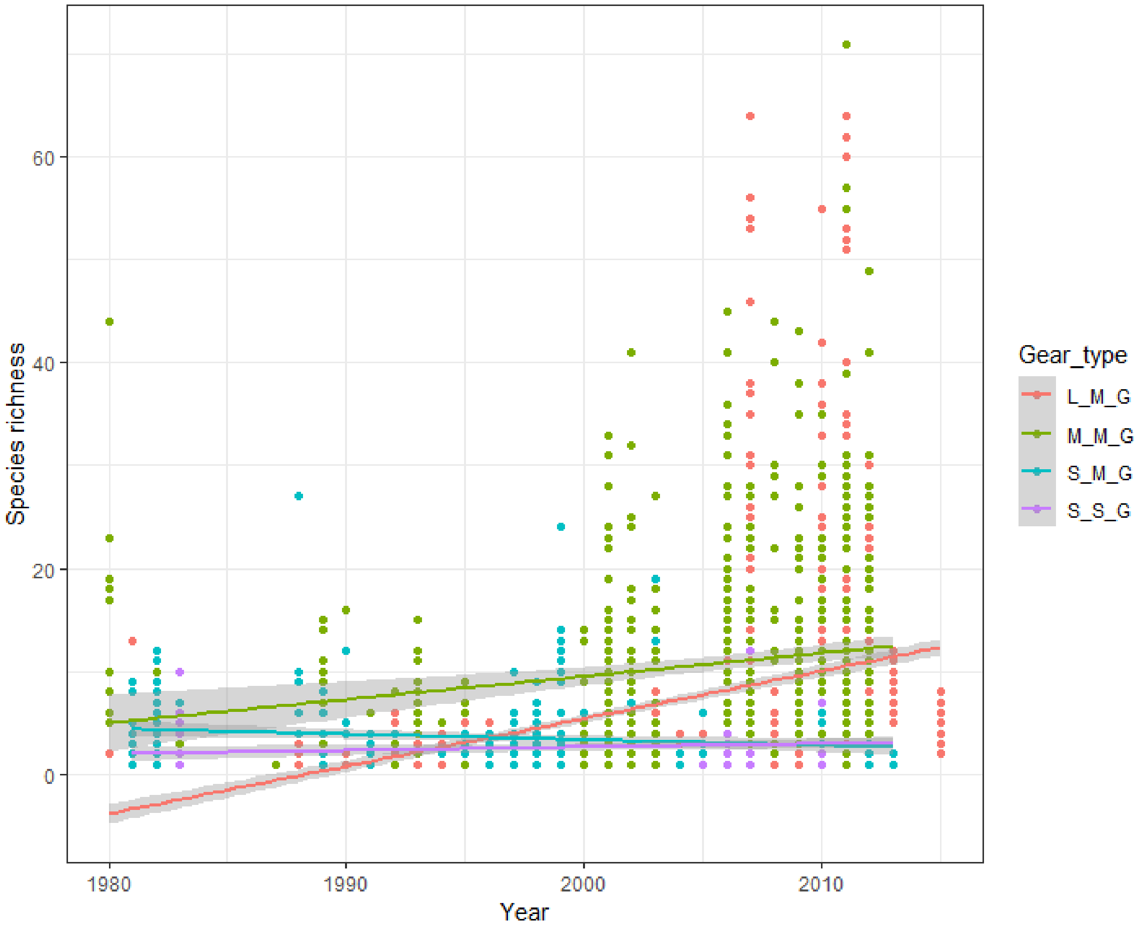


Figure 7-3: Species richness over time (years 1980 – 2015) for 4 gear categories (final records used for all analyses).

Relationships between benthic invertebrate species richness, 15 environmental predictors and gear catchability category (4 level factor) was investigated using BRTs fitted with a Poisson error distribution, a tree complexity of 5, a learning rate of 0.01 (to fit between 1000 and 3000 trees for each model), a bag fraction of 0.7 and 10-fold cross validation using the R package dismo (Hijmans et al. 2017). The 'simplify' function was used to reduce the number of environmental predictors used in the analysis and therefore produce a more parsimonious model that was less likely to be overfitted (Elith et al. 2006).

Models were bootstrapped 200 times (75% of the data used for training and 25% for evaluation). Models were predicted geographically (1km^2 grid cells) for two gear types: LLG and MMG. Mean predicted species richness distributions and 95% confidence intervals were calculated. Mean geographical predictions for both gear types were calculated to represent an ensemble model. Geographic predictions were limited to water depths of 2500m; including deeper regions would have been desirable, but benthic invertebrate samples from sites deeper than 2500m were limited.

Coverage of the environmental space

As an added measure of uncertainty 'coverage of the environmental space by samples' was estimated (Smith et al. 2013). The 'environmental space' is the multidimensional space when each variable is treated as a dimension. The species location data can be projected into this space, where some parts of this environmental space will contain many samples (and are therefore well covered by the biological data) and other parts of this environmental space will contain few samples (and therefore the relationship between the environment and the biological samples are poorly understood resulting in potentially less certain predictions).

The degree to which the environmental conditions of each predictive site was covered by the samples was quantified by randomly sampling 20 000 values from the environmental space and assigning a value of 0 to these, indicating that these were ‘false’ sample sites. These were combined with the true samples, to which a value of 1 was assigned. A BRT model was then used to model the relationship between false (random) samples and true samples for the 15 environmental predictors, using a Bernoulli error distribution. Predictions using this model yielded estimates of the probability of a site occurring in each part of the environmental space. A learning rate that yielded 2000 trees with an interaction depth of 2 was used (so that only pair-wise combinations of the environmental variables were regarded). Predictions were then made spatially, generating values between 0 and 1 (where 0 indicated little understanding of the environmental space and 1 a perfect understanding), according to how well each cell was represented by the samples.

Species turnover and classification

Species turnover was predicted, using the R package “GradientForest” (Ellis et al. 2012), separately for the two sampling gear categories with the largest number of samples: 190 species at 659 unique locations from large gear types with moderate sample areas (LMG); 115 species at 1064 unique locations from medium sized gear types with moderate sample areas (MMG). Species turnover was then combined (using the combineGF function in the R package “GradientForest), which was then classified to produce 5, 30, 50 and 100 spatial groups (inferred benthic invertebrate species assemblages) using the same methods as described in Stephenson et al. (2018).

7.2.5 Results

Benthic invertebrate species richness

The mean deviance explained by the model was relatively high at 0.45 and the mean explained deviance of the withheld dataset was nearly identical (0.45) providing evidence that the models were not overfitted (Table 7-3). There was a reasonable correlation between observed and expected species richness when comparing the predicted values of the evaluation dataset with observed values (mean correlation 0.58) (Table 7-3).

Table 7-3: Model performance statistics from 200 bootstrap BRT model runs. Mean, coefficient off variation (CV = standard deviation/ mean), and standard deviation of: deviance explained by the model using training data (internal deviance); mean deviance explained by the model using the withheld evaluation data (external deviance) and the mean correlation between expected (predicted) and observed values of the evaluation data (E/O correlation).

	Internal deviance	External deviance	O/E correlation
Mean	0.45	0.45	0.58
CV	0.06	0.10	0.08
Std Dev	0.02	0.05	0.04508342

Partial dependence plots show the marginal effect of each predictor variable on the species richness, after accounting for all the other predictor variables in the model (Elith et al. 2006) where a fitted value of 0 (the y-axis on the plots in fig x) is interpreted as having no influence, with positive and negative values representing positive and negative responses of the dependant variable. The partial dependence plots highlighted that gear type was the most influential predictor of species richness (explaining 18.3% of the variability explained by the model) with the highest species richness (unsurprisingly) predicted to occur from gear types classified as MMG (e.g., benthic sleds).

