

# Review of New Zealand's Key Biogenic Habitats

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## Executive summary

The New Zealand marine environment supports a diverse range of biogenic habitats – defined as those created by living plants (e.g. kelp forests, seagrass meadows, mangrove forests) or animals (e.g. bryozoan thickets, sponge garden, tubeworm fields) where their three-dimension structure provides shelter, protection and resources for other marine flora and fauna. This report reviews the available information on the extent and state of 15 key biogenic habitats occurring within New Zealand waters.

Biogenic habitats are colourful and full of marine life and as such are aesthetically valuable to society for tourism (e.g. swimming, kayaking, diving and boating). They are also commercially and recreationally harvested as food (e.g. scallops, green-lipped mussels, seaweed), and indirectly valuable to the New Zealand economy and culturally through the provision of essential fish habitat (EFH) for many fishery and taonga species (e.g. snapper, blue cod, tarakihi), especially during crucial life stages (e.g. nursery and spawning grounds).

Biogenic habitats provide numerous ecosystem services that keep our marine environments healthy, including stabilising coastal sediments, provision of food, recycling nutrients and mitigating coastal erosion and inundation. Habitat-forming plants, such as kelp forests and seagrass meadows, are some of the most productive habitats on Earth, while habitat-forming invertebrates, such as beds of large bivalves, act as ‘marine vacuum cleaners’ filtering large volumes of water resulting in cleaner waterways.

While international and national literature are available on the relative importance of biogenic habitats, this review identified significant and extensive data gaps on where biogenic habitats occur within New Zealand. It is clear from these findings that New Zealand is still very much in the discovery phase of documenting these habitats. This is highlighted by the absence of national inventories for 13 of the 15 biogenic habitats, while the two national inventories (for seagrass and mangroves) contain recognised gaps. As a result, current estimates of biogenic habitats are likely to greatly under-represent the real extent and location of biogenic habitats within New Zealand’s marine environment.

Museum records (i.e. based on specimen collections) are valuable to determine biogeographic distributions, but do not adequately predict where biogenic habitats are, as “one tree does not make a forest”. Densities of habitat-forming species are needed to verify ‘habitat-forming aggregations’. Although species densities (from sampled abundances, weights or volumes) are collected on most research surveys, these data are currently retained in disparate and project-specific datasets. Compiling existing density data into a national dataset would be a cost-effective<sup>1</sup> first step to addressing some of these critical gaps, whereby targeted surveys could then be prioritised based on gaps in these data.

Three of the fifteen biogenic habitats were inadequately represented in Museum databases, due to poor preservation (e.g. most tubeworms), poor sample retention (e.g. rhodoliths), or being rarely collected during benthic sampling (e.g. xenophyophores). Consequently, little is known of their distribution, abundance or taxonomic identities - even though they are known to form extensive habitats in some areas. Targeted sampling of these habitats and improved collection methods are necessary to resolve this, and should be a priority of future surveys.

The absence of baseline and temporal monitoring surveys for all but a few biogenic habitats, makes it highly problematic to assess whether habitat loss has occurred (i.e. hard to know what you’ve lost if you don’t know how much you had). Information on threats and stressors, however, can provide valuable insight into the likely impacts and trajectories of these habitats. Existing literature suggests

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<sup>1</sup> compared to collecting new survey data

that the top three threats to biogenic habitats are increasing ocean temperatures, sedimentation and benthic fishing activity, but based on the findings of this review the relative magnitude of these likely varies with distance offshore. Biogenic habitats growing along the coastal fringe (e.g. seagrass meadows, mangrove forests) and near the coast (e.g. kelp forests) are known to be sensitive to coastal development, with increased sedimentation, declines in water quality, and changing climate conditions predicted to have the greatest impacts. Offshore habitats are expected to be impacted less by coastal development, and more by benthic fishing disturbances, which are highest on the mid-shelf and upper continental slopes, and often target biogenic habitats (e.g. bryozoan thickets and tubeworm fields) due to their known association with commercial fish species.

Those biogenic habitats that are susceptible to breakage and dislodgement are likely to be heavily impacted by ongoing fishing activities, with extensive areas already showing signs of damage and loss (e.g. bryozoan thickets off Patea Shoals, Separation Point, Otago shelf and Foveaux Strait, and horse mussels beds in the Hauraki Gulf and outer banks of Marlborough Sounds). Deep-sea coral thickets have undergone substantial damage and community loss on heavily fished seamounts with no evidence of recovery observed even a decade after fishing activity has been removed.

Loss of biogenic habitats and their services have been linked to rapid degradation of waterways, cascading impacts on marine biodiversity and significant loss of aesthetic, commercial and recreational values. However, within New Zealand few historic baselines exist to determine how much habitat has already been lost or damaged, or what that loss means to the health of these ecosystems, and the diversity of species that rely on them.

Managing and safe-guarding New Zealand's biogenic habitats will require more targeted surveys to document the spatial extent and condition of these habitats. Priority should be given to biogenic habitats (e.g. wireweed fields and bryozoan thickets) that are already known targets of commercial fisheries, those known to be particularly vulnerable to fishing damage (e.g. bryozoan thickets, horse mussel) or are known nursery or spawning habitats (e.g. wireweed fields, bryozoan thickets, horse mussel beds) for fishery species. Accurately documenting these habitats is important for marine policy making and management, while the protection (and restoration) of these habitats may be vital for not only the habitats themselves and their associated biodiversity, but also for sustaining or even enhancing fishery catches.

# 1 Introduction

## 1.1 Background

The Ministry for the Environment (MfE) and Statistics New Zealand (Stats NZ) are seeking 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.

Biogenic (or living) habitats are "*habitats created or brought about by living organisms (i.e. trees, coral reefs, kelp forests, etc.) that support other animals, plants and organisms*" (Oxford English Dictionary). Habitat-forming species are often sedentary and can grow in isolation. However, when they occur in aggregations they form three-dimensional structure that visually and functionally characterise an area<sup>2</sup> providing shelter, protection and resources (i.e. homes and food) for other marine flora and fauna. These habitats can occur over extensive areas of the seafloor and support higher biodiversity than adjacent habitats, and as such are often referred to as hotspots of biodiversity (MacDiarmid et al. 2013). Biogenic habitats (e.g. kelp forests and seagrass meadows) are some of the most productive and diverse communities on Earth (Costanza et al. 1997; 2014; Solan et al. 2004; Krumhansl et al. 2016). Living habitats also provide ecosystem services that keep our marine environments healthy (Thrush et al. 2001; Morrison et al. 2014a). For example, many habitat-forming species are suspension feeders (e.g. shellfish, sponges, bryozoans and other 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 may also stabilise coastal sediments, provide us with food, recycle nutrients and mitigate coastal erosion and inundation (Solan et al. 2004; Airoidi and Beck 2007; Townsend et al. 2011). However, they are also sensitive to environmental change and are vulnerable to marine stressors and threats, including overfishing, habitat destruction, and increased sedimentation and pollution, that can lead to habitat degradation and loss (Thrush et al. 2001; Thrush and Dayton 2002; Solan et al. 2004; Airoidi and Beck 2007; Morrison et al. 2014a). Globally, habitat loss is particularly severe in coastal marine ecosystems, which are now subjected to intense human pressures with over ~60 % of the world's population living within 100 km of the coast (Burke et al. 2001). Threats and stressors associated with urban expansions are expected to intensify as human populations continue to grow. The loss of critical biogenic habitats has been documented around the world, with losses expected to increase (Burke et al. 2001; Airoidi and Beck 2007; Thrush et al. 2016). Habitat loss can also have severe, cascading and long-lasting effects, whereby the loss of their ecosystem function can lead to large-scale declines and even the collapse of the broader ecosystem (Jackson et al. 2001; Thrush et al. 2001; Airoidi and Beck 2007; Diaz and Rosenberg 2008). In Chesapeake Bay, for example, large-scale loss of oyster beds (~ 164,000 acres in the last 25 years) has been associated with significant reductions in water quality, followed by large-scale losses of seagrass beds (~50% loss), and the collapse of the Blue crab fishery (Rothschild et al. 1994; Airoidi and Beck 2007), and the development and spread of anoxic 'dead zones' (Diaz and Rosenberg 2008).

New Zealand's marine environment supports a diverse array of biogenic habitats across a wide range of depths (intertidal, subtidal, continental shelf and slopes, and the deep-sea) and habitats (rocky reefs to soft-sediments), where they form a variety of complex structural morphologies - thickets, forests, meadows, fields, mounds and/or beds (review in Morrison et al. 2014a). A wide variety of biogenic habitats have been described that include extensive tubeworm meadows, rhodolith beds,

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<sup>2</sup> These may be emergent (above-ground) structures (e.g. sponge gardens and coral reefs), relict material from living organism (e.g. dead shell debris) or can be non-emergent (below-ground) created by the activity of infaunal animals beneath the surface of the seafloor (often referred to as bioengineers). In this review only living and at least partially emergent (i.e. epibenthic) habitats are examined and reviewed in this report (as defined in DOC and MPI 2011 and MacDiarmid et al. 2013).

coral thickets, bryozoan and coral thickets, sea pen fields, diverse and extensive sponge gardens (MacDiarmid et al. 2013; Morrison et al. 2014a; Jones et al. 2016; 2018). These bedforms may be comprised of a single 'monospecific' species (e.g. kelp forests of *Ecklonia radiata*) to multi-species communities (e.g. sponge gardens comprising a mixture of many different species). Some species may be early colonisers that are the first species to arrive and stabilise otherwise dynamic soft-sediments (e.g. infaunal tubeworms) or colonise loose material (e.g. calcareous tubeworms), while other species are characterised as later stage colonisers that settle and grow once suitable conditions are provided (e.g. bryozoan thickets and epifaunal sponges) (Jones et al. 2018). Communities associated with biogenic habitats within New Zealand can be extremely diverse (Morrison et al. 2014a; Jones et al. 2018). For example, a biogenic survey of 35 sites on New Zealand's continental shelf recorded >1000 species, indicating the important role biogenic habitats play in enhancing seafloor biodiversity (Jones et al. 2018).

In 2011, a national gap analysis was undertaken by the Department of Conservation (DOC and MPI 2011), collating a wide range of benthic and environmental information (e.g. BOMAC). While this provided a national-scale classification it was unable to discern local fine scale habitats (DOC and MPI 2011; Ford et al. 2016). MacDiarmid et al. (2013) described and defined 13 sensitive marine benthic habitats, all of which are considered key biogenic habitats in this review. While this provided an excellent overview of these habitats, only limited information was provided on the distribution of these habitats within New Zealand waters. Morrison et al. (2014a) reviewed the importance of biogenic habitats to New Zealand fishery species, showing that many fishery species were strongly associated with various biogenic habitats (e.g. horse mussel beds, bryozoan thickets, sponge gardens and tubeworm fields) as adult refuge, but also during crucial life cycle stages (as nursery habitats and spawning grounds), but identified that little was known about where these habitats were or how extensive they might be. Biogenic habitats on the mid to outer continental shelf have long been known by fishers as important fishery habitats, however little was known about where exactly these habitats occurred around New Zealand. A wide range of research surveys have described, sampled and in some situations mapped biogenic habitats (e.g. review in Morrison et al. 2014b; Anderson et al. 2014; Wood et al. 2013). In addition to traditional surveys, researchers in 2009 interviewed long time fishers and asked them to draw polygons around areas where they had encountered biogenic types of habitat (Jones et al. 2016 see below). A research survey was then undertaken in 2011 from the Three King Islands down to Stewart Island to ground-truth a subset of these habitats (Jones et al. 2018). In this review, these studies along with finer scale mapping and monitoring surveys, national species occurrence records and other biogenic studies are examined to determine the current state, impacts and pressures on key biogenic habitats within the New Zealand marine jurisdiction.

## 1.2 Aim of this report

The aim of this desk-based review was to compile available data and review literature to determine the current state, impacts and pressures on key biogenic habitats (as determined by experts during the consultation workshop) within the New Zealand territorial sea and EEZ. Use national-scale datasets along with regional case studies to assess and map the current distribution, extent and condition of key biogenic habitats, identify gaps in the knowledge, and make recommendations for future research.

## 2 Methods

### 2.1 Approach

To determine the current distribution, extent, and condition of key biogenic habitats, NIWA's approach was to first source and map all digitally available point-source data for up to 15 key biogenic habitats (as determined by an expert panel workshop) and their respective key habitat-

forming species (also determined by the panel). This was expected to provide a national-scale assessment of the biogeographic distribution of these taxa, along with a visual assessment and overview of data gaps. Next, regional scale examples for each key habitat were examined and plotted, using quantitative survey data and maps (e.g. aerial, acoustic, and underwater video and diver surveys) that along with a review of published and grey literature would characterize what was known about each habitat type. Using these data and information along with expert opinion, an assessment of the condition of these habitats at a national scale was categorised using condition indices. Known threats and stressors were then examined relative to national and regional data layers to determine current conditions and the likely trajectories of these habitats. A gap analysis approach, using the combination of all this information, was undertaken to determine the extent of information for each key habitat within the coastal and oceanic waters of New Zealand's EEZ, and provide recommendations for addressing these gaps.

## 2.2 Scoping workshop

A representative panel of experts (the Panel), made up of ecological and taxonomic experts, with expertise in one or more key biogenic habitats within New Zealand waters, was convened. Specialists included members from NIWA's Wellington, Nelson, Hamilton and Auckland offices, the Universities of Otago and Waikato, the Department of Conservation (DOC), the Ministry for the Environment (MfE) and Statistics New Zealand. The panel consisted of:

- Dr Tara J. Anderson – Project Manager and Panel Chairperson, Marine Ecologist: Biogenic habitats and benthic communities, NIWA Wellington
  - Dr Alison MacDiarmid – Sensitive marine habitats and benthic risk assessments, NIWA Wellington
  - Dr Mark Morrison – Fishery ecologist, fish-biogenic habitats, NIWA Auckland
  - Dr Ashley Rowden – Deep-sea benthic ecology and fisheries, NIWA Wellington
  - Dr Anna Wood – NZ Bryozoans, the University of Otago
  - Dr Bruce Marshall – NZ Mollusc taxonomy specialist, TePapa National Museum
  - David Harris – Statistical Analyst, Statistics New Zealand
  - Dr Debbie Freeman – Marine biodiversity and conservation, DOC Wellington
  - Ms Di Tracey – NZ's deep-water coral specialist, NIWA Wellington
  - Dr Dennis Gordon Read – NZ's Bryozoan taxonomy specialist, NIWA Wellington
  - Dr Wendy Nelson – NZ's Macroalgal specialist, NIWA Wellington
  - Dr Geoff Read – NZ's Polychaete taxonomy specialist, NIWA Wellington
  - Ms Jackie le Roux – Environmental Science and Systems Monitoring team, MfE Wellington
  - Ms Constance Nutsford – MfE Wellington
  - Dr Kareen Schnabel – Marine invertebrate ecology and NIWA Collections, NIWA Wellington
  - Dr Ken Grange – Fiordland Guardian, NZ black coral specialist, NIWA Emeritus.
  - Dr Kura Paul-Burke – Marine ecologist and Mātauranga Māori, NIWA Hamilton
  - Dr Mary Livingston – NZ biodiversity and Principal Adviser of Fisheries Science at New Zealand MPI, Wellington.
  - Mr Tilmann Steinmetz – GIS mapping specialist, NIWA Wellington
- Expert contributions (Unable to attend the workshop, but contributing to this review)*
- Dr Malcolm Clark – Deep-sea benthic ecology and fisheries, NIWA Wellington
  - Prof. Chris Battershill – Coastal and Marine Ecosystems, Sponge ecology and biotechnology specialist, University of Waikato, Tauranga.
  - Dr Michelle Kelly – Sponge taxonomy specialist, NIWA Auckland.

During the consultation workshop, the panel discussed and then ranked a list of biogenic habitats in terms of importance, before habitats were selected for inclusion in this review. An initial habitat list was based on the 'sensitive habitats' identified and defined by MacDiarmid et al. (2013) and 'coastal habitats' identified in a report by the Department of Conservation (DOC) and MfE (DOC and MPI 2011). It was decided that some habitats should be sub-divided because they formed distinct habitat types that provided different ecosystem services, while other habitats should be combined as they often co-occurred and provided similar ecosystem services and were subjected to similar threats and stressors. In considering biogenic habitats for this review, panel members from MfE and New Zealand Statistics identified that rarity or a lack of information should not preclude a habitat from being included in this review; as knowing that a habitat is rare, or that not much is known, is important for management and reporting purposes. Many non-endemic species that occur in New Zealand waters are also known to form biogenic habitats, but these are not within the scope of this report.

The following is the final list of biogenic habitats to be included in this review:

- Seagrass meadows
- Mangrove forests
- Kelp forests
- Algal meadows
- Rhodolith beds
- Bryozoan thickets
- Sponge gardens
- Stony coral and other habitat-forming corals)
- Beds of large shellfish
- Calcareous tubeworm mounds
- Non-calcareous tubeworm fields
- Deep-Sea chemoautotrophic tubeworm patches
- Sea pen and whip fields
- Xenophyophore beds

## 2.3 Data sources

The panel identified a wide range of data sources that may be useful for each of the selected biogenic habitats and their determined/associated key species. Data layers were sourced and then examined for relevance. To represent the best available information for each habitat (and their key-species), multiple data sources are plotted together in ArcGIS v10.6, with the specific datasets and layers described below<sup>3</sup>:

### 2.3.1 National data - marine flora

Benthic flora records for key habitat-forming species occurring within New Zealand waters were sourced primarily from the Australasian Virtual Herbarium (AVH) and then supplemented by more detailed macroalgal datasets from NIWA.

1. **The Australasian Virtual Herbarium (AVH)** online database. Distribution records for seagrass, mangroves, kelp forest and algal meadow key species were searched for and extracted using a combination of 'phylum', 'family', 'genera', and 'species' (as one or more columns might be blank for some records) and with the spatial extent as 'New Zealand'. The AVH collection represents the most comprehensive collection of New Zealand flora records that contains distribution records supplied by a suite of sources, including the New Zealand Virtual Herbarium; Massey University; Auckland War Memorial Museum Herbarium; Herbarium of the Museum of New Zealand Te Papa Tongarewa; Scion; Museum of New Zealand Te Papa Tongarewa; Landcare Research NZ Ltd; Auckland War Memorial Museum; University of Canterbury. Records for Flora presented in this report were extracted in April 2018.
2. **NIWA-Internal macroalgal data.** Distribution records were provided by NIWA-Wellington for i) all rhodolith forming species within New Zealand, and ii) all Fucale and Laminariales kelps for coastal New Zealand n=6,419 records (broader species review in D'Archino et al. in press). Data compiled in February 2018.

### 2.3.2 National data - marine invertebrates

Benthic invertebrate records for key habitat-forming species occurring within New Zealand waters were sourced from several locations. National-scale data were sourced primarily from four Collections databases (Ocean Biogeographic Information System, New Zealand Node (OBIS-NZ) online database, The National Te Papa Natural History Collection, and NIWA National Invertebrate Collection), which were then supplemented by additional datasets for different biogenic habitats (e.g. bryozoans; Wood et al. 2012), each described below. For each biogenic habitat type, exports were defined by 'key-species' (using a combination of 'phylum', 'order', 'family', 'genera' and 'species' - as one or more columns might be blank for some records) with the spatial extent listed as 'New Zealand.'

3. **Ocean Biogeographic Information System, Southwestern Pacific Node (OBIS-NZ)** is an online database<sup>4</sup> that provides species occurrences for a wide range of taxa within New Zealand's EEZ and the wider south Pacific and has the highest number of invertebrate records for New Zealand waters of any database (n=1,048,576 marine invertebrate records). Most Biogenic habitats and/or their key habitat-forming species are represented to some level in this database. OBIS records for all benthic invertebrates within New Zealand waters were extracted in February

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<sup>3</sup> The purpose of this project was to review digitally available data. It was not the purpose of this review to collate, merge and/or groom any data, however some formatting was necessary prior to plotting (see: Section 2.4, below).

<sup>4</sup> OBIS-NZ is a Census of Marine Life website (<http://www.iobis.org>) that collates geo-referenced records of species occurrences from a wide range of taxa for New Zealand's EEZ. Data are listed by taxonomic information (i.e., Phylum, Class, Order, Family, Genus, Species) and geographic location (latitude and longitude).

2018<sup>5</sup>. As this single dataset was simply too large to manipulate and plot within ArcGIS, these data were first imported into SAS and extracted by key-species into separate datasets for each biogenic habitat, using a combination of 'phylum', 'Order', 'Family', 'Genera', and 'species' (as one or more columns might be blank for some records).

4. **The National Te Papa Natural History Collection (Te Papa).** The Te Papa natural history collections (here on referred to as Te Papa) are in two collection facilities in Wellington (Cable and Tory Street) and contain the national collection of plant and animal specimens housing more than 1 million collection lots. It is the largest, most comprehensive collection of New Zealand fauna and flora, with most major taxonomic groups of plants and animals represented. The database management software KEmu was queried to extract all marine invertebrates (totalling n= 88,748) for the New Zealand region (provided by Bruce Marshall, Rick Webber and Carol Stevenson on 8 October 2015).<sup>6</sup>
5. **NIWA Invertebrate Collection (NIWA Inverts).** NIWA's Invertebrate Collection (here on referred to as NIWA-Inverts), located at the NIWA's Greta Point campus in Wellington, is a repository for marine invertebrates from almost all phyla found in the New Zealand region, the wider Southwest Pacific and the Ross Sea. It houses an estimated 300,000 collection lots that have been collected over half a century of biological research (Schnabel et al. 2014). Collection records for benthic marine invertebrate species (n=84,405) were extracted using the database management software Specify.
6. **Vulnerable Marine Ecosystem (VME) data.** A VME dataset was compiled by Anderson et al. (2014) from occurrence records of species associated with vulnerable marine ecosystems (VMEs) in water depths greater than 200 m. These data were used to predict species distribution using environmental variables and habitat suitability modelling across continental slope and deep-sea areas where sampling does not exist. The VME-data comprise presence data from a combination of sources including the NIWA Invertebrate Collection Specify Database NIWA-*Invert*; the Ministry for Primary Industries (MPI), research MPI-*trawl*; Centralised Observer database MPI-*COD*. Both MPI databases are managed by NIWA for MPI and are regularly updated with revised identifications when corals are returned from sea (Tracey and Mills 2016, see descriptions below). Pseudo-absence data were also used by Anderson et al. (2014) defined as 'all occurrences where some type of VME taxon was collected'. This dataset includes the verified (confirmed by coral taxonomists) fisheries-observer coral dataset as well as all available fisheries-observer coral data (non-verified), in combination with scientific research data collected from research biodiversity and trawl surveys. Both the presence, pseudo-absences and modelled distributions for key habitat-forming species (the stony branching corals: *Enallopsammia rostrata*, *Solenosmilia variabilis*, *Madrepora oculata*, *Goniocorella dumosa*), black corals, gorgonian octocorals, and sea pens) were extracted and presented in this review.
7. **Bryozoan dataset for New Zealand (n=523 records).** A frame-building bryozoan species-level dataset was compiled by Wood et al. (2013) to examine the actual occurrence of frame-building species from specimen records and their predicted distribution based on habitat suitability modelling. Data were mined from a variety of sources described in Wood et al. (2013). Key frame-building bryozoan species were extracted from this dataset and used in this review.
8. **Bryozoan dataset for Southland (n=654 records).** A bryozoan species-level dataset for sampling collections (e.g. dredging) all around southern New Zealand over the last decade (2010-2018) was provided by Abigail Smith, at the University of Otago (unpublished data). Data includes

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<sup>5</sup> Although OBIS data is available on-line, this extremely large OBIS-NZ EEZ dataset (1,048,576 records) was obtained directly from NIWA-Wellington who host the New Zealand OBIS Portal.

<sup>6</sup> Auckland Museum data was provided by Severine Hannam and Tom Trnski. However, these data were not used as most species in the dataset represented habitat-responders (e.g. mobile crustaceans) rather than the key habitat-formers reviewed here.

presence and absence records at species-level (along with position and depth). Only the key frame-building bryozoan species are used in this review.

9. **MPI research fisheries bycatch datasets.** Several fishery research survey datasets were provided by MPI to examine the distribution and abundance of habitat-forming species collected as either target and/or bycatch during these surveys. These databases are managed by NIWA for MPI and are regularly updated with revised identifications (Tracey and Mills 2016). MPI research fishery catch and bycatch data were provided from:

- i) The Centralised Observer Database (**MPI-COD**).
- ii) MPI's research trawl database (**MPI-Trawl** n= 18,213 records).
- iii) MPI's Oyster bycatch data (n= 1050 records).
- iv) MPI's commercial Scallop dredge and bycatch data (n= 15,360 records).
- v) Challenger Scallop SCA7 scallop dredge fishery effort and catch data for 1994 to 2012 (n= 15,360 records).

NB: VME data collations include bycatch data from MPI-COD and MPI-Trawl, so no additional records were plotted for deep-sea corals, sponges and sea pen taxa. However, these datasets were examined and plotted (where available) for targeted catch and bycatch of key habitat-forming species for coastal and shelf regions.

### 2.3.3 Spatial data layers

Additional data layers were provided from a variety of sources and came in a variety of formats and spatial scales. Most of these layers are used to provide spatial information in conjunction with literature reviews for regional case studies. These data include:

10. **New Zealand Land Cover Database - Mangrove spatial layer (LCDB-Mangroves).** LCDB (version 4.1) is a multi-temporal, thematic classification of New Zealand's land and wetland cover, with national-scale coverage (LINZ 1:50,000 topographic database). It contains 33 mainland classes (35 including the offshore Chatham Islands), one of which is a spatial polygon layer for mangroves. This represents a national-scale inventory of Mangroves in New Zealand, based on remote sensing from four nominal time steps; summer 1996/97, summer 2001/02, summer 2008/09, and summer 2012/13, with variable results depending on factors such as scale, image quality, image interpretation and field verification. While metadata associated with this spatial layer is clear, fine-scale metadata associated with individual polygons within estuaries are not well documented (Helen Kettles, *pers. obs.* DOC SeaSketch Project).

**Table 2-1: Summary of data used for national-scale distribution maps.** Data values presented are numbers of records for key habitat-forming species (as defined in each section below within New Zealand’s territorial and EEZ boundaries. \* depict data sources already included in the underlined dataset; Δ = Key species not represented in Collections databases due to undescribed and unnamed taxa or were not able to be extracted by metadata requirements; C=Calcareous; NC=Non-Calcareous; DS=deep-sea. Some specimen records may occur in multiple datasets (duplicates) so totaling the number of specimen records should be done with caution.

Biogenic habitat	No of key species	AVH <sup>7</sup> Flora	NIWA-Macroalgae	OBIS-NZ	Te Papa	NIWA-Inverts	VME-data	National Bryozoa	Southland Bryozoa
Seagrass beds	1	<u>42</u>	.	*	*	.	.	.	.
Mangroves forests	1	<u>25</u>	.	*	*	.	.	.	.
Kelp forests	8 genera	<u>679</u>	3,886	*	*	.	.	.	.
Algal meadows	6 taxa	<u>404</u>	.	*	*	.	.	.	.
Rhodolith beds	taxa-level	*	42	.	.	.	.	.	.
Bryozoan thickets	8	.	.	755	153	1,614 <sup>8</sup>	.	523	654
Sponge gardens	11 genera	.	.	819	48	698 <sup>9</sup>	Δ	.	.
Shellfish beds	4	.	.	17,632 <sup>10</sup>	327	248	.	.	.
C tubeworm mounds	1	.	.	24	2	25	.	.	.
NC tubeworm fields	5	.	.	Δ	Δ	Δ	.	.	.
DS chemoautotrophic tubeworm patches	3	.	.	.	.	100	.	.	.
Stony-coral thickets	8	.	.	*	*	*	<u>1,354</u>	.	.
Bush Coral fields	taxa-level	.	.	*	*	*	<u>1,995</u>	.	.
Sea pen fields	taxa-level	.	.	*1206	*59	*416	843 <sup>11</sup>	..	.
Xenophyophore beds	taxa-level	.	.	.	.	16	.	.	.

<sup>7</sup> AVH records compiled from numerous New Zealand sources (see AVH methods above).

<sup>8</sup> In addition, bryozoan abundance data was also used. A total of 1,573 NIWA-Invert records were used to calculate the total abundance (based on all recorded bryozoans) at a site to indicate the likely presence of bryozoan thickets.

<sup>9</sup> In addition, sponge abundance data was also used. A total of 2,383 NIWA-Invert records were used to calculate the total abundance (based on all recorded sponges) at a site to indicate the likely presence of sponge gardens.

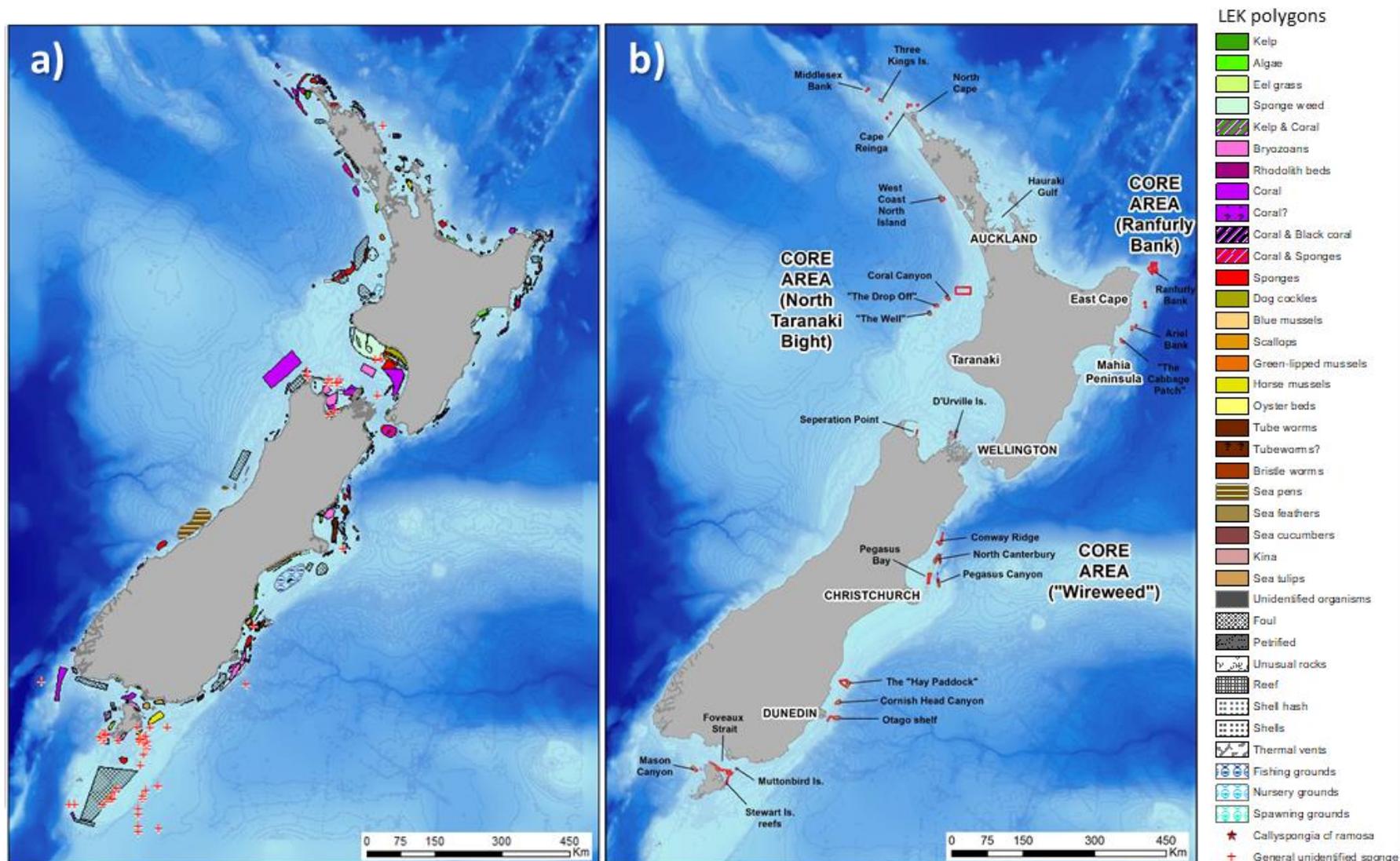
<sup>10</sup> Only 143 OBIS-NS records contained abundance data for key habitat-forming bivalves.

<sup>11</sup> VME data only includes samples collected deeper than 200 m water depth, and therefore do not represent continental shelf distributions, as such data from OBIS-NZ, NIWA-Inverts and Te Papa were also included. Of these Sea pen records extracted from OBIS-NZ (n=1206), NIWA-Inverts (416 records) and Te Papa (n=59), 123, 68 and 13 records (respectively) were collected from depths ≤ 200 m..

11. **DOC's New Zealand Estuarine Systems - SeaSketch project.** A national inventory for seagrass and mangroves has been compiled by the New Zealand Department of Conservation, in collaboration with regional councils using the SeaSketch web-online database (<https://www.doc.govt.nz/nature/habitats/estuaries/our-estuaries/seagrass-and-mangrove-extent/>). Seagrass and mangrove inventories include spatial polygon layers from one or more time periods that have been collected and digitised, where metadata are adequately documented. As sampling time varies considerably between locations, time is categorised simply as 'most recent' depicting the most recently completed survey in that area, the 'second most recent' and the 'third most recent' layer, respectively. For example, if seagrass was mapped in an area in 1948, 2006 and 2011, then the 'most recent' seagrass layer would contain the 2011 data, the 'second most recent' seagrass layer would contain the 2006 data, and the 'third most recent' seagrass layer would contain the 1948 data. Each polygon provides information on the exact year the polygon was sampled, along with other specific metadata. Data were sourced mostly from local councils and other available sources (e.g. LCBD-Mangroves where polygon-metadata can be determined). Data and maps presented in the report here provide summary examples of this information.
12. **NIWA's Kaipara Harbour Seagrass Maps.** Kaipara harbour seagrass polygons were provided by NIWA's 'fish in seagrass' programme (Morrison et al. 2014c). Data in this layer were collected and digitised from aerial photographs taken in 2007-2008, then converted to ArcGIS v10.4 shapefile polygons. These data layers and associated metadata were then provided to the DOC for inclusion in the SeaSketch project, and subsequently used by DOC to calculate the national seagrass cover total now presented in this report.
13. **NIWA's Local Ecological Knowledge (LEK-maps)** interviewee polygons made by long time fishers (Jones et al. 2016). Long-term commercial fishers (mainly trawler-men) were interviewed face-to-face around New Zealand, to describe places where they had encountered different or usual catches of 'biogenic'/habitat-forming species. A selection of visual aids (photographs, and some specimens) and nautical charts were used during the interviews, with fishers asked to draw areas on the charts where they had picked up large volumes of biogenic material in the trawl, or they had damaged, snagged, or even lost gear (see Jones et al. 2016 for a full description of the methods<sup>12</sup>). These marked charts were later digitised, collated and plotted in ArcGIS v10.4 (Jones et al. 2016; Figure 2-1a), and were provided here to examine relative to other data layers.
14. **NIWA's Biogenic Ground-truthing surveys (LEK-ground-truthing).** In 2011, a subset of the LEK-polygon maps was used to target biogenic habitat field surveys (NIWA RV *Tangaroa* surveys TAN1105 and TAN1108), as described in Jones et al. (2018) (survey sites presented in Figure 2-1b).

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<sup>12</sup> Jones et al. (2016) emphasized that LEK polygons represent a valuable, but in many places, unverified indication of where biogenic habitats might exist on the New Zealand continental shelf. Some fisher-drawn areas are at a relatively coarse resolution, and in some instances, may include a proportion of non-biogenic habitat, conversely the biogenic habitat may well extend beyond the polygon, or may no longer be present due to historical changes.



**Figure 2-1:** a) LEK polygons depicting biogenic habitats around New Zealand, and b) survey areas used to ground-truth these polygons. Note that the Chatham Rise shallower areas (e.g. Mernoo Bank) were not included in LEK interviews (from Figure 1 of Jones et al. 2016). Only three areas (the 'Core' areas) have been examined in detail (Source-b Jones et al. 2018); Zoomed in areas of LEK Polygons and Core areas are also presented in Jones et al. 2016, and Jones et al. 2018, respectively).

15. **Department of Conservation's (DOC) Marine Reserves - Habitat mapping layers:** DOC manages 44 marine reserves, two marine parks, three marine protected areas, and six marine mammal sanctuaries. Cape Rodney to Ōkarakari Point Marine Reserve (near Leigh) was the first marine reserve in New Zealand (established in 1975). Benthic habitats throughout this reserve were mapped by intensive diver surveys between 1975-1977 (Ayling 1978). These maps depicted 2 key biogenic habitats; kelp forests (dominated by *Ecklonia radiata*), and sponge gardens (mixed sponge assemblage). Thirty years later benthic habitats were partially re-mapped in 2000 (using radio-acoustics, Parsons et al. 2004) and fully remapped in 2006 (using a combination of aerial and side-scan sonar imagery and underwater video and manta board dive surveys, Leleu et al. 2012). A series of other marine reserves have been mapped around New Zealand for DOC, with fine-scale habitat maps delineated based on a range of multibeam and side-scan sonar imagery, and ground-truthed using a mixture of underwater video and diver surveys (DOC and MPI 2011). Hierarchical classifications, using DOC's Coastal Classification and Mapping Scheme (which includes biogenic habitat categories), have been used to characterise these mapped habitats (described in DOC and MPI 2011). In addition, a wide range of data layers (including many of the layers described above) have been integrated in ArcGIS to create a national-scale coastal marine habitat classification for New Zealand (methods described in detail in DOC and MPI 2011), and provide an indication of predominantly physical marine environments. Individual Marine Protected Area (MPA) maps and the national-scale coastal marine habitat classification maps were examined relative to national and regional biogenic data layers. The national classification maps did not correlate or delineate known biogenic habitats, but the fine-scale MPA maps provide detailed spatial extents of benthic habitats within (and for some extending outside) these marine reserves.

Several other data layers were provided and examined. These included:

1) the **Benthic-Optimised Marine Environment Classification (BOMECE)**. This is a modelled layer that provides a national-scale prediction of environmental classes around New Zealand, based on the relationships between national distributions of eight groups of taxa (many of which are used in the present review) and a variety of environmental variables (e.g. temperature, depth, salinity, suspended sediments, seabed relief) (Leathwick et al. 2012). However, this classification presently does not depict fine scale features such as individual seamounts or biogenic habitats (Bowden et al. 2011; Ford et al. 2016). In this review, BOMECE was examined relative to national and regional data layers, but did not correlate or delineate known biogenic habitats, and was therefore not included in the national or regional maps within this report. However, BOMECE has been examined and reviewed in detail elsewhere (DOC and MPI 2011; Leathwick et al. 2012; Baird et al. 2015; Ford et al. 2016).

2) **Underwater video imagery and seabed characterisations** are regularly collected on a wide range of benthic surveys in coastal, offshore, and deep-sea environments (e.g. NIWA's fibre-optic nearshore CBedcam, continental shelf Coastcam or deep-sea DTIS, respectively), and provide excellent information on the presence, abundance, health, and spatial distribution (at least along each video-transects). Project-specific video-data are presented in this report (where digital data were available) to describe biogenic habitat examples at local/regional scales. However, at present no nationally or regionally combined datasets are available, with most underwater video analysis data stored on a project-by-project basis by relevant agencies and universities.

## 2.4 Data clipping and outliers

For this review, some preliminary data assessments and formatting were undertaken as a necessity, but no formal data integration, QA/QC and grooming was undertaken as part of this project. Many of the dataset provided for this review, have had substantial data grooming (e.g. VME-data, Wood et al. (2013) bryozoan data, NIWA-Inverts). However, the compiled datasets still required some pre-review formatting. Many of the datasets contained a variety of records that lay outside New

Zealand's EEZ (deep-water Collections data e.g. VME-data); had incorrect positional data that plotted marine taxa on the land (AVH, Te Papa, NIWA-Inverts); or contained a variety of data errors, duplicates (within and between datasets, e.g. Many NIWA-Inverts data are included in the Te Papa dataset, while a variety of NIWA-Inverts and Te Papa data are included in OBIS-NZ) or had unexplained positions (outliers representing GPS entry errors). Each dataset was imported into SAS and duplicate records were removed where possible prior to data collation and mapping, or where excessive overlap occurred, the dataset with the least number of records was dropped. Each dataset was then imported as shapefiles into ArcGIS v10.6. To remove any records that plotted up either outside of New Zealand's EEZ or erroneously plotted on the land, each dataset was clipped to a spatial polygon created to encompass all marine areas between the land (based on New Zealand's land raster depicting positive land elevation) and New Zealand's EEZ. Following the removal of these data points, remaining erroneous spatial positions (e.g. macroalgae plotting out in open ocean) were then assessed by specialists and removed where they were deemed to be incorrect (based on expert-knowledge).

## 2.5 Data limitations and bias

National scale data presented in this report are mostly compiled from Museum/Collections databases (>92%). Although these data provide extremely valuable information about the biogeographic distribution of New Zealand's fauna and flora, they also have limitations and biases. Collections data represent presence-only data (no absences) of where a specimen (animal or plant) was collected from, but does not provide data on locations that were searched but where no animal or plant was found. This means that there is no way to determine whether areas not-marked on these maps represent unsearched areas or areas searched where no specimens were found. Some duplicate records were identified and removed, but it is likely that many duplicate Collections records are present within the multiple data sources (e.g. specimen records are frequently shared between agencies, e.g. between NIWA-Inverts, Te Papa and OBIS-NZ). However, this is likely to have little impact for the purposes used here, as duplicate records simply plot over each other and contribute no visual bias in the national distribution plots, however, duplicate records may inflate (by an unknown amount) the total numbers of records for those habitats where they exist.

While presence data definitively identifies the occurrence of habitat-forming species, a single presence record cannot determine the presence of a biogenic habitat (i.e. a single tree may not represent a forest). Collections data also span many decades, and in some cases over a century. While these collections provide the only national-scale information, caution is required in their use and interpretation (Ford et al. 2016). For example, while these collections do provide a valuable record about where biogenic habitats 'do' (recent collections) and 'have' (older collections) occurred, it is unknown whether older collections represent habitats that persist today or no longer exist. Collection effort may also reflect many different surveys targeting different species with different sampling methods over these time scales, therefore comparisons between sites may differ because of the species collected (infaunal worms but no epifauna at one site, compared to sponges and epifauna but no infauna sampled at another site). Where available, the abundance of habitat-forming species has been used to provide stronger evidence of areas likely to support biogenic habitats.

Collections data are also frequently biased towards rare, hard to identify, or new species (i.e. common easily-recognised species are rarely sent to museums for identification), and locations that are easy to access (e.g. specimens from intertidal sites are represented more frequently than subtidal or offshore sites). Many of the data presented here (e.g. NIWA-Inverts and VME-data) include data from a variety of targeted offshore research studies, such as Vulnerable Marine Ecosystems (e.g. such as deep-sea vents, methane seeps, canyons, seamounts and other raised or complex bathymetric features), as well as baseline surveys in areas where oil, gas, and minerals are also

present (e.g. the Chatham Rise and the Kermadec Trench). While these data provide an extremely rich source of presence, abundance, and absence data for many species, they are also inherently biased towards these ecosystems, while other seafloor areas (e.g. deep-sea plains) remain poorly represented relative to their areal availability. NIWA-Inverts also include targeted biogenic surveys undertaken around New Zealand (Jones et al. 2018) to groundtruth a subset of LEK maps (Jones et al. 2016). More information will be known for all taxa at these targeted research sites, while other 'unsampled' areas may be of equal or higher value, but have not been sampled. This is important when determining why species are distributed in a certain way. For example, it is unclear whether the absence of sea pens across the continental shelf is a true absence, or an artefact of low sampling effort across much of New Zealand's continental shelf.

## 2.6 Literature searches

Literature searches were carried out to locate national literature on biogenic habitats for the 15 key biogenic habitats. A substantial amount of information has already been collated during past NIWA reporting and published studies (e.g. covering reviews on biogenic habitats, sensitive marine habitats, vulnerable marine ecosystems, risk assessments, and fishing effects within New Zealand). These provide an important contribution to this report. Other literature searches, included standard marine bibliographic sources (Science Direct, Web of Science, Wiley, Google scholar), and web sites of marine research organisations. The literature search was made using a combination of key words for biogenic habitat [biogenic, habitat and forming, 3-dimensional (combined with 'marine')] and specific descriptions of each biogenic habitat type ('NAME', 'BED FORM', 'NAME + HABITAT' or HABITAT-FORMING or SHELTER or REFUGE or 3 THREE DIMENSIONAL, etc.). For example, seagrass meadows were searched as well as seagrass beds, seagrass habitat, etc.; similarly, kelp forests were searched as well as macroalgae, *Macrocystis*, *Ecklonia*, etc., canopy habitat-forming, seaweed + habitat, etc. Habitats were also searched in relation to other key words, including monitoring, mapping, modelling, predict modelling, climate change, sedimentation, ocean acidification, productivity, temperature, nutrient, New Zealand, satellite, drone/AUV, single beam, multibeam, side scan sonar, Lidar, towed video. New Zealand references also include unpublished data such as National Agency (e.g. NIWA, DOC, MPI) reports, masters and PhD theses, personal communications. The literature search was undertaken between February and May 2018.