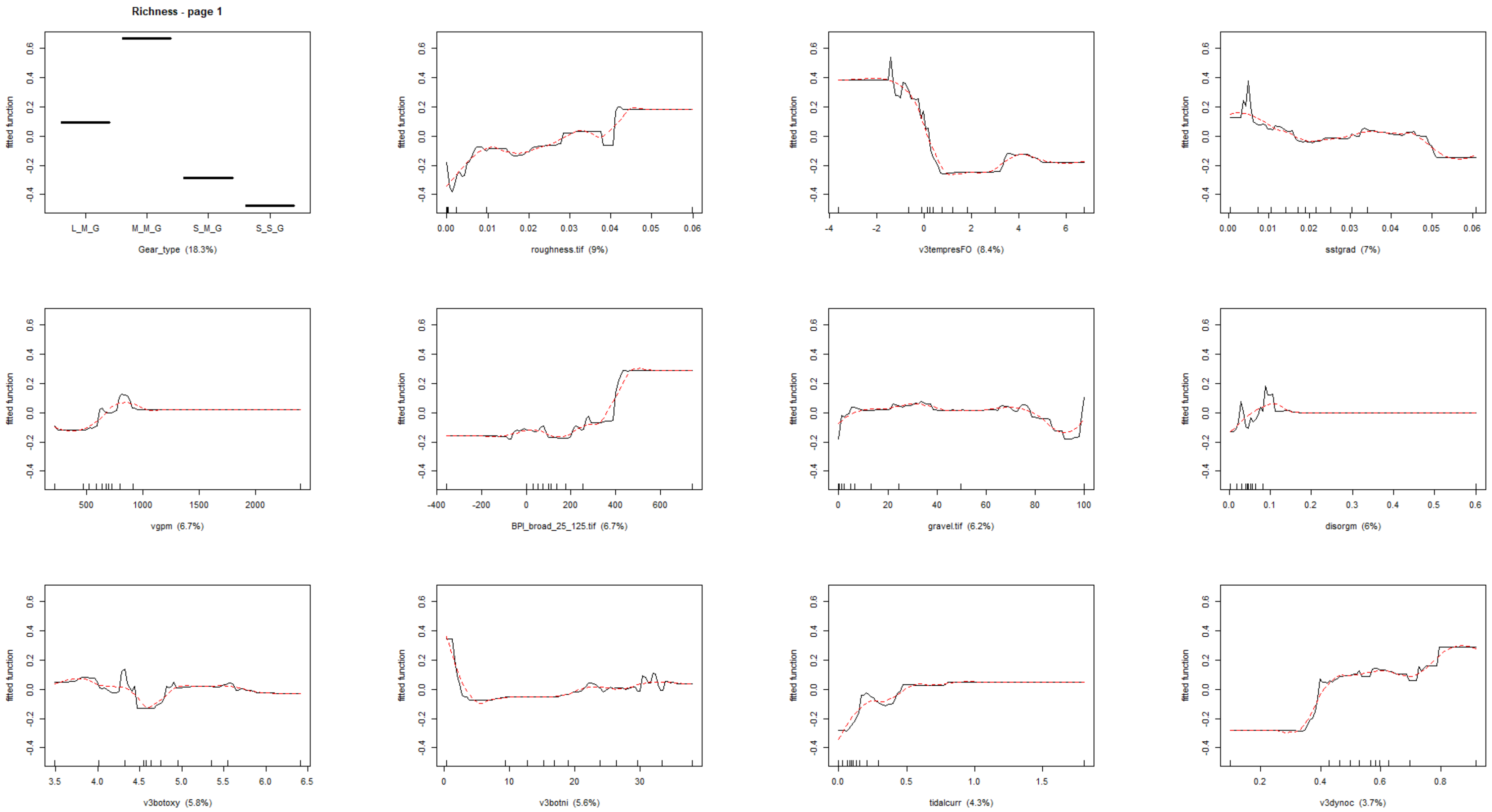


Figure 7-4: Partial dependence plots for benthic invertebrate species richness BRT models.

Ensemble geographical predictions of benthic invertebrate species richness and 95% confidence intervals are shown in Figure 7-5. Areas of high species richness are concentrated on the east coast of the South Island and the north-west of the Campbell plateau. Overall, the values for the 95% confidence layer are very low across the whole of the study area, however, the limited number of spatially clustered records means caution should be used when interpreting both the predicted species richness and the uncertainty for those areas which were not well sampled (see section 5.2 - Coverage of the environmental space for further detail).

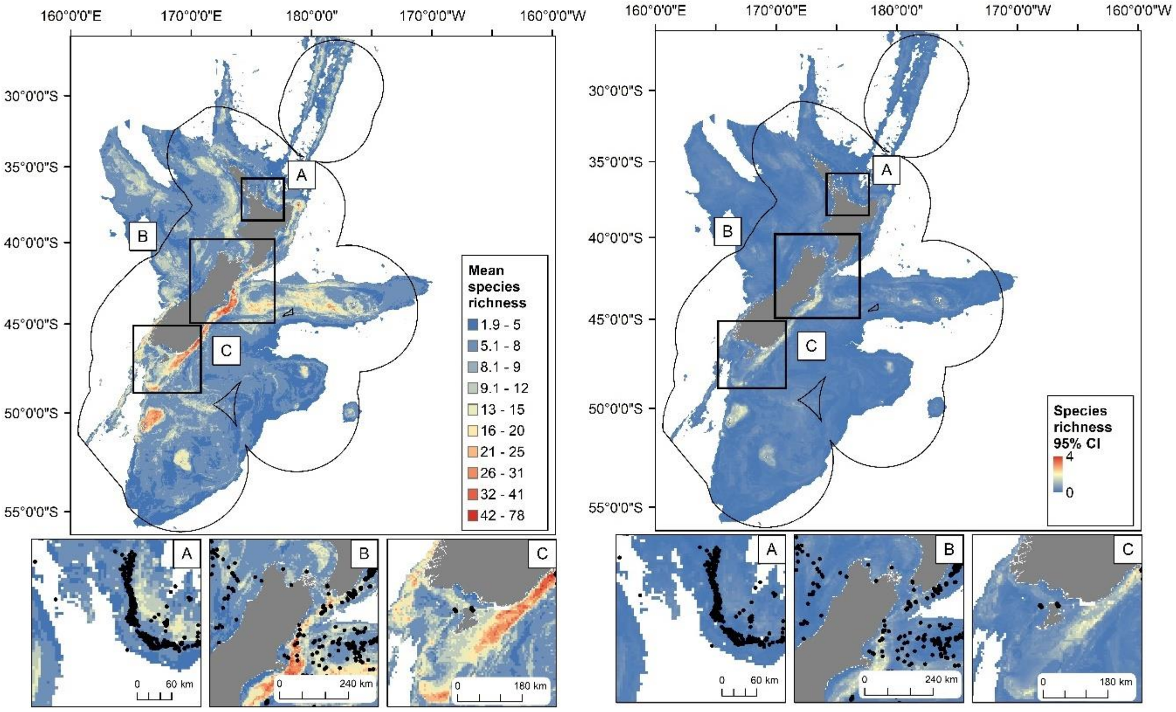


Figure 7-5: Mean ensemble geographical predictions of benthic invertebrate species richness (left) and 95% confidence intervals (right) from bootstrapped BRT models to depths of 2500m. Inset maps, with location of records (black dots): A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Coverage of the environmental space

Modelling of the coverage of the environmental space produced a spatially explicit layer indicating the areas where predictions were extrapolated beyond the environmental characteristics of the input data (Figure 7-6, environmental coverage = 0). Poorly covered areas included: the Hauraki Gulf, the inshore west coasts of the North Island to the Taranaki bight, Tasman and Golden Bays and the north-west of the South Island, deeper water north of the Challenger plateau and most of the Campbell and Bounty Plateaus. Areas where coverage was good included: the rest of north-eastern North Island, East Cape, the Chatham Rise and Challenger Plateau (Figure 7-6). Examining the coverage of the environmental space is particularly useful because BRT predictions are not extrapolated into unsampled areas (i.e., the predicted values shown will simply be those of the closest environmental space). In addition, the confidence estimates remain low for these poorly sampled areas because the bootstrapping requires variability between samples to estimate prediction error. Predictions of benthic invertebrate species richness with environmental coverage values of 0 should be treated with caution.

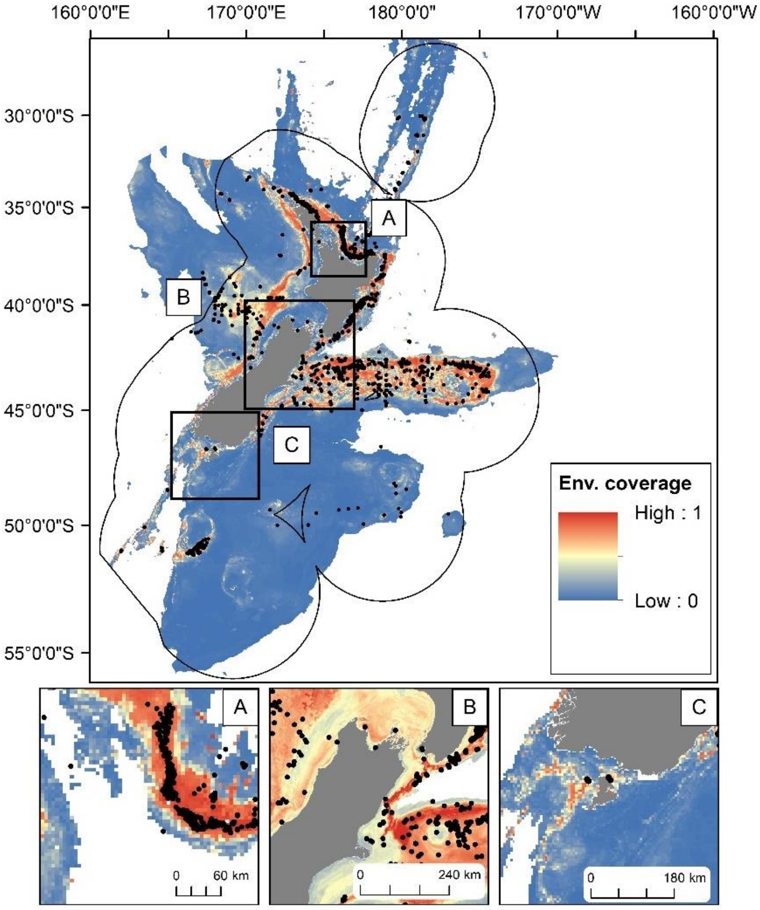


Figure 7-6: Predicted coverage of the environmental space (relative scale 0 – 1, where 0 indicated little understanding of the environmental space and 1 a good understanding). Inset maps, with location of records (black dots): A) Hauraki Gulf; B) south of the North Island and north of the South Island; C) south of the South Island.

Benthic invertebrate species turnover

Large gear types, sampling over medium-sized areas which were not selective (LMG).

The GF model for LMG sampling gear category was fitted using 1064 observations. All available species (n = 115) had an R_2f greater than zero in this model (i.e., all models had at least some predictive power). Species performance in this model (R_2f) averaged 0.5, with a range from 0.27 (*Phylladiorhynchus pusillus* – species of squat lobster) to 0.91 (*Metanephrops challengeri* – pink lobster).

Environmental transformations from the final GF model, constructed using the split information contained in the individual species models, indicate both the overall influence of each environmental predictor and the cumulative changes in species turnover along its range (Figure 7-7), while the ranges of the fitted functions indicate the relative amounts of species turnover associated with each predictor (Stephenson et al. 2018). Steep parts of the curve indicate fast assemblage turnover, and flatter parts of the curve indicate more homogenous regions (Ellis et al. 2012;Pitcher et al. 2012). Greatest species turnover was associated with the predictor describing dissolved oxygen concentrations at depth (*BotOxy*) (maximum cumulative importance: 0.06), followed closely by water depth (*Bathy*), a measure of productivity - VGPM (*VGPM*), and dissolved organic matter (*Disorgm*), with maximum values ca. 0.05 (Figure 7-7). Turnover in relation to other environmental predictors was generally lower (ranging from 0.005 – 0.04). Inspection of the fitted functions for these predictors indicate that most showed a levelling off in species turnover at higher values, e.g., at depths > 1500 m, tidal current speeds > 1.0 m s^{-1}, and dissolved organic matter > 0.12 mgC m^{-2} d^{-1} (Figure 7-7).

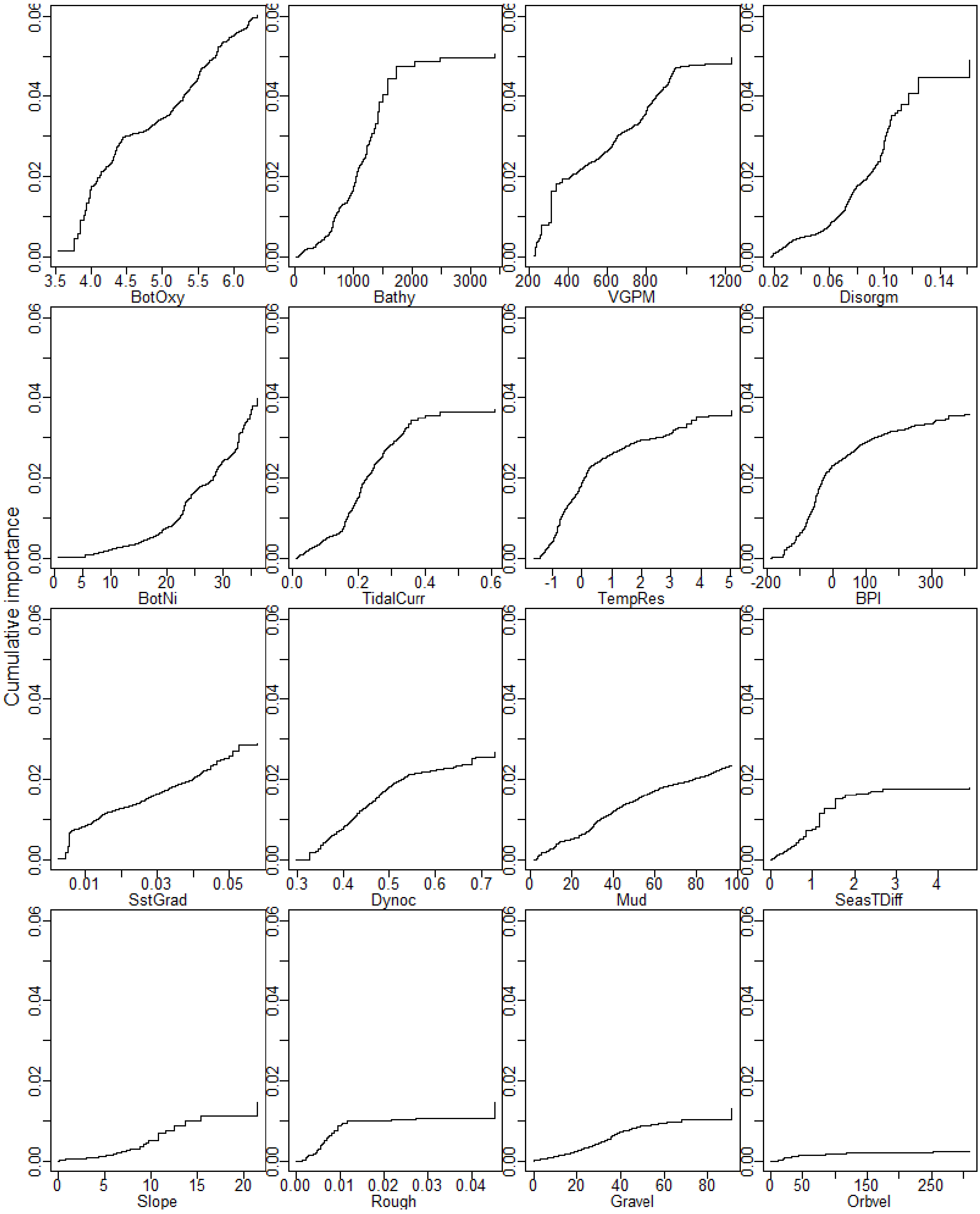


Figure 7-7: Functions fitted by the final GF model for sampling gear category LMG using 1064 observations, indicating relative species turnover along the range of each predictor.