Biogenic habitat definitions were sourced from published New Zealand or international literature (where available), but where absent, were based on expert-sourced definitions following the methods of MacDiarmid et al. (2013). MacDiarmid et al. (2013) described and defined 13 sensitive marine benthic habitats, all of which are considered key biogenic habitats in this review.

## 2.7 Condition level and categories

Of the fifteen species/groups covered in this report, only seagrass (*Zostera muelleri*) has been through a formal IUCN Red List<sup>13</sup> Categories and Criteria process. The other 14 biogenic habitats can be classed only as Not Evaluated (NE).

As an interim measure, we have used a qualitative scoring scheme to provide a best estimate of biogenic habitat condition, with the strong caveat that extensive spatial and temporal datasets are not available, and there is a fundamental reliance on expert opinion, general observations, comparative studies, and inference. These are an average at the national scale – specific sites may differ in assessment.

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<sup>13</sup> see [http://www.iucnredlist.org/static/categories\\_criteria\\_3\\_1](http://www.iucnredlist.org/static/categories_criteria_3_1).

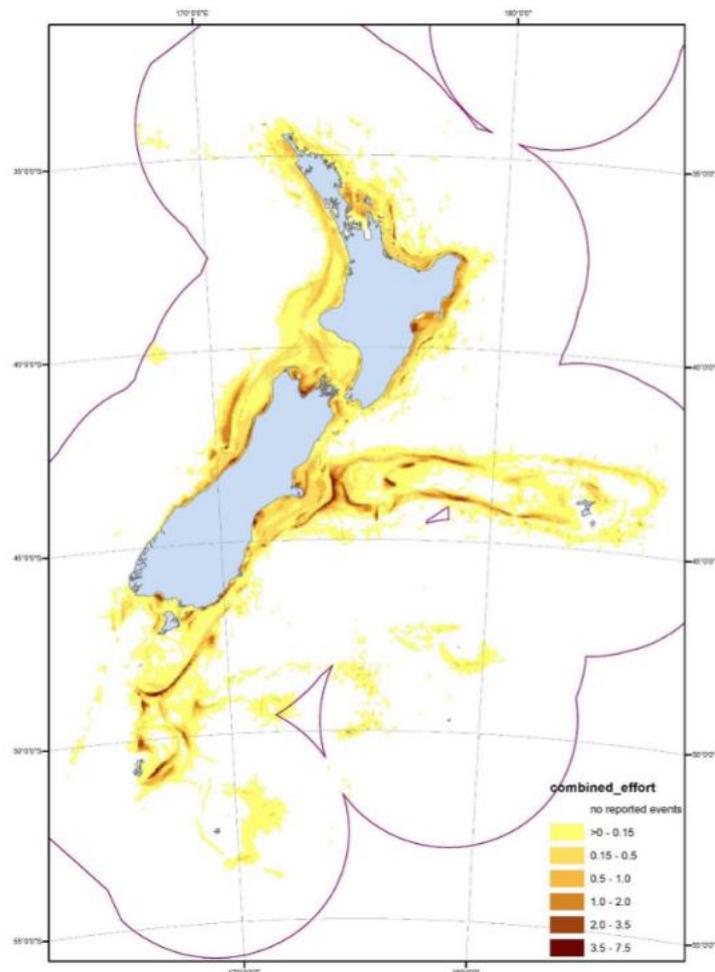
**Table 2-2: Condition indices for spatial, temporal and health of Biogenic Habitats at a national scale.**

<b>CONDITION INDEX</b>	<b>DESCRIPTION/DEFINITION</b>
<b>National coverage</b>	
rare/poor	Fewer than five spatial locations known
sparse	Five to ten locations known, but large gaps in knowledge
some, but patchy	>10 locations, some regional locations known well, but still large gaps
good	Broad geographic coverage, with some locations known better than others
very good	National inventory available (but some important gaps)
excellent	National inventory available and verified
<b>Temporal change</b>	
Increased	Some increases have been recorded (quantified or qualitatively described). May include rank increase (25%, 50%, 75%, 100%, 2-fold, 4-fold etc.)
Stable	Habitat may be dynamic (some increases and decrease) but overall negligible change
Decreased	Some decreases have been recorded (quantified or qualitatively described). May include rank decrease (25%, 50%, 75%)
Complete loss	Habitat may occur in small amounts, but is ecologically/functional extinct (i.e. it's no longer performing it's ecosystem role).
Unknown	Not enough information available to determine temporal change.
<b>Habitat health</b>	
Very good	>90% of individual animals or plants comprising the habitat are healthy looking, with no observed damage, breakage or deterioration.
Good	75-90% of individual animals or plants comprising the habitat are healthy looking, with no systematic signs of damage, breakage or deterioration.
Moderate	50-75% of individual animals or plants comprising the habitat are healthy looking, with consistent signs of damage, breakage or deterioration.
Poor	Large and/or systematic signs of damage, breakage or deterioration, with >50% of animals or plants comprising the habitat in poor health, loss of habitat is also seen.
Unknown	No information is available on the health of animals of plants comprising the habitat.
<b>Ecoservice function</b>	
Very good	Ecosystem services are fully functional
Good	Most ecosystem services are fully functional, but degradation or decline in at least one ecosystem function has occurred
Moderate	Noticeable degradation or decline in some ecosystem functions
Poor	Severe degradation or decline in ecosystem function
Defunct	Habitat is ecologically/functional extinct (i.e. it's no longer performing it's ecosystem role).
Unknown	No information is available to determine the state of services being provided
<b>Trajectory</b>	<b><i>Change in habitat coverage predicted into the future</i></b>

<b>CONDITION INDEX</b>	<b>DESCRIPTION/DEFINITION</b>
Increasing	Increases expected based on present knowledge of threats and stressors and current trajectory
Stable	No change expected as threats of stressors have been removed (through protection or mitigation), or expected based on present knowledge of threats and stressors and current trajectory
Declining	Some decreases have been recorded (quantified or qualitatively described). May include rank decrease (25%, 50%, 75%)
Recovering	Threats and stressors have been removed, with recovery now expected
No-recovery	Threats and stressors continue to repress recovery; or threats and stressors removed but habitat-forming species show no signs of recovery
Unknown	Not enough information available to determine temporal change.
<b>Confidence</b>	<b>Evidence/confidence</b>
Excellent	Spatio-temporal quantitative at national scale
Very good	Spatio-temporal semi-quantitative or excellent description at many locations (but gaps still present)
Good	Spatial and/or temporal descriptions, with some areas known well
Moderate	Some limited data and descriptions available for some locations
Low	Limited descriptive data and indirect evidence, large gaps in knowledge.
Poor	No corroborating evidence

## 2.8 Threats and stressors

Biogenic habitats are often sensitive to and adversely affected by a variety of anthropogenic activities (Bradstock and Gordon 1983, Morrison 2014a). Commercial fishing is common in New Zealand's coastal and oceanic waters, with the most common benthic fishing methods being trawling, shellfish dredging, and Danish seining (Baird et al. 2015). Trawling is carried out throughout the EEZ in waters < 1600 m, particularly in water less than 500 m depth (Figure 2-2); shellfish dredging targets inner shelf oyster and scallop beds; while Danish seines target mixed inshore species such as snapper, gurnard and John Dory.



**Figure 2-2: Fishing intensity (number of times fished, averaged over most recent 5 years available) in New Zealand waters.** Map generated by combining data from Black et al. (2013) and Baird et al. (2015) (Source: Figure 73 from Tuck et al. 2017).

The distribution and intensity of bottom trawling in the coastal and deep-water trawl fisheries within New Zealand is now well described at a 5 km by 5 km grid scale (Baird et al. 2015; Tuck et al. 2017; Figure 2-2) Two spatial data layers on coastal and deep-water benthic fishing effort were provided by NIWA with permission from the Ministry for Primary Industries (MPI). These are used in this review to examine the likely footprint of benthic fishing activity on key biogenic habitats (where known) within New Zealand's EEZ. These included:

- i) **The coastal trawl footprint** of bottom-contact trawling for 2008-12 (Baird et al. 2015) uses fishing data from the Trawl Catch Effort Return (TCER) forms that provide individual trawl positions for vessels under 28 m from 2008 to 2012 for New Zealand waters.

- ii) **The Deepwater trawl footprint** for bottom-contact trawling for 1990-2016 (Baird and Wood 2018) uses data from the Trawl Catch Effort Processing Return (TCEPR) forms that record individual trawl positions primarily for vessels larger than 28 m operating in water depths of >200 m-1600 m for New Zealand waters.
- iii) In addition, a combined '**Fishing intensity**' layer - modelled as the combination of these two data layers (described fully in Tuck et al. 2017; and shown in Figure 2-2) is provided to show the national intensity of benthic fishing activity.

To examine the relationship between biogenic habitats and benthic fisheries pressure, we overlaid fishing effort on known, LEK and predicted occurrence of biogenic habitats (where available). We use these plots in combinations with searched literature and expert opinion to generate a rank of i) the likely impacts from historic fishing activities, and ii) the likely trajectory of impacts to biogenic habitats into the future.

## 2.9 Gap analysis

This report integrates the outcomes of the steps above, including international and grey literature on biogenic habitats (including their key habitat-forming species), GIS data layers, and habitat suitability models for key biogenic (where available) to examine and identify key gaps in the state of knowledge for each key biogenic habitat within New Zealand waters.

## 3 Review of current knowledge

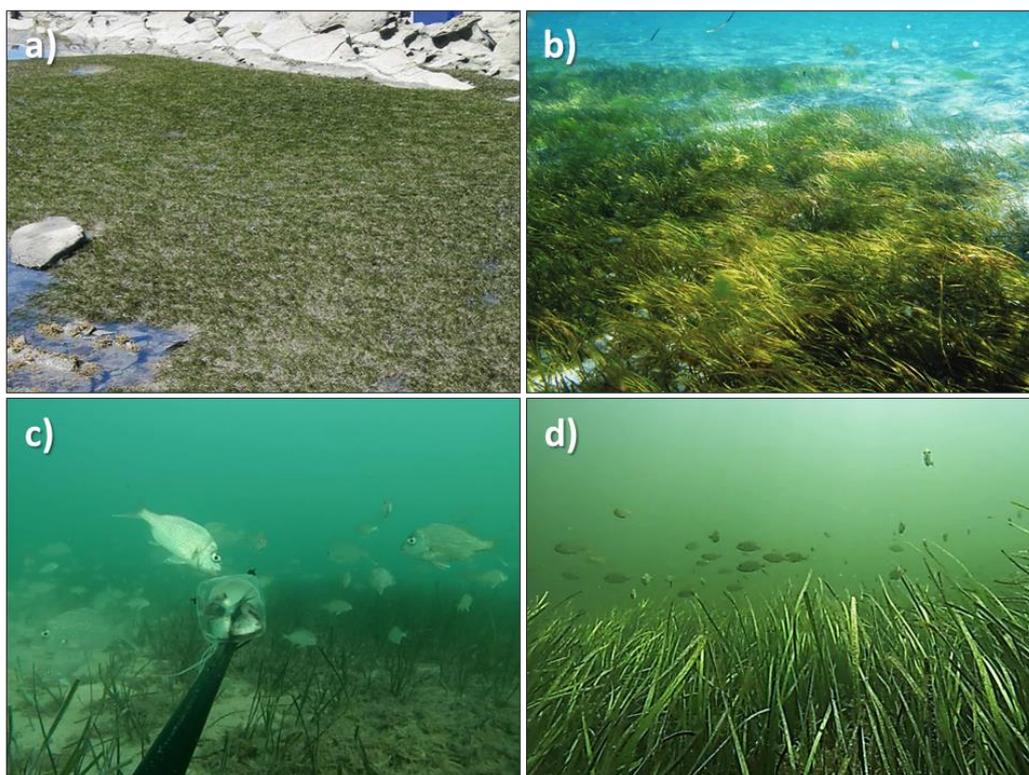
### 3.1 Seagrass meadows

#### 3.1.1 Habitat description and definition

Seagrasses are a unique group of flowering plants that can exist fully submerged in the sea. As a collective group they are globally distributed, with approximately 60 species worldwide, across 12 genera. Seagrass meadows are one of the most productive ecosystems in the world, even more so than coral reefs (Constanza et al. 1997, Grech et al. 2012, Matheson and Wadhwa 2012). They are an important habitat-former in many coastal areas ranging from the subarctic to temperate and equatorial regions and reach their most southerly global distribution at Stewart Island, New Zealand (Hemminga and Duarte 2000, Turner and Schwarz 2006).

The spatial extent of seagrass at a site can range from small patches of only a few metres, up to large expanses covering kilometres, and approaching 100% plant cover. Seagrass grows through the lateral extension of rhizomes and the upward growth of individual blade sheaves. Its main mode of production is clonal rather than sexual reproduction, although flowering plants have recently been discovered in New Zealand (Dos Santos and Matheson 2017). It provides a biogenic habitat function for many species, including both epifaunal and infaunal invertebrates, and more mobile species groups such as crabs, shrimps, small/juvenile fish, and squids (Morrison et al. 2014a).

**Definition:** Seagrass meadows are defined as areas of continuous/dominant (>60%) plant cover, within an area of 10,000 m<sup>2</sup> or more. Areas smaller than this are more appropriately referred to as seagrass patches.



**Figure 3-1: Photographs of a-b) intertidal and c-d) subtidal Seagrass meadows.** a) intertidal seagrass on a rocky shore (Gisborne region); b) intertidal seagrass at high tide (southern Farewell Spit); c–d) subtidal seagrass meadows supporting juvenile snapper nurseries (eastern Bay of Islands and Rangaunu Harbour respectively) (Source of images: a) Jacquie Reed; b) Glen Carbines; c–d, Meredith Lowe).

### 3.1.2 Key species

New Zealand has only one species of seagrass (*Zostera capricorni*), which is indigenous only to New Zealand and southern parts of Australia. Historically, New Zealand specimens have also been referred to as *Z. novazelandica* and/or *Z. muelleri* but now all are synonymised as a single species. The conservation status of this species in New Zealand is At Risk – declining (de Lange et al. 2017).

### 3.1.3 Provision of ecosystem service

Seagrass species are internationally recognised as providing a diverse range of ecological goods and services. Ecosystem services provided by seagrasses include:

- High primary productivity to both detrital and grazing food webs (Keough and Jenkins 1995, Turner and Schwarz 2004, 2006, Connolly et al. 2005),
- Nutrient recycling (see review Turner and Schwarz 2006) and being a significant repository for what is termed “blue carbon” (i.e., as a marine primary producer) (Matheson and Wadhwa 2012), the release of oxygen, and the trapping of nutrients.
- Attenuating water flow (Eckman 1987, Foncesca and Koehl 2006, Widdows et al. 2008), and trapping and stabilisation of bottom sediments (Foncesca et al. 1983, Gacia and Duarte 2001). Increased biodiversity in northern (van Houte-Howes et al. 2004; Alfaro 2006; Schwarz et al. 2006) and southern New Zealand (e.g. Mills and Berkenbusch 2009); provision of refugia from predation and prey availability for fish and macrofaunal communities (Attrill et al. 2000, Hindell et al. 2000, 2001).
- Acts as crucial nursery habitat (including feeding/foraging) for a variety of taxonomic and functional groups, including the juveniles of important recreational and commercial fisheries species, such as snapper (Orth et al. 2006, Grech et al. 2012).

New Zealand research has quantified seagrass-associated meiofaunal (e.g. Hicks 1986, 1989; Bell and Hicks, 1991) and macrofaunal communities (e.g. Henriques 1980, Woods and Schiel 1997, Turner et al. 1999; Schwarz et al. 2006, Morrison et al. 2014a). Subtidal seagrass may support higher macrofaunal density/biomass/productivity than intertidal meadows in both northern (van Houte-Howes et al. 2004; Alfaro 2006; Schwarz et al. 2006) and southern New Zealand (e.g. Mills and Berkenbusch 2009). This may be a result of the large fluctuations in intertidal environmental conditions (i.e. periodic desiccation and fluctuating temperatures), resulting in reduced growth (shorter blade lengths), and lower overall diversity and productivity (Schwarz et al. 2006). In contrast, subtidal environmental conditions are more environmentally benign and stable (i.e. reduced effects of currents/waves; provide shelter from predation; support larval settlement), and are characterized by more complex structure, with higher density and longer stems providing up to 20 times more surface area for epifaunal animals to graze (Schwarz et al. 2006).

Morrison et al. (2014a) sampled both intertidal and subtidal seagrass assemblages around mainland New Zealand. For fish, the subtidal seagrass meadows from northern New Zealand were found to be important juvenile fish nurseries, particularly for snapper and trevally. However, the relative fish nursery value of seagrass meadows varied strongly between seagrass systems; depending upon depth (tidal position), coast, landscape setting and latitude. From Cook Strait south, species such as juvenile snapper, trevally and parore were absent, and species diversity dropped; while spotties and piper continued to occur in high numbers. Down in Southland, the abundances of pipefish and juvenile leather jackets increased. From a strictly fisheries-based view point (i.e., for the higher economic value species of snapper and trevally), this means that northern subtidal seagrass meadows are of much higher economic value. These results showed that the value of seagrass habitat was contextual, being affected by factors such as biogeography and local setting, as well as habitat quality (e.g., seagrass blade height and density, water depth, and patchiness) (Morrison et al. 2014a).

Ongoing 2017/2018 MBIE-funded 'Juvenile fish bottlenecks' research has further confirmed the very high nursery value of northern subtidal seagrass beds as juvenile fish nurseries, in particular for snapper (Figure 3-1) (Morrison et al. unpubl. data). That 5-year research programme is looking at how these nurseries (and other non-seagrass habitat coastal ones) function and what threats they face. In east Northland these subtidal seagrass nurseries are found in Parengarenga, Rangaunu, and Whangarei Harbours, and the Bay of Islands. In the Hauraki Gulf, subtidal seagrass is effectively functionally extinct.

#### 3.1.4 Data sources

- **AVH - The Australasian Virtual Herbarium (Atlas of Living Australia occurrence, May 2018)**, Distribution records were searched for genera "*Zostera*" using location as 'New Zealand'. Records for kelp species presented in this report were extracted in April 2018.
- **New Zealand Estuarine Systems SeaSketch project data** from the New Zealand Department of Conservation, in collaboration with regional councils, visualised for "*Zostera*". Data represents all the estuarine data collated from agencies for Seagrass and Mangroves. Data and maps presented in the current report provide a summary of this standardised information, extracted in November 2018.
- **Kaipara Harbour juvenile fish in seagrass programme data.** Seagrass polygons were provided from the MPI project on the Kaipara Harbour as an area of significance for fisheries (Morrison et al. 2014c).

#### 3.1.5 Biogeographic distribution

##### National scale

A national scale inventory of seagrass for New Zealand has been collated by DOC's SeaSketch project. This includes all available seagrass datasets from around New Zealand. These data include spatial polygons showing the extent of seagrass within coastal areas and includes spatial layers from one, or more, time periods (Table 3-1). As of November 2018, this database represents most large areas of known seagrass and at 294 km<sup>2</sup> (the 'most recent' layers, including those with incomplete metadata) provides the best available estimate of the total extent. This value is likely to be conservative, as it does not include data from smaller areas of seagrass around New Zealand that have yet to be collated (also see below) or have not yet been mapped (e.g. northern Kaipara Harbour<sup>14</sup>). This national seagrass value of 294 km<sup>2</sup> is substantially higher than the previous value of 44 km<sup>2</sup> reported in the UNEP-WCMC database<sup>15</sup>, and while seagrass may have increased in places the very large difference between these values may largely reflect that lack of collected and/or collated spatial datasets prior to November 2018.

One hundred and two seagrass datasets have been compiled, however, only datasets with adequate metadata are included in the final SeaSketch project<sup>16</sup>. As of November 2018, the SeaSketch project includes 48 estuary datasets that have incomplete metadata<sup>17</sup> (23 related to seagrass) that are not be included in the November 2018 national seagrass layers. Missing metadata include i) having

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<sup>14</sup> However, we note that little seagrass is present in the northern Kaipara Harbour (M. Morrison pers. obs.).

<sup>15</sup> UNEP-WCMC, Short FT (2018). Global distribution of seagrasses (version 6.0). Sixth update to the data layer used in Green and Short (2003). Cambridge (UK): UN Environment World Conservation Monitoring Centre. URL: <http://data.unep-wcmc.org/datasets/7>

<sup>16</sup> The SeaSketch project for seagrass and mangroves data was published online in November 2018. See <https://www.doc.govt.nz/nature/habitats/estuaries/our-estuaries/seagrass-and-mangrove-extent/>.

<sup>17</sup> Metadata required for each survey includes the date of survey, name of the estuarine system (e.g. Tauranga Harbour), density, area (ha), IP and a bibliography reference with link to a copy of the report. If density data is included it is being represented visually as three classes (low <20%, medium 20–50% or high >50% or simply as "present").

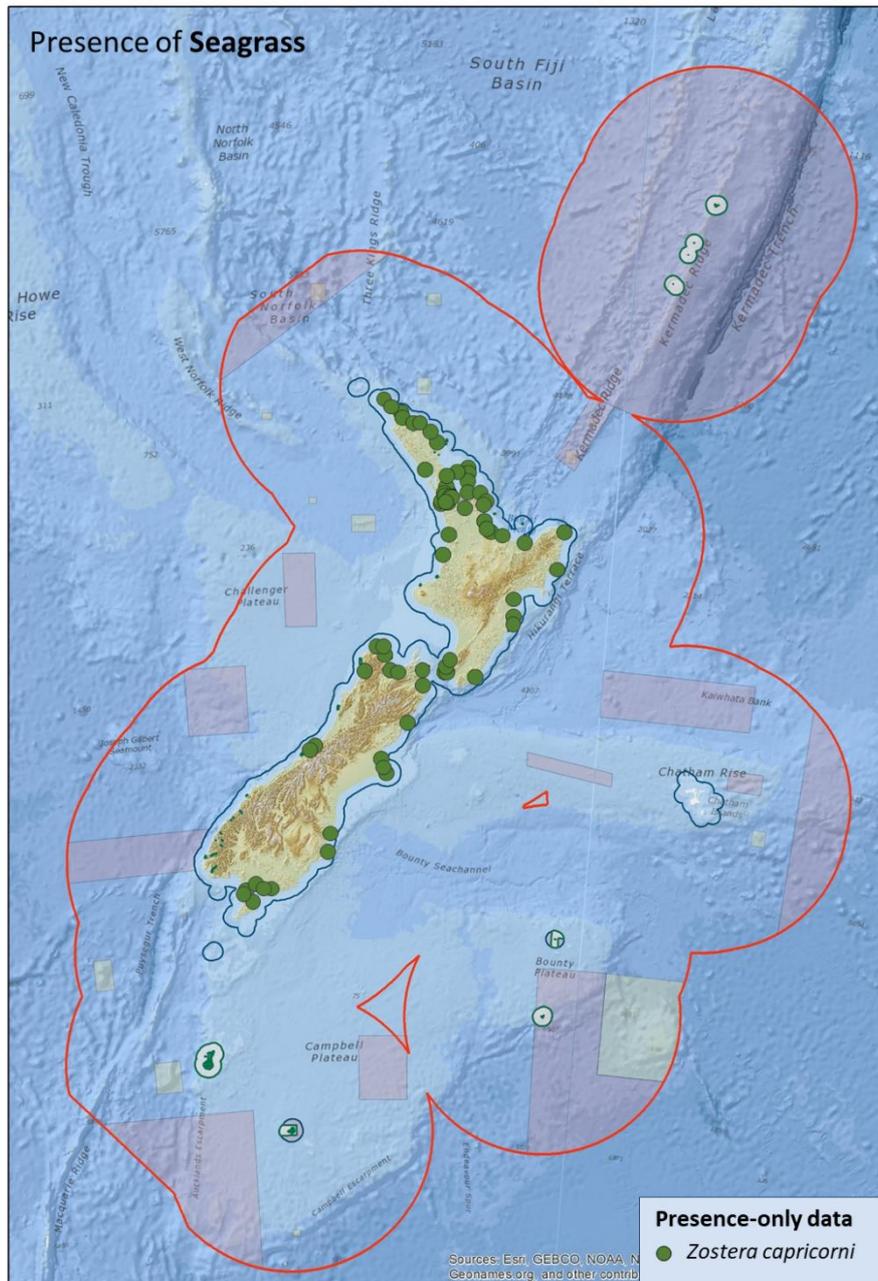
spatial data but missing the associated report reference or no link to it (96%), or ii) unclear reporting about the year of the spatial data layer (4%).

DOC continues to liaise with regional councils to solve these metadata issues and is also aware of some other seagrass and mangrove data that could be added to these national layers. These have been mentioned in reports, or via personal communications, and are for a range of places including Kaipara Parengarenga, Rangaunu and Whangarei harbours, and the Bay of Islands (East Northland); Manukau, Kawhia, and Aotea harbours (west coast North Island); Hawkes Bay; Pāuatahanui Inlet (Wellington), Karamea/Otumahana Estuary (upper west coast South Island) and Otago Harbour. Further resources are required to locate these data layers and add them to the national inventory. In addition, other surveys in a range of estuaries will have been carried out since collating these datasets by regional councils as part of their ongoing monitoring. These data layers will also need to be added to the national inventory.

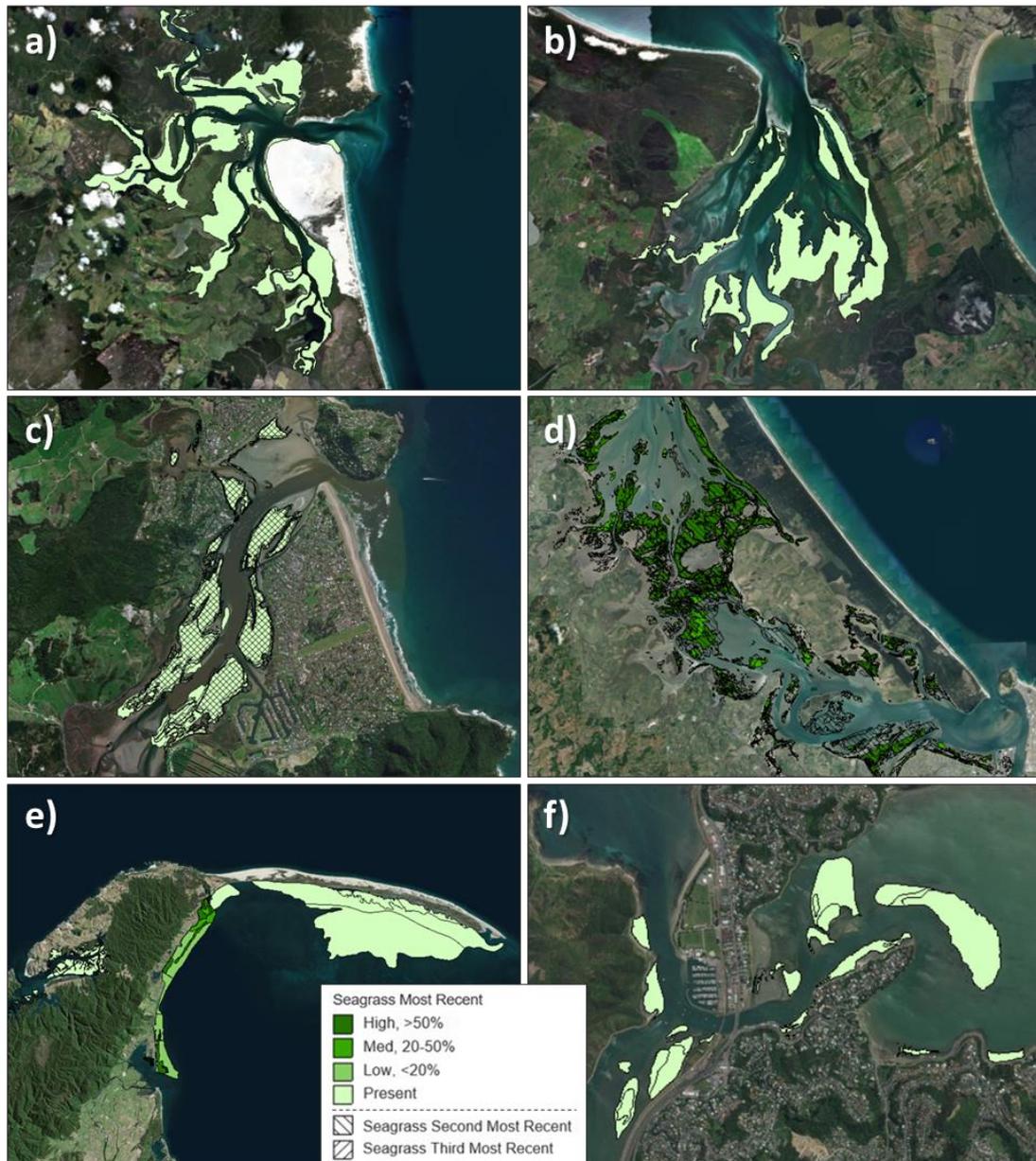
**Table 3-1: Number of seagrass datasets contained within the SeaSketch Programme, held by DOC, November 2018.** These data are irrespective of any missing metadata. Categorised by the number of temporal datasets per estuary (e.g. 53 estuaries have only one associated dataset, 20 have two, and so on).

Number of temporal datasets per estuary	Number of estuaries
1	53
2	20
3	14
4	9
5	1
10*	1
<b>Total</b>	<b>98</b>

\*For Tauranga Harbour only two of the datasets obtained cover the entire estuary, the remaining surveys were of a small arm of the harbour.



**Figure 3-2: Biogeographic distribution of Seagrass (*Zostera capricorni*) around New Zealand, based on presence-only specimen data.** Data presented are sourced from AVH - The Australasian Virtual Herbarium (Atlas of Living Australia occurrence data), April 2018. Red lines = New Zealand’s EEZ boundary, blue line = New Zealand’s 12 nm territorial boundary, red lightly-shaded areas = Benthic Protection Areas (BPA’s), green lightly-shaded areas= seamount closures.



**Figure 3-3: Regional examples of the types of spatial and temporal information from the SeaSketch project on the distribution of Seagrass around New Zealand<sup>18</sup>.** Example regions presented here are: a) Parengarenga Harbour, Northland; b) Rangaunu Harbour, Northland; c) Tairua Harbour, Coromandel; d) Tauranga Harbour; e) southern Farewell Spit, Golden Bay, and f) Porirua Harbour, Wellington region. Data presented are presence, and/or seagrass density from various years, depicted as ‘most recent’, ‘second most recent’ and ‘third most recent’. Imagery provided November 2018.

<sup>18</sup> The SeaSketch project for seagrass and mangroves data was published online in November 2018. See <https://www.doc.govt.nz/nature/habitats/estuaries/our-estuaries/seagrass-and-mangrove-extent/>.

## Regional scale/case studies

Large seagrass meadows remain in east Northland (Parengarenga, Rangaunu, Kaipara harbours, and the recent recovery of large areas in Whangarei Harbour), the upper west coast Northland Island (Aotea and Kawhia Harbours), the Bay of Plenty (Tauranga Harbour), the north-western tip of the South Island (Farewell Spit, Wanganui Inlet), and in Southland (Bluff Harbour; Paterson Inlet, Stewart Island). Smaller beds also exist in many smaller estuaries (e.g., see figure 1 in Inglis 2003), although most are not documented in the scientific literature.

A range of studies on the extent of seagrass have been undertaken, usually within an individual estuary (e.g. Figure 3-3; Figure 3-5; Figure 3-6 and Figure 3-7)<sup>19</sup>, and are now collated within the DOC SeaSketch project as discussed above (e.g. Figure 3-3). Areas supporting extensive, dense and high-quality seagrass tend to be located far away from high-density urban regions (e.g. Parengarenga and Rangaunu Harbours in the far north - Figure 3-3a-b). These two harbours represent some of New Zealand's best examples of dense contiguous seagrass meadows that cover 100s of hectares.

Whangarei Harbour's seagrass meadows have also substantially re-appeared over the last decade, after having been absent since the 1960s following large human impacts (discharge of cement work 'fines', and dredge spoil from port development, see Morrison 2003). Significant beds also occur in the eastern Bay of Islands, and the Kaipara Harbour (Figure 3-6 and Figure 3-7). Further south, other notable beds occur in Kawhia Harbour (west coast Northland), Porirua Harbour north of Wellington (e.g. Figure 3-3f), southern Farewell Spit and Whanganui Inlet in the south-west of the South Island (Figure 3-3e and Figure 3-5); Bluff Harbour at the bottom of the South Island; and Paterson and Cooks Inlets on Stewart Island. Some of the seagrass beds in these areas have been mapped using various approaches, with associated variations in data quality and resolution; most have been one-off studies to answer spatial rather than longer-term variation questions.

## Temporal scale

Reported global seagrass loss has increased almost 10-fold over the last four decades, leading to the conclusion by many seagrass researchers that this plant group is in global crisis (Orth et al. 2006). Waycott et al. (2008) compiled quantitative data from 215 sites covering the period 1879–2006 (including two northern New Zealand sites), encompassing 1128 observations from around the world. They found that seagrass meadows had declined in all areas where data was available (29% of the overall 11 592 km<sup>2</sup>; mean annual decline of 1.5% per yr<sup>-1</sup>), starting from the earliest records in 1879. There were significantly more declines in seagrass meadows than predicted by chance, with a cumulative 3370 km<sup>2</sup> of seagrass being lost (27 km<sup>2</sup> per yr<sup>-1</sup>). Loss rates accelerated over the last eight decades, from a 1% yr<sup>-1</sup> decline before 1940, increasing to 5% yr<sup>-1</sup> after 1980, and to 35% of total seagrass loss occurring from 1980 onwards. Documented causes for these declines included direct impacts from coastal development and dredging activities (21 sites), and indirect impacts from declining water quality (35 sites). Natural processes such as storm damage and biological disturbance were implicated for 6 sites. Conversely, 29 sites had increased seagrass cover attributed to improved water quality and habitat remediation (11 sites), and recovery following storm damage or episodes of wasting disease (Waycott et al. 2008).

New Zealand seagrass meadows, consistent with international studies, have declined in abundance over the last 100 or so years (Inglis 2003, Morrison et al. 2009; 2014a–c). Historical losses in many estuaries, including many presented here, are thought to have been large, although they are poorly documented, and many cases have gone unrecorded. However, evidence of recovery in some areas has also been identified (e.g. Figure 3-4; Figure 3-2).

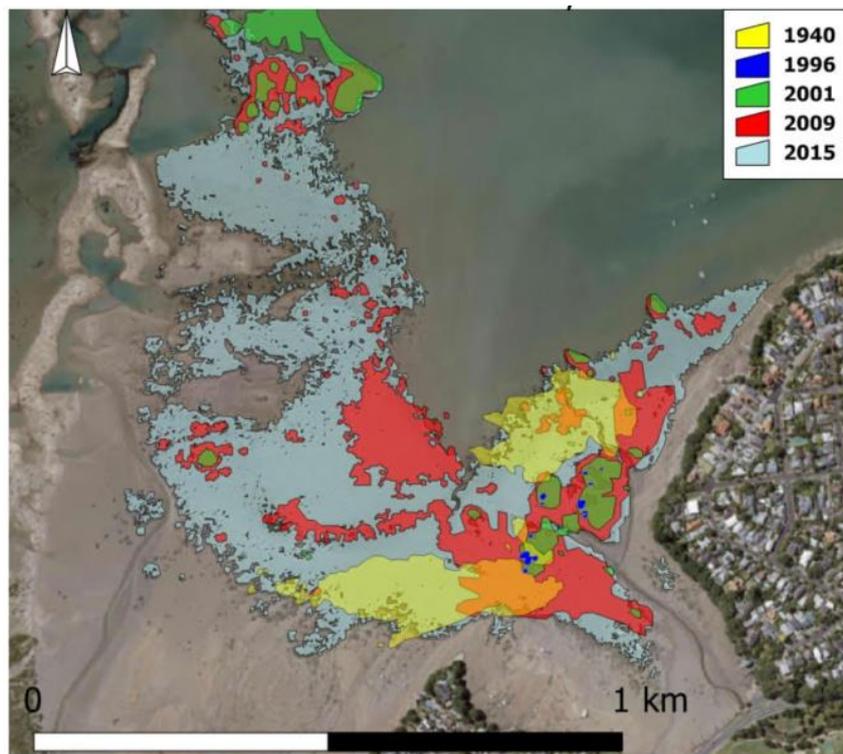
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<sup>19</sup> Note these figures are not proportionally scaled to each other

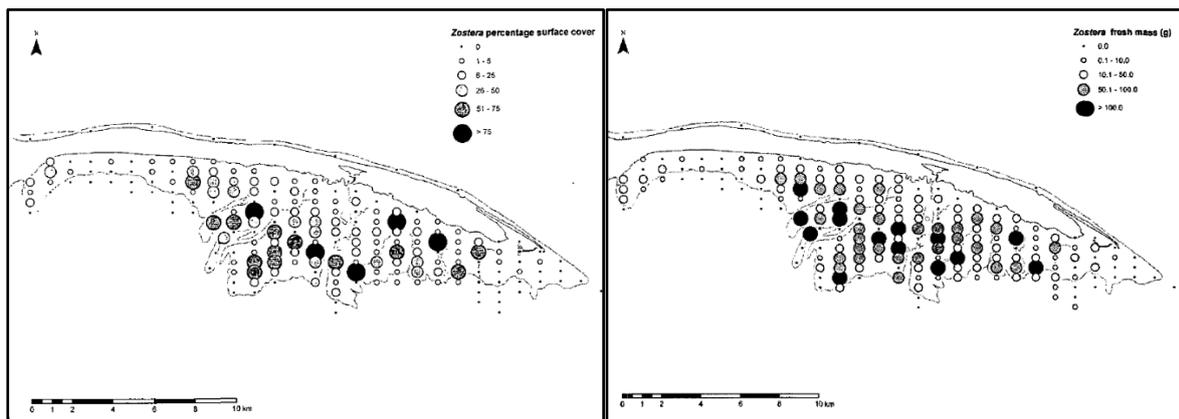
**Table 3-2: Summary of changes in some New Zealand Seagrass meadows.**

Place	Extent/change	Time-scale	Suspected cause	Reference
Whangarei Harbour	Complete loss of 12–14 km <sup>2</sup>	Late 1960s	Dumping of 5 million tonnes of sediment ‘fines’ into the estuary from port expansion and a cement works	Morrison (2003)
	Substantial increase but not quantified (>6 km <sup>2</sup> )	Since 2008	Unknown	See Google Earth imagery 2008–2017
Eastern Bay of Islands sub-tidal seagrass meadows  Mainland bays near Rawhiti (Kaimarama, Hauai, Kaingahoa)  Offshore islands (Otiao, Urupukapuka)	Decline from about 320 000 m <sup>2</sup> to <10 000 m <sup>2</sup> (97% loss)  Little change, 170 000 m <sup>2</sup> seagrass cover	Between 1961 and 2004–05	Nutrient enrichment and land-based sedimentation, boat effluent, grey water discharges (which often contains phosphorus)	Matheson et al. (2010)
Waitemata Harbour	Extensive loss	By 1930s	Port and reclamation work	Powell (1937)
	Increase at Cox’s Bay, from 7.29 to 43.51 ha	1940 to 2015	Not stated	Lundquist et al. <i>in review</i> . (Figure 3-4)
	New areas of seagrass have appeared along beaches on the lower western side of Tamaki Strait (e.g. Kohimarima Bay, outer Tamaki Estuary); limited in extent, only a small subtidal fringe.	Since mid-2010s	Unknown	M. Morrison, NIWA, pers. obs.
Manukau Harbour	“lush beds more than a mile across”	Late 1960s	Not stated	Morton and Miller (1973)
	Some recovery	Mid to late 2010s	Unknown	See Google Earth imagery

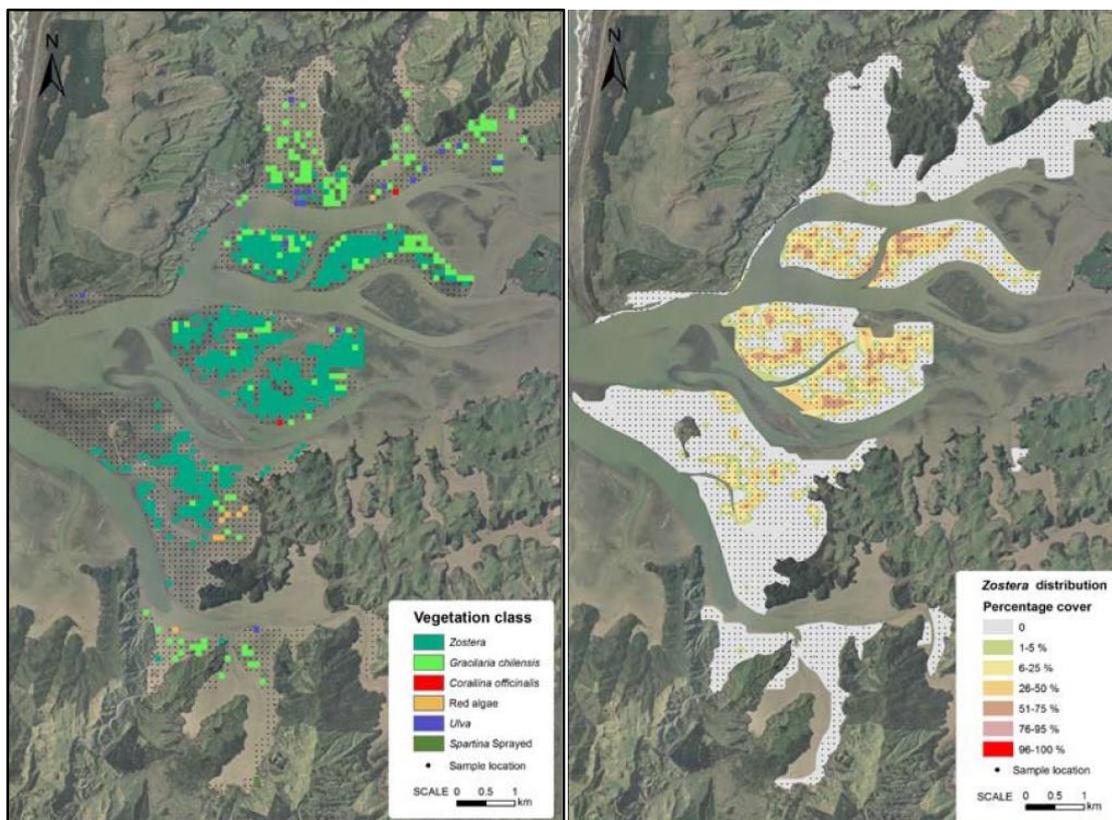
Place	Extent/change	Time-scale	Suspected cause	Reference
Tauranga Harbour	34% of Tauranga's seagrass (and 90% of subtidal seagrass)  Losses before 1959 stated	Between 1959 and 1996	Land-based sedimentation strongly inferred.	Park (1999)
Avon-Heathcote Harbour	Complete loss	Not stated	Not stated	Inglis (2003)
Kaipara Harbour	Increase  Decrease	Since early 2000's  Mid-to-late 2010's	Not stated  Unknown	Bulmar et al. 2012)  See Google Earth Imagery 2018.



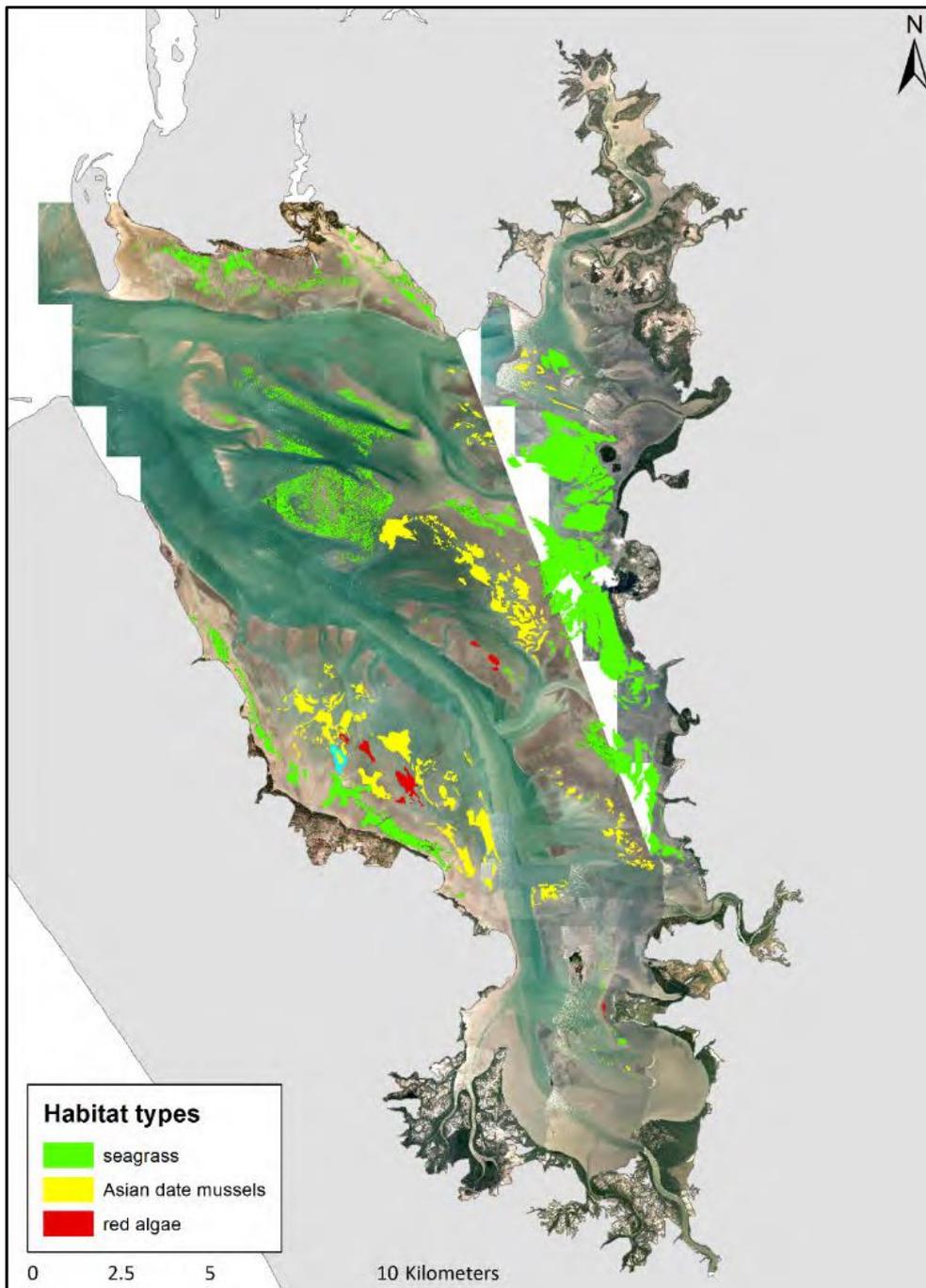
**Figure 3-4: Temporal changes in seagrass cover from 1940 to 2015 in the Waitemata Harbour, Auckland.** Polygons were digitised from aerial photographs, and depict large changes in the extent of seagrass meadows at this location, including a significant loss by 1996 to a significant expansion by 2015 (Source: Figure 1 in Lundquist et al. *in review*).