Species turnover functions produced by the GF model were used to create a transformed set of environmental predictor layers (using the predict function (Pitcher et al. 2011)), with values in these layers representing species turnover along the range of each environmental predictor (Figure 7-8).

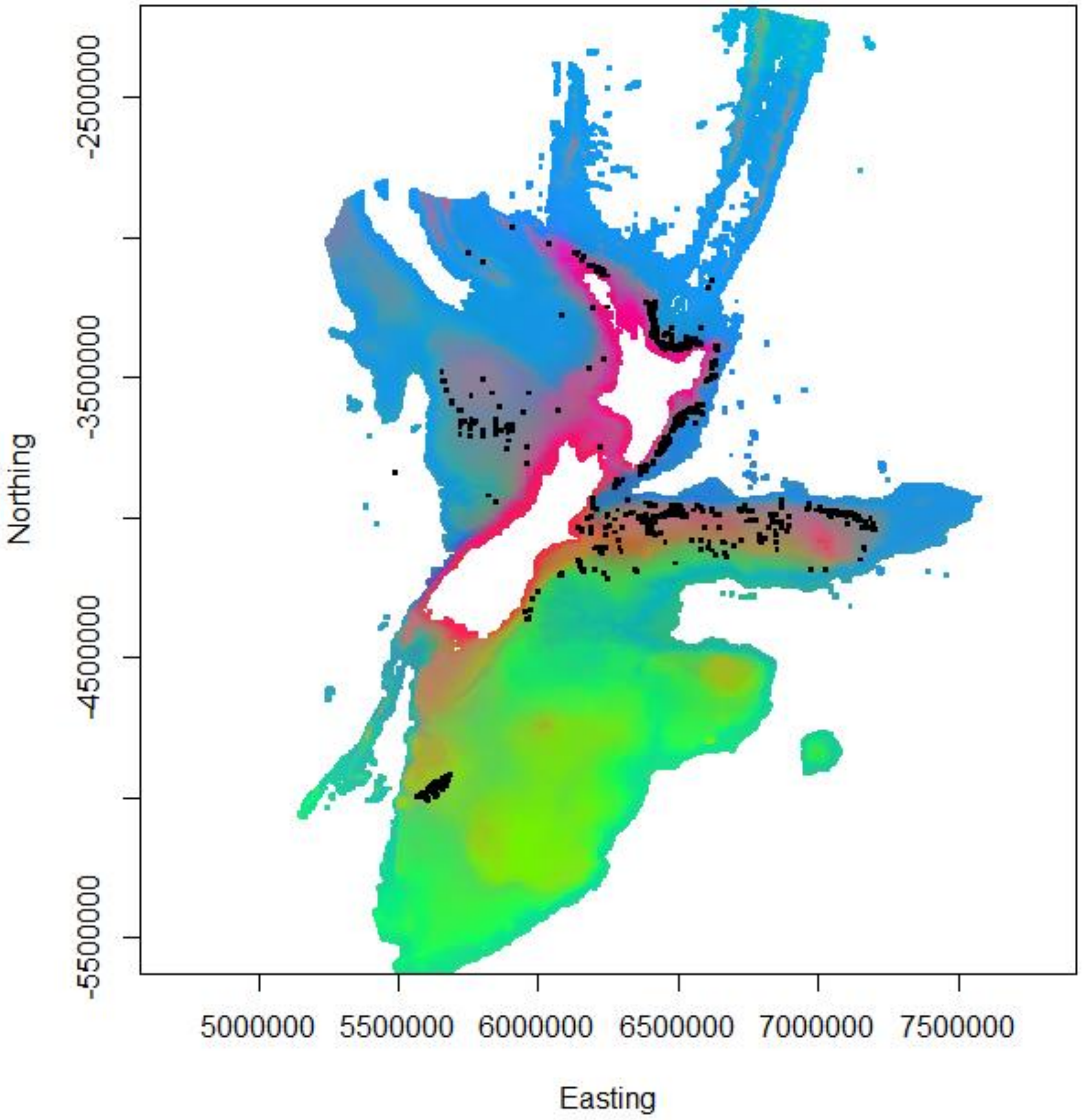


Figure 7-8: Distributions in geographic space of transformed environmental layers derived from a Gradient Forest model fitted to 1064 samples collected with gear type LMG (black squares) for the seas within the New Zealand Extended Continental Shelf to a depth of 2500 m; Colours are based on the first three axes of a PCA analysis so that similarities/differences in colour correspond broadly to intergroup similarities/differences with respect to the transformed environmental variables**.**

Medium-sized gear types, with medium-sized sample areas which were not selective (MMG).

The GF model for MMG sampling gear category was fitted using 659 observations. All available species (*n* = 190) had an R_2f greater than zero in this model (i.e., all models had at least some predictive power). Species performance in this model (R_2f) has slightly lower R_2f than that fitted for LMG sampling gears, with and R_2f of 0.46, and ranging from 0.26 (*Bathymophila alabida* – species of marine gastropod mollusk) to 0.8 (*Goniocidaris florigera* – species of sea urchin).

Greatest species turnover was associated with the predictors describing tidal current (*TidalCurr*) and dynamic oceanography (Dynoc) (maximum cumulative importance: 0.05), followed by water depth (*Bathy*), and two predictors describing seafloor characteristics, Bathymetric Position Index – Broad (*BPI*), and seafloor roughness (*Rough*) with maximum values ca. 0.035 (Figure 7-9). Turnover in relation to other environmental predictors was generally lower (ranging from 0.01 – 0.03). Inspection of the fitted functions for these predictors indicate that some had broadly linear relationships with species turnover were as others showed a levelling off in species turnover at higher values, e.g., tidal current speeds > 0.8 $m\ s^{-1}$, depths > 1500 m, and dissolved organic matter > 0.15 $mgC\ m^{-2}\ d^{-1}$ (Figure 7-9).