**Figure 3-5: Southern Farewell Spit seagrass sampled in 2003, using a 1000 x 500 m resolution sampling grid.** Left) percentage surface cover, visually assessed using a 0.25 m<sup>2</sup> quadrat, and a 6-class categorisation scale; right) biomass per 3 x 100 mm cores, expressed as ‘squeezed dry’ wet weights (Figures 7 and 9, from Battley et al. 2005).



**Figure 3-6: Kawhia Harbour seagrass sampled in 2007/2008.** Initial sampling effort was directed by aerial photographs, with a 100-m resolution sampling grid laid over less muddy areas (where the various target species including seagrass were located). At each point, the target species were assessed using a 7-class cover categorisation. Left) vegetation classes; right) density (percentage cover per quadrat) and distribution of seagrass in the sampled areas of Kawhia Harbour, displayed as a raster model based on interpolation of original point dataset (Figures 14, 15 from Hillock and Rohan 2011).



**Figure 3-7: South Kaipara Harbour seagrass sampled in 2011/12.** Three biogenic habitat types were mapped using infra-red imagery, which detects plant pigments. The primary mapping target was subtidal seagrass meadows, which occurred on the central sandbanks of the harbour; this area and the northern sector (intertidal seagrass) were mapped at 0.15 m<sup>2</sup> pixel resolution using infra-red intensity detection algorithms. Intertidal seagrass occurring on the broader surrounding intertidal flats was manually digitised at a much coarser resolution, due to sun glint/glare issues. Asian date mussels (*Arcuatula senhousia*, a non-indigenous species) beds were also mapped, including a subset which were covered with an especially heavy canopy cover (100%) of foliose red macroalgae. Estimated habitat extents were seagrass 20.7 km<sup>2</sup> (c 50% subtidal), date mussels 6.6 km<sup>2</sup>, date mussels with heavy red algae cover 0.6 km<sup>2</sup> (from Figure 89, Table 16, Morrison et al. 2014c).

### 3.1.6 Stressors and threats

*Zostera muelleri* is suggested to be largely an intertidal species, and only extends into subtidal areas where the water quality and clarity are high, allowing it to maintain high photosynthesis rates (Turner and Schwarz 2006). This trait, and seagrass occurrence in regions where human activities are widespread and diverse (e.g. estuary shorelines), makes it particularly vulnerable to human driven stressors and threats. These include:

- Increased suspended sediments and sedimentation, and associated reductions in water column light levels, and overgrowth by epiphytic algae benefit from higher nutrient levels from land run-off preventing adequate light reaching seagrass blades (Inglis 2003; Turner and Schwarz 2006).
- Environmental degradation of coastal areas (e.g. see Turner and Schwarz 2006), including nutrient enrichment from anthropogenic sources (e.g. septic tank leachate, stream and storm-water inflows, water currents moving contaminants, boat effluent, and grey water discharge [which often contains phosphorus], described in detail in Matheson et al. 2010).
- Coastal development, vehicles on foreshores, swing moorings, dredging, and dumping of spoil on or around seagrass meadows (e.g., as described for Whangarei Harbour by Morrison 2003).
- Intensive grazing by black swans (e.g. Tauranga Harbour, Matheson et al. 2008).
- Seagrass beds are also vulnerable to disease. Pathogens have been implicated in seagrass loss, e.g., the slime mould (*Labyrinthula zosterae*) was implicated in the loss of seagrass loss in 1960s in the wider Waitemata Harbour and Christchurch (Armiger 1965; Inglis 2003).
- Climate change impacts such as coastal squeeze, and increased temperature and turbidity (Kettles and Bell 2016).

### 3.1.7 Condition

In 2011, New Zealand's only seagrass species, *Zostera muelleri* (cf was assigned to the IUCN Red List category as 'Least Concern' in an article describing an extinction risk assessment of the world's seagrass species (Short et al. 2011) (but see concerns of Matheson et al. 2011).

Seagrass distribution is widespread within estuaries and harbours, but condition (spatial extent, length of blades and health of plants) is quite variable, with the best seagrass habitats occurring far away from populated urban areas (e.g. Rangaunu and Parengarenga harbours in the far north) (Morrison et al. 2014a). In other areas such as the greater Hauraki Gulf, loss of seagrass beds, particularly subtidal seagrass, has occurred and can be argued to be functionally extinct from within this region. Limited historical evidence suggests New Zealand has experienced extensive declines in seagrass habitats since the late nineteenth and early twentieth centuries (Inglis 2003). However, there is also evidence of recovery in some estuaries and harbours (e.g., Whangarei Harbour, Tauranga Harbour, and parts of the Waitemata and southern Tamaki Strait beaches, DOC's SeaSketch web-GIS project<sup>20</sup>), along with cyclic patterns of increases and decreases over several years (e.g. Bay of Islands, Booth 2018).

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<sup>20</sup> The SeaSketch project for seagrass and mangroves data was published online in November 2018. See <https://www.doc.govt.nz/nature/habitats/estuaries/our-estuaries/seagrass-and-mangrove-extent/>.

**Table 3-3: Overall condition status of Seagrass within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Confidence rating
Decreased 25–50% <sup>1</sup>	Good	Good	Stable/Increasing	Good-Moderate

<sup>1</sup> But some recovery and increases in some areas.

### Overall condition summary

Wide spread seagrass distribution in estuaries and harbours, but condition variable, with best seagrass habitats occurring far away from populated urban areas (e.g. Rangaunu and Parengarenga harbours in the far north) (Morrison et al. 2014a).

Limited historical evidence suggests New Zealand has experienced extensive declines in seagrass habitats since the late nineteenth and early twentieth centuries (Inglis 2003), but there is also evidence of recovery in some estuaries.

#### 3.1.8 Knowledge gaps

A national scale assessment of seagrass extent is currently being collated by DOC’s SeaSketch project. This inventory includes temporal changes in extent and/or seagrass densities of some meadows for some estuaries, but does not currently include information on the health of these seagrass meadows. Data collated and presented in SeaSketch represent the best available data<sup>21</sup>, but does not yet represent a full or systematic survey of New Zealand coastlines. Data provided presently are mostly from local councils, while digitised seagrass layers known from other locations (e.g. agencies and universities) are in many places missing. DOC has identified the difficulty in gaining access to different data layers (e.g. no seagrass polygons were present for the Kaipara Harbour – known for extensive seagrass meadows), and/or the associated adequate metadata for the polygon layers provided (e.g. some polygons were missing the year they were collected, etc.). Many regional seagrass maps showing changes through time that were identified and used in this report, were missing from SeaSketch project, but have now been provided to DOC for inclusion (e.g. Kaipara seagrass layers). Polygon data layers are also variable in the quality of information provided. Some spatial and/or temporal polygons provide spatial extent with no estimates of seagrass density, while other polygons have associated low, moderate or high-density categories. It is hoped that this project continues to be supported to inclusion of i) existing data layers not yet found/provided, ii) inclusion of missing metadata for polygons already provided, iii) inclusion of new spatial and temporal datasets and they are collected by councils, agencies and institutions. With the advent of drone technology collection of aerial imagery is becoming cheaper with routine monitoring of coastal seagrass meadows becoming more attainable for management and research purposes.

<sup>21</sup> Confidence rating is high (2a-b): Consensus among experts supported by unpublished data (not been peer-reviewed but is considered sound), though data may be lacking.

In terms of future research, a review of soft sediment assemblages in New Zealand (Rowden et al. 2012) included a section on seagrass (Schwarz and Sutherland 2012). Their recommendations for future research were:

- Undertake surveys that will establish the current (and as far as possible, the past) distribution of mangrove and seagrass (including subtidal) habitat around New Zealand. Such surveys can be based upon a variety of already available information, but they are likely to also require the acquisition of new data derived using direct (e.g. diver-surveys) and indirect mapping methods (e.g. using aerial photographs).
- Carry out studies of the genetic diversity of seagrass and mangrove populations, as a first step to appreciating the possible ecological significance of any such diversity.
- Determine the spatial and temporal use of seagrass and mangrove habitat by different life stages of fish and 'shellfish' (with an emphasis on commercial species), paying attention to understanding any relationship between fish/shellfish utilisation of macrophyte habitat and the presence of their food items (e.g. epiphytic algae, macrofauna).
- Quantify the production of organic matter by seagrass and mangroves and the subsequent transfer of such matter to other systems, to begin an understanding of their role in marine ecosystem function of these habitats in New Zealand. Examine the dynamics of seagrass recession, mortality, colonisation and expansion processes at the scale of a patch and a seagrass bed as part of studies that attempt to understand the impact of specific anthropogenic activities on seagrass and improve the ability to manage this habitat. Studies that consider the effect of anthropogenic impacts on mangrove habitat should also be conducted.
- Determine the influence of differing nutrient concentrations on seagrass and mangrove growth to understand how regional changes in nutrient inputs to coastal waters will impact these habitats at the 'landscape' scale. An assessment of the influence of likely climate change on the large-scale distribution of these macrophyte habitats could be usefully conducted.
- Using natural markers such as otolith chemistry to assess what proportion of total recruitment these seagrass systems contribute to adjacent coastal fisheries, versus alternative nursery habitats (in the sense of either the Beck et al. 2001, or Dahlgren et al. 2006 approaches) [now underway in the MBIE Endeavour Fund programme 'Juvenile Fish Bottlenecks (COX1618)]
- Determine what specific components of the subtidal seagrass meadows contribute the most (e.g. high blade density sub-tidal fringes, or extensive shallow sub-tidal flat expanses; seagrass habitat edges or interiors), in terms of fish numbers, and growth and survivorship rates.
- Quantify how these seagrass complexes vary over time, both in response to direct human land and marine based activities, and indirect impacts such as storm frequencies and intensities increasing with climate change, as well as through natural long-term cycles (suspected to operate at decadal scales).
- Incorporate the above into habitat landscape models of fisheries productivity
- Estimate the economic value of seagrass for fisheries species, as a per unit area metric (in the sense of Peterson et al. 2003, Blandon and zu Ermgassen 2014).
- Develop a national inventory of seagrass distribution, integrating with a current DOC project assembling data and maps on seagrass [now nearing completion, see above], and incorporating Local Ecological Knowledge (LEK) on historical distribution.

**Table 3-4: Gap analysis summary for Seagrass meadows.**

Type	Description
<b>Distribution &amp; function</b>	A national inventory for spatial distribution, with some temporal data, is now available. Not all seagrass areas are represented, as this has been collated from many sources and different years, rather than being a formal systematic stock-take over a single time period. There is a relatively good understanding of general seagrass physiology and ecological functions, though key knowledge gaps remain (e.g. what are the specific drivers of seagrass recovery and natural temporal fluctuations).
<b>Biological &amp; taxonomic</b>	Only one species is present in New Zealand, but taxonomy under review. Biology is relatively well known.
<b>Management &amp; conservation</b>	Seagrass meadow are not well represented within Marine Reserves. Seagrass occurs in only a few marine reserves (e.g. Westhaven – Te Tai Tapu Marine Reserve - sheltered estuary near Farewell Spit; and Te Angiangi Marine Reserve – rocky platforms in Hawkes Bay). Estuary-focussed marine reserves are rare. Their specific ecological values also vary latitudinally and with coast/setting, these functions are not covered by any form of systematic protection at present. The key threat comes from land-based issues such as sediment and nutrient run-off, which marine reserves do not safeguard against.

## 3.2 Mangrove forests

### 3.2.1 Habitat description and definition

Mangrove forests can range in tree size and density from over 10 m tall, with large-boled trunks (> 1 m circumference) and open under-canopies; through to short shrubs (< 2 m tall) thickets, that form dense, impenetrable thickets. Across their distributional range in New Zealand (see section 3.2.5) there is a general cline of larger trees in the north and shorter and smaller trees in the south. For instance, mangroves in Tauranga Harbour do not exceed 2–3 m in height (Figure 3-8). Large expanses of ‘stunted’ short trees (often about 1 m tall) are also common on high intertidal flats, flanking narrower ribbons of taller and broader trees that immediately flank tidal channels.

**Definition<sup>22</sup>:** For present purposes, mangrove forests are defined as areas of continuous tree occurrence, often forming a canopy, extending alongshore for at least 200 m, and across-shore for at least 50. Areas smaller than this are more appropriately referred to as mangrove patches.



**Figure 3-8: Examples of two different types of mangrove forests found in northern New Zealand.** Growth form: a) short (c. 1.4 m) and dense mangrove trees found along their southern distribution limit, Tauranga Harbour, East Coast; b) tall (c. 6–8 m) and large mangrove trees, Kaipara Harbour, West Coast. Photographs taken by Meredith Lowe, NIWA, and Kerry Webster, NRC) (images sourced from Figure 8 of Morrison et al. 2014c).

### 3.2.2 Key species

New Zealand has only one species of mangrove, *Avicennia marina australasica* which is present in all estuaries on the west coast of the North Island (except the Waikato River mouth) from Kawhia to Herekino, and on the east coast of the North Island from Parengarenga to west of Ohiwa Harbour. *A. marina australasica* is a native species, but also occurs in temperate Australia. Taxonomically, it is viewed as a sub-species with *Avicennia marina* (grey mangrove), which occurs in both the southern and northern hemispheres (Morrisey et al. 2007, 2010). It has been present in New Zealand for at least 19 million years, as indicated by *Avicennia*-type silicified woods associated with lower Miocene rocks from the Kaipara Harbour

<sup>22</sup> Based on expert opinion from the authors of this report, as not previously defined.

### 3.2.3 Provision of ecosystem service

An exhaustive review of ecological information on mangroves in New Zealand was undertaken by Morrisey et al. (2007), followed by a subsequent global review of what is known about temperate mangrove forests (including New Zealand) (Morrisey et al. 2010). These reviews identified a broad range of ecosystem services, including:

- The production of large volumes of organic matter, including leaves, twigs and other woody material, flowers and fruit. Litter production rates for adult trees (i.e., not saplings) vary from 0.61–8.1 t ha<sup>-1</sup> yr<sup>-1</sup>, with the smaller value from stunted (0.8 m tall) plants in Puhinui Creek, Auckland (NIWA and Landcare unpublished data) and the larger from 4 m-high trees in Tuff Crater, Auckland (Woodroffe 1985). The average value for full-size mature trees was 3.6 (SD 2.05) t ha<sup>-1</sup> yr<sup>-1</sup>.
- The in-situ support of benthic invertebrate assemblages. However, the benthic invertebrate fauna of New Zealand's mangroves forests appears to be modest in both abundances and species diversity compared to other estuarine habitats (Ellis et al. 2004, Morrisey et al. 2003, 2007; Alfaro 2006; Lowe 2013).
- The support of terrestrial insects, through these are poorly known. This includes moths, mites, lemon-tree borer, ants, scale insects, spiders and wood lice (Cox 1977, Dugdale 1990, Morrisey et al. 2007)
- Crisp et al. (1990) noted that various geckos have been found among mangroves in northern harbours (particularly Rangaunu and Hokianga), most commonly Pacific and forest geckos (*Hoplodactylus pacificus* and *H. granulatus*).
- Use as habitat by birds. Cox (1977) recorded 12 species regularly associated with mangroves in the Kaipara Harbour: white-faced heron (*Ardea novaehollandiae*), harrier (*Circus approximans*), chaffinch (*Fringilla coelebs*), grey warbler (*Gerygone igata*), Australian magpie (*Gymnorhina tibicen*), kingfisher (*Halcyon sancta*), welcome swallow (*Hirundo tahitica neoxena*), house sparrow (*Passer domesticus*), pukeko (*Porphyrio porphyrio*), blackbird (*Turdus merula*) and silvereye (*Zosterops lateralis*). Species breeding in the mangroves were grey warbler, silvereye, fantail (*Rhipidura fuliginosa*), house sparrow and shining cuckoo (*Chrysococcyx lucidus*) (in the nest of a grey warbler). A further 5 species, including roosting colonies of little black shags (*Phalacrocorax sulcirostris*) and pied shags (*P. varius*), were recorded in mangroves at other locations (Parengarenga, Hatea, Kaipara, Manukau, Waitemata and Ohiva). Other studies also reported bittern (*Botaurus poiciloptilus*) and banded rail (*Gallirallus philippensis assimilis*) mangrove habitat use (Miller and Miller 1991, Cox 1977). Cox concluded that mangroves are generally a marginal habitat for birds, while Morrisey et al. (2007) concluded that the available evidence (across all studies reviewed) suggested that no New Zealand birds are exclusively found in mangroves, but that many species make extensive use of them for roosting, feeding or breeding.
- Sediment trapping. Mangroves enhance sediment accretion by damping currents, attenuating waves and altering patterns of water flow. The presence of mangrove forests encourages the settling of fine silts, clays and organic-rich sediments, which are either transported into the system or produced in-situ from the mangrove plants (Bird 1971, Kathiresan and Bingham 2001, Nicholls and Ellis 2002. Morrisey et al. 2007).
- Erosion protection. By reducing the velocity of currents and attenuating waves mangroves are important for erosion control (Othman 1994, Beard 2006, UNEP-WCMC 2006), and that the horizontal subterranean roots of mangroves have a role in stabilizing sediments (Jennerjahn and Ittekkot 2002).

- There are no invertebrate fisheries species which use mangroves in New Zealand, in contrast with tropical regions, where prawn fisheries are often heavily reliant on mangroves as nursery grounds (e.g., Manson et al. 2005, Nagelkerken et al. 2008). Of note however, the invasive greasy-back prawn *Metapenaeus bennettiae* (likely to have arrived from Australia) appears to be established and expanding in range and abundance in the Hauraki Gulf. Individuals were caught in the Mahurangi, Okura, and Te Makatu estuaries in 2010, and were found to be widespread in deeper coastal areas around east Waikato Island and the western inner Firth of Thames in 2017 and 2018; M, Morrison, unpubl. data, pers. obs.). Reports of catches (targeted recreational) in mangrove dominated tidal reaches of upper Whangarei Harbour have also been made. This commercially and recreationally valued species is likely to continue to increase in northern New Zealand, and may allow for the establishment of a fishery. The role of mangroves in this scenario remains unclear.
- Fish usage. In New Zealand, fine mesh fyke nets were used to quantify small fish assemblages leaving mangrove forests with the falling tide (reviews in Morrisey et al. 2007, 2010). Eight estuaries were sampled, encompassing a (putative) environmental gradient from relatively pristine to heavily modified by human activity, across the east and west coasts. Nineteen fish species were sampled (17 000 individuals in total), with 88 per cent being small semi-pelagic schooling species (mulletts, pilchards, and smelt), while 98% were juvenile life history stages. Four species dominated the catch (92%): yellow-eyed mullet (*Aldrichetta forsteri*), grey mullet (*M. cephalus*), estuarine triple-fin (*Grahamina nigripinne*) and the pilchard (*Sardinops neopilchardus*). Most of the remaining species were demersal fish, including short-finned eels (*Anguilla australis*), parore (*Girella triscuspidata*), sand flounder (*Rhombosolea plebia*) and yellow-belly flounder (*Rhombosolea leporina*). Only occasional individuals of the remaining nine species were caught, including two commercial species (snapper, *Pagrus auratus*, and kahawai, *Arripis trutta*).
- Individual fish species varied in their response to forest and physical environmental variables, with only short finned eels showing a direct relationship with mangrove forest architecture, being positively associated with increasing mangrove habitat complexity (seedlings, saplings and number of trees). The habitat quality (e.g. suspended sediment, water turbidity) and geographical setting of mangrove forests strongly influenced the fish assemblages that they supported, emphasising that it is not just the presence of mangroves *per se* that needs to be considered when assessing habitat functions and values.
- Using the nursery habitat definitions of Beck et al. (2001) and Dahlgren et al. (2006), only short-finned eels, parore and grey mullet occurred in sufficiently high and/or widespread abundance to distinguish mangroves from other estuarine habitats. Based on the consistent and widespread numbers of short-finned eels and parore in mangroves, and low abundance in alternative estuarine habitats (except for subtidal seagrass and brown algae for parore), mangroves were classed as nurseries for short-finned eels (both east and west coasts), parore (east coast only) and grey mullet (west coast only).
- More recent extensive targeted field collections of juvenile grey mullet nurseries identified many additional grey mullet nursery areas, some not associated with mangroves (e.g. Kawhia Harbour), using methods with a much higher probability of detecting juvenile grey mullet. It is now unclear whether juvenile grey mullet have a facultative relationship with mangroves, or simply co-occur in upper estuarine muddy environments in northern New Zealand. Gut content analysis of fyke net caught fish, and of the mangrove benthos, suggests that juvenile grey mullet largely feed on zooplankton swept into the mangrove forests, as well as some detrital material (Lowe 2013), and receive little direct food value directly from in situ mangrove habitat.

- Juvenile grey mullet daily growth rates, as estimated across 14 estuaries, also decline significantly as the proportion of the intertidal flats occupied by mangroves increases (mangrove cover 0 to 50%, growth rate declines by a third,  $R^2 = 0.50$ ,  $P = 0.01$ ), although other factors are also significantly correlated with this growth rate decline (sediment, nitrogen and phosphorus inputs) (Mohd Zain 2014). It may be that a trade-off between shelter from predators (e.g. mangrove forests) and food supply (non-mangrove habitats) is operating; experimental work is now needed to assess the explicit (if any) functional relationships between grey mullet and mangroves.

### 3.2.4 Data sources

- **AVH - The Australasian Virtual Herbarium (Atlas of Living Australia occurrence, May 2018).** Twenty-five records from AVH for the northern part of the North Island were extracted. An additional 43 records (along with 9 historical records where Mangroves no longer occur) are plotted in Morrisey et al. (2007) (see Figure 3-9) and are discussed below.
- **New Zealand Estuarine Systems SeaSketch project data** from the New Zealand Department of Conservation, in collaboration with regional councils, visualised for “*Avicennia*”. Data and maps presented in the current report provide a summary of this standardised information extracted in November 2018.

### 3.2.5 Biogeographic distribution

#### National scale

New Zealand mangroves are confined in their distribution to the upper half of the North Island where they form dense stands and forests along the more sheltered shores of most major estuaries, shallow harbours, lagoons, tidal creeks and rivers north of Kawhia (Figure 3-9 and Figure 3-10). Historically, mangroves extended much further south, with pollen found in sediment cores from Sponge Bay and Awapuni (Poverty Bay), approximately 140 km south of present-day southernmost natural limits (Morrisey et al. 2007; Figure 3-9). In stark contrast to most other countries, New Zealand’s mangroves have expanded in spatial extent over the last 50 years at a significant rate (Morrisey et al. 2010; Lundquist et al. 2017). Mangrove expansion has occurred mainly in a seaward direction over tidal flats (for example in a 117% increase in Tauranga Harbour) (Morrisey et al. 2010; Lundquist et al. 2017).

The Nature Conservation Council (1984) produced a mangrove distribution inventory in 1983, using aerial photography from 1970 to 1983, with an estimated total mangrove extent of 193.43 km<sup>2</sup>. Compared to the current Land Cover Database (LCDB) estimate, there was a 32 km<sup>2</sup> positive discrepancy, which may represent a net increase over the last 20 years (to 2003, Morrisey et al. 2007). However, the LCDB is known to contain errors, as well-established mangroves have been observed in areas where they are absent in the LCDB (e.g., M. Morrison, pers. obs.).

A national scale inventory of mangrove extent for New Zealand has been collated by DOC’s SeaSketch project and includes 103 mangrove datasets. This inventory, published in November 2018, includes temporal changes in extent and/or density of mangroves for most estuaries, but is limited by the same metadata issues of past comparisons (e.g. LCDB areal polygons without metadata, or missing the year collected). As of November 2018, the SeaSketch database represents 215 km<sup>2</sup> of mangroves in the ‘most recent’ layers (including those with incomplete metadata). Metadata required for each survey includes the date of survey, name of the estuarine system (e.g. Tauranga Harbour), density, area (ha), IP and a bibliography reference with link to a copy of the report. If density data is included it is represented visually by three classes (low <20%, medium 20-50% or high >50% or simply as “present”).

As of November 2018, 25 of the 48 estuary datasets that have incomplete metadata for mangroves and are therefore not included in the national SeaSketch layers. Missing metadata include (percentages in the list below are of mangrove data that have incomplete metadata):

- Having spatial data but missing the associated report reference or no link to it (84%).
- It is unclear in the report’s methodology about the year for the spatial data (12%).
- There was not enough information to classify the habitat at an area into the density categories (4%).

**Table 3-5: Number of mangrove datasets contained within the SeaSketch Programme, held by DOC, November 2018.** These data are irrespective of any missing metadata. Categorised by the number of temporal datasets per estuary (e.g. 36 estuaries have only one associated dataset, 31 have two, and so on).

Number of temporal datasets per estuary	Number of Estuaries
1	28
2	30
3	27
4	10
5	0
10	0
<b>Total</b>	<b>95</b>

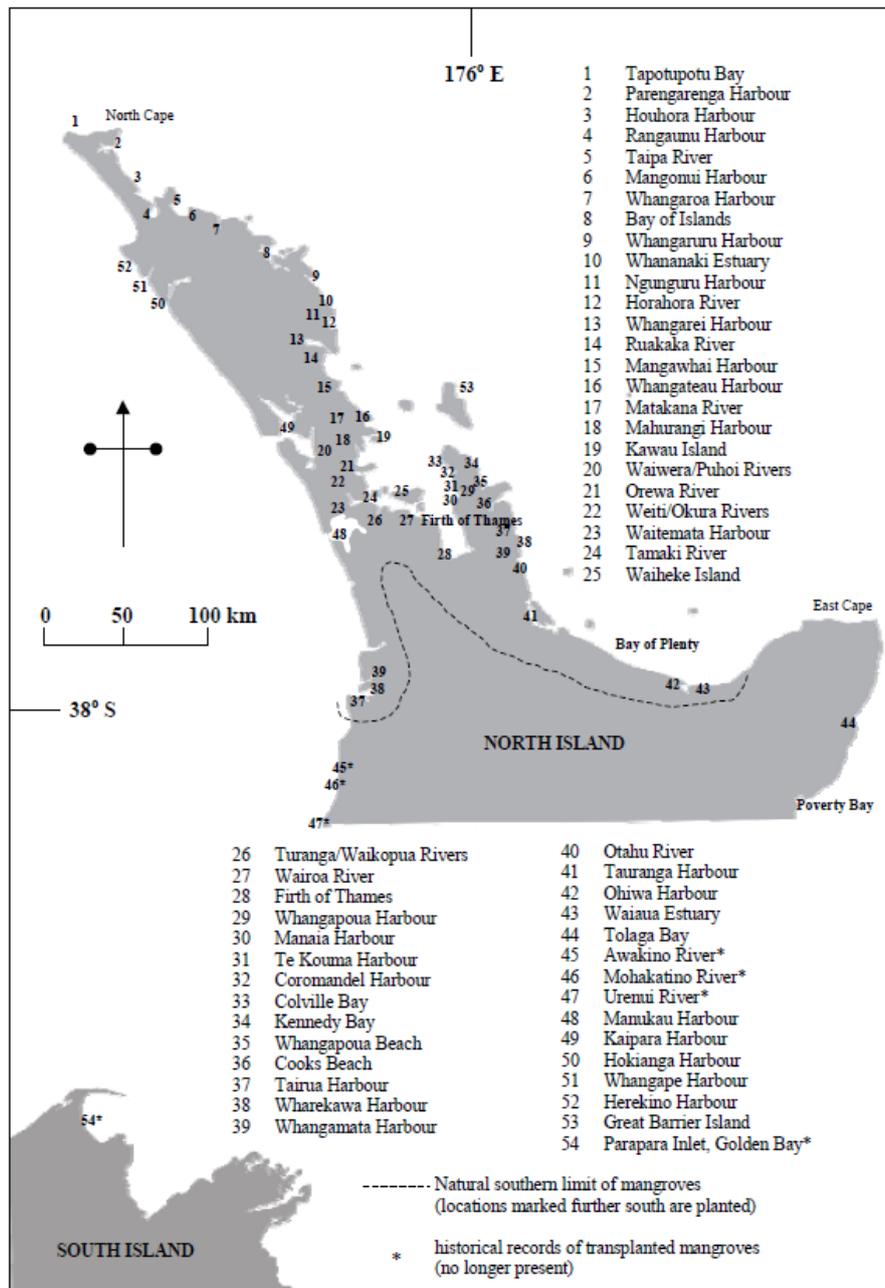
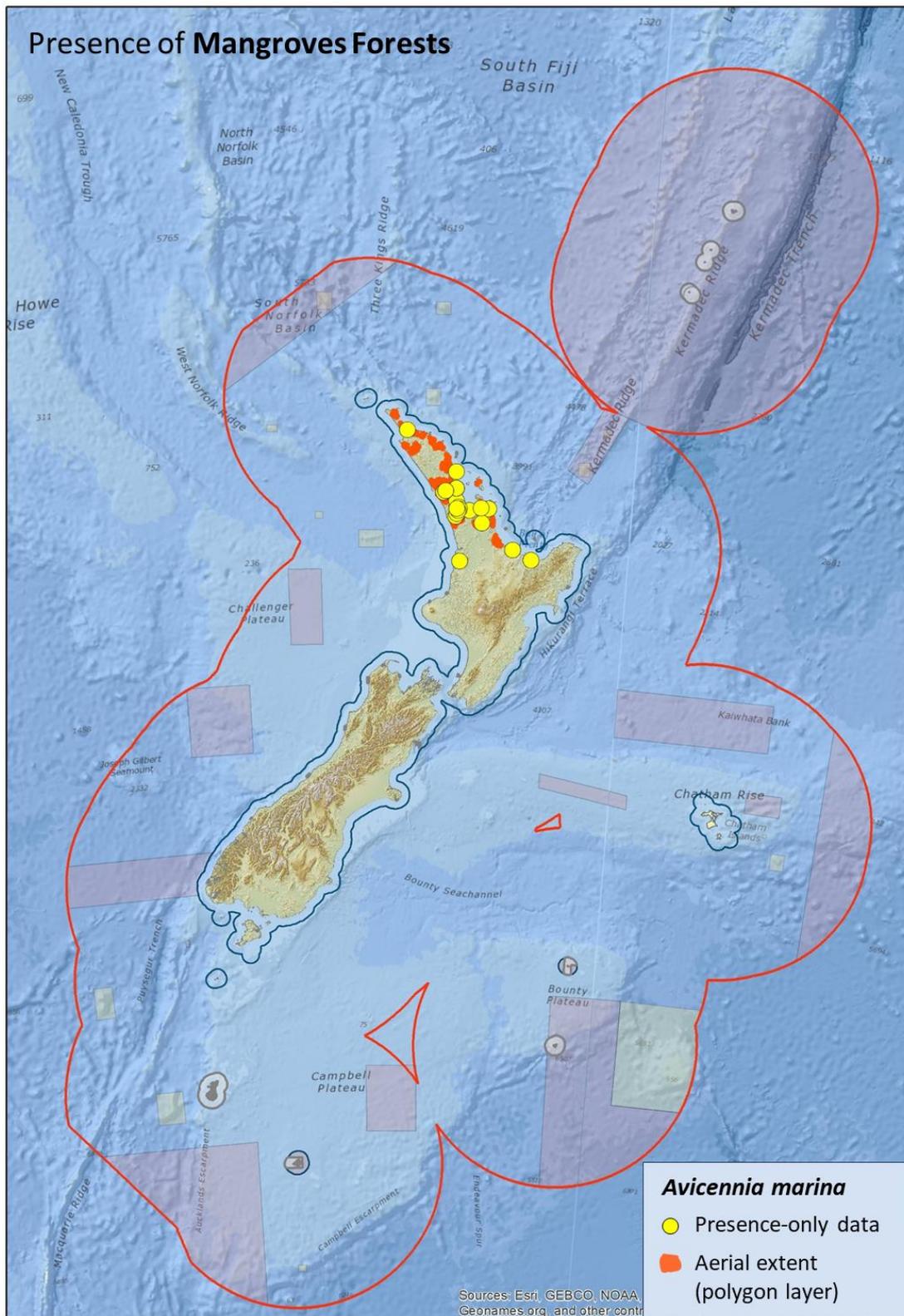


Figure 3-9: Distribution of mangroves in New Zealand, providing detailed list of estuaries and harbours where mangroves have been recorded (after Crisp et al. 1990; Figure 1 of Morrissey et al. 2007).

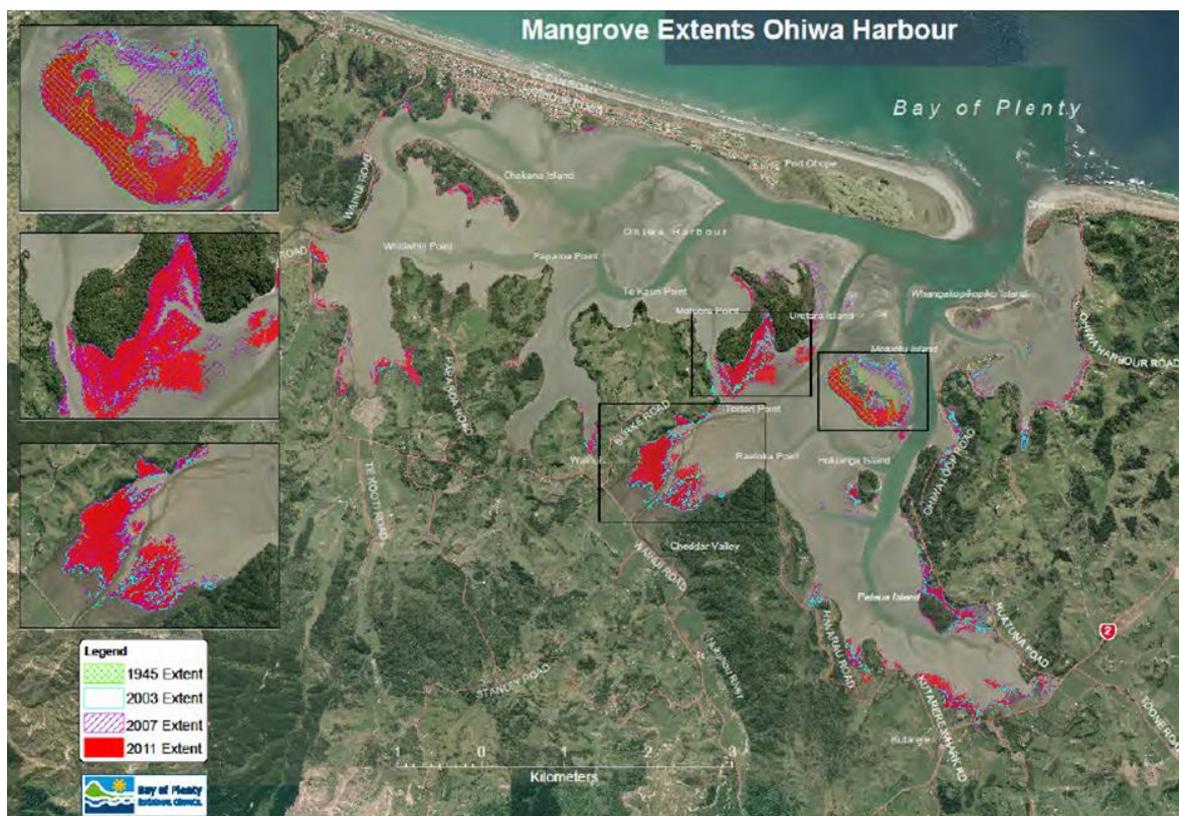


**Figure 3-10: Biogeographic distribution of Mangrove Forests within New Zealand’s marine environment.** Records are presence-only specimen data from AVH - The Australasian Virtual Herbarium (Atlas of Living Australia occurrence data), April 2018.

## Regional scale/case studies

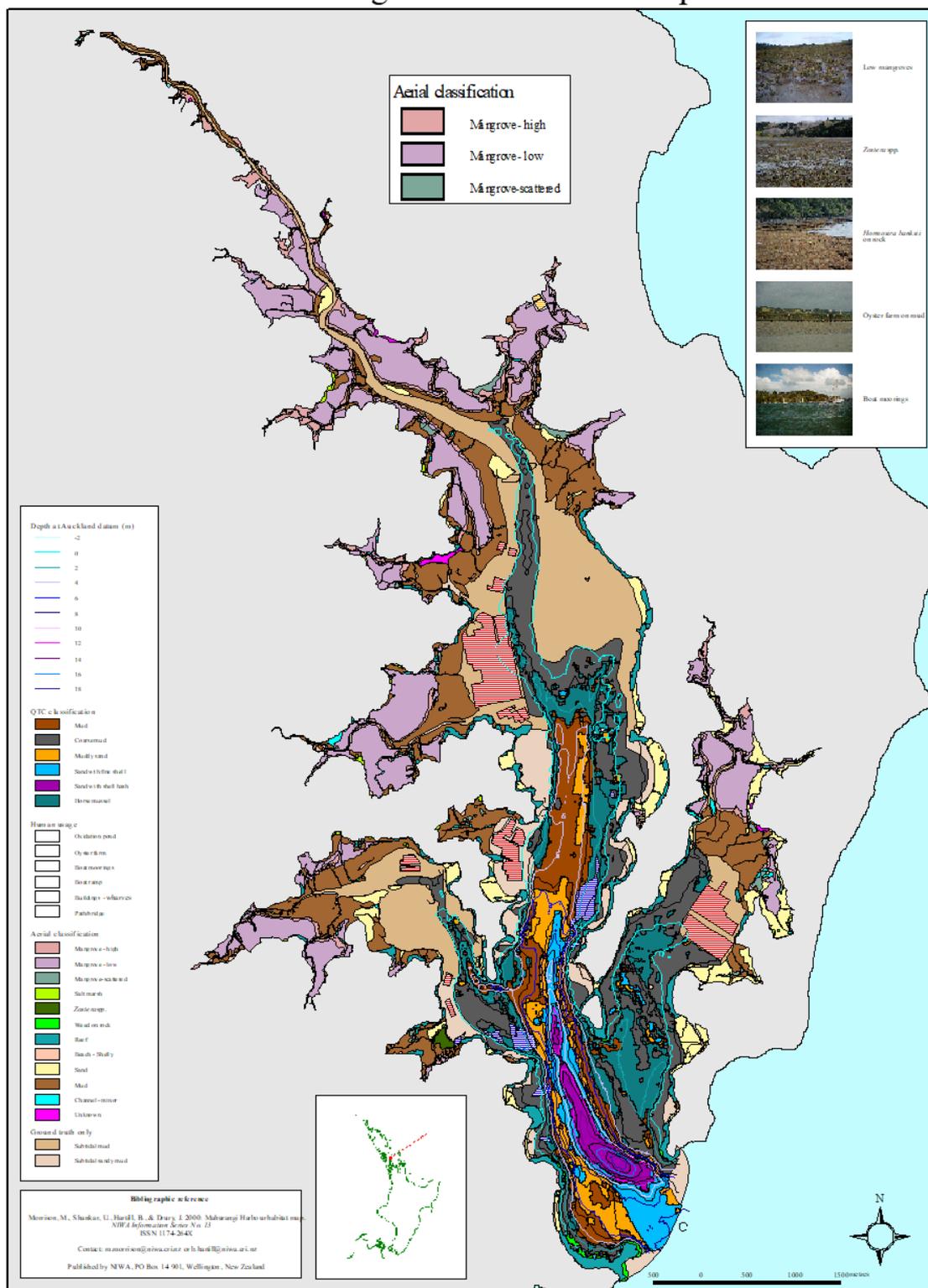
Shallow, low-energy and gently-shelving shorelines are required both for mangrove seedlings to anchor, and for ongoing growth and survival. The preferred substrate type is soft, muddy, waterlogged sediment, but mangroves will also grow on volcanic rock, sand and soil. Seedlings are shade-tolerant up to the end of their cotyledon stage, and high light intensity is crucial for their ongoing development and survival. Further development from this stage may be arrested if conditions are not suitable, with plants remaining in a 'seedling bank' for several years before progressing to the next size class (Morrissey et al. 2007)

Optimal seedling growth occurs in substrates with a salinity range of between 10 and 50‰ seawater, with the photosynthetic performance of adult plants also being affected by salinity. Mangroves can tolerate a wide range of salt concentrations and can grow in waterlogged soils of salinities ranging from 0 to 90 psu. Elevated nutrient loadings (particularly nitrogen) are thought to play a part in the acceleration of mangrove spread in some New Zealand estuaries, by contributing to enhanced growth rates and biomass, and increasing their potential to produce more propagules. However, no conclusive evidence yet exists that nutrients are the main causal factor of the observed expansion. Occasional large-scale die-backs of mangroves can occur naturally, including through the pathogenic fungus *Phytophthora*, and severe winter frosts (Morrissey et al. 2007). Some examples of maps of mangrove distributions are given below, note that these are not proportional to each other (Figure 3-11, Figure 3-12 and Figure 3-13).

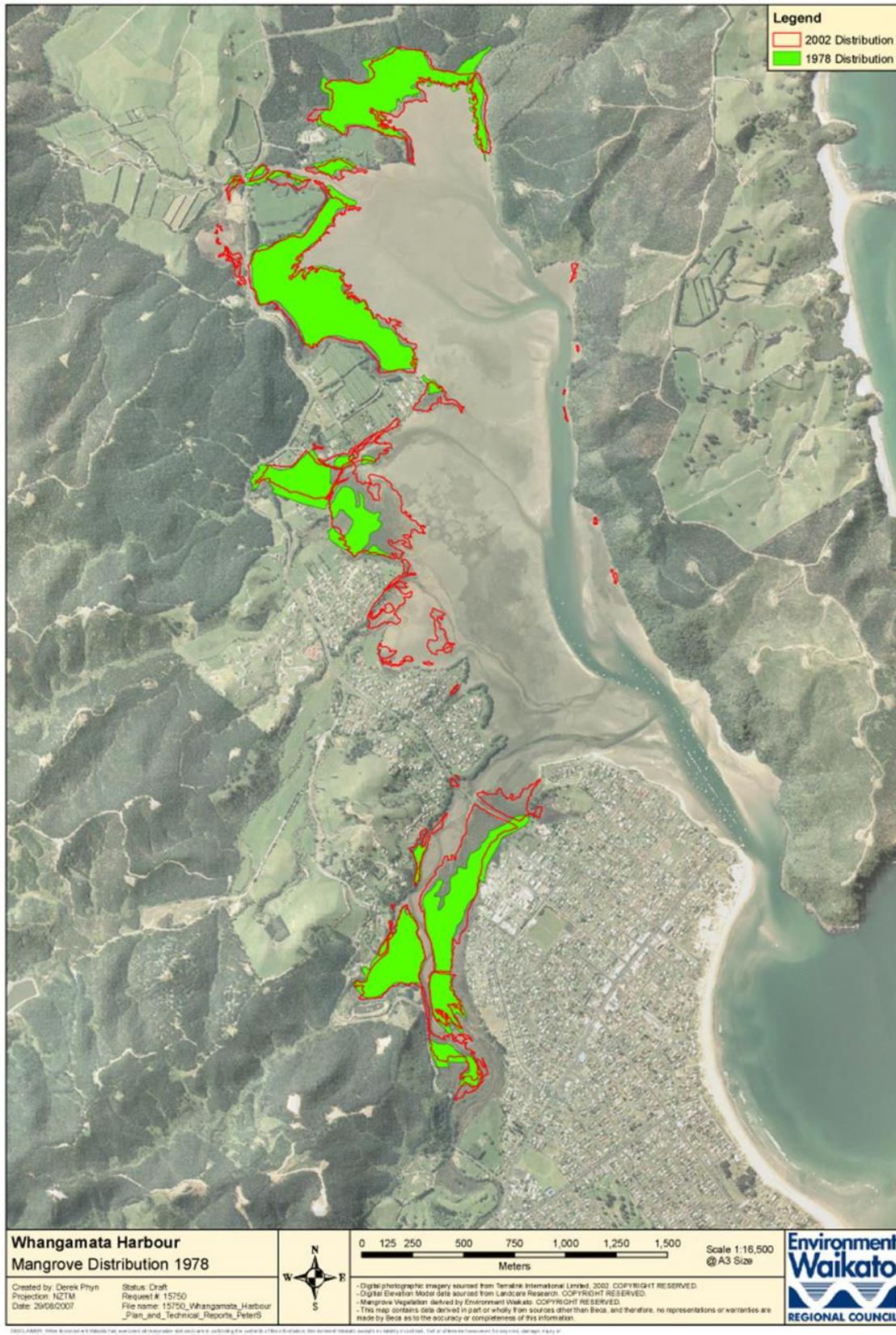


**Figure 3-11: Mangrove spatial extents in Ōhiwa Harbour, Bay of Plenty.** Coloured polygons depict changes in mangrove cover from 1945 up to 2011 with insets showing the Motuotū Island, Uretara Island and Nukuhou River Mouth areas (Figure 4 of Park 2015).