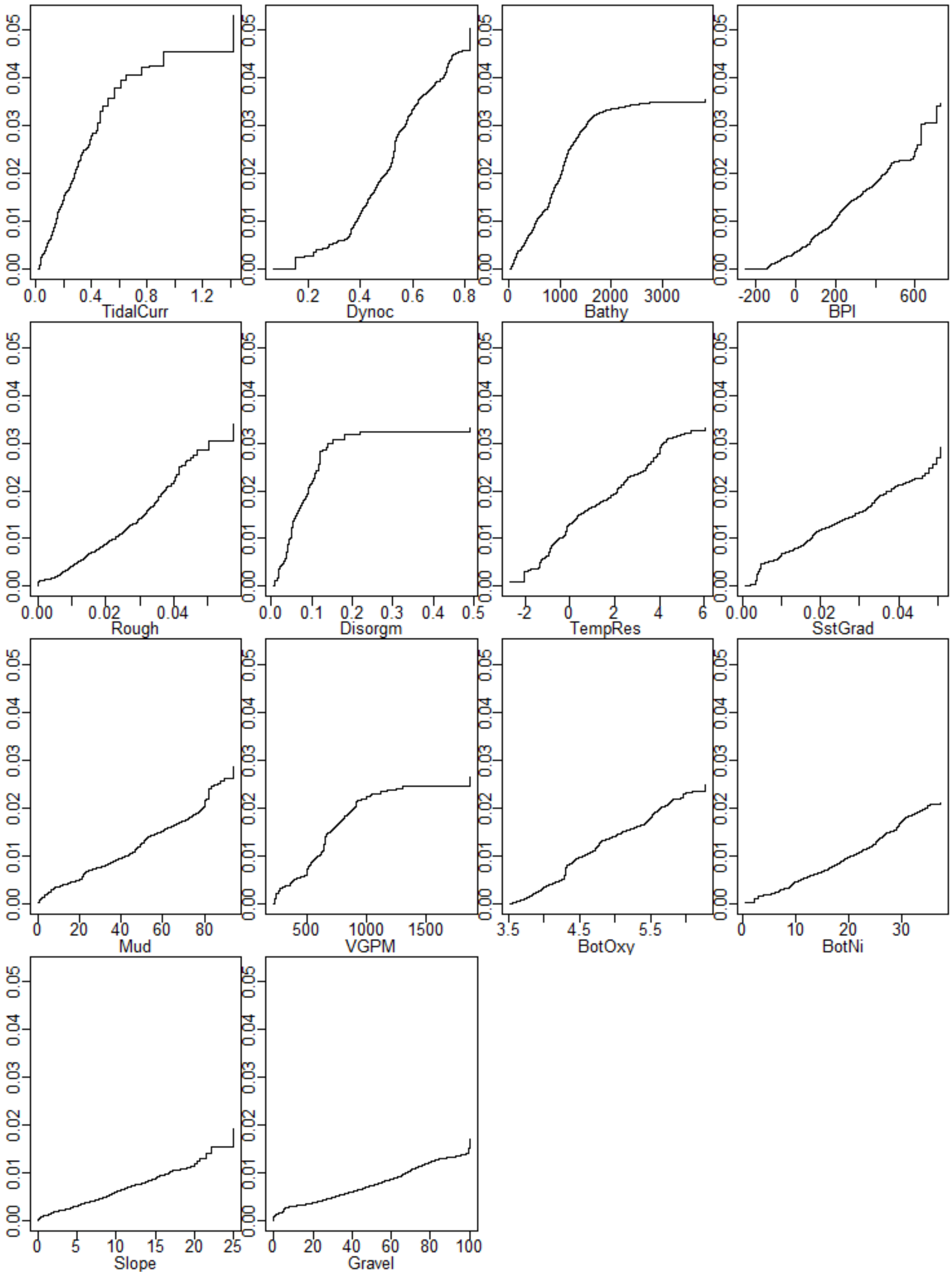


Figure 7-9: Functions fitted by the final GF model for sampling gear category MMG using 659 observations, indicating relative species turnover along the range of each predictor.

Species turnover functions produced by the GF model fitted to 659 samples collected with gear type MMG were used to create a transformed set of environmental predictor layers, with values in these layers representing species turnover along the range of each environmental predictor (Figure 7-10).

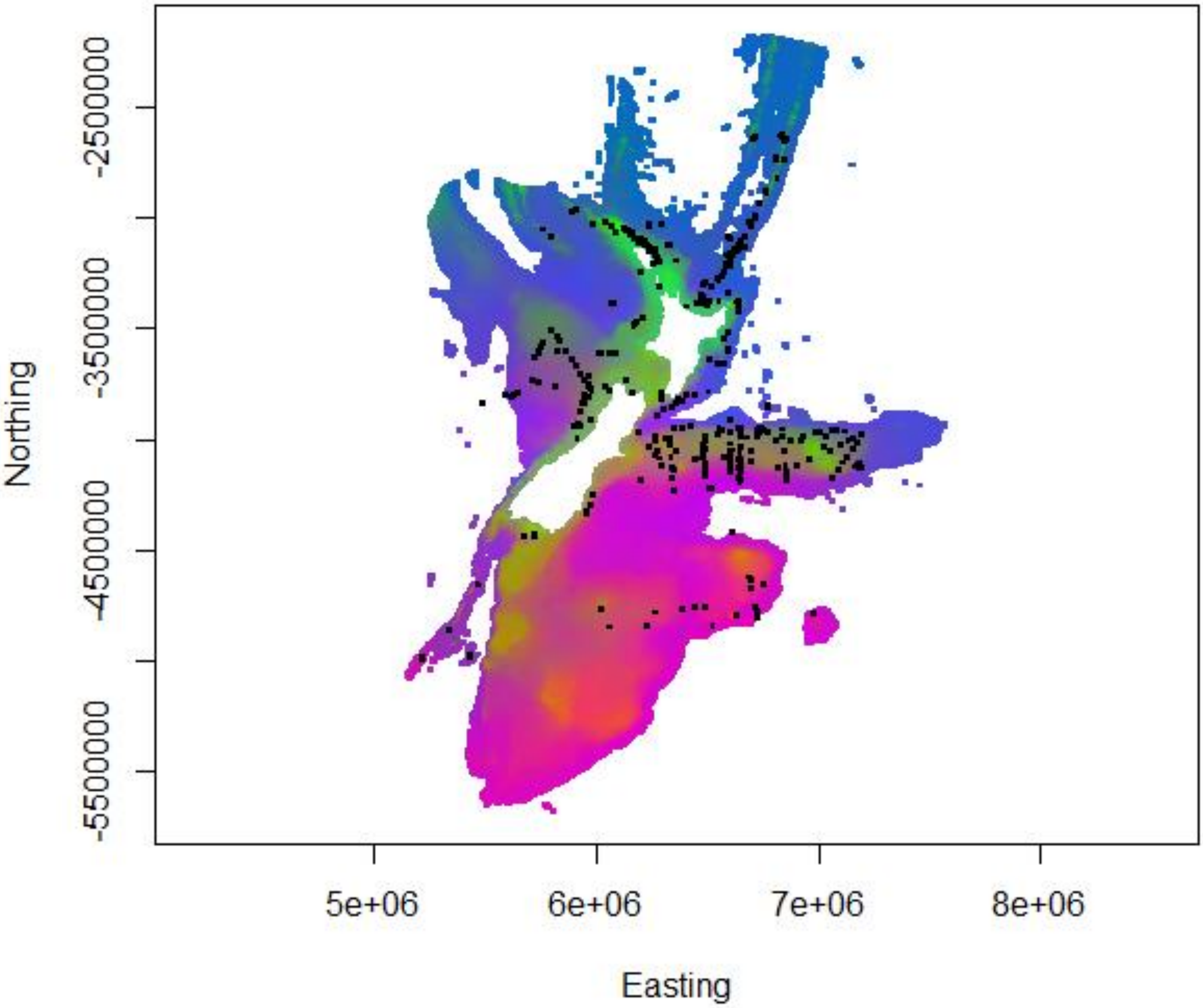


Figure 7-10: Distributions in geographic space of transformed environmental layers derived from a Gradient Forest model fitted to 659 samples collected with gear type MMG (black squares) for the seas within the New Zealand Extended Continental Shelf to a depth of 2500 m; Colours are based on the first three axes of a PCA analysis so that similarities/differences in colour correspond broadly to intergroup similarities/differences with respect to the transformed environmental variables.

Combined LMG and MMG species turnover

Species turnover along the range of each predictor fitted for the final combined GF model (Figure 7-11), and predictions into PCA (Figure 7-12) geographic space (Figure 7-13) reflect similar patterns as discussed above.