## Mahurangi Harbour habitat map



**Figure 3-12: Habitat map, including mangrove forests, of Mahurangi Harbour in 2000, derived from aerial photography, and acoustic survey (QTC View). Mangroves were digitised into three classes using stereo imagery: high mangroves, low mangroves, and scattered mangroves (Morrison et al. 2000).**



**Figure 3-13: Map of Whangamata Estuary, eastern Coromandel Peninsula, with overlaid mangrove distribution showing temporal changes in Mangrove distribution between 1978 (green polygons) and 2002 (red polylines).** Source: Waikato Regional Council.

### 3.2.6 Stressors and threats

- **Mangrove Loss:** Land-use practices and reclamation of land. There is strong anecdotal evidence that significant mangrove loss has occurred historically at some locations, largely to create farmland, but true losses are unknown (Morrisey et al. 2010). Documented examples include the Hokianga Harbour, where mangrove extent reduced from 6.3 to 2.7 km<sup>2</sup> (57% decline) (Shaw et al. 1990); and in the Manukau Harbour, where mangrove extent reduced from about 5.8 to 4.5 km<sup>2</sup>, between 1955–60 and 1981 (22% decline) (Crisp et al. 1990). From 1977, mangroves were fully nationally protected from infilling (e.g., to create farmland), and since that time clearance of mangroves has been a controlled activity (i.e., consents are required).
- **Mangrove Expansion:** In recent years a great deal of attention has focused on the ongoing expansion of mangrove forests in estuaries, which clashes with some human societal amenity and economic values such as beach access for walking and water activities, house views, boat launching, and the perceived or real loss of alternative habitat types such as sand flats and seagrass meadows. Mangrove clearance is now a permitted activity through changes in some regional council policies, with associated caveats. A new review by Horstman et al. (2018) covers the social and biological issue of mangrove spread and associated control in detail, including the general lack of recovery of systems to the states desired by groups clearing mangroves, and associated unwanted side-effects arising from mangrove clearance.
- **Physiological stress/southern range restrictions:** The main factors limiting the south-ward range of mangroves, appear to be physiological stress. This may include physiological limitations to frost/chilling (non-freezing) conditions, or latitudinal limits set by constraints on internal water transport because of vessel size, and embolism in the xylem vessels following freezing. It is also possible that establishment of plants in suitable microclimates further south of the present limits may be prevented by dispersal barriers (unsuitable coastline) and unfavourable ocean currents (Morrisey et al. 2007).

### 3.2.7 Condition

In recent decades mangroves have greatly expanded in spatial extent in many estuaries, e.g., a 117% increase in Tauranga Harbour over the last 50 years (see Morrisey et al. 2010); and the development of a large forest in the upper Firth of Thames, changing from a wide mangrove-free shelly beach in the 1950s, to a mangrove forest more than a kilometre wide, which is still expanding seawards (Swales et al. 2007).

Even estuaries considered to be in good ecological condition have been affected, with Rangaunu Harbour mangroves expanding by 33% between 1944 and 1981 (Shaw et al. 1990). This forest is the largest in New Zealand at 31 km<sup>2</sup>, and covering 30% of the harbour's intertidal area (May 1999). In combination with the harbour's extensive seagrass meadows, it generates more than 21 000 t yr<sup>-1</sup> of detritus dry weight (May 1999). Whether this production finds its way into trophic food webs that include fisheries is not known. There is still debate on what is driving mangrove expansions, and why, if it is primarily sedimentation-driven, there was such a time lag in response to the widespread historical clearance of land catchments. A detailed discussion of the dynamics of mangrove expansion and drivers in New Zealand, as well as known mapped changes, is given in Morrisey et al. (2007) (see Table 4 for areal estimates). Overall, mangroves can be viewed as one of the very few (if not the only) marine biogenic habitats that is expanding in spatial extent in New Zealand. Given that New Zealand mangroves are at the southern-most extent of their range world-wide and that this is thought to be at least partially controlled by climate, on-going global warming also offers the possibility for them to extend their range southwards (Morrisey et al. 2010).

**Table 3-6: Overall condition status of Mangroves within New Zealand.**

<b>Change in coverage</b>	<b>Habitat condition</b>	<b>Ecoservices Condition</b>	<b>Likely future trajectory</b>	<b>Evidence/confidence</b>
<b>2-fold increase</b>	<b>Good</b>	<b>Good</b>	<b>Increasing</b>	<b>Good</b>

### **Overall summary within NZ**

New Zealand's mangrove forests are common in the upper North Island (Morrison et al. 2010), with spatial coverage increasing nationally (16.5% between 1970 and 1983 - National Nature Council 1984), with expansion of Mangrove forests occurring mostly in a seaward direction out over intertidal flats.

There is strong anecdotal evidence that significant mangrove loss has occurred historically at some locations (e.g. 57% loss in Hokianga Harbour) largely to create farmland, but true losses are not known (Morrisey et al. 2010).

### 3.2.8 Knowledge gaps

The national scale assessment of mangrove forest extent has been collated by DOC's SeaSketch project. This inventory published in November 2018 includes temporal changes in extent and/or density of mangroves for most estuaries, but does not currently include information on the health of mangrove forests. Data collated and presented in SeaSketch along with a published review of mangroves in New Zealand (Morrisey et al. 2007)<sup>23</sup> represent the best available data, but do not yet represent a full or systematic survey of New Zealand coastline. DOC continues to liaise with regional councils to solve these metadata issues and is also aware of some other mangrove data that could be adding to these national layers. These have been mentioned in reports, or via personal communications, and are for a range of places e.g. Kaipara Parengarenga, Rangaunu and Whangarei harbours, and the Bay of Islands (East Northland): Manukau, Kawhia, and Aotea harbours (west coast North Island); Hawkes Bay; Pāuatahanui Inlet (Wellington), Karamea/Otumahana Estuary (upper west coast South Island) and Otago Harbour. Further resources are required to locate these and add them to the existing layers.

Recommendations for future mangrove research has been provided in a review of soft sediment assemblages in New Zealand (Schwarz and Sutherland 2012, within Rowden et al. 2012), and includes:

- Undertake surveys that will establish the current (and as far as possible, the past) distribution of mangrove and seagrass (including subtidal) habitat around New Zealand. Such surveys can be based upon a variety of already available information, but they are likely to also require the acquisition of new data derived using direct (e.g. diver-surveys) and indirect mapping methods (e.g. using aerial photographs), which is expected to become increasingly easier to do using drones instead of expensive aeroplanes.
- Carry out studies of the genetic diversity of seagrass and mangrove populations, as a first step to appreciating the possible ecological significance of any such diversity.
- Determine the spatial and temporal use of seagrass and mangrove habitat by different life stages of fish and 'shellfish' (with an emphasis on commercial species), paying attention to understanding any relationship between fish/shellfish utilisation of macrophyte habitat and the presence of their food items (e.g. epiphytic algae, macrofauna).
- Quantify the production of organic matter by seagrass and mangroves, and the subsequent transfer of such matter to other systems (e.g. using stable isotopes), to begin an understanding of their role in marine ecosystem function of these habitats in New Zealand. Studies that consider the effect of anthropogenic impacts on mangrove habitat should also be conducted.
- Determine the influence of differing nutrient concentrations on seagrass and mangrove growth to understand how regional changes in nutrient inputs to coastal waters will impact these habitats at the 'landscape' scale. An assessment of the influence of likely climate change on the large-scale distribution of these macrophyte habitats could be usefully conducted.

A subsequent national review of the links between biogenic habitat and fisheries production by Morrison et al. (2014a) also made several suggestions for further research, although they identified that mangroves were a lower priority habitat for fish research.

Their specific suggestions were:

- Experimental work to assess if juvenile grey mullet has a positive facultative relationship with mangrove forests: or alternatively whether increases in mangrove coverage of intertidal flats

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<sup>23</sup> Confidence rating is high (2c): Consensus among experts supported by reliable peer-reviewed data or information (published journal articles or reports).

(and/or associated environmental changes) may be adversely affecting the productivity and health of juvenile grey mullet nurseries.

- Combined empirical and modelling approaches to assess whether changing distributions of mangrove provide a net benefit or loss to juvenile fish production, as the habitat landscape shifts within estuaries (mangroves increase, other habitats shrink). This is not a mangrove-specific suggestion, because a range of other habitats would also be included (e.g. seagrass meadows); the question involves all estuarine habitats, and how they operate as a habitat landscape.
- Assessment of whether the provision of mangrove habitat to short-finned eels is significant in the context of the wider freshwater-dominated population habitat dynamics of this species

**Table 3-7: Gap analysis summary for Mangrove forests.**

Type	Description
<b>Distribution &amp; function</b>	National inventory for spatial distribution, with some temporal data is now available. There is a relatively good understanding of the ecological function of Mangrove forests, though knowledge gaps remain.
<b>Biological &amp; taxonomic</b>	Only one species is present in New Zealand, <i>Avicennia marina australasica</i> , with the biology of this subspecies relatively well understood.
<b>Management &amp; conservation</b>	Mangrove forests are well represented within 16 Mangrove reserves as well as several Marine Reserves within New Zealand - most notably Waikaraka Marine Reserve in Whangarei, which protects an area of 227.5 ha, of which almost the entire area is mangrove forest; Te Matuku Marine Reserve on Waiheke Island; and Long Bay - Okura Marine Reserve. Approximately 2000 ha (or about 10% of total mangrove cover) is currently protected. In addition, the Resource Management Act (1991) allows governing bodies to uphold protection of mangroves against indiscriminate destruction and/or reclamation.

## 3.3 Kelp forests

### 3.3.1 Habitat description and definition

Kelp forests have been recognised as the largest biogenic structures in marine coastal ecosystems (Dayton 1985) and the most productive (Mann 1973, Smale et al. 2013). The term ‘Kelp’ refers to brown algae belonging to the order Laminariales (or true kelps), although, often this term includes large brown algae belonging to the order Fucales (or seawracks). The difference is in their reproductive strategies and whether they have two alternate life history phases (Laminariales) or have a direct life history (Fucales). The species that form kelp forests vary in their size, morphology and spatial distributions. Thirteen genera of large brown algae occur in New Zealand, four Laminariales, (including the introduced Asian kelp, *Undaria*) and nine Fucales. Generally, kelp species consist of a holdfast that attaches the plant to the substratum, a flexible stipe and a frond or blade.

In New Zealand, kelp forests of Laminariales and Fucales dominate rocky reefs, from the low intertidal to subtidal zones - 0-15 (25) m water depths - forming lush forests that provide habitats for fish and invertebrates and provides an under-story microclimate for a diverse array of other macroalgae species. Most kelp forests grow on rocky reefs, although some species (including *Carpophyllum* spp., *Ecklonia radiata* and *Macrocystis pyrifera*) can also attach to cobbles and gravel. However, only *Macrocystis* with its progressively massive dome-like holdfast (made up of many branching cylindrical haptera) can consolidate the sediment. Kelp species tolerances to wave exposure vary. *Macrocystis pyrifera* grows in sheltered areas where there is water exchange but no strong wave exposure. *Lessonia* spp., *Marginariella* spp., *E. radiata*, *Landsburgia* spp., can be found subtidally on open coasts, while the hardy Bull Kelp, *Durvillaea* spp., grows in very exposed high-current, intertidal, coastal zones.

Usually shallow subtidal forests comprise multiple species, while *M. pyrifera*, the only species with a floating canopy, can form large beds mostly by itself. In deeper water *Ecklonia radiata* can also form monospecific, dense beds, while most abundant species on the rocky shore are *Durvillaea* spp. (Bull kelp), *Carpophyllum* spp., *Cystophora* spp., *Xiphophora* spp. and *Hormosira banksii*. While most kelps occur in shallow coastal depths, *E. radiata* beds have been recorded in several New Zealand locations in water depths as deep as 90 m – for example in the clear waters on the Mernoo Bank on the Chatham Rise and Ranfurly Bank off East Cape (Nelson et al. 2014).

**Definition:** A Kelp Forest is defined as either a monospecific or mixed-species stand of mature brown algae from the orders Laminariales and Fucales that form complete canopy cover with > 4 adult plants per m<sup>2</sup> (based on Shears et al. 2004; but also see broader description in Schiel 2003). Kelp forest canopies may form either surface canopies (*M. pyrifera*, Figure 3-14a-c) or canopies closer to the seabed (e.g. *E. radiata*, Figure 3-14e) (Schiel 2003).

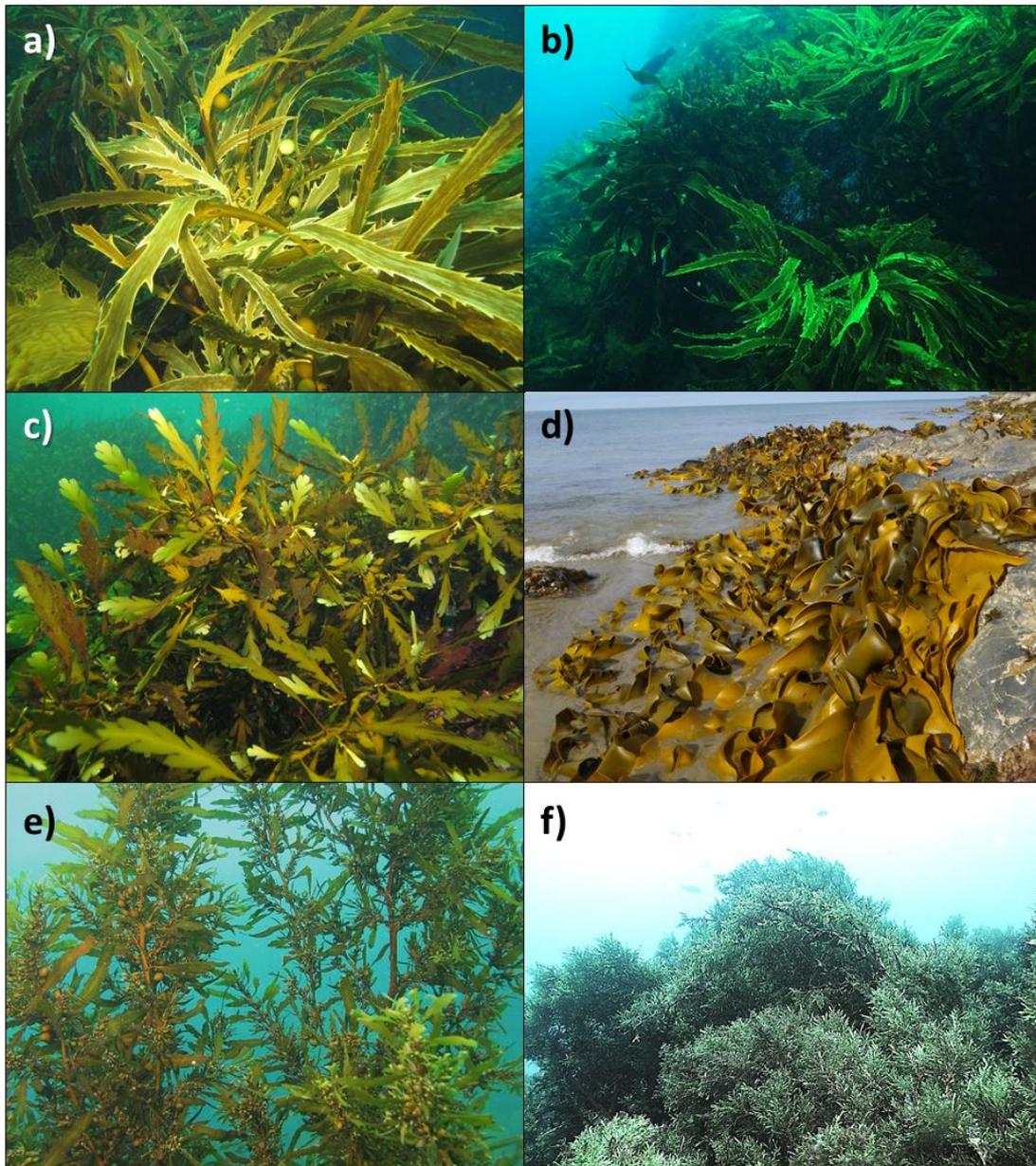
### 3.3.2 Key species

New Zealand has several species that form distinct kelp forests. Key species are:

- *Macrocystis pyrifera* (Brown algae, Order: Laminariales; Family: Laminariaceae)
- *Ecklonia radiata* (Brown algae Order, Laminariales, Family Lessoniaceae)
- *Lessonia* spp. (Brown algae, Order, Laminariales; Family: Lessoniaceae)
- *Carpophyllum* spp. (Brown algae Order: Fucales; Family: Sargassaceae)
- *Marginariella* spp. (Brown algae, Order: Fucales; Family: Seirococcaceae)
- *Landsburgia* spp. (Brown algae, Order: Fucales; Family: Sargassaceae)
- *Sargassum* spp. (Brown algae, Order: Fucales; Family: Sargassaceae)
- *Durvillaea* spp. (Brown algae, Order: Fucales; Family Durvillaeaceae)



**Figure 3-14: Photographs of key kelp-forest species I.** a-c) *Macrocystis pyrifera* (Giant kelp) in Wellington harbour, d) *Lessonia variegata*, e) *Ecklonia radiata* from the Three Kings, f) *Carpophyllum maschalocarpum* from the Wellington south coast. Photographs taken by Roberta D'Archino, NIWA.



**Figure 3-15: Photographs of key kelp-forest species II.** a) *Marginariella boryana* from Port Pegasus, Stewart Island, b-c) *Landsburgia quercifolia* from Fiordland, d) *Durvillaea antarctica* from Bluff (New Zealand Bull Kelp), e) *Sargassum sinclairii* from Wellington south coast, f) *Sargassum johnsonii* from Manawatāwhi/Three Kings. Photographs taken by Roberta D’Archino, NIWA.

### 3.3.3 Provision of ecosystem service

- Macroalgae are photosynthetic plants that utilise CO<sub>2</sub> and are an important primary producer in the nearshore coastal environment.
- Sequestration of organic carbon and long-term carbon storage (Krause-Jensen and Duarte 2016) through the export of material to the deep sea and as refractory, taxon-specific compounds in sediments.
- Kelp forests provide three-dimensional canopy cover to a wide range of flora and fauna, by provision of food and refugia for invertebrates and fish (e.g. paua, rock lobsters, and many fish species) (Foster and Schiel 1985, Choat and Ayling 1987, Choat and Schiel 1982).
- The structure of the plant itself is known to host a wide range of species, within and around their holdfasts (Ojeda and Santelices 1984, Ronowicz et al. 2018), on and in their stipe and fronds host different species (e.g. gammarid amphipods and isopods, Taylor and Cole 1994) or colonial bryozoans and hydrozoans (Hepburn and Hurd 2005). Many species are dependent on kelps (e.g. sea urchins, butterflyfish *Odax pullus* that feed primarily on kelp blades). Very diverse sub canopy flora also depends on the canopy cover provided by kelp forests. A decline in kelp will induce decline in other species including commercial species, such as abalone and rock lobsters (Hinojosa et al. 2014; Wing et al. 2015, Leleu et al. 2012).
- Kelp forests have high aesthetic value for tourism, especially to the diving and snorkeling/free-diving communities and are used by recreational spearfishermen targeting butterflyfish. There is also an important aesthetic value associated with boating, fishing and kayaking around surface-canopies created by *M. pyrifera* (the Giant kelp). Kelp wrack (blades and plants washed up on the adjacent shores – see below) are also collected by local communities to fertilise their gardens.
- Kelp forests are also important nursery and refuge grounds for fish e.g. in Northern New Zealand (from East Cape to the Three Kings) about 130 species of fish occur on rocky reef and associated kelp forest (Francis 1988, Jones 2013).
- Kelp forests can change water movement by physically buffering the wave strength, by slowing water motion (Mork 1996, Gaylord et al. 2007, Stephen and Hepburn 2014); can reduce bottom currents (Jackson and Winant 1983) and will modify the local conditions through the consequences of photosynthetic activity and removal of CO<sub>2</sub> (Cornwall et al. 2015; Hepburn et al. 2011; Raven 2017). A great proportion of this production moves into other trophic levels through the activity of grazers, detritivores and the microbial loop (Krumhansl and Scheibling 2012).
- Drift kelp and kelp wrack may also contribute to productivity across the wider ecosystem (Lastra et al. 2014, Ince et al. 2007 Olabarria et al. 2010). For example, kelp detritus that ends up on the shore is consumed by invertebrates and bird species, and is re-mineralised and made available to nearshore photosynthetic organisms (Duggins et al. 1989; Duggins and Eckman 1994).

### 3.3.4 Data sources

- **AVH - The Australasian Virtual Herbarium (Atlas of Living Australia occurrence, May 2018)**, Distribution records were searched using location as 'New Zealand'. Records for kelp species presented in this report were extracted in April-May 2018.
- **NIWA-internal All-Seaweeds data** extracted for Fucales and Laminariales for coastal New Zealand (data fully presented in D'Archino et al. in press). Data compiled in February 2018.

### 3.3.5 Biogeographic distribution

#### National scale

Kelp forests are widespread around New Zealand, wherever there are suitable substrata (e.g. Schiel 1990; Shears et al. 2004; Shears and Babcock 2007; Nelson 2013), including at Manawatāwhi/Three Kings, Chathams and subantarctic Islands. Some species, such as *Ecklonia radiata*, are very widespread, but because they are common are frequently ignored in floral sampling and hence their apparent distribution is sometimes patchy.

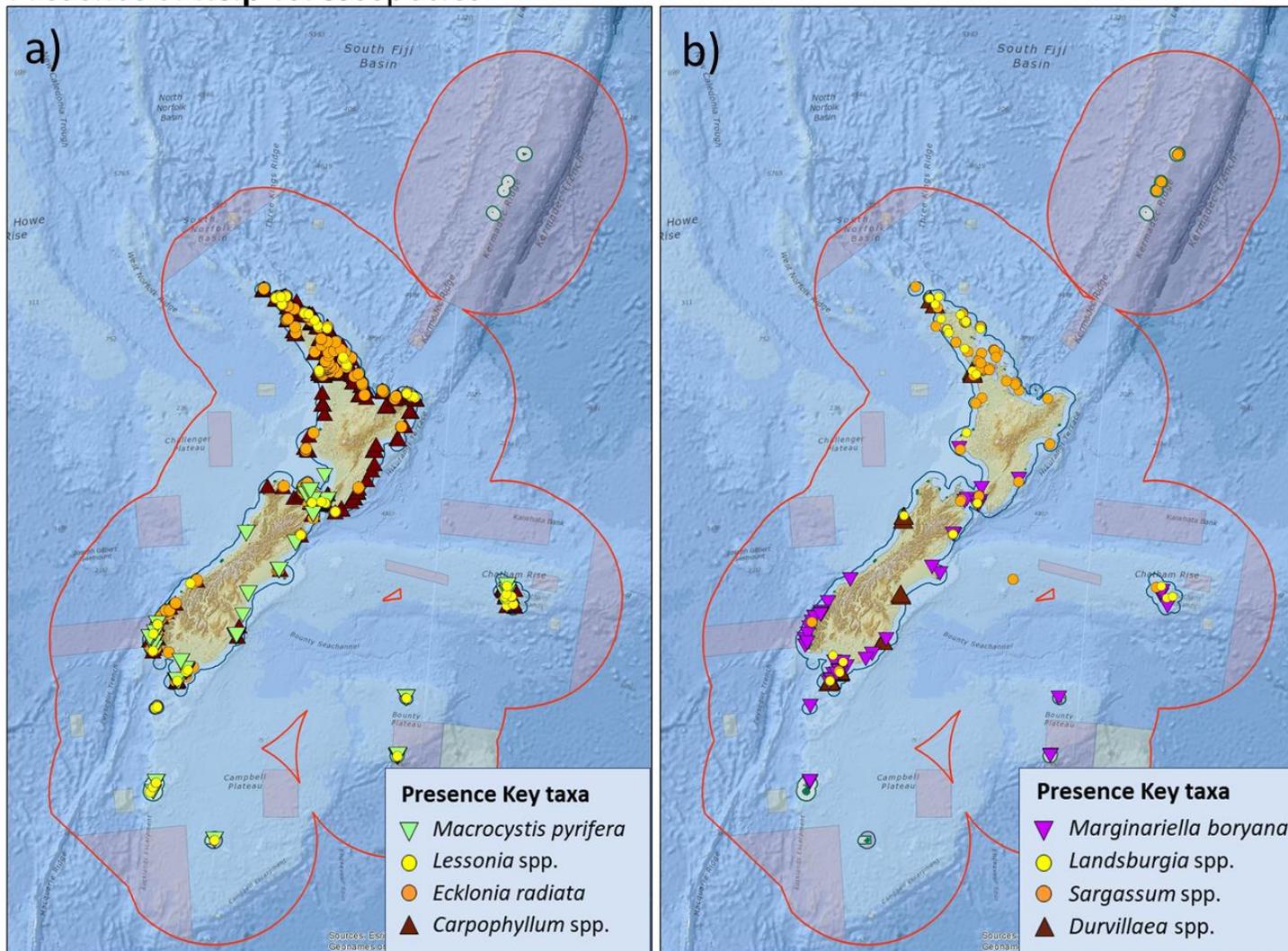
#### Regional scale

Some species have a regional distribution, e.g. *Macrocystis pyrifera* occurs mostly in southern regions (including the subantarctic islands) with its northern occurrence in the Wellington region. Similarly, *Marginariella urvilleana* and *M. boryana*, are mostly southern species with their northern limits in the Cook Strait up to southern Taranaki and the Wairarapa. Examples of northern species are *Carpophyllum angustifolium*, *C. plumosum*, *Sargassum scabridum* and *Xiphophora chondrophylla*. Some species have restricted distribution e.g. *Landsburgia ilicifolia* and *Sargassum johnsonii* which are only found at Manawatāwhi/Three Kings Islands, while *Lessonia tholiformis* and *Landsburgia myricifolia* are found solely at the Chatham Islands.

#### Temporal change

While inter-annual surveys have been undertaken around the New Zealand coast (e.g. Choat and Schiel 1982; Schiel 1990; Shears et al. 2004; Shears and Babcock 2007), except for some specific locations the size of kelp forests have rarely been mapped and monitored. Areas that have been mapped have mostly occurred within coastal marine reserves, such as Ulva Island – Te Wharawhara Marine Reserve (Haggitt 2015); Long Island marine reserve (Haggitt 2017; Kapiti Island Marine Reserve (Laferriere 2016), Okakari point to Cape Rodney Marine Reserve (Ayling 1978; Leleu et al. 2012). However very few mapped habitat areas have been resurveyed to examine the degree of habitat change in time and space. One example where this has been done is within the 'Okakari point to Cape Rodney Marine Reserve' in north-eastern New Zealand. Habitats including kelp forests (or *Ecklonia* forests) were first mapped in 1978, with plant densities of 8 per m<sup>2</sup> in 10-18 m depth zone, with 20-60 plants per m<sup>2</sup> in some localised areas (Ayling 1978). Kelp forests then, were estimated to cover 41.98 Hectares within the Marine Reserve (45.9 ha in total for inside and outside the marine reserve), comprising 7.64% of the total reserve and 29.8% of subtidal rock within the reserve. By 2006, kelp forests had more than doubled to cover 60% of subtidal rock, with areas of new kelp forest expanding out and replacing areas previously mapped as urchin barrens (Leleu et al. 2012; Table 3-8).

## Presence of Kelp-forest species



**Figure 3-16: Distribution of key Kelp forest species around New Zealand, based on presence-only data of identified specimens from NIWA's Seaweed collection. a-b) Kelp species included in these plots are shown in the respective legends.**

**Table 3-8: Total surface area (ha) of habitats mapped between 1977 and 2006 within the Okakari Point to Cape Rodney Marine Reserve.** Habitat area includes inside and outside the reserve. (Source: Table 4 from Leleu et al. 2012, which includes 1977 values from Ayling 1978).

	1977	2006
<i>Ecklonia</i> kelp forest	45.9	96.1
Mixed algae, shallow <i>Carpophyllum</i>	35.1	30.2
Urchin Barrens	44.7	4.5
Algal turf, crustose, coralline	12.0	17.1
Sponge Garden	7.1	6.6
Deep Reef	6.6	8.0
Sand, shell, pebbles, gravel	836.0	965.8

### 3.3.6 Stressors and threats

- Large regional scale climatic changes that effect coastal water temperate, such as El Nino effects and upwelling events, can stress plants overs large spatial scales (Cole and Syms 1999). Storms can remove plants over moderate-sized areas. Kelp forests are likely to be very vulnerable to climate change e.g. increase in temperature, increase of catastrophic events and climate variability. The effects of increasing global water temperatures have already being witnessed for *M. pyrifera* along eastern Tasmania (Johnson et al. 2011). Loss of kelp forests are likely to have substantial and possibly catastrophic consequences on species associated with these habitats (Edgar et al. 2004, Teagle et al. 2017).
- Kelp forests are also likely to be affected by future acidified ocean conditions (Law et al. 2017)
- Increase of sediment and turbidity will decrease the sunlight available for the photosynthesis.
- Kelp forest decline and loss can also result from increased densities and higher grazing pressure from the common sea urchin (*Evechinus chloroticus*) (Andrew and Choat, 1982; Shears and Babcock 2002), where the number of urchin predators (e.g. snapper, bluecod and spiny lobsters) are low (Shears and Babcock 2003). Removal of predatory fishes and crayfish from our coastal ecosystems, is linked with increased densities of urchins resulting in a shift from kelp forest dominated reefs to urchin barrens (Krumhansla et al. 2016). In contrast, inside marine reserves where predatory fish numbers are increasing, urchin numbers are declining and replacement of urchin barrens with kelp forests has been recorded (Leleu et al. 2012; Shears et al. 2014).
- Harmful algal blooms: Outbreaks of some toxic algal plumes during warm weather events can cause cell-wall failure, resulting in death of forest-forming macroalgal species (e.g. *Ecklonia* and *Macrocystis*), and are known to decimate affected kelp-forests, e.g. Seatoun, Wellington 1998 and 2001 events (Chang et al. 1999; Chang pers. comm. to T. Anderson). Increases in global water temperatures would likely see the rise in these events.
- Other threats and stressors include: pollution and the spread of invasive species.

### 3.3.7 Condition

- In other parts of the world, decline or loss of kelp and Fucales have been documented in temperate and subtropical marine ecosystems, particularly on urbanised coasts, e.g., *Phyllospora comosa* (Labill.) C.Agardh around Sydney, decline of *Ecklonia radiata* (C.Agardh) J.Agardh around Adelaide, the giant kelp *M. pyrifera* (L.) C.Agardh around eastern Tasmania (Johnson et al. 2011), loss of Fucales along the Albères coast, Mediterranean Sea (Thibaut et al. 2015), losses of *Sargassum* species from the Sunshine Coast, Queensland.
- D’Archino et al. (2018) have recently reviewed the state of knowledge about kelp forests in New Zealand and highlighted the lack of baseline data necessary to assess whether declines in kelp forests have already occurred. Hay (1990) showed an easterly retraction of *Macrocystis* distribution within the Marlborough Sounds since 1942 and linked it to a slight increase in water temperature. Currently the decline of *Macrocystis* in New Zealand is mostly anecdotal but has been noticed by paua divers and members of the public. The decline of shallow-reef kelp community has been documented in the main basin of Bay of Island where has been replaced by extensive areas of sea-urchin barrens (Booth 2017).

**Table 3-9: Overall condition status of Kelp forests within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Stable (some local losses <sup>1</sup> )	Good	Very good	Stable <sup>2</sup> (but vulnerable)	Good

<sup>1</sup> E.g. losses of *M. pyrifera* have occurred within Tory Channel and other locations in the Marlborough Sounds

<sup>2</sup> Stable under current conditions, but Kelp forests (especially *M. pyrifera*) vulnerable to climate change, with losses predicted to occur as ocean temperatures increase (as already seen in Australia).

#### Overall summary within NZ

Widespread distribution in low intertidal and subtidal rocky reefs, providing essential ecosystem services, from northern New Zealand to the Subantarctic Islands. Possibly some species maybe declining at local to regional scales, but overall kelp forests are in good condition and remains one of the most productive biogenic habitat in New Zealand.

Climate change/increasing ocean temperatures likely to directly impact kelp forest distributions.

### 3.3.8 Knowledge gaps

- Kelp forests in New Zealand are relatively well documented in the published literature (e.g. Shears et al. 2004; Shears and Babcock 2007). However, data available at the national scale are limited to mostly presence-only data (with no absences), with often poor representation of common and easy to recognise habitat-forming species such as *Ecklonia* and *Macrocystis*. There is currently no national scale inventory on the abundance or extent of kelp forest habitats around New Zealand.
- Maps of the spatial extent of kelp forests are rare. Recent aerial mapping surveys using small drones has been successfully undertaken to map the spatial extent of nearshore kelp forest (*M. pyrifera*) at several sites on the south coast of Wellington (D'Archino et al. NIWA unpublished data) and Marlborough Sounds (DOC unpublished data). This approach shows great promise for mapping nearshore kelp forest, particularly for *M. pyrifera*, which forms surface canopies. However, this approach is limited to clear shallow water. Mapping deeper kelp forests would require underwater video surveys or remote sensing methods.
- While inter-annual surveys examining changes in macroalgal densities within kelp forest have been undertaken around the New Zealand coast (e.g. Shears et al. 2004; Shears and Babcock 2007), however, the size of kelp forests and changes in extent have rarely been examined (but see Leleu et al. 2012).
- Little is known about the distribution of offshore and deep-water kelp forests (e.g. 90 m *Ecklonia* forests), or what ecosystem services these deep kelp forests provide.

**Table 3-10: Gap analysis summary for Kelp forests.**

Type	Description
<b>Distribution &amp; function</b>	Nearshore kelp forests well documented, but some common species poorly represented at national scale, few spatial maps. Deep kelp forests poorly known.
<b>Biological &amp; taxonomic</b>	Biology and taxonomy of kelp relatively well understood. Vulnerable to changing water conditions, but resilience and likely responses to climate change largely unknown.
<b>Management &amp; conservation</b>	Nearshore kelp forests are relatively well represented within marine reserves, but deeper and offshore kelp forests are poorly known and not currently protected.

## 3.4 Algal meadows

### 3.4.1 Habitat description and definition

As macroalgae normally require hard substrata for attachment, they are expected to be found less frequently in soft sediment environments. Nevertheless, macroalgae can form extensive meadows on the surface of the soft sediments or on coarser sediments (e.g. shell fragments, cobbles, coarse gravels). Depending on the species, the macroalgae can grow directly in the sediments (e.g. *Caulerpa flexilis*, which has rhizomes that grow through the sediment like seagrass), or can be anchored in the sediment (e.g. *Adamsiella chauvinii* that buries) or attached (e.g. on small cobbles, and shell fragments – e.g. *Ecklonia radiata* and most other species) or unattached algal meadows (e.g., *Adamsiella chauvinii* and *Ulva*). Algal meadows can occur in a wide range of coastal areas and depths, with widespread distribution in harbours and sheltered bays, from the intertidal out to coastal depths of about 70 metres where light levels permit.

Algal meadows provide low-lying three-dimensional structure that can stabilise sediments (in the same way seagrass does) and provide low-lying canopy-cover for a variety of invertebrates and fishes. Macroalgal assemblages often consist of one or more dominant species e.g. *Caulerpa flexilis*, *Adamsiella chauvinii*. The biomass of macroalgae in these habitats can be very high and often changes seasonally e.g. *Ulva* blooms in Otago and Tauranga. These algal beds host biodiversity that has largely been overlooked, e.g., studies on macroalgae associated with soft sediments in Whangarei and Otago Harbours discovered approximately 30% of the currently recognised flora for each region respectively (Neill et al. 2012).

The most common species forming algal meadows are the green algae *Caulerpa flexilis*, *Ulva* spp., *Codium* spp., red algae *Adamsiella chauvinii*, *Stenogramma interruptum*, *Gracilaria truncata*, *Rhodophyllis* spp., *Asparagopsis armata*, *Rhodymenia* spp., and filamentous genera as *Ceramium* and *Polysiphonia sensu lato*. The kelp *Ecklonia radiata* can also grow in algal meadows in quiet water exhibiting the growth form that was previously referred to as *Ecklonia brevipes* J. Agardh, developing several side haptera (holdfasts) directly from the blade that attach to gravel cobbles or rhodolith instead of the usual single holdfast with a single stipe. *Adamsiella* beds are known to densely cover large areas of seafloor where they support elevated species diversity (Rainer 1981; Hare 1992).

**Definition<sup>24</sup>:** Algal Meadows are defined as stands of one or more key species growing over sand, shell or cobble substrates which may or may not be attached to substrata, and which provide greater than  $\geq 35\%$  cover over an area of  $\geq 10 \text{ m}^2$  in seabed imagery (e.g. towed-video). Meadows may be indicated (although not verified) where key species contribute at least 30% of the volume of the catch from towed sample gear or occur in two successive samples collected by point sampling gear, but remote collection methods would need to be verified by direct observation to validate that these plants are growing *in situ* as meadows.

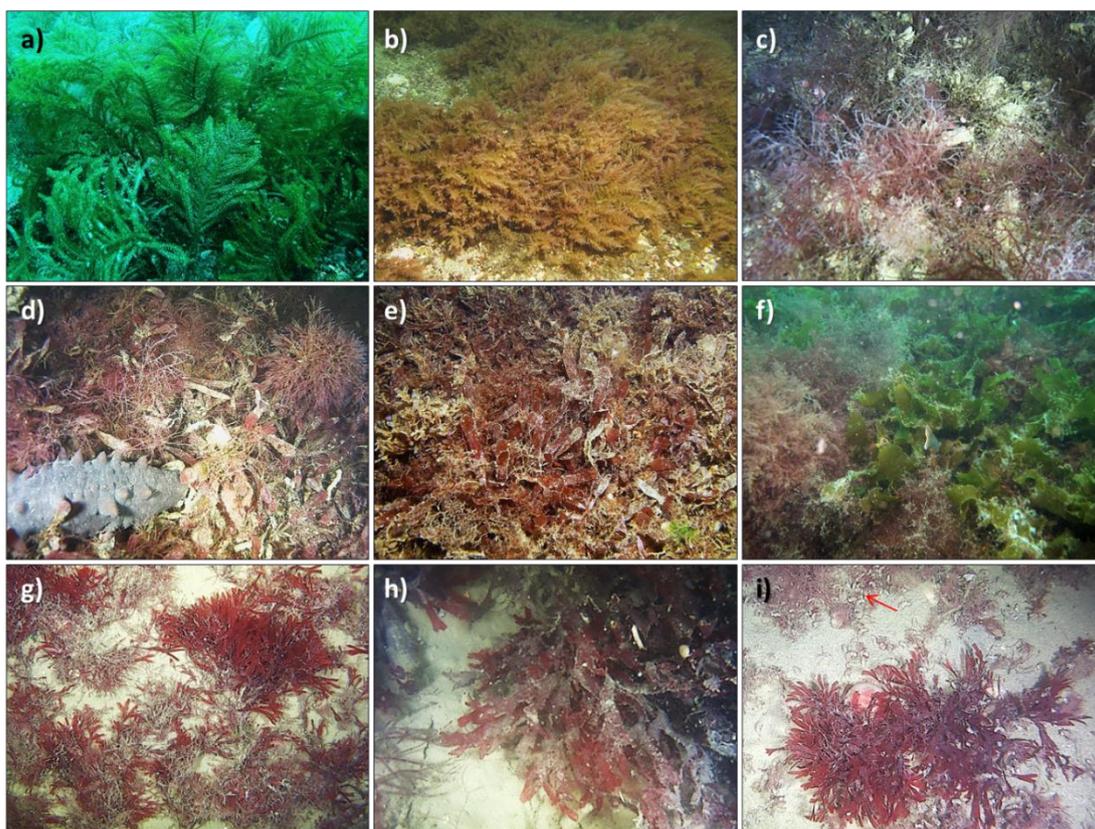
### 3.4.2 Key species

- *Caulerpa flexilis* (Green algae, Family: Caulerpaceae)
- *Adamsiella chauvinii* (Red algae, Family: Rhodomelaceae)
- *Stenogramma interruptum* (Red algae, Family: Phylloporaceae)
- *Gracilaria truncata* (Red algae, Family: Gracilariceae)
- *Asparagopsis* spp. (Red algae, Family: Bonnemaisoniaceae)

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<sup>24</sup> Based on expert opinion from the authors of this report, following the definition framework of MacDiarmid et al. 2013, as not previously defined.

- *Rhodophyllis* spp. (Red algae, Family: Cystocloniaceae)



**Figure 3-17: Photographs of key algal-meadow species.** *Caulerpa flexilis* from the Bay of Islands, b-c) *Asparagopsis* spp. From Port Underwood (c), d-e) *Adamsiella chauvinii* from Port Underwood (d) and Chalky Sound Fiordland (e), f) mixed meadow comprising *Asparagopsis armata* and *Ecklonia radiata* in Port Pegasus, g) *Stenogramma interruptum* from Guards Banks in the Marlborough Sounds, h) *Gracilaria truncata* from Pelorus Sounds, i) *S. interruptum* growing on an *Owenia* Tubeworm Fields in Port Gore, Marlborough Sounds. Photographs taken by Roberta D’Archino (a, b, e and f), and using NIWA’s high-definition inshore CBedcam (c, d, g and h) from NIWA’s-MBIE Bottlenecks programme (C01X1618).

### 3.4.3 Provision of ecosystem service

- Algal meadows are photosynthetic and can be important primary producers,
- Meadow formations can in turn modify water flow and sediment regimes, and function as coastal filters in eutrophic coastal bays and embayments
- Large or patchy meadows can provide living structure to a wide range of flora and fauna, where they can provide habitat, food, refuge for fish and invertebrate.
- Fragmenting or drift macroalgae may be buried in sediments or exported to the deep sea, therefore acting as a Carbon sink, while drift algae washed on shore provide habitat and food for small invertebrates and birds.
- Unattached macroalgae (drift algae) can accumulate intertidally and subtidally over soft sediments and can continue to grow and to photosynthesise – they provide food for invertebrates and fish.

- The occurrence of algal meadows, like seagrasses, can stabilise sediments by trapping fine sediments, while buried rhizomes (roots) can consolidate soft sediment with their specific growth habit e.g. *Caulerpa flexilis* and stolon growth.

#### 3.4.4 Data sources

- **AVH - The Australasian Virtual Herbarium (Atlas of Living Australia occurrence, May 2018)**, Distribution records were sequentially searched using key species names (e.g. '*Gracilaria truncate*') and location as 'New Zealand'. Records for kelp species presented in this report were extracted in April-May 2018.

#### 3.4.5 Biogeographic distribution

##### National scale

Algal meadows generally occur in sheltered areas, bays and harbours in different regions, but to date have not been well documented. There are no data on the size of these meadows and the distribution maps for this study are derived from species records, just indicating their occurrence and potential to form meadows (see maps below).

##### Regional scale/case studies

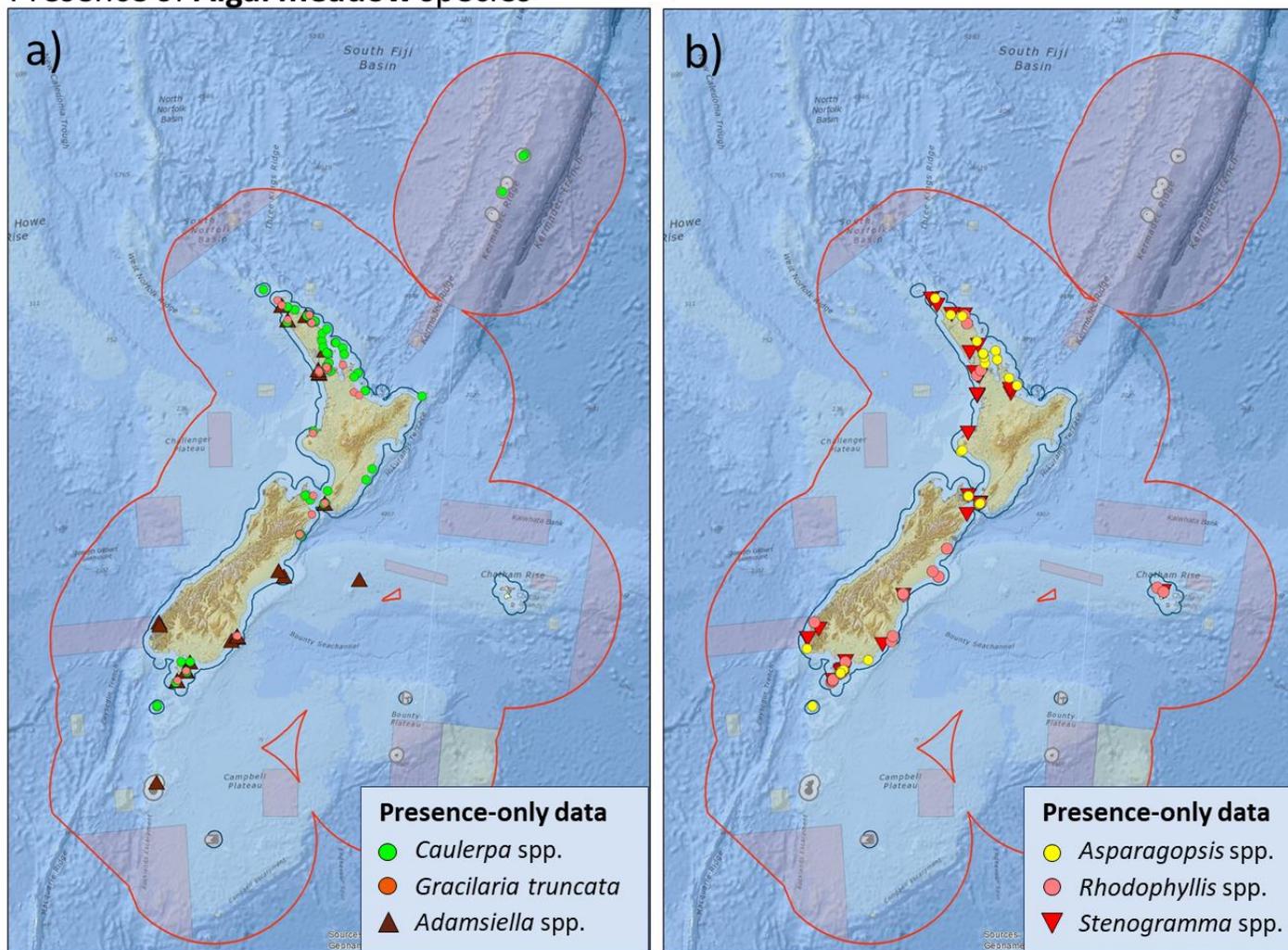
Based on ecological research and underwater diving and video observations large algal meadows are known to occur in the Bay of Islands (e.g., *Caulerpa flexilis*), Whangarei harbour, Wellington Harbour, Marlborough Sounds (e.g. extensive but patchy *Stenogramma interruptum* and *Gracilaria truncata* meadows in Guards and Waitui Bays in the outer sounds and extensive meadows of *Adamsiella chauvinii* in Port Underwood), in Upper Otago harbour (ephemeral meadows of *Adamsiella chauvinii* inshore around Ravenswood), and in Stewart Island (review in Rowden et al. 2012) and Fiordland.

Paterson Inlet supported extensive algal meadows with 100% cover over soft-sediment, dominated by *Adamsiella chauvinii* and *Rhododymenia* spp. These algal-meadows had lower current flow and supported higher numbers of fauna, than adjacent sand habitats (Willan 1981). *Adamsiella chauvinii* meadows in Big Glory Bay, Stewart Island are also extensive and thought to play an important role in stabilising the muddy bottom and providing refuge for a range of associated fauna (Roper et al. 1988), including high densities of echinoderms (Batham 1969).

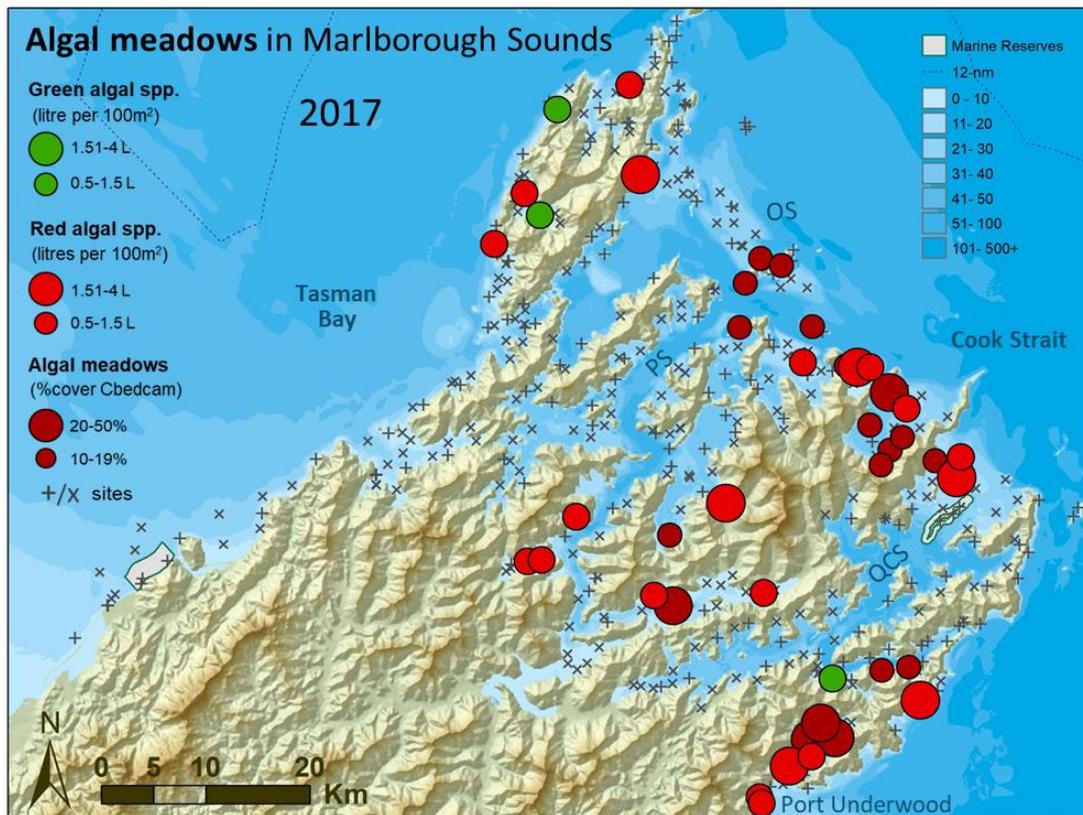
Biodiversity hotspots are known from Bay of Islands, Whangarei harbour, Marlborough Sounds, Otago harbour, Fiordland, and Stewart Island (Paterson Inlet, Port Adventure, Port Pegasus). Only the macrolagae assemblages in Otago and Whangarei harbours have been studied with focus on biodiversity and biomass (Neill et al. 2012, Neill and Nelson 2016). In Otago harbour subtidal red algal meadows have been reported previously, and these consist primarily of *Adamsiella chauvinii* with *Gracilaria truncata* and associated species of Delesseriaceae (e.g., species of *Schizoseris*, *Haraldiophyllum crispatum*). In Whangarei harbour subtidal populations of *Gracilaria truncata* were also present but did not form such extensive meadows.

Extensive algal meadows comprised of *Adamsiella* spp. have been recorded attached to small shells or pebbles occur over substantial areas of muddy sediment at the southern end of Evans Bay, Wellington Harbour (discovered during NIWA's routine biosecurity surveys, MacDiarmid et al. 2013).

## Presence of Algal meadow species



**Figure 3-18: Distribution of key algal-meadow species around New Zealand, based on presence-only specimen data.** Data presented are sourced from AVH - The Australasian Virtual Herbarium (Atlas of Living Australia occurrence data), May 2018. a-b) Kelp species included in these plots are shown in respective legends.



Data from NIWA's MBIE-Bottlenecks Juvenile fish Program - 2017 Beam Trawl survey (3-30 m depth)

**Figure 3-19: Distribution and abundance of algal meadows (spp.) within the Marlborough Sounds sampled using beam trawls and underwater CBedcam video during NIWA's-MBIE Bottlenecks programme (C01X1618).** all sampling undertaken in March-May 2017; Burgundy circles and + = Sites sampled using NIWA's high-definition CBedcam video system, where circle size represents % cover of algae on the seabed (as per legend). Red and green circles and x = Sites sampled by small (3-m wide) benthic beam trawl, where circle size represent the volume of algae caught in the net, divided by tow length and standardised to 100 m<sup>2</sup>.

### 3.4.6 Stressors and threats

*Key stressors and threats to this species:*

- Algal meadows may be impacted by invasive species, boat anchoring, sedimentation, and pollution. Future threats may include marina expansion, reclamation, and general effects of climate change.
- Scallop-dredging and bottom-trawling pose a threat as macroalgal meadows often co-occur in coastal areas associated with scallop beds and fishery areas.
- Climate change and increases in catastrophic events involving increases in temperature or sedimentation
- Algal meadows on soft sediments are poorly protected with few occurring within existing marine reserves.

### 3.4.7 Condition

- There are insufficient data to determine the condition of algal meadows around New Zealand.

**Table 3-11: Overall condition status of Algal meadows within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Unknown <sup>1</sup>	Good <sup>2</sup> (where known)	Good <sup>2</sup> (where known)	Unknown <sup>1</sup>	Moderate <sup>1,2</sup>

<sup>1</sup> Limited data available on the composition, extent and health of algal meadows,

<sup>2</sup> Existing national information based mostly on expert descriptions or inferred from survey data.

### Overall summary within NZ

Wide spread distribution in harbours and sheltered bays, provide good ecosystem services but not enough data available on the distribution and size of the meadows, and little known about changes to meadows over time.

#### 3.4.8 Knowledge gaps

- Lack of systematic data on regional and national distribution of species that are known to form algal meadows
- Ecosystem functions in soft sediment ecosystems has received very little attention in New Zealand (Adams 1972, Nelson 2008), with macroalgae in these largely overlooked, not only with respect to their contributions to productivity but also to system complexity (Neill et al. 2012).
- Lack of spatial mapping. There is insufficient data available on the distribution and size of the algal meadows, even in places where algal meadows have been recorded.
- Biodiversity associated with algal meadows has been significantly under-estimated and is poorly documented.

**Table 3-12: Gap analysis summary for Algal meadows.**

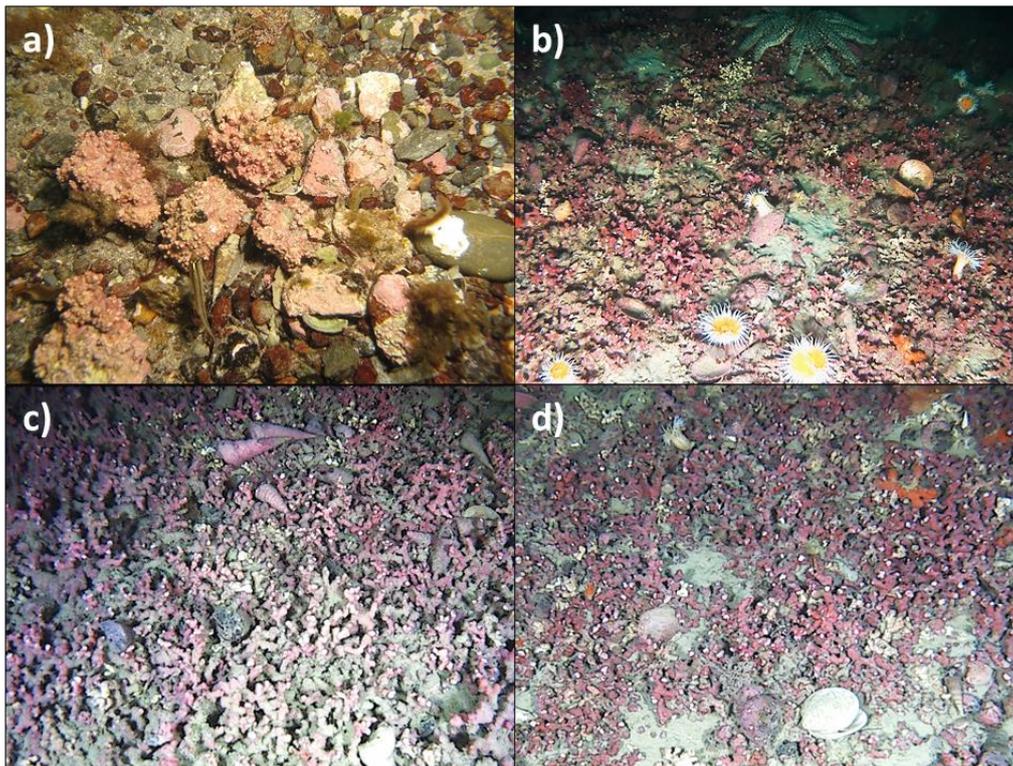
Type	Description
<b>Distribution &amp; function</b>	Distribution and function of algal meadows on soft-sediments are poorly documented, but some meadows known to occur over extensive areas, but little to no spatial mapping exists around most of New Zealand.
<b>Biological &amp; taxonomic</b>	Taxonomy and biology of generic groups is described, but likely to represent species-groups not yet separated or adequately described.
<b>Management &amp; conservation</b>	Biogenic habitats over soft-sediments, especially those with extensive algal meadows, are poorly represented in marine reserves. Little is known about the vulnerability or recovery rates of algal meadows relative to stressors and disturbances.

## 3.5 Rhodolith beds

### 3.5.1 Habitat description and definition

Rhodoliths (known as maërl in Europe) are free-living, calcified red algae. Individual rhodoliths may start growing around a fragment of shell or rock, or they can be composed entirely of coralline algae. Rhodoliths are typically found in clear subtidal water on sediments with coarse sand, gravel or shell debris (Nelson et al. 2012). The complex morphology of rhodoliths provides a very heterogeneous habitat. As rhodoliths are not attached to the bottom, they can roll and move with waves and currents, and this movement results in the rhodoliths having different shape and forms (e.g. spheroidal, ellipsoidal, branching). The branching or rounded thalli collectively create a fragile, structured biogenic matrix over coarse or fine carbonate sediments. Rhodoliths can also be formed by more than one species and can include other encrusting organisms such as bryozoans and gastropods (Harvey and Woelkerling 2007). At present at least four species of non-geniculate coralline algae are known to form rhodoliths, but their distribution around New Zealand is poorly understood (Nelson and Neill 2017).

**Definition:** Rhodolith beds are defined as free-living coralline thalli (individual rhodoliths) that occur on the seabed in greater than  $\geq 10\%$  cover, or a single occurrence of a rhodolith species in a towed or point sample (Steller et al. 2003).



**Figure 3-20: Photographic examples of Rhodolith beds from a) the Bay of Islands, b), French Pass, c-d) Admiralty Bay in the Marlborough Sounds.** Organisms associated with rhodolith beds in these images include triplefin and brown filamentous macroalgae (a), starfish and anemones (b), screw shells and other small gastropods (c) encrusting sponges and bryozoans (d). Image from: a) Fiordland, Roberta D'Archino NIWA, b-d) Marlborough Sounds, NIWA's CBedCam Towed-video footage.

Internationally rhodolith beds have been identified as critically important biodiversity hotspots, where heterogeneous macro- and micro-habitats support high benthic biodiversity and abundance of marine animals and algae in comparison with surrounding habitats (Steller et al. 2003; Nelson 2009). Rhodolith beds also host commercially important species, as well as many rare and unusual species (Nelson 2009). International studies have shown that productive fisheries are often coincident with rhodolith (or Maërl) beds and it is thought that the high level of functional diversity that rhodolith beds provide may be an important driver in maintaining productivity. Their complex habitat structure also provides refugia for small juvenile fish and settlement habitat for shellfish larvae (Nelson et al. 2012). For example, rhodolith beds have been identified as important nursery areas for commercial species such as queen scallops, crabs, and fish (Kamenos et al. 2004a,b,c; Nelson et al. 2012), and are home to high densities of broodstock bivalves (Nelson 2009).

### 3.5.2 Key species

At present three genera (*Lithothamnion*, *Sporolithon* and *Lithophyllum*) are known to occur in New Zealand, but only two species are commonly found in New Zealand (*Sporolithon durum* and *Lithothamnion crispatum*) (Harvey et al. 2005, Farr et al. 2009).

- *Sporolithon durum* (Red algae, Division: Rhodophyta, Family: Sporolithaceae)
- *Lithothamnion crispatum* (Red algae, Division: Rhodophyta, Family: Hapalidiaceae)

### 3.5.3 Provision of Ecosystem Service

- Rhodoliths form complex low-lying living and relict structure, are considered to act as ecosystem engineers modifying the physical characteristics of their environment
- Rhodoliths are important primary producers, can stabilise large areas of sediments, and are important in carbon sequestration (Amado-Filho et al. 2012).
- They provide living structure that provide refuge for a wide range of fauna (e.g. encrusting Bryozoa, boring Polychaetes), flora and fish, and provide nursery areas for juvenile stages including commercial species, and settlement habitat for shellfish larvae (Nelson et al. 2014).

### 3.5.4 Data sources

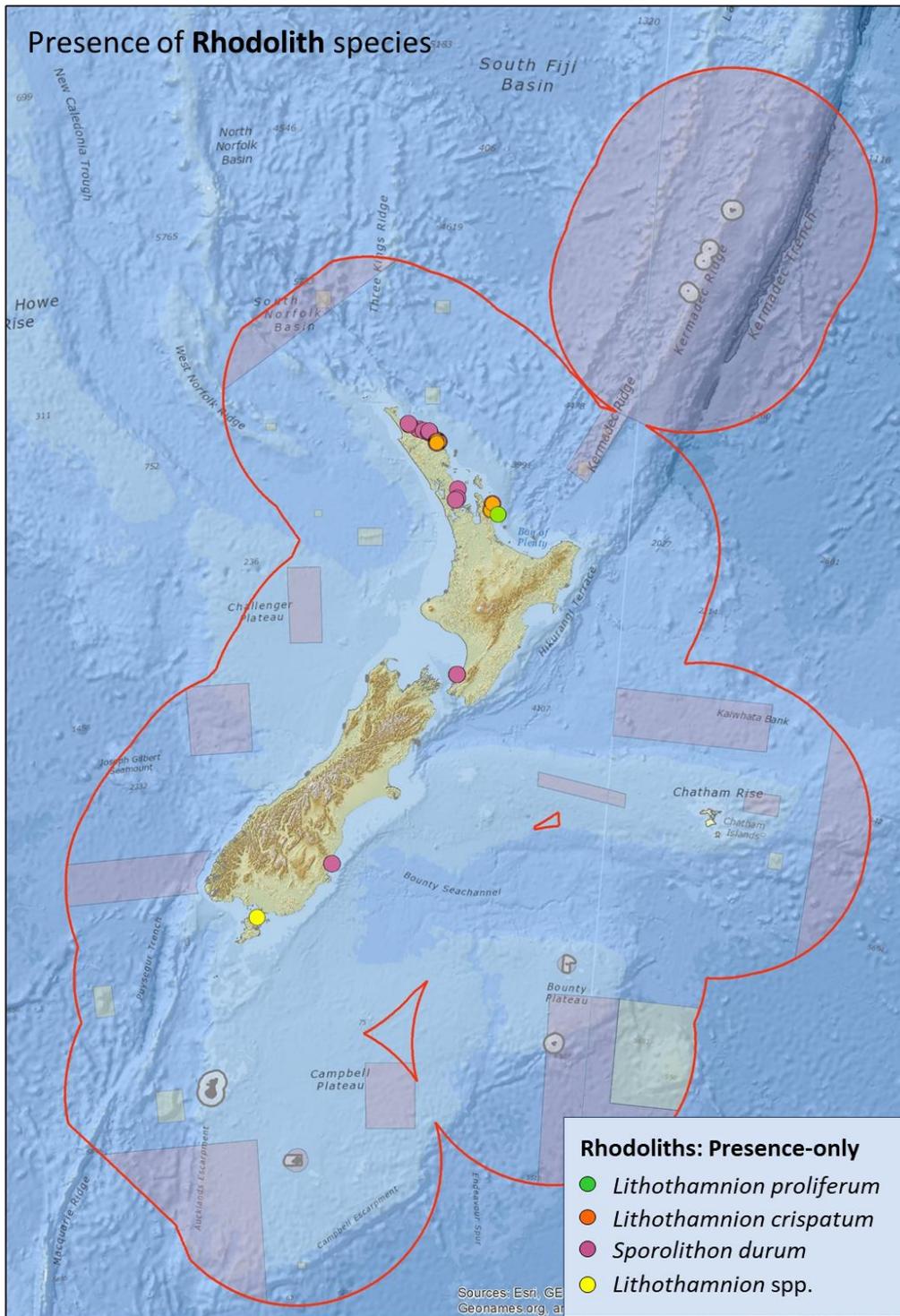
- **NIWA-internal All-Macroalgae data** records extracted for 'rhodolith' forming species for New Zealand. Data compiled in May 2018 by Neill (NIWA Wellington).

### 3.5.5 Biogeographic distribution

#### National scale

Very little information exists about the location, extent or ecosystem functioning of rhodolith beds in New Zealand. It is likely that they occur in the EEZ at localities characterised by strong currents within the photic zone (layer that receives sunlight) to depths of 200 m depending on water clarity, particularly around the margins of reefs or elevated banks. Most investigations to date have been in diving depths less than about 30 m.

Rhodoliths beds have also been documented as far north as the Kermadec Islands, around the North and South Islands, and as far south as Bluff Harbour. They have also been recorded in high-current areas in French Pass, Admiralty Bay and the eastern side of D'Urville Island (NIWA's MBIE Bottlenecks survey, 2017 unpublished data), Tonga Island Marine Reserve in Tasman Bay, and Okiwi Bay in Croisilles Harbour, Nelson.



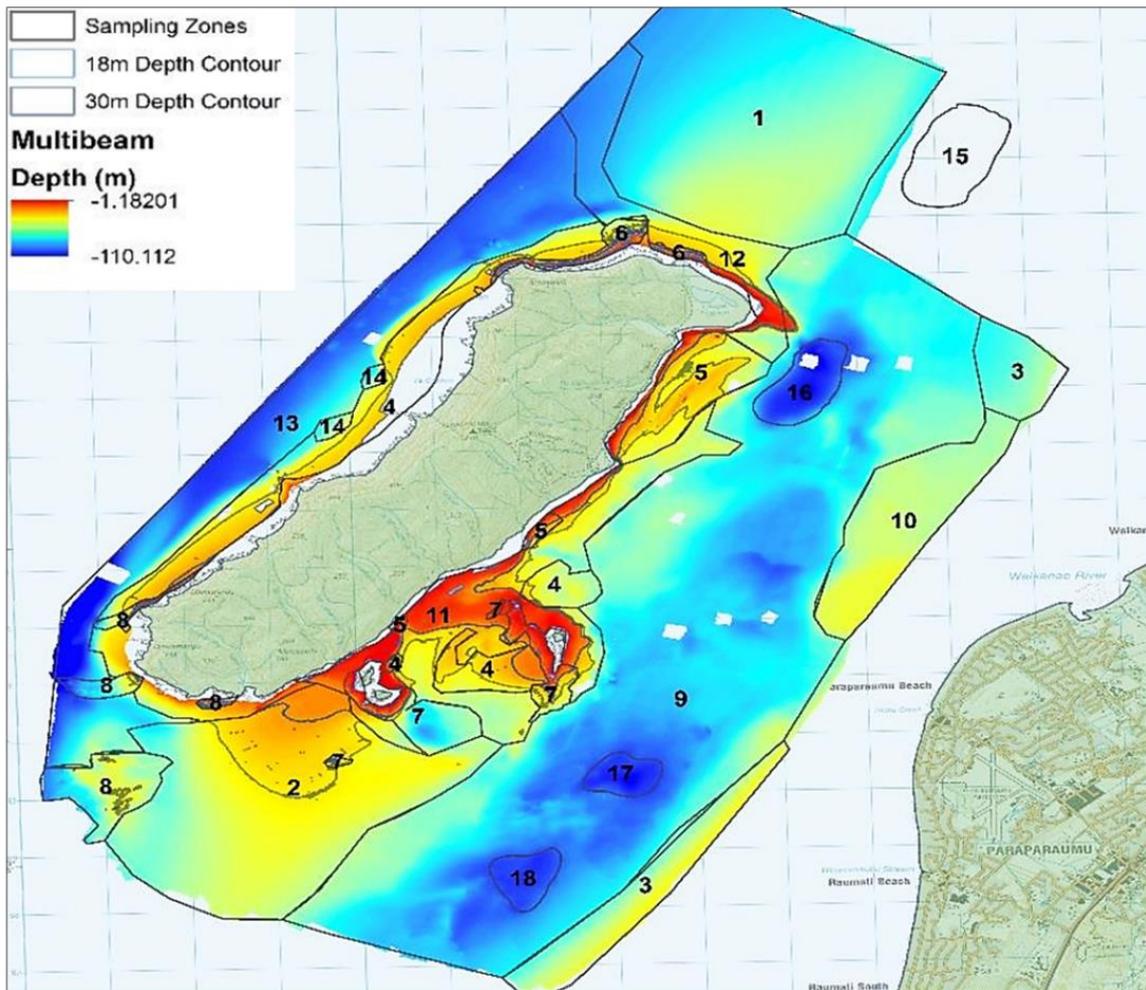
**Figure 3-21: Distribution of Rhodoliths around New Zealand, based on presence-only data of identified specimens, collected by NIWA.** Rhodolith species included in these plots are the two common New Zealand species (*Lithothamnion crispatum* and *Sporolithon durum*), along with *Lithothamnion proliferum* and *Lithothamnion* spp.

Extensive rhodolith beds, that form important biogenic habitats have been reported from the Bay of Islands, Cavalli Islands, Kapiti Island, Marlborough Sounds, Bluff, and Fiordland. However, rarely do rhodolith specimens get retained and submitted for specimen identification, so national distributions are poorly known or described. As a result, New Zealand's inventory on the distribution of Rhodolith beds relies mostly on a variety of partial descriptions that are variable in information quality. For example, Rhodolith beds have been identified i) during field surveys on northern macroalgal diversity, where rhodoliths beds were identified along Pūwheke beach to the south of Rangaunu Harbour in Great Exhibition Bay in about 8-15 m depth – growing in association with *Caulerpa flexilis*, but the extent of these beds is unknown; ii) Rhodoliths have also been recorded in some surveys as field descriptions. Tangaroa voyage to the Kermadec islands (survey No. TAN1612, summarised in AEBR 179, reports), for example, note that “*Rhodolith beds were common in the shallower areas off Macauley Island, L’Esperance Rock and Star of Bengal Bank*”, but no specimens were retained; iii) Collections of rhodoliths have been made at consecutive sites around a number of offshore islands in north-eastern New Zealand, e.g. in channels between islands of the Cavalli group, but the extent of these beds and the depth range is unknown. In New Zealand few Rhodolith beds have been studied in detail (e.g. Bay of Islands - Farr et al. 2009, Neill et al. 2015, also see examples of case studies below), while data on other beds are scarce in relationship to distribution, size of the bed and species composition. Therefore, rhodolith beds are thought to be more widespread than currently known.

#### Regional scale/case studies

**Kapiti Island:** Extensive Rhodolith beds, comprised of *Sporolithon durum*, are known to occur in 6-15 m water depth, approximately 200 m offshore on the eastern side of Kapiti Island (Battershill et al. 1993). These Rhodolith fields comprised cobbles and rhodoliths over soft-sediments, and extended 100s of metres alongshore, although the full extent and density of the beds was not determined in this survey. Associated bryozoan species, including those that can form thickets, have also been collected from these beds, indicating the importance of Rhodolith beds as a complex habitat for other biogenic habitats. Importantly, the Kapiti Island rhodolith beds are the only ones known from the lower North Island, with apparently the largest aggregations within New Zealand (MacDiarmid et al. 2013). In November 2015, Multibeam bathymetry, using NIWA's Kongsberg EM2040 off the RV Ikatere, was collected around Kapiti Island. Multibeam derived variables (e.g. depth, slope, rugosity) were then used in a Benthic Terrain Model (BTM), within ArcGIS, to delineate 18 geomorphic zones that were then visually ground-truthed using a suite of drop-camera (n=214), video transects (n=8), Scuba dives (n=46) and benthic tows (n=4) (Laferriere 2016). Rhodolith Beds were identified in three BTM Zones within the Reserve: in Zone 3 (46% Rhodolith bed and 31% Horse mussels) and Zone 4 (46% Rhodolith Beds and 54% mobile invertebrates - mainly brittle stars), and to a lesser extent in Zone 11 (10% cover) (Source: Figure 3 from Laferriere 2016).

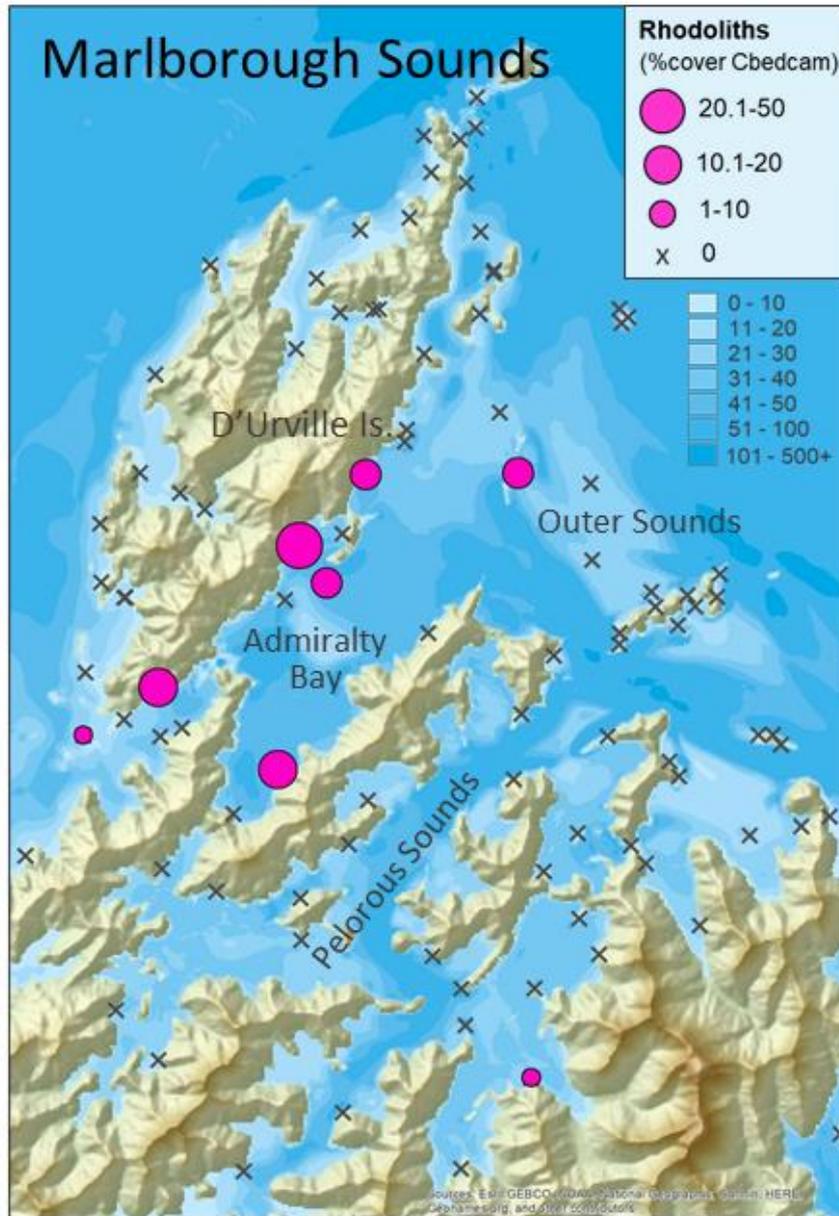
## Kapiti Island Marine Reserve - Habitat map



**Figure 3-22: Kapiti Island Marine Reserve ‘geomorphic zones’ map, based on multibeam bathymetry, Benthic Terrain Modelling (BTM) and visual ground-truthing surveys.** Drop-camera surveys characterised Rhodolith Beds in Zone 3 (46% Rhodolith bed and 31% Horse mussels) and Zone 4 (46% Rhodolith Beds and 54% mobile invertebrates), and to a lesser extent in Zone 11 (10% cover) (Source: Figure 3 from Laferriere 2016).

**Bay of Islands:** In the Bay of Islands, rhodolith beds have been recorded from Kahuwhera Bay and Te Miko Reef. Collections of *Sporolithon durum* rhodoliths were made from five sites within the Bay of Islands and from five sites on the shelf outside the Bay of Islands, while *Lithothamnion crispatum* rhodoliths were collected from five sites within the Bay of Islands, and from one site on the shelf outside the Bay (Nelson and D’Archino, 2010).

**Marlborough Sounds:** Extensive and dense rhodolith beds were recorded in the high current environment of Admiralty Bay and adjoining French Pass (Figure 3-23). French Pass has some of the strongest currents in the New Zealand. Rhodolith beds in these areas were alive and healthy, and supported a range of marine flora and fauna (T. Anderson per. obs. April 2017). Rhodolith beds have also been recorded from the Abel Tasman coast, Okiwi Bay in Croisilles Harbour (near Hobbs Bay) and Tasman Bay (Davidson 1992, Davidson et al. 2014, 2016, 2017).



**Figure 3-23: Rhodolith mean percent cover recorded during NIWA's CBedcam benthic video sites undertaken within the Marlborough Sounds in April-May 2017 (NIWA's MBIE Bottlenecks juvenile fish-habitat surveys). Video transect were approx. 10 minutes in duration, x = stations where no rhodoliths were observed.**

### 3.5.6 Stressors and threats

- Ocean acidification, fishing methods or activities that disturb sediments/benthic habitats
- Rhodoliths, like other calcified macroalgae, will be impacted by acidification of the oceans and increasing temperature resulting from global climate change. Internationally there is an extensive literature on rhodolith beds (e.g. Riosmena-Rodriguez et al. 2017) as they have been recognised as productive ecosystems at risk from the decrease in pH associated with changing ocean chemistry (ocean acidification).
- Rhodoliths are at risk from the impacts of a range of human activities including physical disturbance (especially trawling, dredging, boat anchoring)
- Reduction in water quality (offshore dumping) and pollution.
- Sedimentation, although little is known about how much deposition different rhodolith species may be able to withstand.
- Alterations to water movement (marine engineering) and aquaculture installations (shellfish rafts and lines, fish cages).



**Figure 3-24:** The effect of boat anchor damage on a rhodolith bed in Tonga Island Marine Reserve, Tasman Bay. (Source: Plate 18, Davidson and Freeman 2013).

### 3.5.7 Condition

- Internationally there is an extensive literature on rhodolith beds as they have been recognised as productive ecosystems at risk from the decrease in pH associated with changing ocean chemistry (ocean acidification).
- They are also at risk from sedimentation deriving from land use activities in adjacent catchments (Morrison et al. 2010).

The Bay of Islands Oceans 20/20 Survey in 2009/2010 examined the sedimentation regime in that area. Sediment and modelling studies demonstrated that increased suspended sediments could be a significant threat to water quality while fine sediment deposition was at higher than average rates that may smother and bury some low-lying habitats, such as rhodoliths, where average sedimentation exceeds resuspension and movement of these sediments (Swales et al. 2010, Pritchard et al. 2010). Areas identified to be sensitive included the well-developed Rhodolith beds in Te Rawhiti Inlet in the Bay of Islands.

**Table 3-13: Overall condition status of Rhodolith beds within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Unknown <sup>1</sup>	unknown <sup>1</sup>	unknown <sup>1</sup>	Unknown/vulnerable <sup>1,2</sup>	Low/poor <sup>1</sup>

<sup>1</sup> Large gaps in national inventory for Rhodoliths, with little to no information available on extent, health or ecosystem status, although rhodolith beds in several locations are known to be important.

<sup>2</sup> Considered a vulnerable biogenic habitat as overlapping sedimentation and/or benthic fishing activity threats exist in most places where rhodolith occur

#### Overall condition status within NZ

Rhodolith beds are poorly known in New Zealand with little known about distribution and size of the beds. They are expected to be more widespread than reflected in the currently known distribution data. Rhodolith beds provide critical ecosystem services including creating refugia and habitats for diverse and often rare species, and larvae settlement. They are known to occur in areas where increasing sedimentation exists, and where dredging and bottom fishing also occur, but it is unclear how vulnerable they are to these disturbances.

### 3.5.8 Knowledge gaps

There is no national or regional inventory on rhodolith beds. Specimen data did not reflect known occurrences within New Zealand. During this review, survey descriptions of rhodoliths were found as far north as the Kermadec Islands, and often were recorded as a major component of survey catches (e.g. 85 kg were collected from one sample in the Kermadecs), yet nationally very few if any specimens are retained and preserved. Consequently, the distributions of rhodolith beds around New Zealand are not well described, with very little to nothing is known about the species that comprise these beds, the depths they occur in, or the spatial extent of the beds they form.

Despite multiple attempts to address this issue, there have been no surveys to date to document the distribution of rhodoliths in New Zealand. Consequently, all records are opportunistic and a consequence of field work that is unrelated. A change in collection methods for this species is vitally required. Specialist recommend that at least one handful of representative rhodoliths be retained (bagged in silica gel crystals) from any site where rhodoliths are collected. For many rhodolith beds that have already been identified, specimen collections are still required to describe the species comprising these beds. Surveys mapping the spatial extent and monitoring the health of these beds is also mostly absent, but are likely to be critical in managing these unique habitats.

International literature suggests that rhodoliths are vulnerable to disturbance and sedimentation. Within New Zealand, rhodolith beds are known to occur in areas where dredging and bottom fishing also occur, but it is unclear what the effects of these disturbances are on New Zealand rhodolith beds. Rhodoliths are also thought to be susceptible to sedimentation, although some beds in New Zealand have been found in high silty environments (e.g. Bay of Islands and Admiralty Bay). It is unclear whether these beds are resilient to sedimentation, or whether beds in these locations are being impacted. Although rhodolith beds within New Zealand support a wide range of species, including a high proportion of rare species, little is known about overall ecosystem functioning of rhodolith beds in New Zealand, or how these threats and stressors will alter these ecosystems.

**Table 3-14: Gap analysis summary for Rhodolith beds.**

Type	Description
<b>Distribution &amp; function</b>	Distribution and function of rhodolith beds poorly documented, with little quantitative data available either regionally or nationally. High biodiversity and high number of rare species found in the few rhodolith beds examined.
<b>Biological &amp; taxonomic</b>	Taxonomy and biology of rhodolith-forming species within New Zealand is very poorly known.
<b>Management &amp; conservation</b>	Rhodolith beds are known to occur within several New Zealand Marine Reserves (e.g. Kapiti Is and Tonga Is. Marine Reserves), but overall diversity is likely to be poorly represented. Rhodolith beds may still incur ongoing damage, due to boats anchoring, within Marine Reserves. Extensive rhodolith beds also occur within the proposed Kermadec-Rangitahua Ocean Sanctuary. Many notable rhodolith beds are not currently protected.

## 3.6 Bryozoan thickets

### 3.6.1 Habitat description and definition

Bryozoans (sometimes referred to in other parts of the world as sea mats, moss animals or false lace corals) are creatures that form colonies somewhat resembling small corals. Each colony is made up of tiny individuals, each with a miniscule gut and a crown of tentacles that capture microscopic food particles. Colonies themselves range in size through five orders of magnitude from 0.2 mm to 2 metres in size, the largest-documented being from Western Port in Victoria, Australia (A. Flynn et al. *unpublished data*). There are approximately 1000 species of marine bryozoans in New Zealand's EEZ, not all yet formally named or described (Gordon et al. 2009), of which about 50 coastal/shelf species form colonies large or robust enough (5–30 cm height or width) to be considered as providing three-dimensional habitat. Some 27 species provide habitat over hundreds of square kilometres of seafloor (Wood et al. 2013), whereas a majority of the 50 species are either at the smaller end of the colony-size spectrum, sparsely distributed, or non-attractive to epibionts, and are excluded from further consideration here.

The most significant habitat-forming bryozoans are those that are rigidly erect, widely distributed, and provide three-dimensional structure. Included among these (but their importance varies in different parts of their distribution) are *Cinctipora elegans*, *Celleporaria agglutinans*, *Hippomenella vellicata*, *Galeopsis porcellanicus* and *Galeopsis polyporus*, *Celleporina grandis*, *Diaperoecia purpurascens*, *Hornera robusta* and *Hornera foliacea*, *Adeonellopsis* spp., and *Arachnopusia unicornis* (see also Wood et al. 2013). Several other species are rigidly erect and may contribute to thickets, but to a much lesser extent (e.g. '*Heteropora*' *neozelanica* and *Cellaria tenuirostris*). Except for *C. elegans* and *H. foliacea*, which are not found north of Cook Strait, most habitat-forming bryozoan species are fairly widespread around New Zealand. All are erect, either branching and tree-like or foliose.

**Definition:** Bryozoan Beds (or Thickets) are defined as habitats where frame-building bryozoan species dominate (at least) square metres of seafloor (Wood et al. 2012; MacDiarmid et al. 2013). Frame-building bryozoans are defined as heavily-calcified species that regularly attain sizes over 50 mm in three-dimensions (Wood et al. 2012).

### 3.6.2 Key species

There are 27 species of habitat-forming bryozoans found in New Zealand (Wood et al. 2012), with eight key species known to contribute significantly to habitat complexity (listed below). A lot of bryozoan species can co-occur in bryozoan thickets and reefs, and many can help to form reefs.

The top eight species that make a substantial contribution to bryozoan reefs are:

- *Arachnopusia unicornis* (Family: Arachnopusiidae)
- *Cellaria immersa* (Family: Cellariidae)
- *Celleporaria agglutinans* (known as the 'Tasman Bay coral') (Family: Lepraliellidae)
- *Cinctipora elegans* (Family: Cinctiporidae)
- *Diaperoecia purpurascens* (Family: Diaperoeciidae)
- *Galeopsis porcellanicus* (Family: Celleporidae)
- *Hippomenella vellicata* (Family: Hippopodinidae)
- *Hornera robusta* (Family: Horneridae)

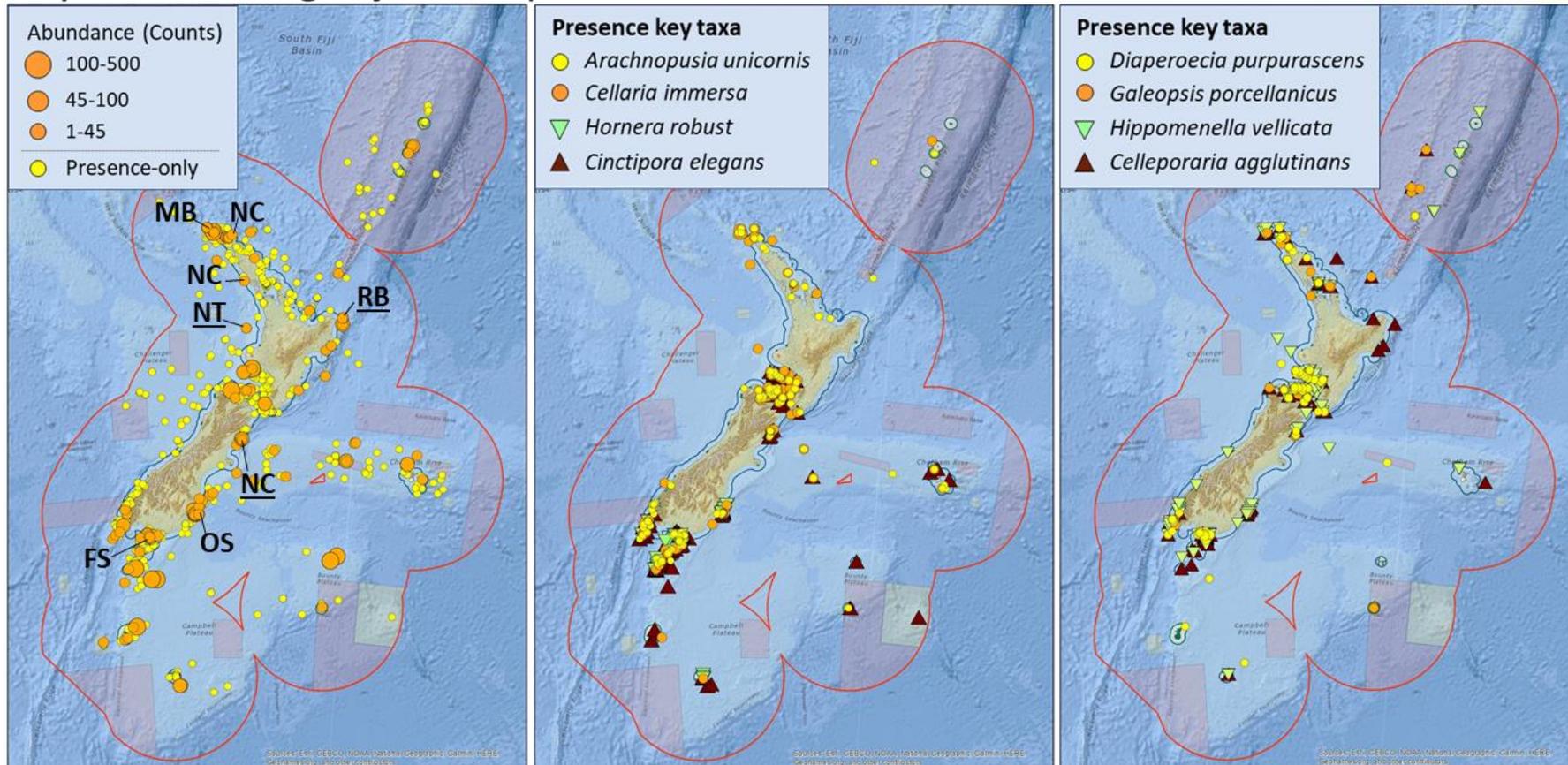


**Figure 3-25: Example of reef-building bryozoan species.** a) *Galeopsis polyporus* Three Kings; b) *C. elegans* Otago shelf, c-d) *C. elegans* and red algae; e) handful of reef-forming bryozoa species; f-g, i) low-lying bryozoan rubble and reef on Rangitoto Bank, eastern-side of D'Urville island; h) Horse mussel bed west of Chetwode Islands, Marlborough Sounds, with live mussels heavily encrusted with branching bryozoans (Photographs a,b provide by Dennis Gordon NIWA-Wellington, c-e by Sean Handley NIWA-Nelson; f-i from NIWA's CBedcam towed-camera imagery)..