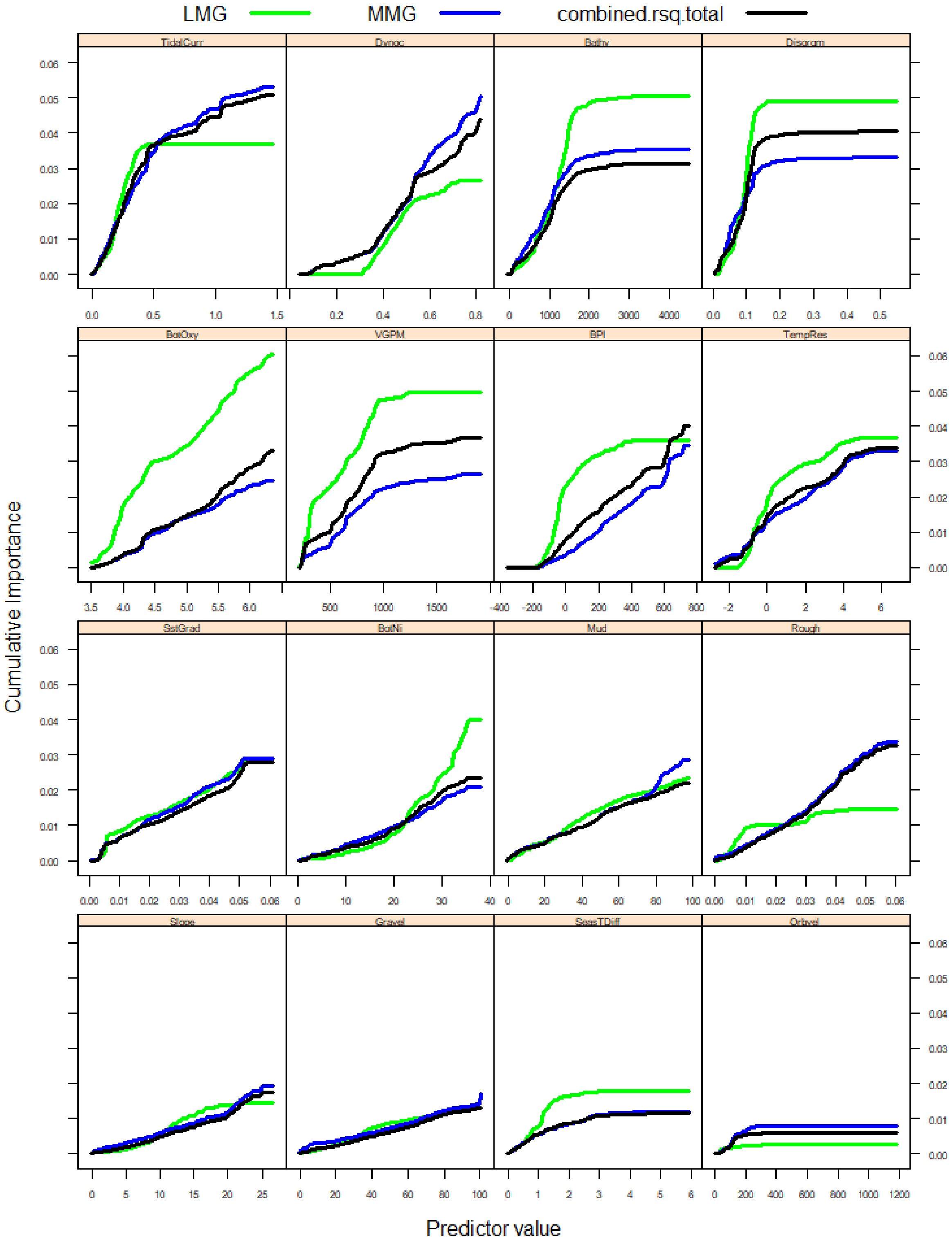


Figure 7-11: Weighted mean relative species turnover along the range of each predictor fitted for the final combined GF model (black lines) with the relative species turnover shown for sampling gear category LMG (green lines) and MMG (blue lines).

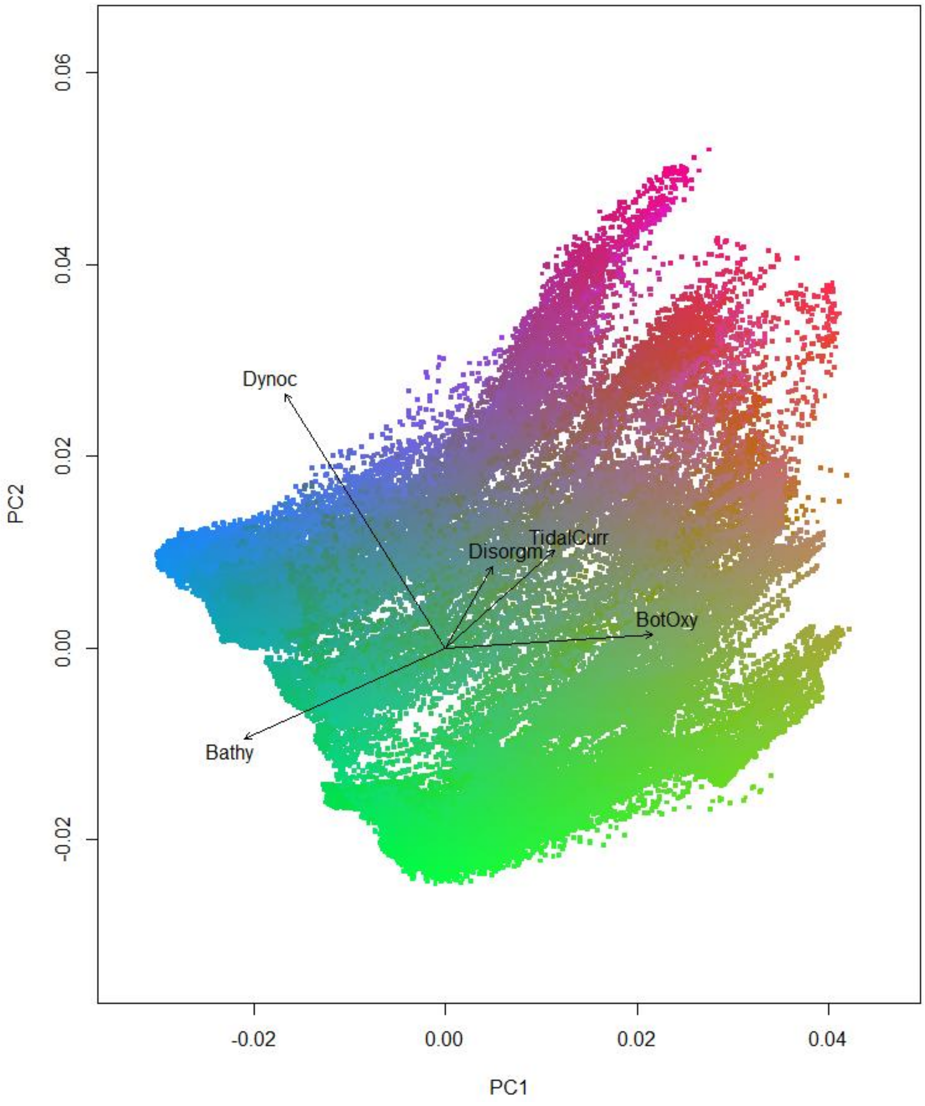


Figure 7-12: Distributions in PCA space of transformed environmental layers derived from a Gradient Forest model fitted to the combined LMG and MMG samples. Colours are based on the first three axes of a PCA analysis so that similarities/differences in colour correspond broadly to intergroup similarities/differences with respect to the transformed environmental variables. Vectors indicate correlations with the five most important environmental predictors.