### 3.6.3 Provision of ecosystem service

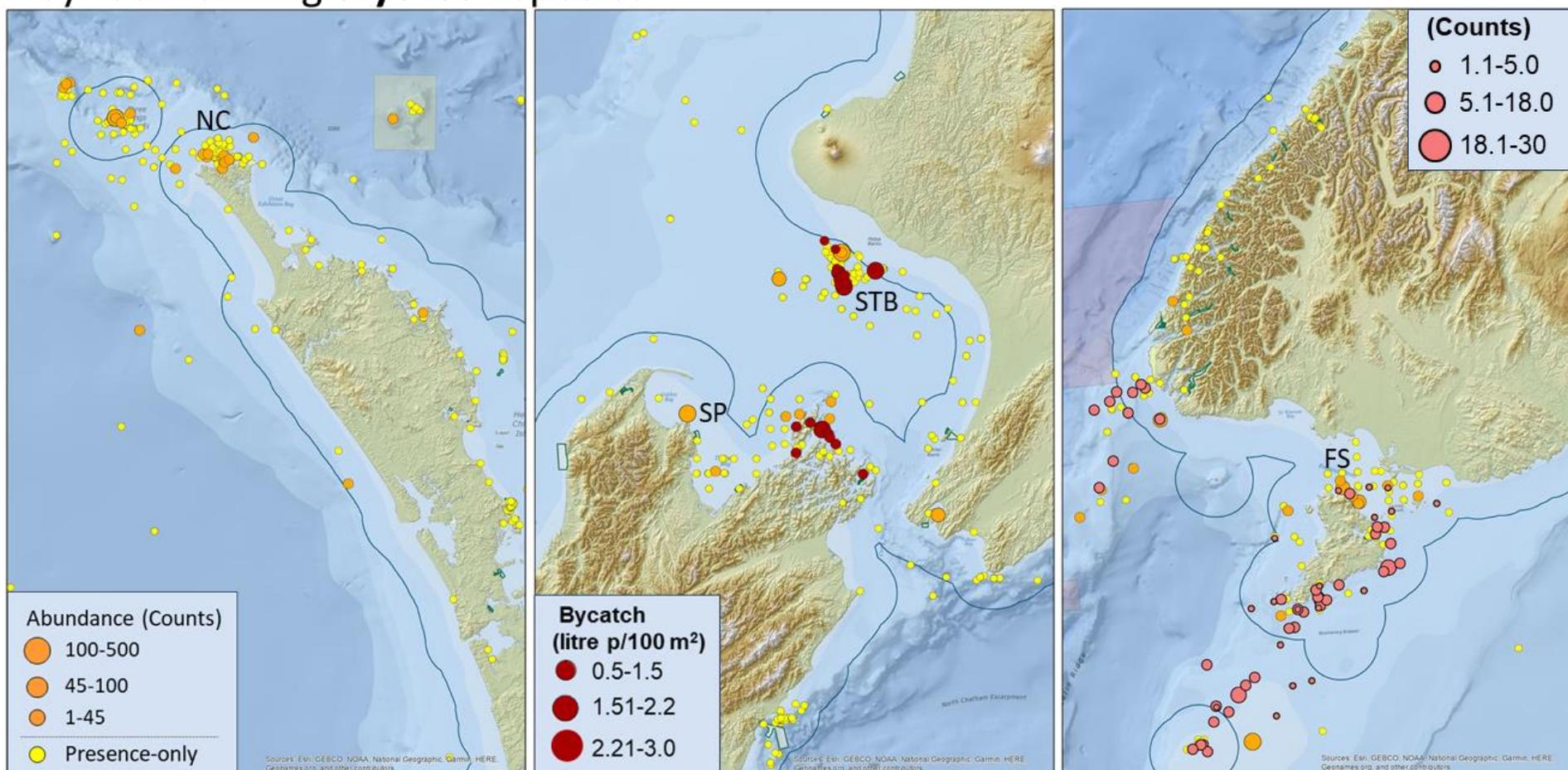
- Fixing carbon by suspension-feeding (all bryozoan species)
- Sediment stabilisation (some species). Bryozoans also trap sediments within their structures and this is often associated with more diverse biological assemblages (Wood et al. 2012). Thus, the presence of habitat-forming bryozoans can allow more or different species to persist, and bryozoan habitat is thought to be important for generating and maintaining the biodiversity of an area (Wood 2005).
- Bryozoan thickets and mounds like seagrass habitats can reduce current flow in and around the thickets due to boundary conditions, providing more hospitable environments and more protection to species.
- Provision of three-dimensionality, thereby adding to structural habitat complexity; provision of attachment surfaces, thereby local elevating species richness; provision of food to predators (generally micro-predators) (Cranfield et al. 2004).

## Key reef-forming bryozoan species



**Figure 3-26: Known distribution of key reef-building bryozoan species in New Zealand.** a) Total abundance (orange bubble plots) of the eight-key reef-building species from NIWA's Specify data, and their presence (yellow circles) from all available datasets (OBIS-NZ, TePapa, and University datasets). b-c) Presence-only plots for each of the eight-key species (depicted in legends). Abundance = raw/unstandardized counts from NIWA dredge collected sampling, and are used here simply to determine where reefs or patch reefs (rather than isolated individuals) may occur. Sites surveyed in Jones et al. 2018 are depicted as: MB=Middlesex Bank, NC=North Cape, NC=North West Coast (Canyons), NT=North Taranaki Bight(Canyons), RB=Ranfurly Bank, NC=North Canterbury, OS=Otago Shelf, FS=Foveaux Strait. Underlined site names (left figure)= the three core sites examined in detail in Jones et al. 2018.

## Key reef-forming bryozoan species

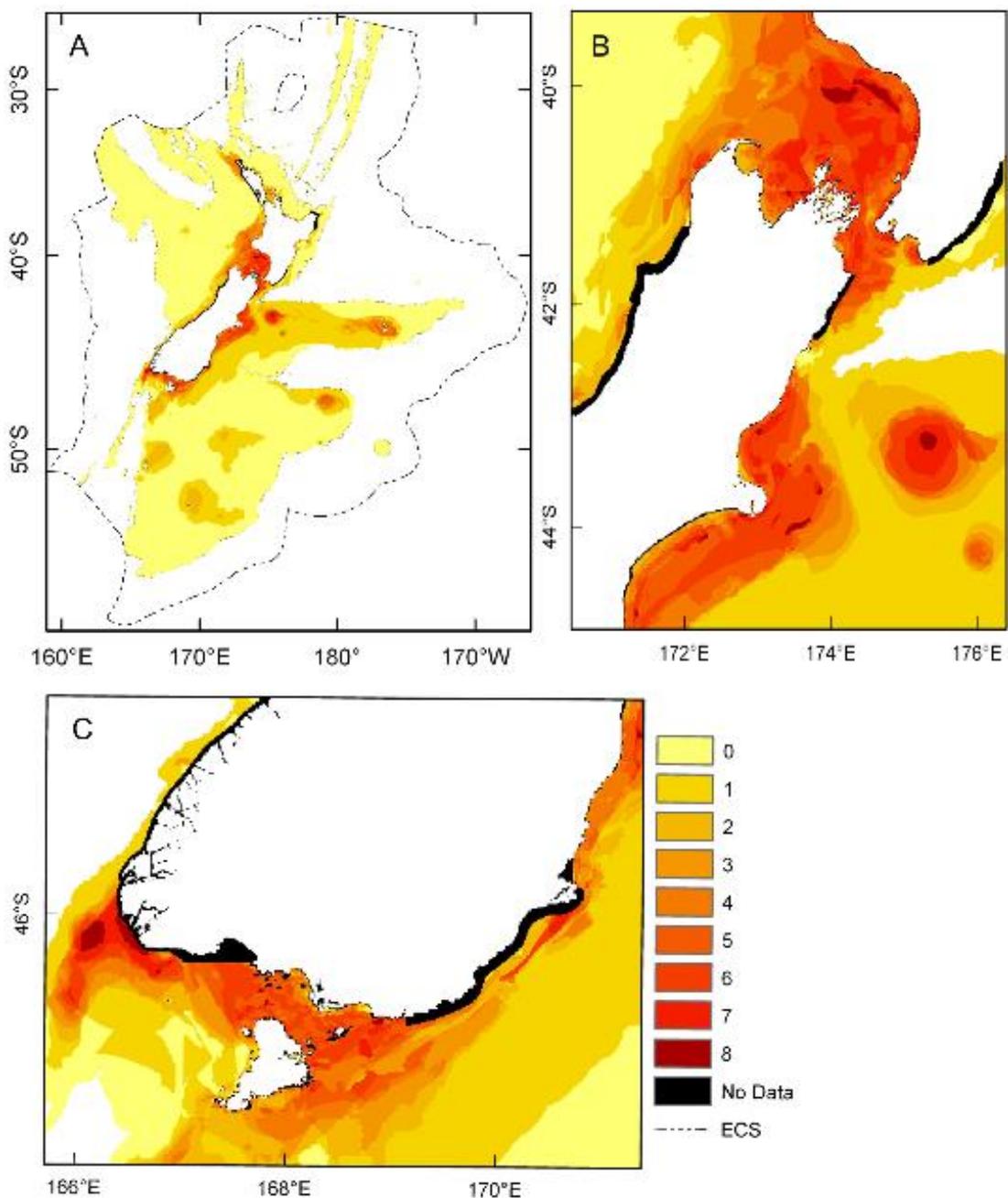


**Figure 3-27: Bryozoan presence and abundance across the northern central and southern regions of New Zealand.** a-c) Total abundance (orange bubble plots) of the eight-key reef-building species (combined) from NIWA's Specify data, and their presence (yellow circles) from all available datasets (OBIS-NZ, TePapa, and University datasets); b) red circles represent bryozoa by-catch volume (in litres p/100m<sup>2</sup>) from Marlborough Sounds and the South Taranaki Bight; c) pink circles represent bryozoa counts from university surveys (A. Smith, Otago University). Abundance = raw/unstandardized counts, and are used here simply to determine where reefs or patch reefs (rather than isolated individuals) may occur. Areas of known thickets are label: NC= North Cape, STB=South Taranaki Bight, SP=Separation Point, FS= Foveaux Strait.

- Many bryozoan reefs and thickets provide bright coloured coral-like habitats, and where present in coastal areas have a high aesthetic value for tourism, to the diving and free-diving communities.

### 3.6.4 Data sources

- Museum specimen identification datasets (OBIS-NZ, NIWA-Inverts and Te Papa) (Table 2-1), where data were extracted for key-habitat forming species (as defined in section '3.6.2 Key species') for New Zealand.
- University datasets from Abigail Smith and Anna Wood were extracted using the same search specifications as above (data records range from 1911-2011).



**Figure 3-28: Predicted hotspots of habitat-forming bryozoans.** Legend values 0-8 = the number of species predicted to find suitable habitat (Source: Figure 14 Wood et al. 2013).

### 3.6.5 Biogeographic distribution

#### National scale

Many species contribute to habitat-forming bryozoan thickets. However, key habitat-forming species are required to generate these thickets/reefs. *Cinctipora elegans* and *Hornera foliacea* are found south of Cook Strait; while all other key reef-forming species are widespread around New Zealand's continental shelf. Important regions where bryozoan thickets have been recorded, include: Three Kings Shelf, Mernoo Bank, Otago Shelf, South Taranaki Bight/Whanganui Shelf, Foveaux Strait, Paterson Inlet- Stewart Island, Snares Platform, plus smaller coastal areas of high current flow and suitable substratum (e.g. many parts of east coast of both islands (including Ritchie Bank off Hawke Bay), greater Cook Strait, South Island west coast, Fiordland sills, and offshore islands (Batson and Probert 2000; Wood and Probert 2013; Figure 3-26). As with sponges, no national inventory of bryozoan thicket/habitat occurrence and extent exists for New Zealand, either for individual species, or species complexes. Many areas of importance, however, were identified through LEK-interviews with long-time fishers (largely trawling, depth range 10 – circa 250+ m) and marked up as polygons on charts (Jones et al. 2016; Figure 2-1). Many of these areas (e.g. bryozoan thickets off the north Otago Shelf) were sampled and videoed in NIWA's subsequent biogenic habitat survey undertaken around the New Zealand coast (Jones et al. 2018).

#### Regional scale/case studies

**Otago Shelf:** On the mid to outer shelf off Otago Peninsula, patchy low-lying bryozoan thickets are present in a relative narrow band in water depths of 75-110 m (Figure 3-25b and Figure 3-29a), where they provide structural habitat (Wood and Probert 2103) for a diverse epibenthic community that includes many commercial fishes, as well as juveniles of commercial targeted species, such as juvenile blue cod and red cod (Batson and Probert 2000). Although *C. elegans* is the most dominant species, six additional frame-building species, including four key species (*C. elegans*, *H. robusta*, *C. agglutinans*, *H. vellicata*, and *Adeonellopsis* spp.) and two contributing species (*H. foliacea*, *Celleporina grandis*) help comprise these thickets; with *C. agglutinans* and *C. grandis* becoming more dominant in outer shelf locations (Batson and Probert 2000; Wood and Probert 2103). There is also some evidence that wireweed complex (e.g. *Phyllochaetopterus socialis*) may provide sediment stability and epibenthic surfaces for attachment during the early colonisation of thickets (Batson 2000; Batson and Probert 2000).

**Foveaux Strait:** *Cinctipora elegans* is the primary reef-forming bryozoan in Foveaux Strait where its compact colonies form kilometre scale patchy thickets in water depths of 70 - 90 m (Figure 3-29b). These thickets are thought to have been heavily reduced in extent by the dredge fishery targeting the Bluff oyster, *Ostrea chilensis* (Batson 2000; Batson and Probert 2000, Cranfield et al. 2001; but see Michael 2007), which supported higher densities of Bluff oysters than adjacent habitats (Batson 2000; Batson and Probert 2000). One hundred and thirty years of dredge fishing is believed to have diminished both the complexity and distribution of these reefs (Cranfield et al. 1999; Batson and Probert 2000).

**Separation Point, Tasman Bay:** Bryozoan thickets, dominated by the reef-building bryozoa *Celleporaria agglutinans* along with *Hippomenella vellicata*, occur extensively across the seabed in depths of 10-35 m around Separation Point, in the Tasman Bay (Bradstock and Gordon 1983). In 1980, a 146 km<sup>2</sup> area off Separation Point an exclusion zone was closed to power-fishing (trawling, seining and dredging) to protect the seabed and the commercial fish species associated with these

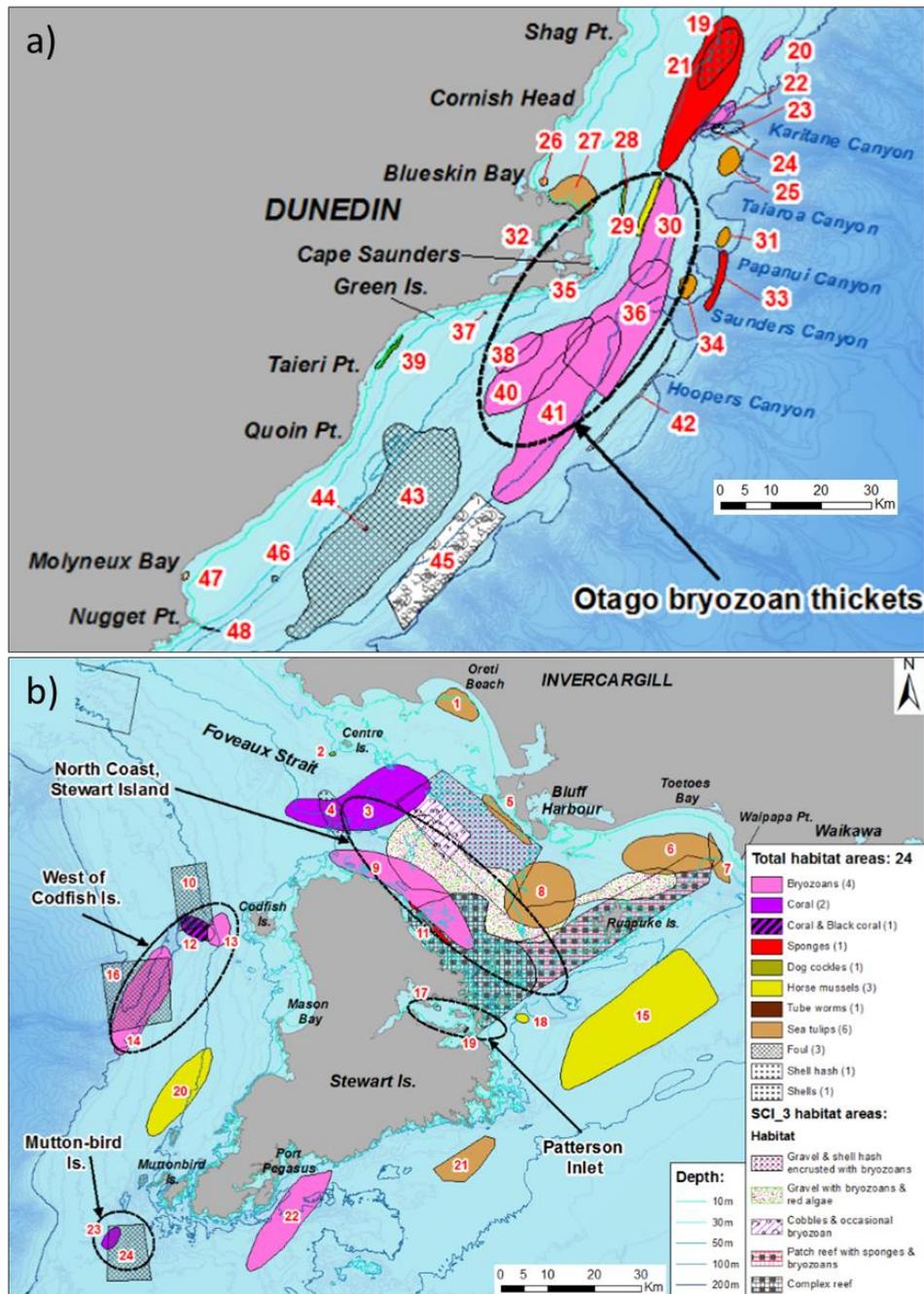
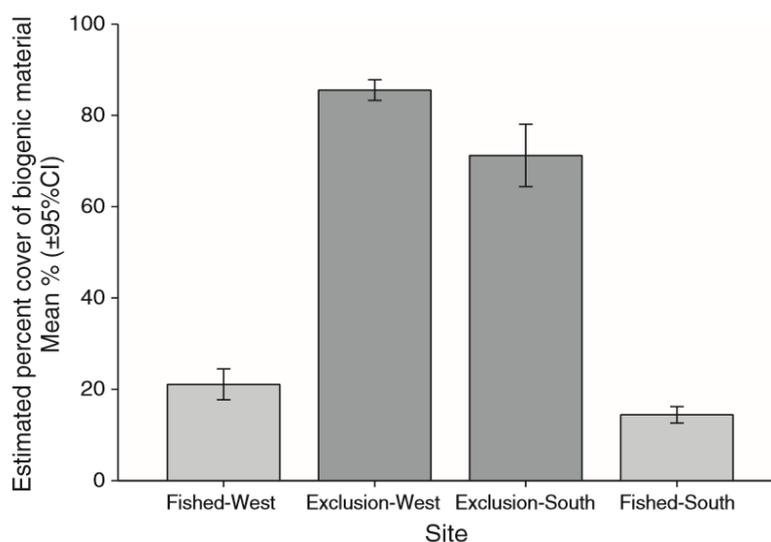


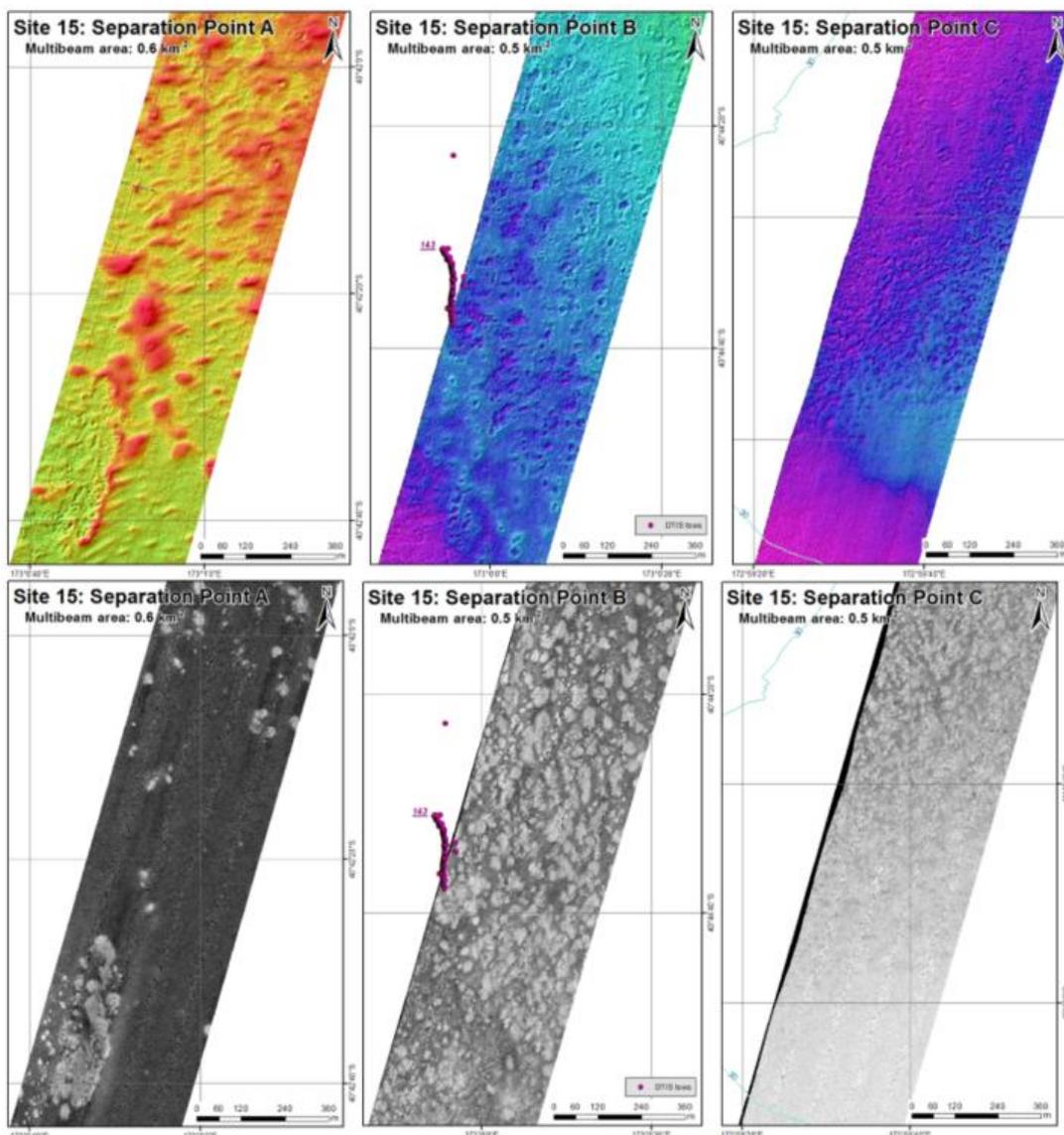
Figure 3-29: LEK maps for a) Otago shelf and b) Foveaux Strait and Stewart Island indicating the location of bryozoan (and 'coral') fields - depicted by pink (and purple and purple striped) polygons. Each fisher-drawn area has been assigned a unique number, specific to this regional section (red). Some key sites are circled and labelled as black text on white background (Source: figures 16 and 17 of Jones et al. 2016).

thickets (Grange et al. 2003). *C. agglutinans* along with *H. vellicate* are encrusting species that over time form large reef-like structures (or mounds) each up to 40 cm tall and 50 cm wide (Grange et al. 2003). Both species used to be very common off Separation Point in Abel Tasman National Park, and in Torrent Bay (the latter now eliminated) where they formed complex low-lying mounds that supported a diverse range of epibiont species (e.g. 92 taxa - mostly other bryozoans, as well as brachiopods, sponges, hydroids were collected from a single dredge at Separation Point), horse mussels, and a variety of small, mobile epifauna (Grange et al. 2003). A side scan survey in 2002 quantified the reefs as extending over 55 km<sup>2</sup> of the seabed (representing 38% of the protected area) and were also present outside the protected area (Grange et al. 2003). These mounds also provided refuge and a good source of food (abundant mobile epifauna) for juveniles of commercial fishes, such as snapper and tarakihi (Bradstock and Gordon 1983). In 2008, sampling and sidescan imagery collected inside and outside of western and southern sides of the exclusion zone, found significantly higher bryozoan material (Figure 3-30) and over a four-fold larger area of seafloor inside the exclusion zone, while significant trawl activity (trawl marks visible in the seafloor imagery) was recorded outside to the south and to a lesser extent to the west (Handley et al. 2014).



**Figure 3-30: Estimated mean % cover of biogenic material, comparing inside and outside the Separation Point exclusion zone.** Inside and outside samples were collected from the western and southern sides of the reserve (Source: from Figure 3a, Handley et al. 2014, n=12 replicates).

Although individual sites have not been monitored through time, these inside and outside comparisons indicate a marked shift in community state from a diverse and very productive bryozoan/suspension-dominated community to a much more depauperate and less productive community dominated by deposit feeders, scavengers and predators (Handley et al. 2014). Multibeam imagery depicting complex mound habitats has also been collected in 2011 along a single swath (Jones et al. 2018, Figure 3-31) - where bryozoan thickets had previously been identified in 2003 from side-scan imagery and surveys (Grange et al. 2003).

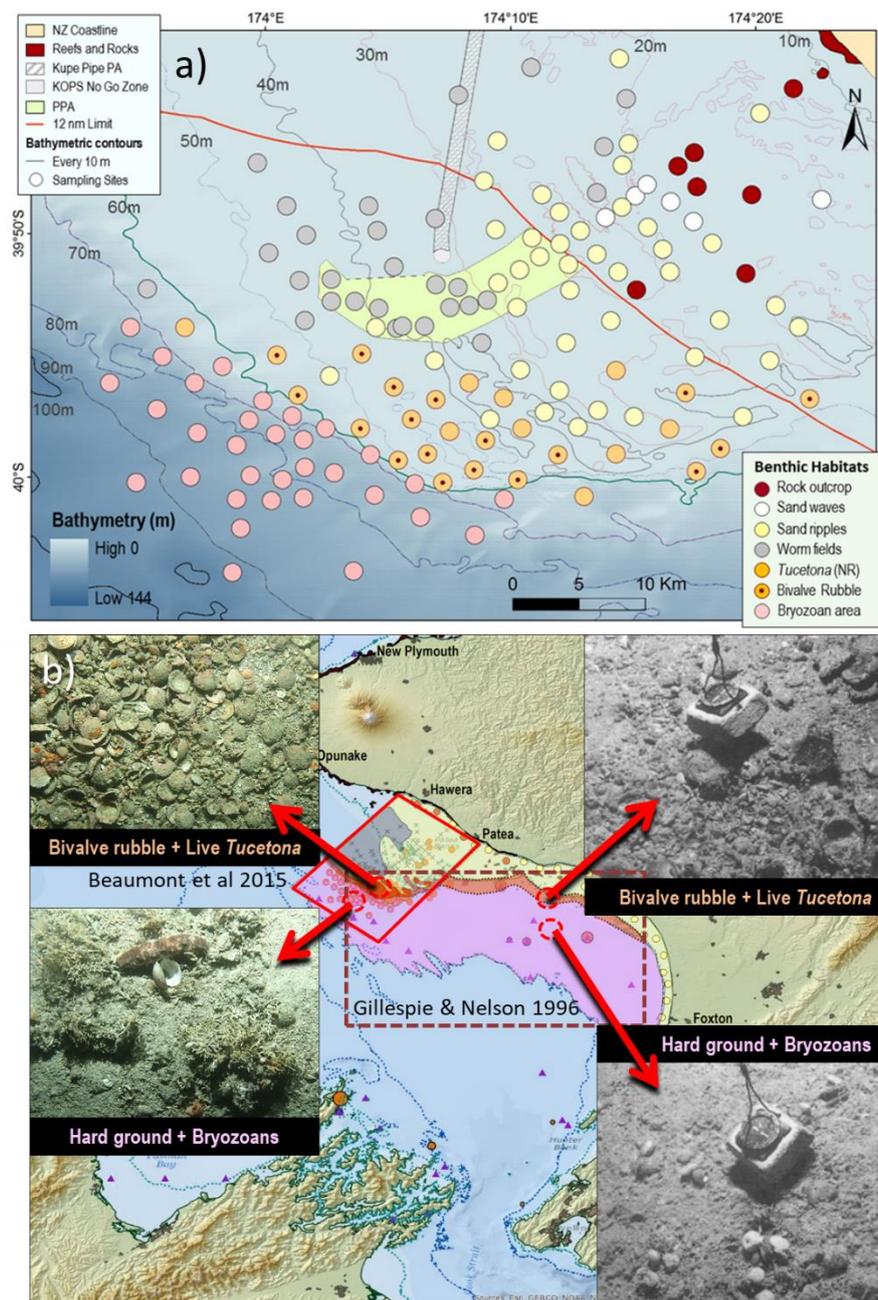


**Figure 3-31: Multibeam bathymetry (top images) and backscatter (bottom images) imagery from inside the Separation Point exclusion zone, in Tasman Bay.** A and B show patches of raised but low-lying features that are thought to show bryozoan mounds surrounded by soft muddy sediments, while C depicts a gradient from raised features into harder packed sands (Source: Figure 30 from Jones et al. 2018).

**South Taranaki Bight.** Offshore of Patea Shoals, in the South Taranaki Bight (STB), *Tucetona laticostata* shell debris accumulates at the base of mid-shelf slope in water depths of 60 m-75 m forming an extensive shell field (Figure 3-32a; Gillespie and Nelson

1996; Beaumont et al. 2015). Shell in this soft-sediment zone provides hard substrata that have been heavily colonised by reef-forming bryozoans (Figure 3-32a), comprising all eight key habitat-forming species (Beaumont et al. 2015, Appendix E), along with a diverse array of sessile organisms (including encrusting and erect sponges, foliose bryozoans, colonial and solitary ascidians, brachiopods and epiphytic bivalves) that collectively bind and stabilise these shells (Beaumont et al. 2015, T. Anderson, NIWA pers. obs.). This low-lying (~< 30 cm high) bryo-shell matrix provides refuge for a range of motile species, including crabs, ophiuroids, holothurians, gastropods, nudibranchs and the deepwater triplefin, *Matanui profundum*, with total diversity and abundance significantly higher

than in neighbouring soft-sediment habitats (Beaumont et al. 2015). Previous studies along with specimen collections from the STB (e.g. TePapa collections) indicate this



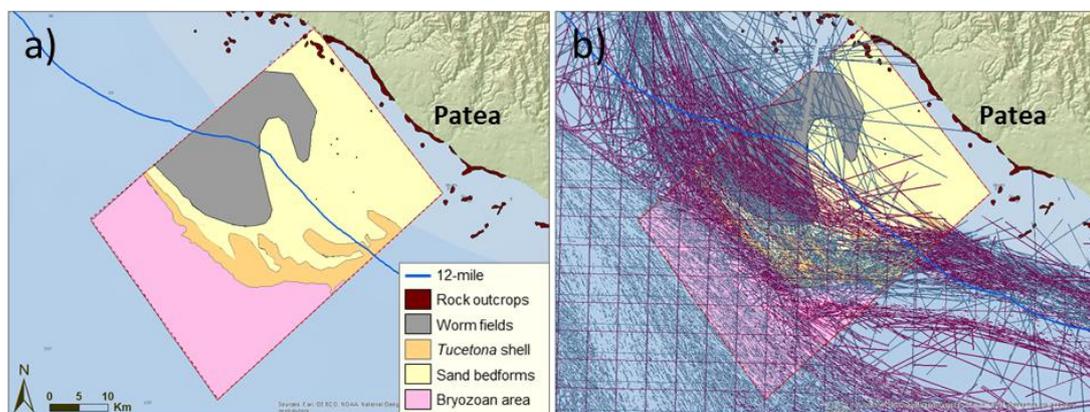
**Figure 3-32: Seabed habitat types, including the location of bryozoan areas - depicted in pink circles and polygons, a) observed within the Patea Shoals region, and b) predicted across the South Taranaki Bight.** Coloured circles (defined in legend of Figure a) represent survey sites sampled and videoed in 2011 (Source: Figure 7 from Beaumont et al. 2015), NR = no rubble; b) Polygons showing predicted distribution of low-lying bryozoa fields across Patea Shoals (red rectangle – based on Beaumont et al. 2015) and the broader South Taranaki Bight (dashed rectangle - based on Te Papa specimen collections and drop camera observations– black and white photographs from Gillespie and Nelson 1996). Colour photographs are from 2011 - Figure 9 from Beaumont et al. 2015.

habitat may occur extensively from north of Patea Shoals down to the Whanganui shelf in water depths of between 55-75 m (Gillespie and Nelson 1996; Figure 3-32b). This habitat, however, does

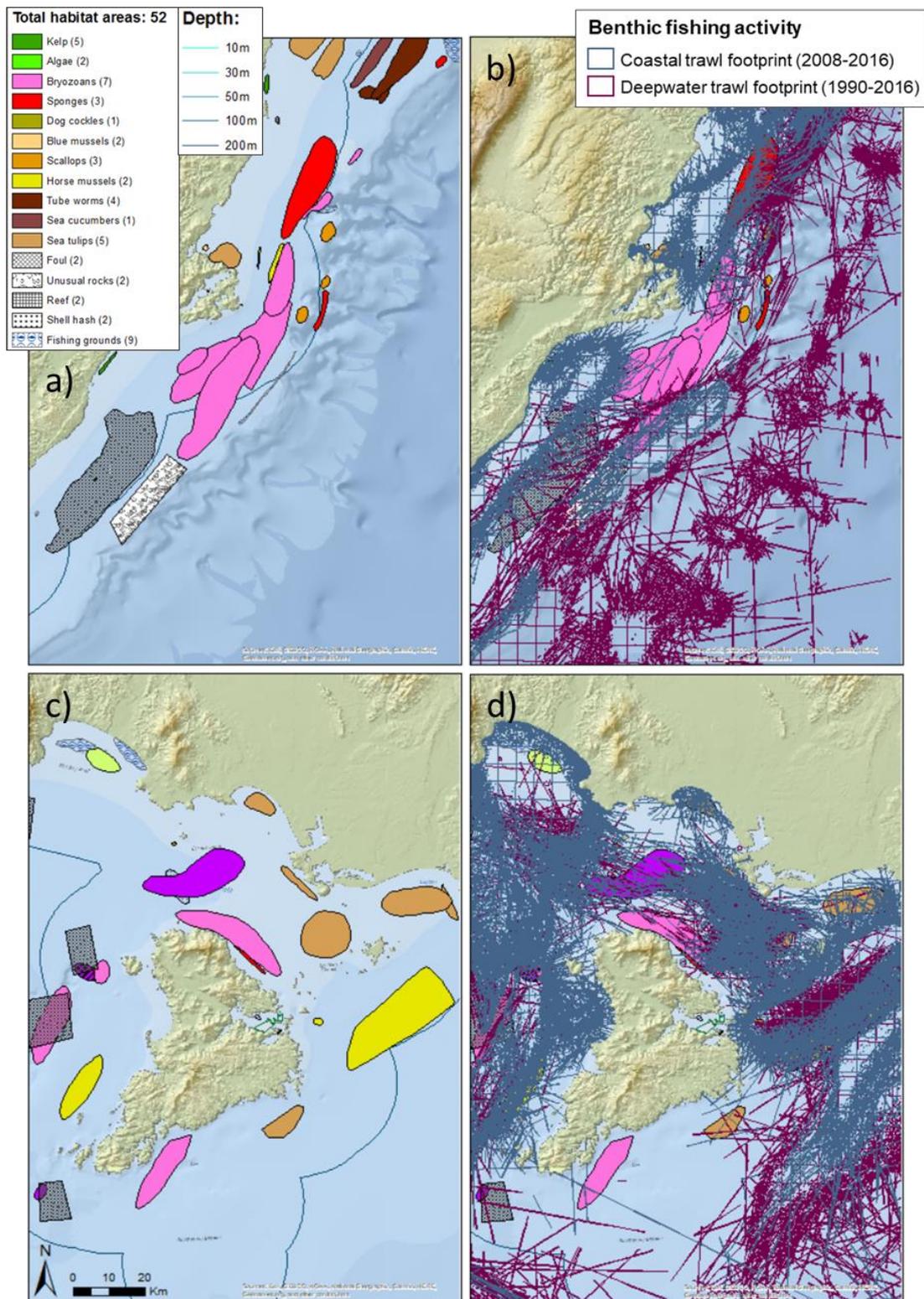
not appear to be pristine, as bryozoa of most species were broken and substantial bryo-debris was present across the zone (images in Beaumont et al. 2015; Gillespie and Nelson 1996). Beaumont et al. (2015) suggested that “On-going bottom trawling in the area may account for the lack of any large, robust colonies. However, the frequency of disturbance in individual areas seems sufficiently low to maintain reasonable biodiversity and moderate colony sizes”.

### 3.6.6 Stressors and threats

- Bryozoan habitat is fragile and vulnerable to disturbance particularly from bottom-contact fishing activities (e.g. dredging and bottom trawling, including scallop dredging, Cryer et al. 2000) which has caused significant loss of this habitat in some areas (review by Wood et al. 2012, but see Michael et al. 2007). Reef-forming bryozoans have been recorded at numerous locations on the continental shelf around New Zealand, in depths where bottom fishing is common (e.g. South Taranaki Bight - Beaumont et al. 2015; Otago Shelf – Batson and Probert 2000; Wood et al. 2012). Benthic fishing activity is a significant threat to bryozoan thickets, especially in mid to outer shelf areas, where fishing activity is high (e.g. Figure 3-33 and Figure 3-34), and often targets fish found in these habitats.
- Sedimentation from land. Bryozoans are suspension feeders and are susceptible to increased suspended sediments and sediment deposition (which can smother colonies and reduce feeding and kill colonies). Bryozoan thickets close to land are likely to be most at risk (e.g. Separation Point).
- Recovery of bryozoan thickets are likely to be in the order decades reflecting the slow growth rates of frame-building species (see review in Batson and Probert 2000).



**Figure 3-33: Benthic fishing activity (fishing effort) overlaid on polygons depicting biogenic habitat over Patea Shoals.** Left image: coloured-polygons delineate different shelf habitats, including patchy bryozoan thickets (pink polygons) and tubeworm fields (grey polygon). Polygons are based on extensive baseline surveys undertaken in 2011 (described in detail in Beaumont et al. 2015; but also see Figure 3-34a); right image: fishing effort overlaid on biogenic habitats. Fishing effort is from the coastal trawl fishery (data from 2008 to 2016 in water depth of 0-250 m) – depicted by grey-blue lines, and the deep-water trawl fishery (data from 1990-2016 mostly in water depths >200 m-1600 m) - depicted by burgundy lines (as per legend in Figure 3-34).



**Figure 3-34: Benthic fishing activity (fishing effort) overlaid on the LEK polygons depicting biogenic habitat on the Otago shelf (a-b) and Foveaux Strait (c-d).** Left image coloured-polygons depict different biogenic habitats (as explained in the legend and Figure 3-29); right image: fishing effort is from i) the coastal trawl fishery (data from 2008 to 2016 in water depth of 0-250 m) and ii) the deepwater trawl fishery (data from 1990-2016 mostly in water depths >200 m-1600 m).

### 3.6.7 Condition

Although few baseline and/or monitoring surveys exist to determine how bryozoan thickets have changed through time, some information exist to suggest that those thickets exposed to bottom fishing activity have undergone physical removal and damage possibly over extensive areas - kms of seafloor (e.g. Otago shelf, Separation Point and Patea Shoals). Protection of bryozoan reefs at Separation Point, following fishing impacts has been slow to recover since the 1940s, and then only very partially (Grange et al. 2003).

**Table 3-15: Overall condition status of Bryozoan thickets within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Decreased	Moderate-Poor <sup>1</sup>	Very Good <sup>2</sup> (where known)	Declining <sup>3</sup>	Moderate/Low <sup>1,2</sup>

<sup>1</sup> Most thickets present in areas where fishing activity is frequent, with evidence of damage and removal based on research surveys, fishery bycatch, historic catches and long-time fisher's accounts relative to known distribution of thickets (e.g. Otago Shelf, Separation Point).

<sup>2</sup> Biodiversity is extremely high in bryozoan thickets, even where damaged (e.g. Separation point, Patea Shoals).

<sup>3</sup> Declines likely due to high sedimentation (especially inshore areas) and/or ongoing disturbance from benthic fishing activities (especially on mid-outer shelf areas).

#### Overall condition status within NZ

Habitat-forming bryozoan species are widely distributed around New Zealand. Colonies can reproduce without attaining large sizes, but attaining habitat-forming status can be compromised by bottom-trawling and survival can be affected by sediment from the land. The Separation Point bryozoan beds are still recovering from benthic fishing activities; Foveaux Strait is compromised by oyster dredging; and affected parts of Otago Shelf are mooted for protection.

### 3.6.8 Knowledge gaps

There is no national inventory on bryozoan thickets. Although several large-scale studies have been undertaken to determine their extent in some areas (e.g. - as described above, based mainly on published literature) and some information about species composition within these thickets, and the depth-zone habitat-formation occurs in. The distributions of bryozoan thickets around New Zealand are not well surveyed beyond these specific studies. The autecology of most key habitat-forming species within this group has never been studied. Reproductive season is known for some species, but growth rates are unknown. The dearth of knowledge is especially critical for *C. elegans*. Absolutely nothing is known about its mode of reproduction (how, where in the colony, when). It is a very special species, comprising the type species of an endemic genus and family, and is globally unique and the most basal species in gene trees of other living members of its order (*Cyclostomata*).

**Table 3-16: Gap analysis summary for Bryozoan thickets.**

Type	Description
<b>Distribution &amp; function</b>	The distributions of bryozoan thickets around New Zealand are not well known, apart from a few fishery-important areas. Bryozoan thickets are known to support high biodiversity and are important to many fishery-important species, but are extremely fragile and vulnerable to physical disturbance, with little known about recovery rates following disturbance.
<b>Biological &amp; taxonomic</b>	Taxonomy of thicket-forming bryozoan species is relatively well known, but basic biology is poorly known for even dominant/key species.
<b>Management &amp; conservation</b>	Bryozoan thickets are poorly represented within Marine Reserves, but are protected within the Separation Point exclusion zone (146 km <sup>2</sup> area) in Tasman Bay – although the current state and extent of these thickets is not known.

## 3.7 Sponge gardens

### 3.7.1 Habitat description and definition

Sponges occur around New Zealand and are a principal component of many rocky reef assemblages, especially below depths at which large algae can grow. They also occur across a range of soft sediment systems, where sufficient hard surfaces are available for initial attachment. The term 'garden' is used for situations where sponges grow in sufficient abundance and extent to form the dominant cover. In shallow north-eastern New Zealand, this is often on flat reef basements covered by a thin layer of coarse sediment, as well as on more topographically complex reef. Comparatively well studied examples include the "Sponge Garden" off Goat Island, within the Cape Rodney to Cape Okakari Marine Reserve (Battershill 1987) and Spirits Bay at the top of Northland (Cryer et al. 2000, Tuck and Hewitt 2013). Many species are present; the dominant habitat formers possess morphologies which provide three-dimensional structure off the seafloor, e.g., bowls, finger, tube, and mound forms. For example, Goat Island's Sponge Garden (about 18–27 m depth, 33 species recorded) is defined by a high density of discrete branching and massive sponges, as well as encrusting sponges, e.g., *Polymastia granulosa*, *Aaptos*, *Raspailia topsenti*, *Axinella* n sp, *Cinachyra* n sp., and algal species (Battershill 1987).