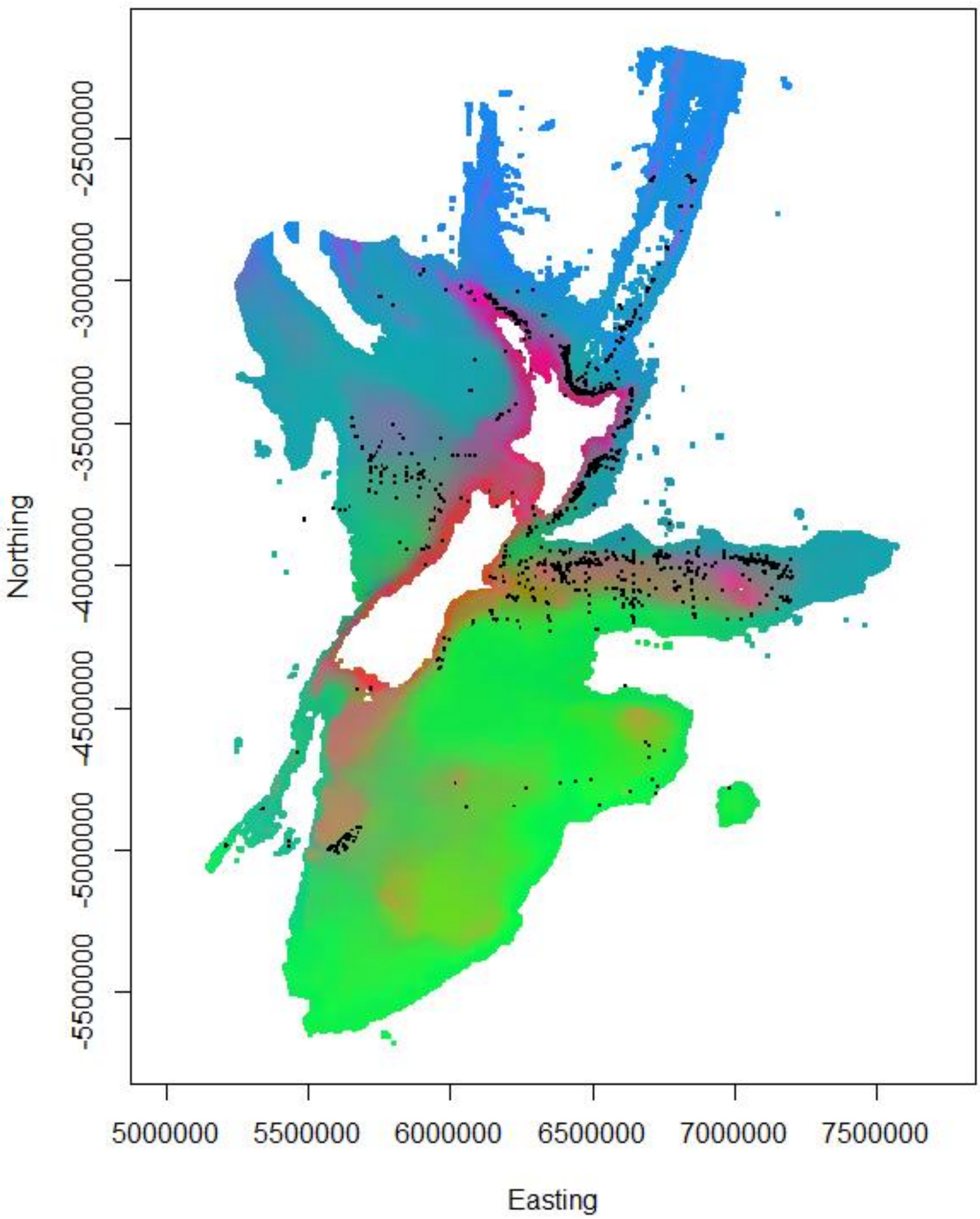


Figure 7-13: Distributions in geographic space of transformed environmental layers derived from a Gradient Forest model fitted to the combined LMG and MMG samples (black squares) for the seas within the New Zealand Extended Continental Shelf to a depth of 2500 m. Colours are based on the first three axes of a PCA analysis (Figure 7-12) so that similarities/differences in colour correspond broadly to intergroup similarities/differences with respect to the transformed environmental variables.

Benthic invertebrate species assemblages

Species turnover derived from transforms of the Gradient Forest model fitted with the combined LMG and MMG samples (Figure 7-13) were classified to various levels (5; 30;50 and 100 groups) to represent benthic invertebrate species assemblages. The classification used was hierarchical, e.g., groups from fine-scale classification (e.g., 100 group classification) are nested within broader-scale classifications (e.g., 5 group classification). Broadly, all groups varied widely not only with respect to the transformed environmental predictors (Figure 7-13), but also in their geographic distributions and extents, and their physical and biological characteristics, as described by the raw environmental predictors and species distribution data (see excel files for further information on mean environmental predictor values, and species frequency presence for classes at each classification level).

A classification with a low number of classes (e.g., five-group classification here, Figure 7-14) can be interpreted as bioregions (Snelder et al. 2007;Leathwick et al. 2012). Group 1 are the deepest waters and are found throughout New Zealand, groups 2 and 5 are found in slightly shallower waters with group 2 found north of the Subtropical Front (STF is a highly productive zone of mixing between high salinity, nutrient poor, warm, northern waters, and low salinity, nutrient rich, cold, southern waters) and group 5 found south of the STF. Group 4 is in mid-water depths with higher tidal currents and Group 3 are all areas in shallow waters surrounding New Zealand which have higher values of dissolved organic matter than the other groups.

For classifications with 30 – 100 groups, environmental differences between classification groups were relatively muted in the deepest waters, but differences in bottom oxygen, tidal current and dissolved organic matter become increasingly important in intermediate and shallow depths (Figure 7-15 and Figure 7-16).

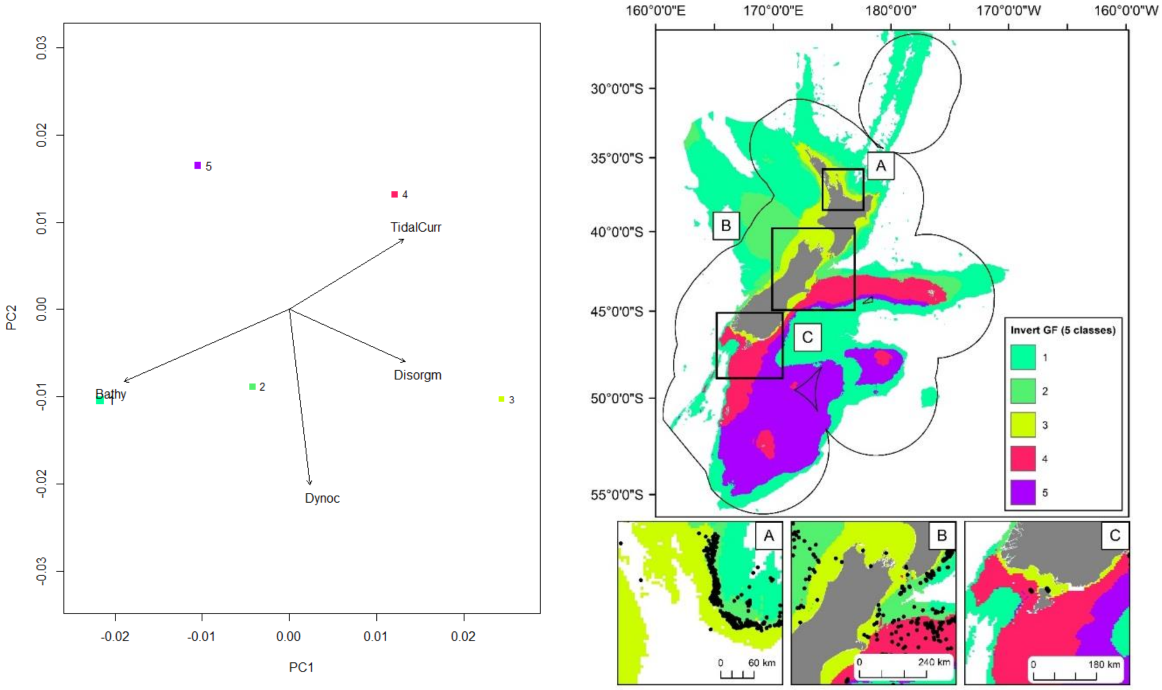


Figure 7-14: Distributions in PCA (left) and geographic space of 5 groups (left) defined by classification of transformed environmental layers for the seas within the New Zealand Extended Continental Shelf to a depth of 2500 m. Colours are based on the first three axes of a PCA analysis applied to the group means for each of the transformed predictor variables (right), so that similarities/differences in colour correspond broadly to intergroup similarities/differences with respect to the transformed environmental variables.

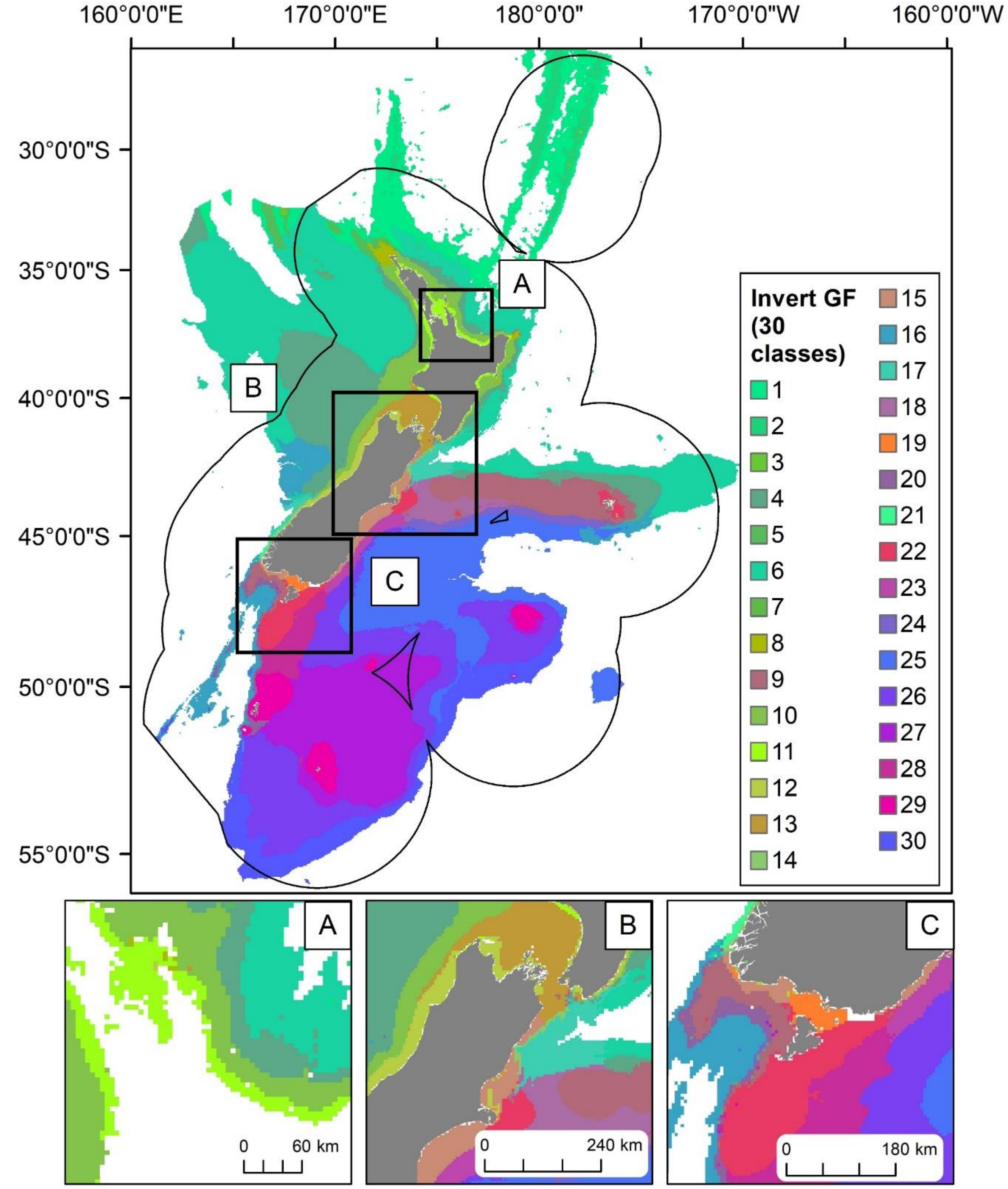


Figure 7-15: Distributions in geographic space of 30 groups defined by classification of transformed environmental layers for the seas within the New Zealand Extended Continental Shelf to a depth of 2500 m. Colours are based on the first three axes of a PCA analysis applied to the group means for each of the transformed predictor variables, so that similarities/differences in colour correspond broadly to intergroup similarities/differences with respect to the transformed environmental variables.

PCA figures, mean species frequency and the mean environmental predictors for Figure 7-15 and Figure 7-16 are available with GIS files in the “Table_info_GISfiles” folder.

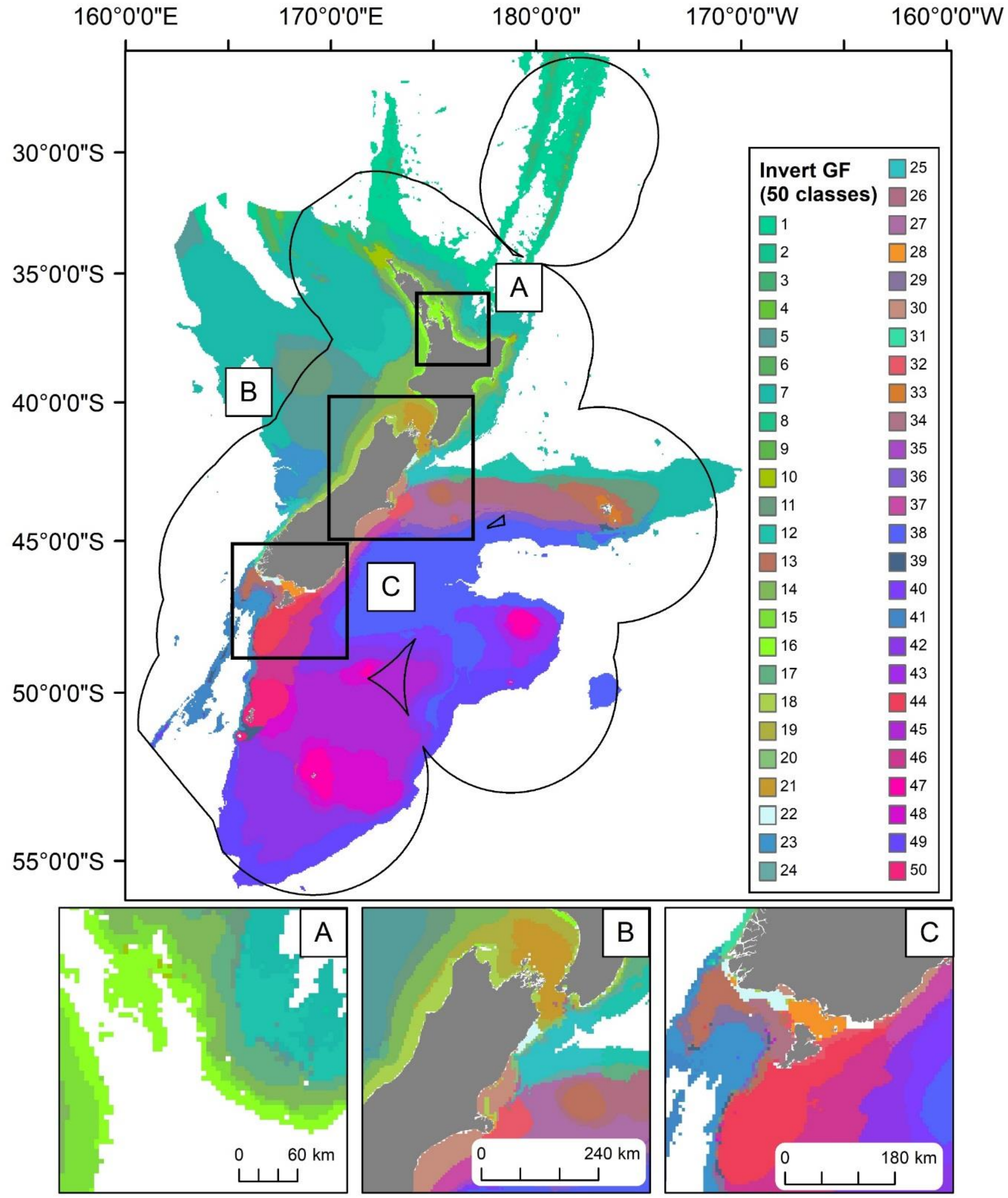


Figure 7-16: Distributions in geographic space of 50 groups defined by classification of transformed environmental layers for the seas within the New Zealand Extended Continental Shelf to a depth of 2500 m. Colours are based on the first three axes of a PCA analysis applied to the group means for each of the transformed predictor variables, so that similarities/differences in colour correspond broadly to intergroup similarities/differences with respect to the transformed environmental variables.