**Definition:** Sponge Gardens are defined as occurring on the seabed in greater than  $\geq 25\%$  cover over an area of 100 m<sup>2</sup> or more, or where sponge specimens contribute to  $\geq 20\%$  of the volume of the catch from towed sampling gear, or  $\geq 25\%$  of the volume in a successive grab samples (MacDiarmid et al. 2013).

### 3.7.2 Key genera/species

- *Aaptos* (Family: Suberitidae)
- *Ecionemia elata* (Family: Ancorinidae)
- *Axinella* spp. (Family: Axinellidae)
- *Callyspongia* spp. (Family: Callyspongiidae)
- *Cinachyra* spp. (Family: Tetillidae)
- *Crella* spp. (Family: Crellidae)
- *Dendrilla rosea* (Family: Darwinellidae)
- *Iophon* spp. (Family: Acarnidae)
- *Ircinia* spp. (Family: Irciniidae)
- *Polymastia granulosa* (Family: Polymastiidae)
- *Raspailia* spp. (Family: Raspailiidae)

### 3.7.3 Data sources

- Museum specimen identification datasets (OBIS-NZ, NIWA-Inverts and Te Papa) (Table 2-1), where data were extracted for key-habitat forming species (as defined in section '3.7.2 Key genera/species') for New Zealand.

### 3.7.4 Provision of ecosystem service

Bell (2008) reviewed the functional role of sponges. He grouped these functions under a range of headings, with an assessment of the international literature, as follows.

- Impacts on substratum

- Bio-erosion
- Reef creation, and substrate stabilisation, consolidation and regeneration
- Importance of sponges on substrate.
- Benthic-pelagic coupling
  - Carbon cycling and energy flow
  - Silicon cycling
  - Oxygen depletion
  - Nitrogen cycling
  - Importance of sponge benthic-pelagic coupling.
- Sponge associations with other organisms
  - Facilitating primary production
  - Secondary production
  - Provision of microhabitat and sponge associations
  - Enhanced predation protection, survival success, range expansions and camouflage through association with sponges
  - Sponge as a settlement substrate
  - Disrupting near-boundary and reef level flow regimes
  - Sponges as agents of biological disturbance
  - Sponges as releasers of chemicals
  - Sponges as tools
  - Importance of sponge interactions and associations
- Sponge gardens also have a high aesthetic value for tourism, especially to the diving and free-diving communities.

Bell (2008) concluded that sponges clearly fulfil many important functional roles across temperate, tropical and polar ecosystems. There was insufficient information to show the relative importance of these different functional roles. He stated that *“determining or ranking the functional roles is difficult, but it is important, since some roles that sponges fulfil will almost certainly be more important than others, and this may vary spatially or temporally”*.

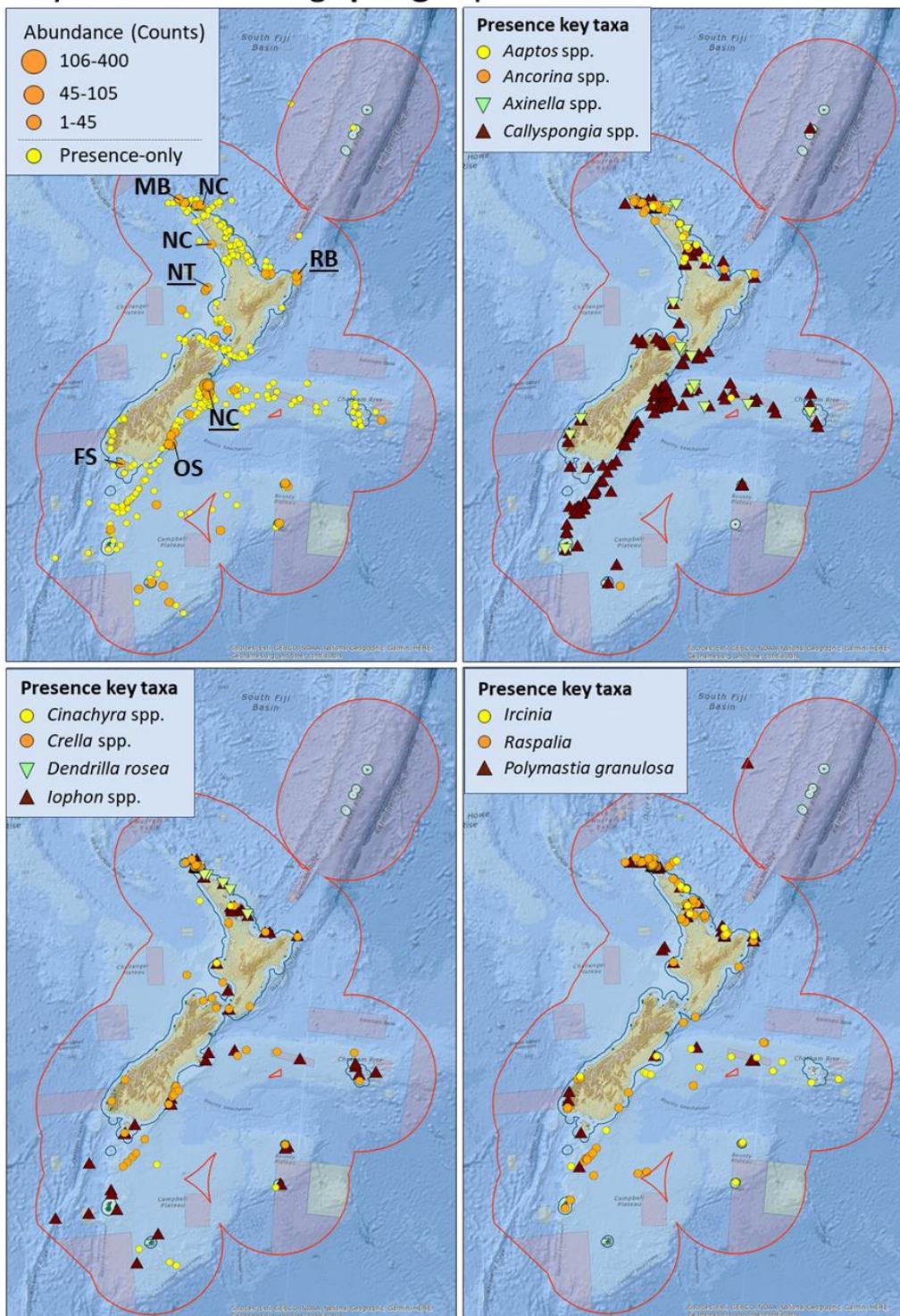
### 3.7.5 Biogeographic distribution

#### National scale

Sponges occur all around New Zealand, from intertidal pools out to the deep abyssal plane (and in freshwater systems), with many species of wide-ranging size, form, colour and composition. New species continue to be described each year, with many places in the continental sea and wider EEZ yet to be well explored by science. As such, their national distribution is poorly described, and tends to be as point samples from general field surveys, rather than at the abundance and assemblage compositions scale.

No national inventory of sponge occurrence and extent exists for New Zealand, either for individual species, or species complexes (including sponge ‘gardens’). Work on Local Ecological Knowledge (LEK) of mainly retired commercial fishers (largely trawling, depth range 10 – circa 250+ m) identified many usual places/areas of sponge abundance (as seen as unusual bycatch, often in initial exploratory fishing, not necessarily in normal fishing ground operations) which along with many other biogenic

## Key habitat-forming sponge species



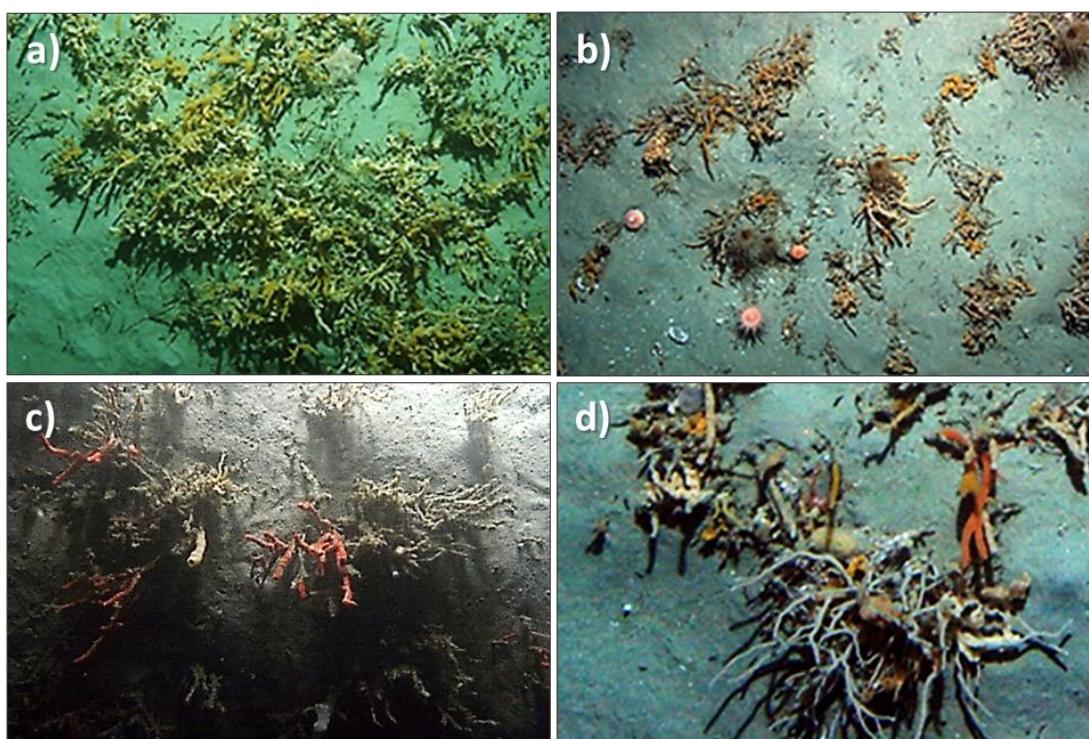
**Figure 3-35: Known distribution of key 'sponge garden' species in New Zealand.** a) Total abundance (orange bubble plots) of all sponge species from NIWA's Specify data, and their presence (yellow circles) from all available datasets (OBIS-NZ, TePapa, and NIWA-Inverts datasets). b-c) Presence-only plots for eleven key species (depicted in legends). Abundance = raw/unstandardized counts from NIWA dredge collected sampling, used here simply to determine where sponge gardens (rather than isolated individuals) may occur. Sites surveyed in Jones et al. 2018 are: MB=Middlesex Bank, NC=North Cape, NC=North West Coast (Canyons), NT=North Taranaki Bight(Canyons), RB=Ranfurly Bank, NC=North Canterbury, OS=Otago Shelf, FS=Foveaux Strait. Underlined site abbreviations (left image) = the three core sites examined in detail in Jones et al. 2018.

habitats were marked up as polygons on charts (e.g. Figure 2-1). In many areas, they were reported as part of a wider biogenic habitat mixture, including coral/black coral, and bryozoans. Large sponge habitat areas were reported off North Cape, Rangaunu Bay, the Poor Knights Islands, Mayor Island, East Cape, Mahia Peninsula, Kaipara Harbour, the North and South Taranaki Bights, Wellington, Otago, Foveaux Strait, north of Jackson's Bay, and the west coast of the South Island. Many species are likely to have contributed to these areas, based on the fisher's accounts, with different sponge species assemblages in different geographic regions (Jones et al. 2018).

### Regional scale/case studies

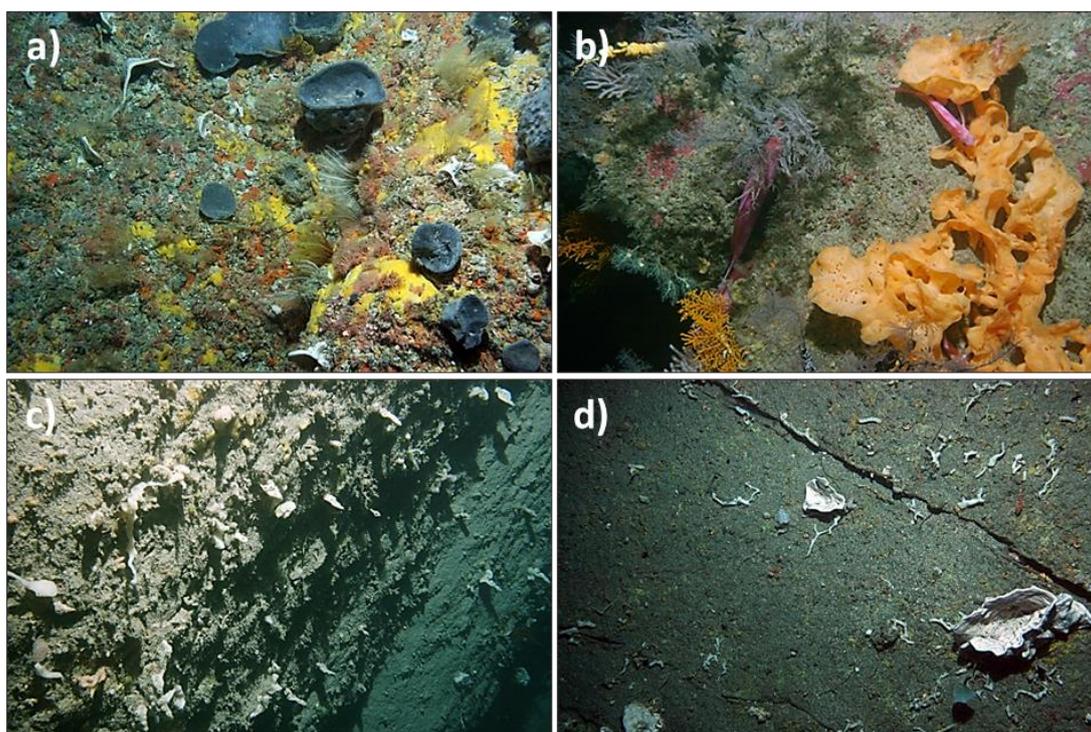
Some work has been done on smaller spatial scales on sponge gardens and assemblages. The most comprehensive one at diving depths was that of Battershill (1987) who studied the spatial and temporal dynamics over several years of a sponge garden in the Leigh Marine Reserve, north of Auckland. Examples of deeper water (70–250 m water depth) sponge assemblages, include:

**The Hay Paddock, off North Otago**, is a soft sediment area that supports a diverse epifaunal species community, living on the tubes of polychaete worms (known as wireweed to fishers) (Figure 3-36). These tubes provide a harder substrate for other species to attach to, including sponges. Combined with similar habitat further north off the north Canterbury Bight (wireweed, see worms section), six different sub-assemblages have been identified statistically for this general habitat type, with an associated sponge species diversity ranging from 6 to 19 species (Table 41 of Jones et al. 2018). Most of these species are 'stringy' in their morphology, with many 'new to science' when first sampled in 2011.



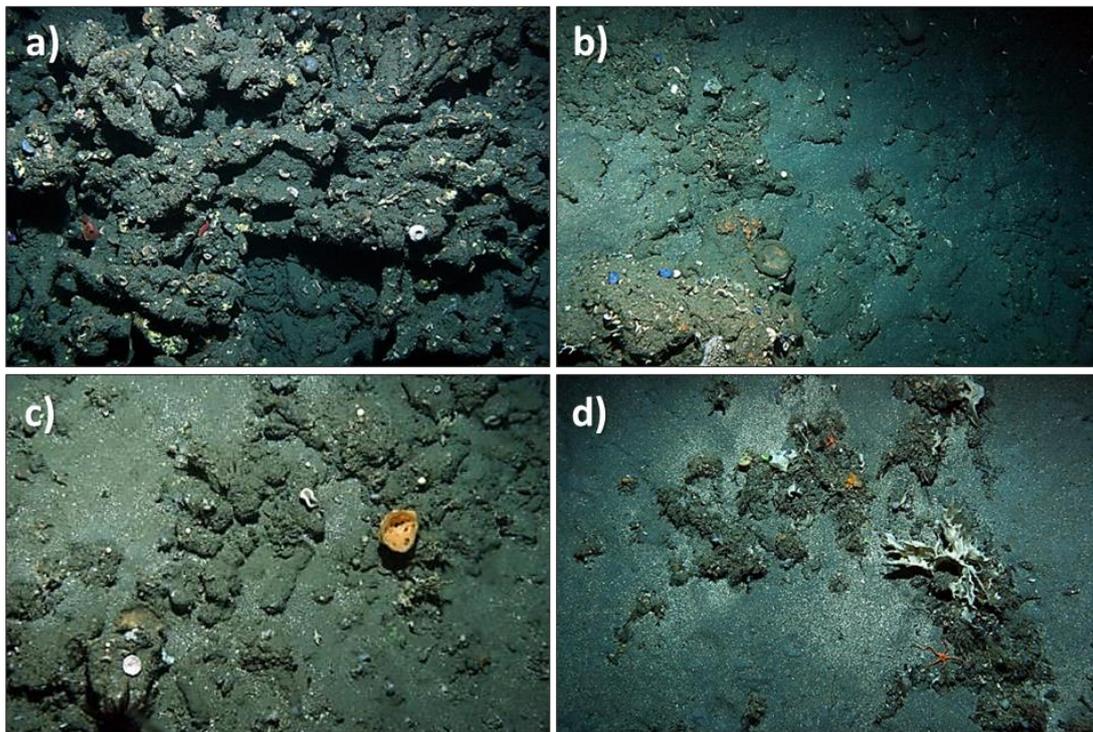
**Figure 3-36: Hay Paddock, northern Otago shelf, sponge examples.** a–d) polychaete worm tubes (wireweed) with associated sponge assemblage, anemones, ascidians, and starfish; c) *Callyspongia* n. sp. 2 (tubular) and 11 (golden) and *Crella incrustans* (red); d) *Haliclona* n. sp. 18 (fat spaghetti strings) (Source: images from Jones et al. 2018).

**Ranfurly Bank, off the East Cape** is a large rocky seafloor feature surrounded on three sides by the continental slope, with a deeper trough to the west connecting it to the mainland. It is semi-oceanic in nature and exposed to high current and open sea conditions. Survey work on its biogenic habitats, using multibeam sonar, towed camera arrays, and beam trawl/rock dredges, statistically revealed four broad assemblages, with the three habitat-forming species assemblages that included sponges having a sponge diversity ranging from 15 to 56 species (some examples below in Figure 3-37) (Table from Jones et al. 2018). Other major contributing biogenic habitat-forming species included macroalgae, bryozoans, hydroids, corals, and ascidians.



**Figure 3-37: Ranfurly Bank, East Cape examples of sponge assemblages.** a) reef outcrops dominated by sponges such as the grey *Ecionemia alata* and white fans of *Xestospongia corallodites*; b) deep northern rocky outcrops with sponges (*Symptella rowi*) and black corals; c, d) sponge and ascidian-encrusted rock faces of the eastern outcrop (sponges including *Xestospongia corallodites* and *Coscinoderma. sp2*) (Source: images from Jones et al. 2018).

**West Coast Canyons, on the North Island.** Canyons and drop-off features, such as bluffs and ridges, that occur along the edge of the continental shelf off the west coast of the north Island, support a range of benthic habitats. While very poorly studied, several of these canyons were investigated in 2011 (Jones et al. 2018). Areas of biogenic rubble (thought to be relict carbonate seep systems) occurred along the canyon sides, along with occasional rock outcrops. These harder surfaces supported a range of encrusting species, including sponges. Four biogenic habitat assemblages/clusters were identified statistically, with three of them having sponge species diversity ranging from 8 to 26 species (Table 31, Jones et al. 2018). Many of these are ‘rock’ sponge species (e.g., blue-coloured *Reidispongia coerulea*), so-called as they are texturally very hard and robust (Figure 3-38).



**Figure 3-38: North Taranaki canyons fauna.** a) rocky outcrops with diverse sponge fauna, including *Petrosia* n sp. 6 (yellow encrusting), *Pleuroma turbinatum* (white cup), and *Aciculites pulchra* (tan ears); b) *Reidispongia coerulea* (blue and white cups), *Pleroma menoui* (furry edged ear), *Psammocinia* cf. *verrucosa* (grey plate) and *Darwinella* sp. (encrusting orange); c) rubble patches with *Rossella ijimai* (orange); d) *Calyx* sp. 5/*Xestospongia coralloides* (white jagged fan), and a small *Symplectella rowi* (orange) (from Figure 81 of Jones et al. 2018).

### Temporal change

Sponge gardens within New Zealand have rarely been mapped and monitored through time, except for a few specific locations, such as within the Okakari Point to Cape Rodney Marine Reserve in north-eastern New Zealand. In 1977, sponge gardens were recorded in water depths >16 m in sand veneered areas where the flat rock platform slowly shelves beneath soft-sediment sands (Ayling 1978). Ayling described these gardens as “visually dominated by three species of orange finger sponges but there are also large numbers of a variety of massive and encrusting sponge”. These deep sponge gardens have remained stable through time with negligible change (<1% ha) recorded from 7.1 ha in 1978 to 6.6 ha in 2006 (Leleu et al. 2012; Table 3-8).

#### 3.7.6 Stressors and threats

- Fishing is arguably having some of the greatest past/present impacts on sponge assemblages, along with land-based sedimentation in coastal regions of New Zealand (Morrison et al. 2009). Little information is available in the New Zealand context on sponges, aside from high profile areas such as Spirits Bay where dredging (and possibly trawling) has reduced high epifaunal biodiversity, including sponges, and the fishery has subsequently been closed in some areas (Tuck and Hewitt 2013).

Tuck et al. (2017) assessed the effects of fishing on soft sediment habitat, fauna and processes in the New Zealand context. As part of a summary of various reviews and meta-analyses of published studies (e.g., Collie et al. 2000; Kaiser et al. 2006), there was general agreement that dredges tend to be more damaging than trawls, with other gears having less, but still detectable impact. Physical impacts of bottom gear were greatest on hard, complex seabed,

and least on unconsolidated sandy habitats. The greatest effects were recorded in low energy environments, and high energy environments were considered more robust, with effects sometimes thought to be negligible. However, this conclusion was tempered with reflection of the lack of an historical perspective on benthic communities, and the long fishing history of the study locations (mostly North-eastern Europe and North America). The reviews also concluded that long-lived species, surface-living species, structurally fragile species, and biogenic habitat forming species were all particularly vulnerable, and such species were frequently found in high energy environments (Tuck et al. 2017).

- Increasing sedimentation in coastal areas is also a threat to sponge species and assemblages. A comprehensive review on the effects of sedimentation by Bell et al. (2015) found that the literature “clearly shows that sponges are influenced by sediment in a variety of ways, most studies confer that sponges are able to tolerate, and in some cases, thrive, in sedimented environments. Critical gaps exist in our understanding of the physiological responses of sponges to sediment, adaptive mechanisms, tolerance limits, and the particularly the effect of sediment on early life history stages”.
- In a review of likely ocean acidification (OA) effects on New Zealand marine systems, Law et al. (2017) found little information on OA sensitivity of temperate sponges. They argued that sponges might be expected to be particularly vulnerable to variations in water chemistry, including pH, given their single layer separation from the external environment (Bergquist 1978), and a limited capacity for acid-base regulation (Pörtner 2008). Calcareous sponges, with a calcium carbonate skeleton and associated mineralogy differences (Smith et al. 2013), were potentially more susceptible than demosponges, with their silica and spongin skeletons. Work on two common demosponge species (*Tethya bergquistae* and *Crella incrustans*) from the Wellington region found a pH reduction from 8 to 7.6 had a small, but significant effect on respiration rate. In contrast, increased temperature (20°C and 22°C) had a negative impact on respiration and survival rate for both, with elevated mortality compared with controls representing average annual and maximum summer temperatures (13.5°C and 18°C). This is consistent with tropical sponge findings (see Bennett et al. 2016), with a general tolerance to reduced pH (Bates 2015), but potentially greater threat from future warming (Bell et al. 2013).
- There is little direct empirical information available on threats to sponge gardens in New Zealand. In the Leigh Marine Reserve, Parsons et al. (2004) compared biological reef community habitat maps created in 1978 (dive surveys Ayling 1978), against maps created in 2000. Over this 22-year period, sponge gardens (in water depth > 12 m) declined from 47% to 14% cover (a 66% decline), as did kelp forest (49% to 24%, a 50% decline). Both were replaced by turfing algae, which increased from 2% to 52%. Turfing algae are more resistant to sedimentation than sponges and kelps, and this was the mechanism proposed to be driving these shifts, along with interactions with kelp (*E. radiata*) die-backs from disease. Bottom sediments in 2000 were composed of a mixture of size grades, with finer grades sitting within the turf (D. Parsons, NIWA, pers. comm.). Inner Goat Island Bay often experiences fine silt plumes extending into the bay during heavy rain-fall events, which discolour the water brown, so land-based sediment inputs probably played a leading role, although no direct evidence exists.
- At a much broader spatial scale, sampling of the upper east Northland continental shelf (North Cape to Poor Knights) observed an apparent large-scale sedimentation gradient on deep reef systems (50-200 m) (os2020.org.nz, Morrison et al. 2010). No formal analyses are available, but video observations indicated that the more southerly reef systems were covered by fine silt layers, with putatively lower biodiversity, while the more northerly reef systems (Rangaunu Bay and north) appeared to be relatively silt free, and with higher biodiversity. Similar observations along the lower East Coast of the North Island (Mahia Peninsula to Ranfurly Bank)

in 2010 also suggested a large scale and substantial sedimentation gradient in that region’s deep reefs, with an inverse relationship between increasing epifaunal biodiversity, and decreasing fine sediment cover (Morrison and Jones, pers. obs.). As these patterns are at the hundreds of kilometres (bioregion) scale, they are concerning, and suggest that significant sedimentation impacts have and are occurring with little or no human awareness of them. No information exists on what has historically occurred, or is now occurring, in terms of land-based activities’ impacts on these communities (Morrison et al. 2009). Fishing is the other key stressor on sponge assemblages (Figure 24), although assemblages on rougher ground have some natural protection from disturbance by actively towed gears. Little information is available in the New Zealand context, aside from in high profile areas such as Spirits Bay where dredging (and possibly trawling) has reduced high epifaunal biodiversity, including sponges, and the fishery has subsequently been closed in some areas (Tuck and Hewitt 2013).

### 3.7.7 Condition

No regional or national scale assessment of sponge garden extent and condition exist. Very few areas have been re-surveyed through time, except for the ‘Sponge Garden’ in the Leigh Marine Reserve, which is protected from bottom disturbance (Cole et al. 1990). Of the few sponge gardens that have been mapped and monitored through time (e.g. within Leigh, Marine Reserve) these have shown to be very stable through time with negligible changes in extent or health (Leleu et al. 2012). However, those occurring outside of marine reserves are less studied. Sponge gardens growing on mid to outer shelf areas are likely to be impacted by benthic fishing activities, albeit to a lesser degree (given their often softer more flexible frames) than rigid more fragile species such as bryozoan thickets. However, few baseline surveys exist, and no monitoring has occurred in these offshore areas.

**Table 3-17: Overall condition status of Sponge Gardens within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Unknown-Stable <sup>1</sup>	Unknown-Moderate <sup>1</sup>	Good-Moderate <sup>2</sup>	Stable-Declining <sup>3</sup>	Moderate/Low <sup>1,2</sup>

<sup>1</sup> Where known – as very few sponge gardens that have been mapped or monitored through time.

<sup>2</sup> Biodiversity is high in sponge gardens, which are also often found growing on or in association with tubeworm fields, bryozoan thickets and/or beds of large shellfish (e.g. Morrison et al. 2014a; Jones et al. 2018).

<sup>3</sup> Expected to be stable where sedimentation is low and benthic fishing activities are absent, but in sub-prime condition or declining where either or both these stressors are present.

#### Overall condition status within NZ

Wide spread distribution of habitat-forming species, provide good ecosystem services, but not enough data available on the distribution and size of sponge gardens, with little known about changes over time.

### 3.7.8 Knowledge gaps

New Zealand (non-taxonomic) sponge habitat studies have been small-scale, and variable in methodology and taxonomic resolution. Most research has also been at shallow water depths, given the limits of SCUBA diving, yet most sponge assemblages are found at depths greater than 30 metres. For example, very extensive areas of deeper continental shelf reefs occur off North Cape on the Reinga Shelf (Jones et al. 2018), along the East Northland coast (Morrison et al. 2010), and south of Stewart Island (NIWA unpublished multibeam imagery). Sponge gardens also occur on some soft sediment systems, such as the “Hay Paddock” sponge assemblage off Oamaru (about 70 m water depth) (Morrison and Jones 2011, Jones et al. 2018). Because of this, large and fundamental information gaps exist.

A review of soft sediment assemblages in New Zealand included a section on subtidal invertebrates (Rowden et al. 2012). Several of their recommendations for future research are still directly relevant to sponges (and can be extended to rocky reef systems), as follows:

- Undertake surveys of the macroinvertebrate soft-sediment assemblages of those inlets and embayments that have received no or limited sampling to date. Such surveys will be resource costly, therefore inlets/embayments should be targeted according to their (1) present or future vulnerability to anthropogenic threats and consequently the need to provide baseline information to assess any disturbance effects, and (2) suitability for providing sites most appropriate for the understanding of the influence of environment on assemblage composition (see following recommendation).
- Carry out studies (mensurative and experimental) that determine the precise nature of the relationship between environmental factors (including habitat complexity) that can vary within and between inlets/embayments, and the occurrence and distribution of macroinvertebrate fauna; such that knowledge of these relationships can be used to model the distribution and composition of assemblages at locations where only environmental data are available.
- Undertake studies that can provide descriptions of the macroinvertebrate soft-sediment assemblages of the continental shelf and slope where little or no information is currently available. Such investigations will be resource costly, therefore the selection of such study areas should ideally be made with reference to testable hypotheses and therefore studies should include sites that: (1) provide a range and replication of large-scale environmental factors thought to influence assemblage composition (e.g. sedimentation rates, overlying primary productivity) (2) are comprised of biogenic substrates (live and dead) that provide habitat complexity at a range of spatial scales (3) include canyon features (that could act as conduits for faunal/system linkages between shelf, slope and adjacent deep-sea) as well as relatively simple non-incised slope (4) allow for an assessment of the impact of disturbance from bottom trawling and mineral/hydrocarbon exploitation (e.g. include sites with similar environmental characteristics but which differ with respect to levels of fishing pressure).
- Conduct experimental studies that will determine the mechanisms involved in the promotion and maintenance of biodiversity by habitat of structural complexity (e.g. bryozoan thickets/beds/reefs). Included in these studies should be assessments of the impact of physical disturbance (at different spatial and temporal scales) on such habitat by fishing, specifically evaluations should allow for an appreciation of the amount of ecological redundancy inherent in such habitats and the recovery time post-disturbance.

A national review of the links between biogenic habitat and fisheries production by Morrison et al. (2014a) also made several suggestions for further sponges as fish habitat research. Suggestions for new research were:

- Battershill (1987) suggested the existence of numerous sponge garden snapper nursery habitats in the Hauraki Gulf. Juvenile snapper are associated with structural complexity as are juveniles of other species, such as trevally, which may also be found nestled in amongst sponge gardens in higher current areas. The contribution to fisheries production is being examined currently within NIWA’s MBIE-funded ‘Juvenile fish habitat bottlenecks’ programme within East Northland and the Hauraki Gulf (snapper), and Marlborough Sounds (blue cod).
- The visual evidence of large scale degradation of continental shelf reefs in upper East Northland and along the lower east North Island suggests underlying human impacts. The evaluation of existing baseline Oceans 2020 data would be a critical step to determining the degree of biogenic habitat degradation and the management measures which could be implemented.
- A large area of New Zealand’s seabed is unexplored. The continental shelf and slope are heavily fished in areas where sponge gardens also occur. The value of these habitats to fisheries is not well understood but they are likely to play an important role in sustaining coastal and offshore fisheries. For example, The Hay Paddock, as a possible unique biogenic habitat assemblage, should be further investigated, including seasonal sampling of its associated fish species to quantify a suspected nursery function for species such as tarakihi (Vooren 1975).

**Table 3-18: Gap analysis summary for Sponge gardens.**

Type	Description
<b>Distribution &amp; function</b>	Sponges are a very diverse taxonomic group, and occupy a wide range of marine environments, as well as occurring in freshwater systems. New species are continuing to be discovered from less well-known areas of New Zealand’s coast, with sponges wider distribution and abundance as habitat formers being largely unknown for large areas of the marine estate. Their general ecological functions are relatively well understood, but the specifics remain as fundamental knowledge gaps.
<b>Biological &amp; taxonomic</b>	New species continue to be discovered, along with range and distributional knowledge. As an example, species that are considered rare in one region based on past knowledge, are sometimes found to be relatively common in other regions when more intensely surveyed.
<b>Management &amp; conservation</b>	Sponges are well represented in marine reserves, which tend to often focus on shallow rocky reef habitats (e.g. diverse sponge gardens are known to occur in Parininihi Marine Reserve in north Taranaki, and the Okakari to Cape Rodney Marine Reserve, near Leigh). However, sponge gardens in deeper rocky reef systems (beyond diving depths) or soft sediment habitats are not well represented in marine reserves, despite these habitats dominating most of the marine estate. Land-based issues such as sediment run-off are key threats to sponges; which marine reserves do not safeguard against.

## 3.8 Stony-coral thickets, and other habitat-forming corals

### 3.8.1 Habitat description and definition

While coral reefs are often thought of as being associated with warm shallow tropical seas (30 m or less), abundant and diverse deep-sea stony coral communities exist on continental shelves, slopes, canyons, and underwater raised features (UTF) including seamounts, knolls and hills throughout the world's oceans, in waters from 50 m to over 3000 m (Cairns et al. 2009; Tracey et al. 2011).

There are several forms of deep-sea coral. Scleractinian stony corals produce relatively large colonies (up to about 1 m in height) that can form large reef-like structures or 'coral thickets' (e.g. Figure 3-39). Often referred to as the engineers of the deep, these stony corals are associated with hard substrate on which they settle and grow. Reefs can extend from the summit of features such as seamounts and knolls, down the flanks to the base region, and are found on other hard-bottom outcrops on slope areas (Clark and Rowden 2009). Stony corals can also be in clumps (e.g., *Goniocorella dumosa* Figure 3-41b).

Other habitat-forming corals include several black coral and gorgonian octocoral species that are distinguished by their erect, often bushy, "tree-like" habit of growth (Figure 3-41 and Figure 3-40). These colonies can vary in size, some with heights exceeding 1-2 metres (e.g., *Paragorgia* spp., bubblegum corals and the *Bathypathes* black coral, Figure 3-41c and Figure 3-40b, respectively). Others in this group form low bushy structures e.g., the primnoid octocoral *Thouarella* spp (Figure 3-40a), and the rasta coral *Narella* spp (Figure 3-34e).

The New Zealand Wildlife Act affords protection to "all deepwater hard corals (all species in the orders Antipatharia, Gorgonacea, Scleractinia, and Family Stylasteridae)". The Order Gorgonacea is now included in the Order Alcyonacea (Watling et al. 2011), although the Wildlife Act 2010 amendment uses the former name Gorgonacea.

#### Definitions:

**Stony-coral thickets** are defined by structure-forming scleractinian species (*Madrepora oculata*, *Solenosmilia variabilis*, *G. dumosa*, *Enallopsammia rostrata*, and *Oculina virgosa*<sup>25</sup>) in densities >15% cover (at the scale of m<sup>2</sup>) over areas of 100s m<sup>2</sup>. Thickets can be identified by using direct sampling or, ideally, by imaging the seabed (MacDiarmid et al. 2013).

**Octocoral and hydrocoral habitats**, are not defined in the EEZ Act, but may comprise mono-specific or mixed species assemblages with various shapes (e.g. tree-like, bottle brush, and sea-fan corals in the). These can occur closely spaced or clustered in densities of >10% cover (at the scale of m<sup>2</sup>) over areas of 100s m<sup>2</sup>.

**Black corals**, are also not defined in the EEZ Act. Black coral colonies are more dispersed and solitary-like in their distribution (e.g. large sentinel black corals e.g., *Bathypathes*), and as such habitat-forming occurrence may be classified like sea pen fields i.e., by two or more individuals per m<sup>2</sup>.

### 3.8.2 Key species

#### Stony corals (Order: Scleractinia)

- *Solenosmilia variabilis* (Family: Caryophylliidae)
- *Goniocorella dumosa* (Family: Caryophylliidae)
- *Madrepora oculata* (Family: Oculinidae)
- *Enallopsammia rostrata* (Family: Dendrophylliidae)

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<sup>25</sup> *Oculina virgosa* this species was previously thought to be endemic.

### Other habitat-forming corals

- Black corals (Order: Antipatharia)
- Octocorals/Gorgonians (Order: Octocorallia)
- Hydrocorals (Order: Anthoathecata, subclass: Stylasteridae)

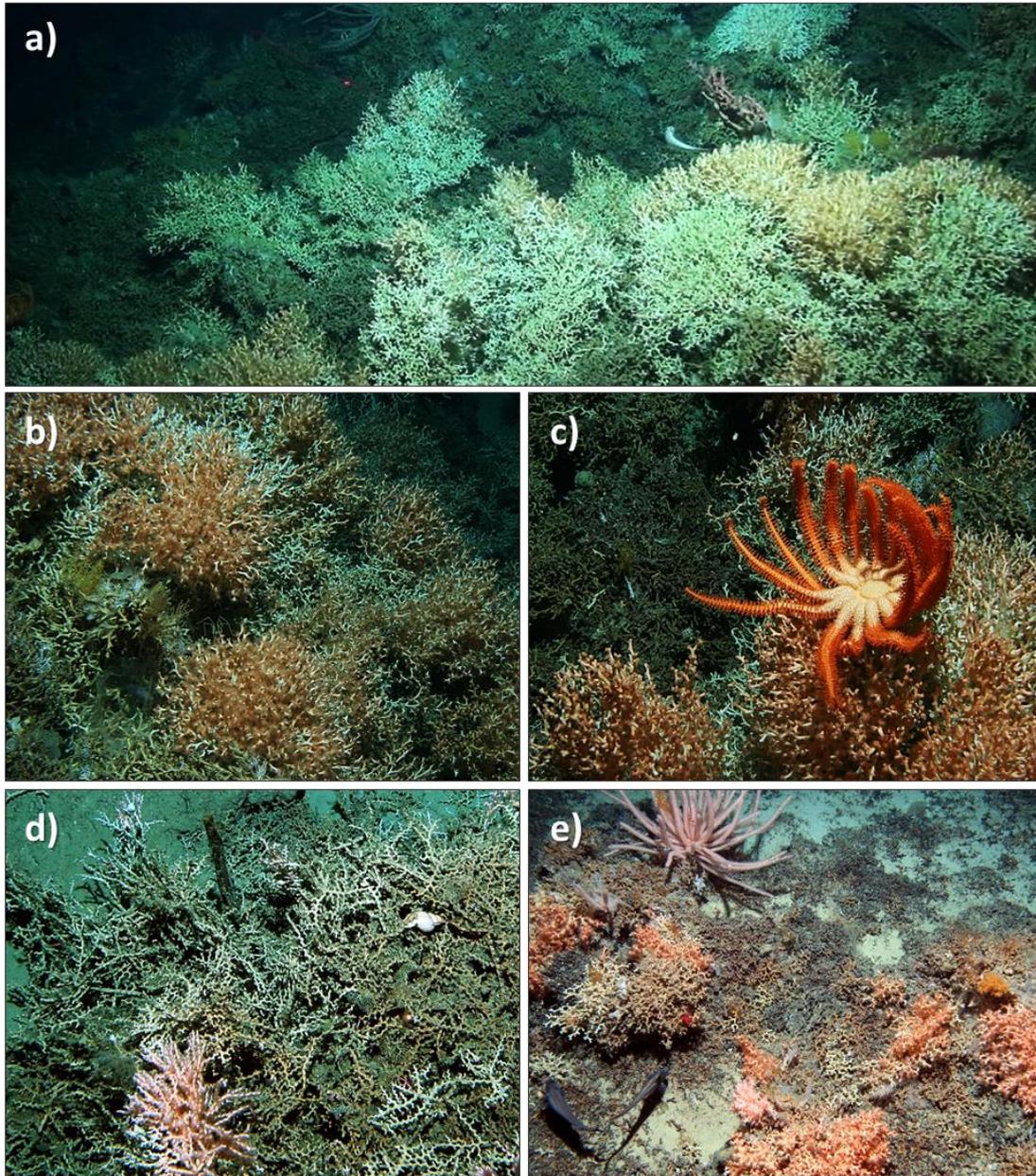
**Antipatharia (black corals)** are an abundant and diverse group found in cold-water fjords as well as throughout the EEZ from shallow waters down to over 2000 m depth. The group is CITES listed and during the last threat classification round three genera / species of black coral were listed as naturally uncommon, or data deficient (Freeman et al. 2014). There are 78 species in the New Zealand region of which seven have recently been described as new to science (Opresko et al. 2014; Opresko 2016). Several species are endemic to the region, and additional new species are yet to be described.

**Octocorallia (Octocorals/Gorgonians)** are a common group throughout the New Zealand region, with over 250 species, divided among 103 genera in 28 families (~ 200 more are undescribed). The gorgonian octocorals (order Alcyonacea) include the charismatic *Paragorgia* spp bubblegum corals, and arborescent tree-like *Primnoa* species (Figure 3-41). The diversity of three families of deep-sea calcified gorgonians (Isididae – bamboo corals, Primnoidae – bottlebrush and tree-like corals, and Chrysogorgiidae – golden corals) is amongst the highest in the world.

**Stylasteridae (Hydrocorals)** are the hard-coral form of hydrozoans. Their skeletons are distinguished from those of stony corals by being generally much smaller and less robust, minutely porous and pitted with small holes for the various polyps. Several species are found throughout the region.

### 3.8.3 Data sources

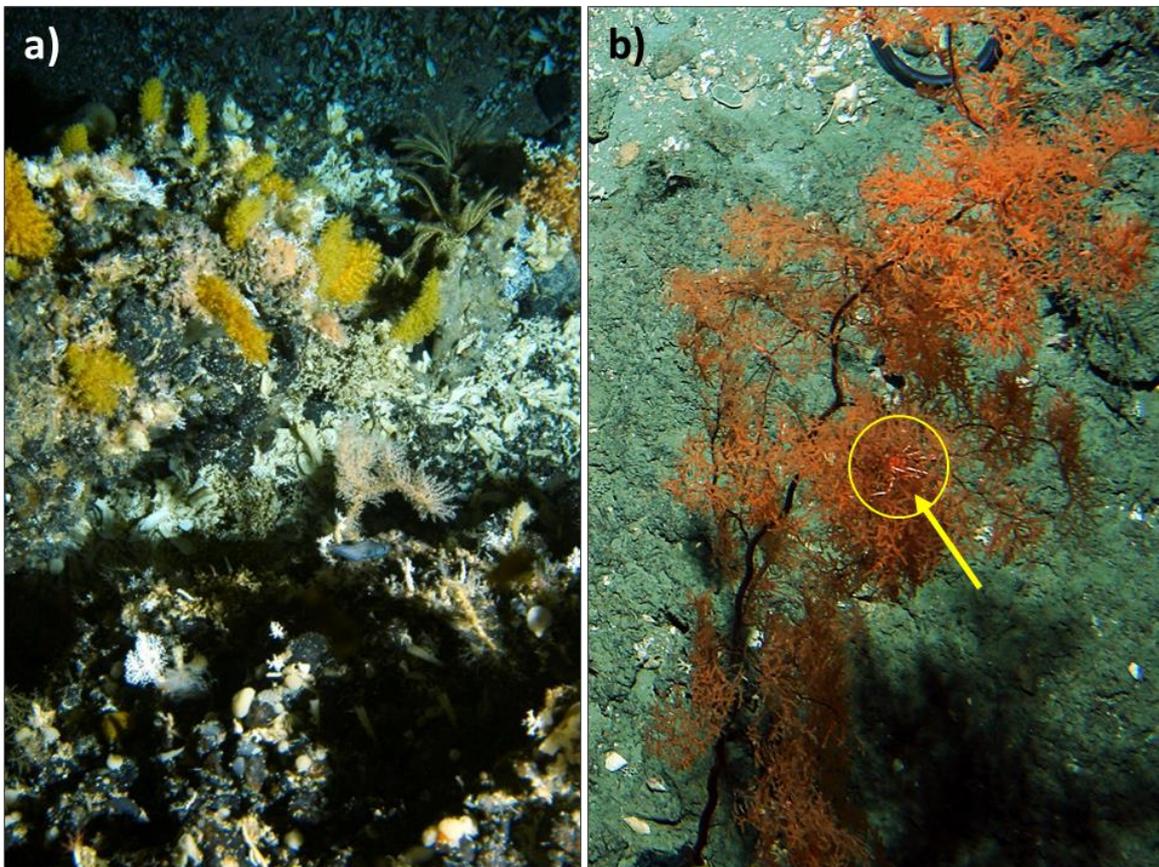
- VME indicator taxa data compiled from Museum Collections (incl. NIWA-Invertebrates, Te Papa, and MPI fishery surveys (MPI-COD and MPI-Trawl) for key species within New Zealand waters (Table 2-1). National Distribution maps for corals represent data from 1874 to 2014 in water depths  $\geq 200$  m.



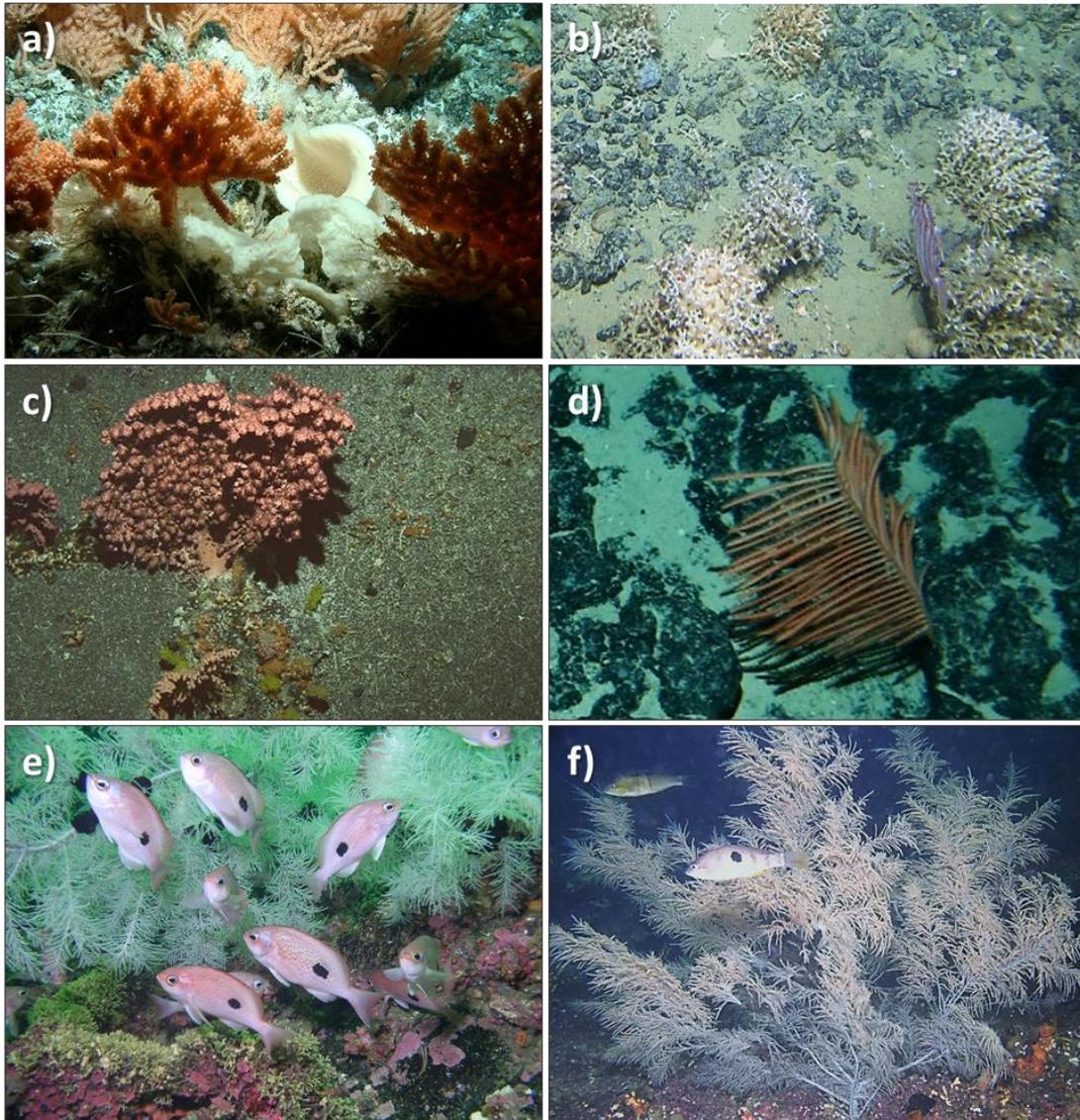
**Figure 3-39: Examples of the branching stony corals that form reef-like structures or thickets on hard substrata within the New Zealand region.** a,b,c,e) scleractinian stony coral *Solenosmilia variabilis* found on seamount summits and flanks, primarily on the Chatham Rise. Note the primnoid *Narella rasta*-octocoral [top left in image-e]; d) scleractinian stony coral *Madrepora oculata*, Chatham Rise. (Images from NIWA DTIS towed-camera).

### 3.8.4 Provision of ecosystem service

- Deep-sea coral communities are a highly diverse group and can form biogenic hot-spots of biodiversity in the deep ocean. They provide habitat, refuge and nursery areas for a broad set of benthic communities. The large thicket or reef-like stony coral forms are often referred to as the engineers of the deep. Their living and dead coral skeletons provide structure, refuge, and shelter for numerous other species (e.g., other corals, sponges (as illustrated in Figure 3-41), bryozoans, various crustaceans, echinodermata (ophiuroids, echinoids, holothurians)).
- Large erect growth forms provide elevated platforms for invertebrates to feed on (e.g., see Figure 3-40b showing a squat lobster on a tall black coral).
- Obligate associations with corals (e.g. the ophiuroid, *Astrobrachion constrictum* is only found on the Black coral, *Antipathes fiordensis*, Grange 1991).



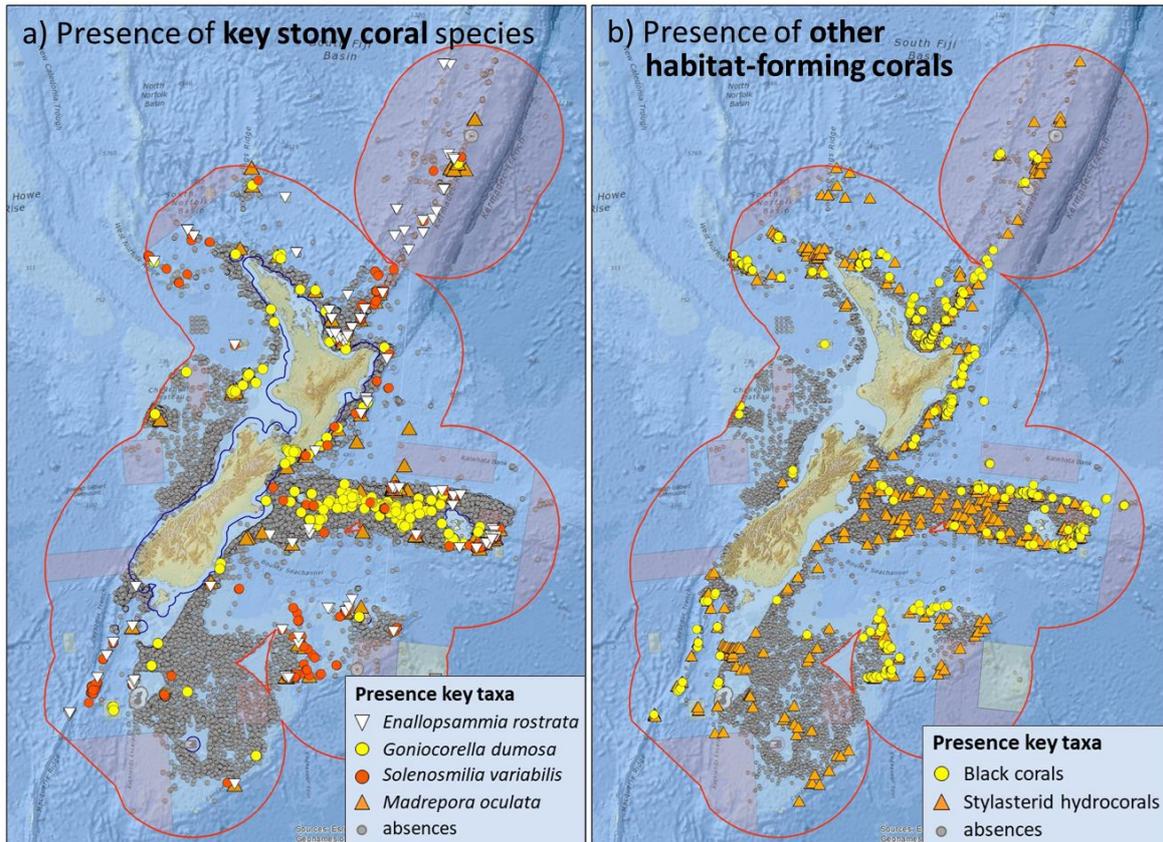
**Figure 3-40: Vulnerable Marine Ecosystems (VME) habitat examples.** a) *Thouarella* octocoral colonies (also see Figure 3-39f); b) Deep-sea *Leiopathes* black coral with a small squat lobster nestled in the branchlets of a black coral (yellow circle and arrow) (Images, NIWA DTIS towed-camera).



**Figure 3-41: New Zealand coral growth forms.** a) Dense community of the bright orange sea fan *Primnoa notialis* surrounding the trumpet hexactinellid sponge *Hyalascus* sp., Macquarie Ridge; b) Branching scleractinian stony coral *Goniocorella dumosa* occurring in small clumps on hard substrate, Chatham Rise; c) A large tree-like colony of *Paragorgia* bubblegum coral, nested at the base of the colony are several small bushy forms of the octocoral *Thouarella* spp., Macquarie Ridge; d) Uni-planar tree-like *Bathypathes* spp. black coral; e-f) Cold water tree-like black coral *Antipathella* spp., Fiordland, with butterfly perch (*Caesioperca lepidoptera*) and spotties (*Notolabrus celidotus*) respectively (Images a-d, NIWA DTIS towed-camera, e-f provided by Sean Handley, NIWA).

### 3.8.5 Biogeographic distribution

Specimens of stony branching and bushy coral species have been collected from a wide range of locations within New Zealand waters (Figure 3-42a-b). Small patch reefs or thickets (up to 600 m long, 20 m wide, and 3 m high) have been directly observed on many seamounts around New Zealand, while *G. dumosa* forms large localised reefs up to 40 m in height and 700 m wide (e.g. Campbell Plateau, in water depths of 334 m Mackay et al. 2014). The modelled distribution likelihoods based on environmental relationships are presented for key coral species (Figure 3-43 and Figure 3-44), but see Anderson et al. (2014) for a more detailed description.

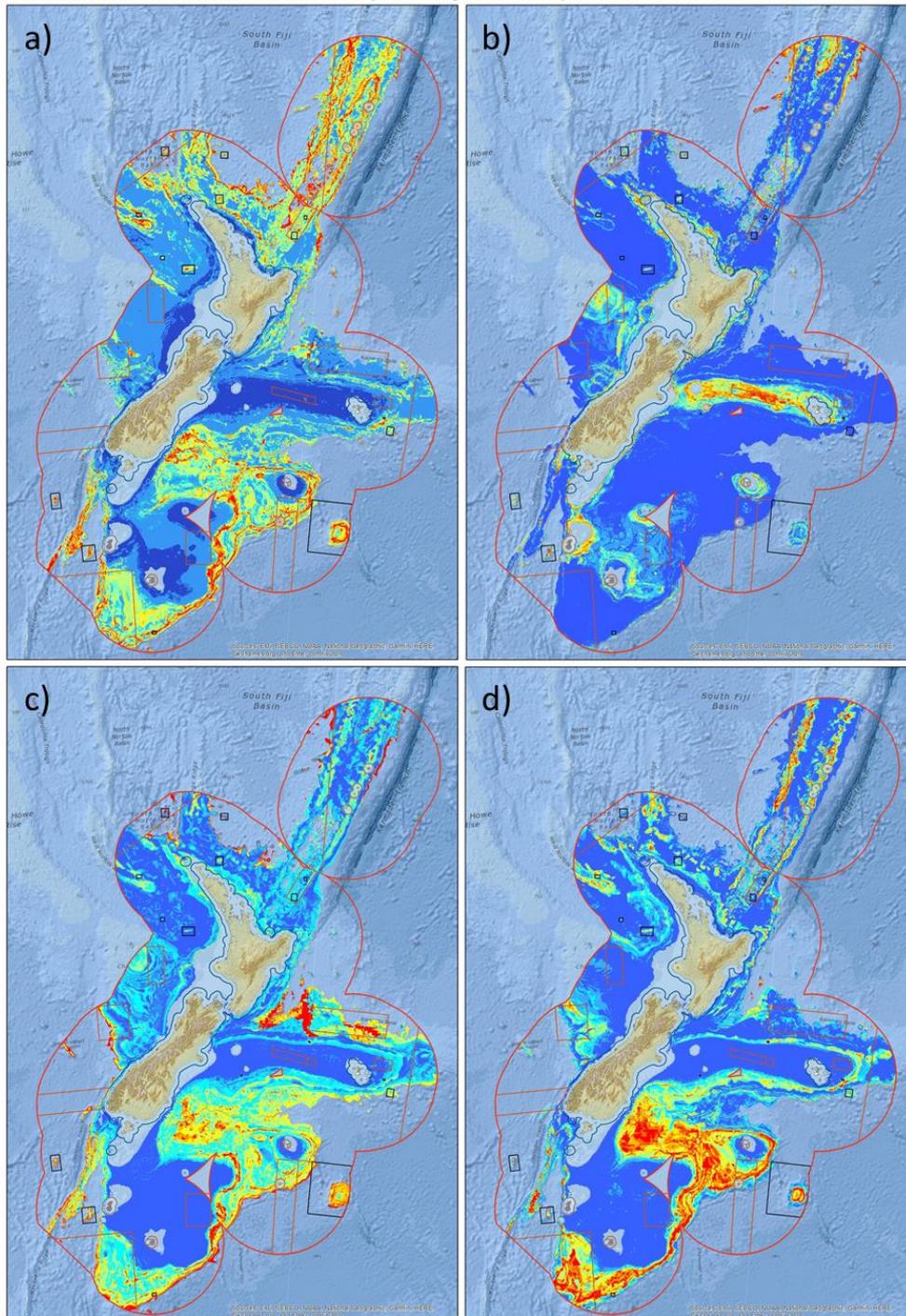


**Figure 3-42: Distribution of key a) stony coral species and b) other habitat-forming growth forms around New Zealand, based on presence (and absence) of identified specimen.** Coral species included in these plots are shown in respective legends.

### 3.8.6 Stressors and threats

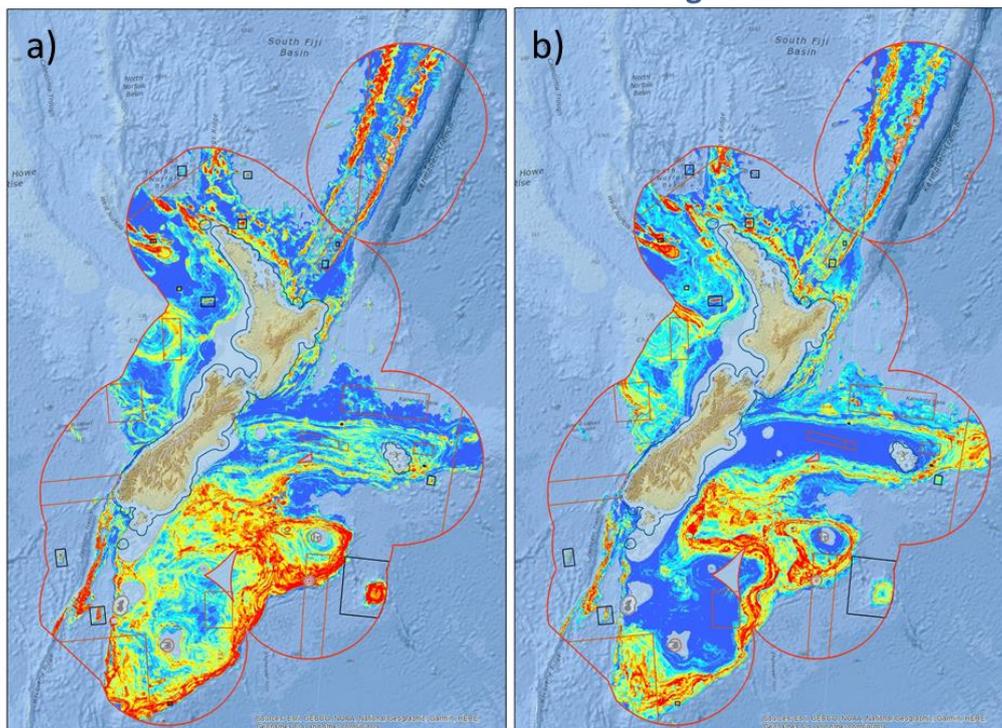
- Deepwater corals in the New Zealand region are at risk from anthropogenic activities such as bottom trawling (Clark and O’Driscoll 2003, Clark and Rowden 2009, Williams et al. 2010). Trawled seamounts are known to support lower average percent cover of stony corals (0.04–0.03%) than untrawled seamounts (12–25%) for two species of thicket-forming corals (*Solenosmilia* and *Madrepora*) (MPI 2017a). Studies on New Zealand seamounts in depths of 700-1000 m suggest that as few as 10 “deep-sea” trawls can eliminate corals from 15 to 20% cover to no visible cover (Clark et al. 2010) - this is significant given that 80% of known seamount features in depths of 800-1200 m have been fished.
- Oil and gas exploration and extraction (Gass and Roberts 2006) can result in physical disturbance during the laying of cables and telecommunications links;
- Waste disposal can create disturbance (Kogan et al. 2003).
- Corals are also threatened by effects from ocean acidification which result in decreased calcification rates (Tracey et al. 2013). This is described internationally by Caldeira and Wickett (2003), Guinotte et al. (2006), and Turley et al. (2007). Around New Zealand the environmental impacts predicted from climate change include sea water warming and ocean acidification (Law et al. 2017; Tracey et al. 2016; Gammon 2016; Gammon et al. 2018).
- Corals are considered vulnerable marine ecosystem (VME) taxa and as a group are considered at significant risk from the effects of fishing activity or other kinds of disturbance as determined by the vulnerability of their components (e.g. habitats, communities or species) (FAO 2009).
- Many deep-sea corals are characterised by their slow growth and extreme longevity (Tracey et al. 2007). Due to their fragile forms, skeletal composition, and location, they are vulnerable to various physical disturbances, such as trawling, mineral exploration, and mining, with some expected to have little or no ability to recover, (Clark and Rowden 2009, Althaus et al. 2009, Clark et al. 2010, Williams et al. 2010; Anderson et al. 2014).

### Predicted distribution of Key stony coral species



**Figure 3-43: Predicted distribution of the reef-like branching stony corals within New Zealand waters.** Key species plotted include: a) *Enallopsammia rostrata*, b) *Goniocorella dumosa*, c) *Madrepora oculata*, d) *Solenosmilia variabilis*. Red, orange and yellow colours depict areas of high, medium and low probability of occurrence, blue= likely absences (image created from GIS data layers from Anderson et al. 2014), with predicted layers cropped to New Zealand's EEZ (details of modelling provided in Anderson et al. 2014).

## Predicted distribution of other habitat-forming corals



**Figure 3-44: Predicted distribution of other habitat-forming corals within New Zealand waters.** a) Stylasterid hydrocorals, b) Black corals. Red orange and yellow colours depict areas of high medium and low probability of occurrence, blue= likely absences (image recreated from GIS layers from Anderson et al. 2014), with predicted layers cropped to New Zealand's EEZ (details of modelling provided in Anderson et al. 2014).

### 3.8.7 Condition

Areas of New Zealand have known impacts from trawling, and there is some evidence of limited recovery in some areas, and no recovery in others. The recovery dynamics of deep-sea habitats impacted by bottom trawling are poorly known. A recent project by Clark et al. (2018) reports on a 'fishing impact recovery comparison' based on repeated towed camera surveys on six small seamounts on the Chatham Rise. These seamounts covered conditions where trawling had ceased, where trawling was still active, and seamounts which were not fished. Surveys were carried out in 2001, 2006, 2009, and 2015 (spanning 15 years).

Univariate community metrics of biodiversity (abundance, species richness, diversity) were almost always higher on the untrawled seamounts, than on the other four seamounts. Multivariate community analyses of each seamount at each time-step showed a similar pattern, with the untrawled seamounts having similar levels and patterns of community structure at one end of the ordination space, a persistently heavily trawled seamount at the other end along with previously heavily trawled and now closed seamount, and intermittently trawled seamounts lying in-between. This ordination matches the gradient in commercial fishing effort. Community structure on the heavily fished seamount was more consistent than on the other seamounts, with persistently lower faunal richness, possibly due to a regular 're-setting' of the community by disturbance from trawling.

Although the analysis over time is confounded by technological changes, there is no evidence that benthic communities on one of the seamounts are recovering following its closure to fishing in 2001.

Anderson et al. (2014) predicted the distribution of protected deep-sea corals in relation to areas where they are at risk of interactions with commercial trawl gear targeting orange roughy and oreo

species on the Chatham Rise. The modelling showed a substantial overlap between predicted coral habitat and the 20-year trawl footprint. However, substantial areas of suitable habitat are predicted to exist across the Exclusive Economic Zone (EEZ) outside of the historic trawl footprint.

**Table 3-19: Overall condition status of Coral thickets and fields within New Zealand relative to benthic fishing history.** NF=Not fished, FP=Fished but now protected, and F=Fished no benthic-protection.

	Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
<b>NF</b>	<b>No Change</b>	<b>Good</b>	<b>Very Good</b>	<b>Stable</b>	<b>Good/Moderate</b>
<b>FP</b>	<b>Decreased 25-75%</b>	<b>Poor</b>	<b>Poor</b>	<b>No-recovery<sup>1</sup></b>	<b>Good/Moderate</b>
<b>F</b>	<b>Decreased 25-75%</b>	<b>Poor</b>	<b>Defunct</b>	<b>No-recovery<sup>2</sup></b>	<b>Good/Moderate</b>

<sup>1</sup> The community structure of coral thickets in the Graveyard Knolls, Northwest Chatham Rise have been compared over time and there is no sign of recovery (e.g. Morgue seamount - following fishery closures in 2001). The scleractinian coral densities on Morgue remain much lower than those on the unfished seamounts.

<sup>2</sup> Coral thickets on the seamount still being fished (Graveyard Seamount) shows little to no recovery, with persistently lower taxa richness, possibly due to a regular “resetting” of the community by disturbance from trawling (Clark et al. 2018).

**Overall condition status within NZ**

There is a widespread distribution of stony- and other habitat-forming corals, but condition of coral thickets is variable based on past fishing impacts (Clark et al. 2018). Where trawling is regularly carried out, and in particular on seamount-like features where corals have localised high density, it is likely that populations have been damaged and are in poor condition. Outside the fishing footprint coral will be in better condition. The overall status throughout New Zealand is uncertain.

### 3.8.8 Knowledge gaps

Coldwater corals are fragile and as such are considered ‘vulnerable marine ecosystem’ taxa that require protection from the impacts of deep-water fishing, drilling and mining.

As the understanding of the structure and function of deep-sea corals and coral communities has increased, so has the appreciation of their value. Unlike the well-studied shallow-water tropical corals, however, knowledge of age, growth, and reproduction for the New Zealand region is poor.

There has been a significant increase in recent years in knowledge of the identification, abundance, diversity, and spatial distribution of deep-sea corals and the various coral communities found within the New Zealand region. However, a more complete understanding of this group’s biology and how their structure and function is affected by various anthropogenic activities is only slowly progressing. Knowledge of the age and growth of protected deep-sea coral species has been identified as key to understanding coral regeneration times following trawl disturbances (Williams et al. 2010, Clark et al. 2016) or other damage.

A pilot ecological risk assessment (ERA) for protected corals in New Zealand was developed by Clark et al. (2014) and identified certain deep-sea protected species as high risk from the effects of bottom trawling. A major limitation of this ERA was data paucity on coral productivity, which relates directly to the recoverability of corals from disturbance. A key priority in filling this information gap is research to determine the age and growth characteristics (especially growth rates) of key New Zealand protected deep-sea coral species.

**Table 3-20: Gap analysis summary for Coral thickets.**

Type	Description
<b>Distribution &amp; function</b>	The distributions of stony coral reef-like structures and other protected coral fauna around New Zealand are reasonably well known, due to deep-sea research surveys and commercial trawl data providing coverage of several underwater topographical features (UTFs), such as seamounts, and for some slope and canyon regions.
<b>Biological &amp; taxonomic</b>	Taxonomy of corals thickets and other coral fauna is relatively well known, but basic biology is poorly known for even dominant/key species.
<b>Management &amp; conservation</b>	<p>Coral-thickets are known to support high biodiversity, but they are extremely fragile and vulnerable to physical disturbance, with areas heavily impacted (mostly from benthic fishing activities) showing no signs of recovery at decadal scales (examples above).</p> <p>Black corals (Order: Antipatharia) and red hydrocorals <i>Errina</i> spp. (Family Stylasteridae) were protected within New Zealand’s EEZ under the Wildlife Act, 1953. Protection was extended to all hard corals in 2010 (schedule 7A of the Wildlife Act). If collected in fishing gear, corals must be returned to the sea.</p> <p>In 2001, 18 seamount closure areas within New Zealand’s EEZ were established to protect representative UTFs (underwater hills, knolls and seamounts) from bottom trawling and dredging (Brodie and Clark 2003). In 2007, 17 Benthic Protection Areas (BPA) were designated to protect 1.2 mil km<sup>2</sup> of seafloor (~30% of New Zealand’s EEZ) from benthic fishing activities - including 23% of underwater topographic features, which included 42% of known seamounts [&gt; 1,000 m in height], and 88% of known active hydrothermal vents (Helson et al. 2010). Within the BPAs, 72.2% of the seafloor are in water depths &gt;2000 m, which are too deep to trawl (Leathwick et al. 2008). Off-bottom trawl fishing is still permitted within BPAs providing the fishing gear is 100 m above the seabed, and independent observers are on board.</p>

## 3.9 Beds of large shellfish

### 3.9.1 Habitat description and definition

Shellfish are a dominant part of New Zealand's soft-sediment coastal and shelf environments (<250 m water depth). Large-bodied shellfish in high densities can form stable bed forms that support a diverse range of sessile and motile epibenthic associates (Morrison et al. 2014a). A wide range of bivalve and brachiopod species when present are biogenic habitat-formers, which provide a wide range of ecosystem services (see below). The relict shells from shellfish can also accumulate over time to provide substantial hard substrata in otherwise 2-dimensional soft-sediments. Dead shell from species such as *Tucetona laticostata*, the robust dog cockle – that is commonly found in high energy environments - can last over long-time scales. For example, the disarticulated valves of this species have been collected from the Wanganui Shelf and carbon dated at  $9,170 \pm 210$  years BP (Gillespie et al. 1998), while those collected from the Bay of Plenty have been dated at  $35,800 \pm 2250$  years (Beu 2004). These shell-debris fields can be colonised and consolidated by other matrix-forming species, such as reef-building bryozoans and encrusting and erect sponges. Living shellfish on the continental slope are often found in high current areas, with the relict shell debris accumulating down slope. These areas have been documented and partially mapped in a few locations (e.g. Patea Shoals and Whanganui shelf: Beaumont et al. 2015 and Gillespie and Nelson 1996), but are likely to be more widespread than specimen records currently depict.

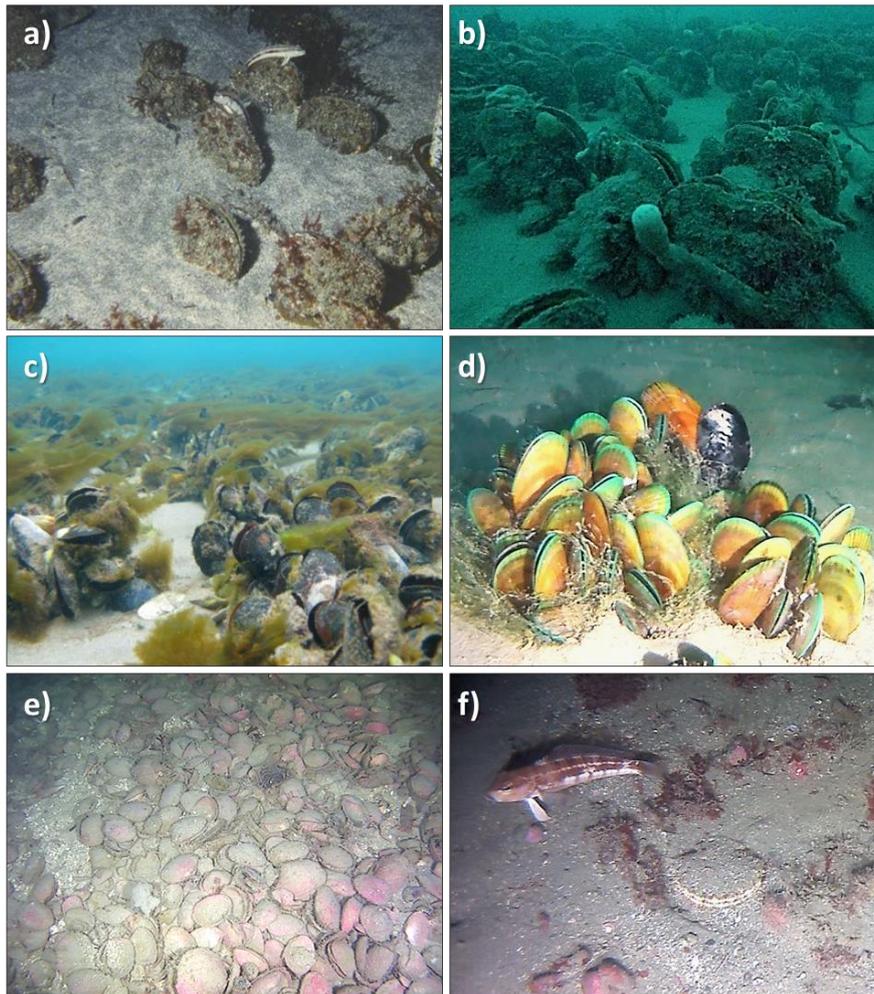
**Definition:** Shellfish beds are defined as the occurrence of large shellfish in densities of  $\geq 30\%$  cover over an area of  $100 \text{ m}^2$  or more, or where catches contribute 30% or more by weight or volume in a single dredge tow or grab sample (MacDiarmid et al. 2013).

### 3.9.2 Key species

- Robust dog cockles, *Tucetona laticostata* (Family: Glycymerididae)
- Horse mussels, *Atrina zelandica* (Family: Pinnidae)
- New Zealand scallops, *Pecten novaezelandiae* (Family: Pectinidae)
- Green-lipped mussels, *Perna canaliculus* (Family: Mytilidae)

### 3.9.3 Provision of ecosystem services

- Bivalves are suspension feeders that can filter high volumes of overlying water, filtering suspended particulates from the water column and can increase water clarity. Loss of bivalve beds from embayments and harbours can result in significant loss of water quality ecosystem services across entire embayments (Rothschild et al. 1994). Historical information suggests that green-lipped mussels were once extensive (est.  $500 \text{ km}^2$ ) within the Firth of Thames (Figure 3-46) and could have potentially filtered the entire water volume of the bay in less than a day, compared to over a year based on current mussel biomass (Morrison et al. 2014a; McLeod 2009). The once clear waters of the Thames, based on historical accounts from European settlement, are now considered a degraded nutrient-enriched environment (review in Morrison et al. 2009).
- Bivalve beds can have a crucial role in ecosystem functioning (MacDiarmid et al. 2013), by reworking sediment as they move; by processing nutrients (Hewitt et al. 2006; Herman et al. 1999); and by altering the flow dynamics across the seabed (Coco et al. 2006). Dense beds of large infaunal bivalves, can also modify and stabilise the sediments around (e.g. Handley, 2017).

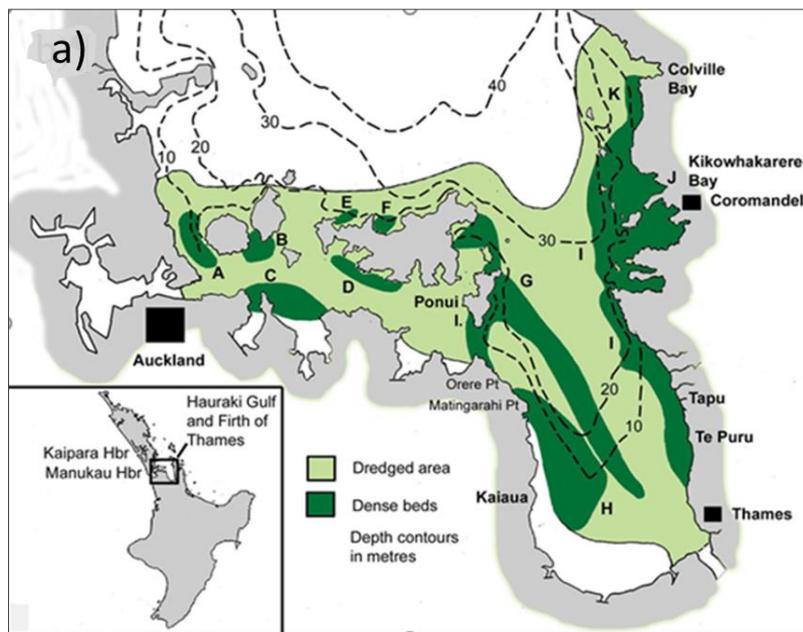


**Figure 3-45: Large bed-forming shellfish beds.** a-b) Horse mussel habitat in Goat Island, Leigh and east of Chetwode Islands, Marlborough Sounds, respectively; c-d) green-lipped mussel growing in clumps on the seabed; e) Robust dog cockle beds of live bivalves beneath the sediment with relict shells accumulating on the seafloor, Rangitoto Bank channel, D’Urville Island (NIWA-MSCB17 Cbedcam); f) scallop and subadult blue cod at Guards Bank, Marlborough Sounds (NIWA-MSCB17 Cbedcam). (Source: a-Figure 21 in Morrison et al. 2014a; Grant-Mackie, 1987; c- McLeod 2009)

- Edible shellfish species have significant cultural and economic value. For example, green-lipped mussels and scallops are highly prized shellfish species that are harvested both commercially and recreationally, and along with horse mussels are all customary kaimoana and taonga species for local iwi.
- Large-sized epibenthic bivalves, such as horse mussels and green-lipped mussels, can provide hard biogenic structures for epibiota in what may otherwise be ‘featureless’ soft-sediment habitat (MacDiarmid et al. 2013). Horse mussel beds support higher diversity and total abundances (Norkko et al. 2006), and provide hard substrata for a wide range of early and late stage epibionts to colonise including reef-forming bryozoans and sponge garden species (Figure 3-26h). Horse mussels, along with other large emergent bivalve species, may therefore play an important initiating-role that enables other biogenic habitats to colonise soft-sediment habitats.
- Bivalve shells can accumulate and sequester carbon, while the accumulation of relict shells from bivalve beds (e.g. *T. laticostata* shell debris) can provide (relict) hard substrata for a

diverse range of flora and fauna (including algae, sponges, bryozoans) to settle and grow, including epibiont encrusters, such as encrusting sponges and bryozoa that jointly bind and consolidate these relict shells. Diversity and abundance of epifaunal communities are significantly higher within bivalve beds (e.g., Commito and Boncavage 1989; Warwick et al. 1997; Cummings et al. 1998) and in the associated relict shell-debris fields (Dewas and O’Shea 2012; Beaumont et al. 2015).

- Horse mussels have recently been identified as an important nursery habitat for juvenile blue cod in the Marlborough Sounds, especially where bryozoan and sponge communities co-occur (NIWA’s MBIE-funded juvenile-habitat surveys (NIWA 2107, unpublished data).



**Figure 3-46: Predicted distribution of historical green-lipped mussel beds within the Firth of Thames-Coromandel-Hauraki Gulf region.** (Source: Figure 5 of Paul 2012, redrawn from Reid 1969).

### 3.9.4 Data sources

- Museum specimen identification datasets (OBIS-NZ, NIWA-Inverts and Te Papa) (Table 2-1), where used to extract data for phylum “Mollusca” and Class “Bivalvia” for New Zealand, and then by key-habitat forming species (as defined in section ‘3.9.2 Key species’). Inspection of the OBIS-NZ records found almost all were sourced from NIWA-Inverts (99.7%), so OBIS-NZ records were not used.
- **MPI trawl database.** Data from research trawl surveys were extracted for key-habitat forming species. These included NZ scallops, Robust dog cockles, and horse mussels, but not green-lipped mussels (no data). Bycatch are in green weight.
- **MPI scallop database.** Data from research dredge surveys targeting scallops were extracted for the period 1994–2014 for key-habitat forming species. This includes NZ scallops, robust dog cockles, and horse mussels, but not green-lipped mussels (no data). Survey catches are available as counts and green weight. Data from scallop surveys in SCA 7 were collected by Challenger Scallop Enhancement Company Ltd. (CSEC) as part of a Memorandum of Understanding with MPI; these will be loaded to the MPI *scallop* database in 2018.

### 3.9.5 Biogeographic distribution

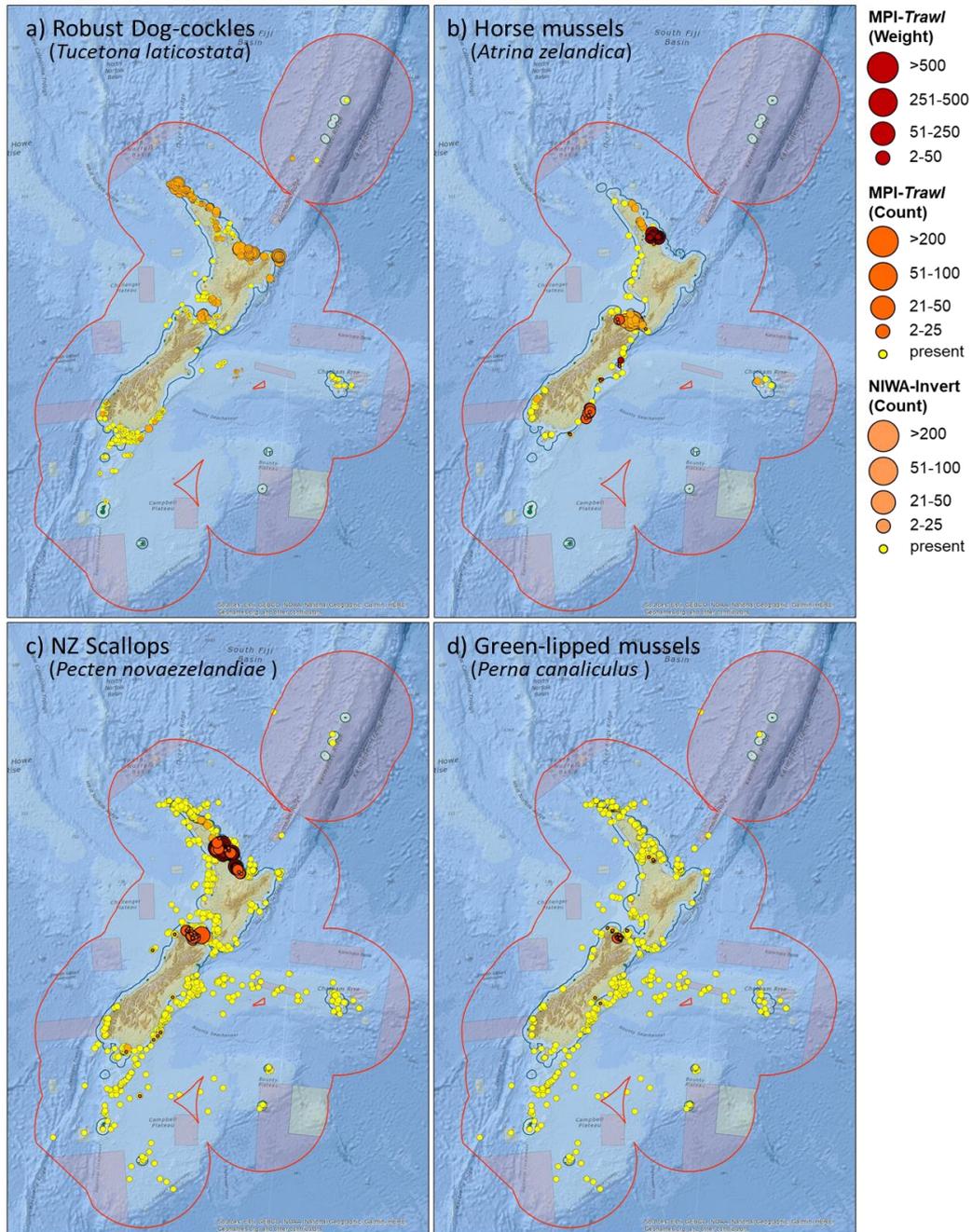
#### National scale

Morrison et al. (2014a) identified that bivalve beds occur around most of mainland New Zealand, from “Cape Reinga to North Cape (Keane 1986, Cryer et al. 2000), Northland (Mimiwhangata, Kerr and Grace 2005), Greater Omaha Bay (Taylor and Morrison 2008), Kawau Bay (Battershill et al. 1985, M.M., pers. obs.), Noises Islands and Tarakihi Island (inner Hauraki Gulf) (Dewas and O’Shea 2012, M.M., pers. obs., respectively), the inner South Taranaki Bight (Gillespie and Nelson 1996 – see Bryozoans), Tasman and Golden bays (Grange et al. 2003), Marlborough Sounds (Davidson et al. 2010), and Foveaux Strait (Michael 2007). McKnight (1969) also recorded them off the Manukau Harbour entrance, Hawkes Bay, Wanganui, Cape Farewell, Tasman Bay, Cape Palliser, Timaru, Oamaru, near Bligh Sound, and off the entrance to Doubtful Sound, Chalky Island” (Figure 3-47; Figure 3-48 and Figure 3-49).

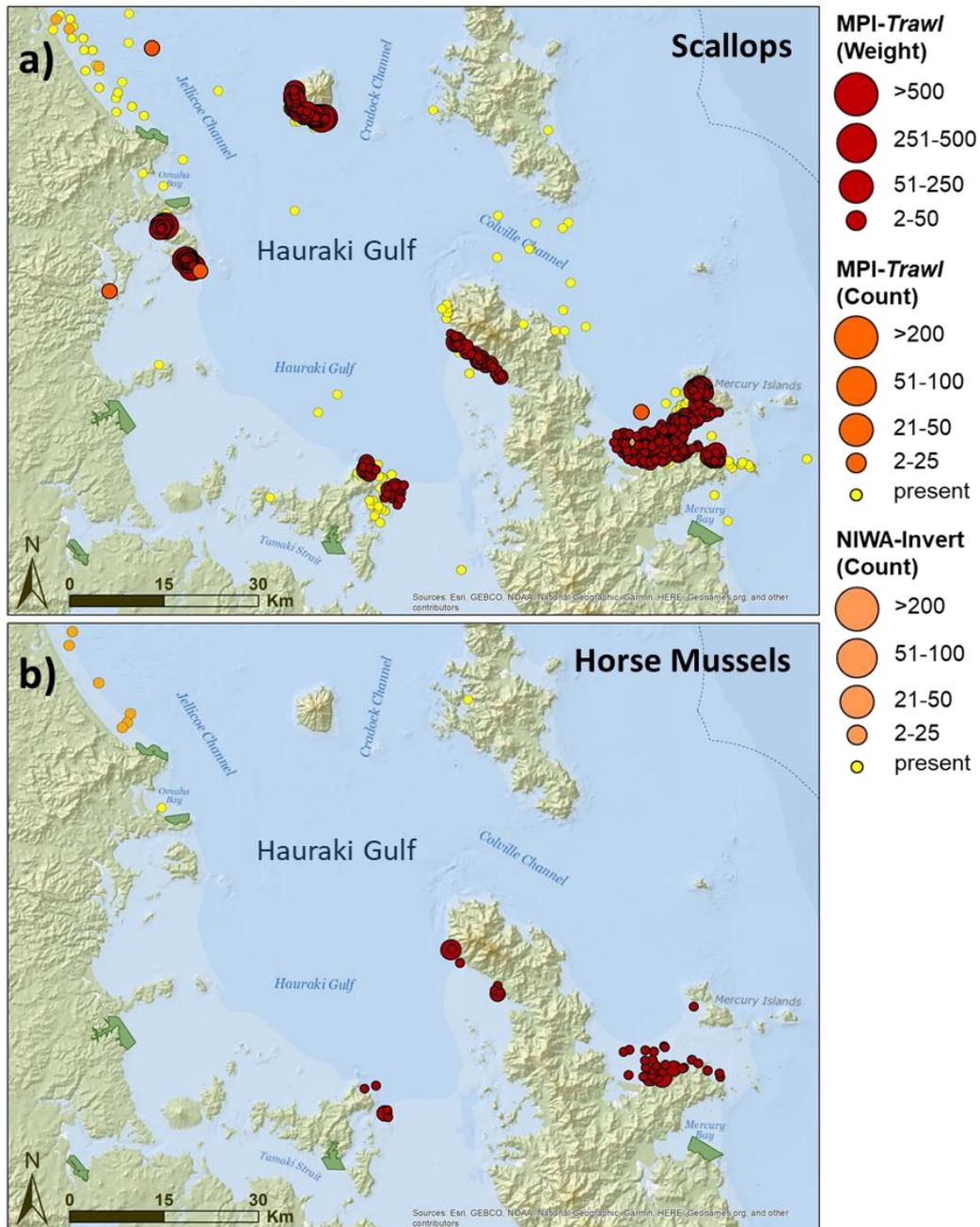
#### Regional scale/case studies

**Robust dog-cockles.** *Tucetona* beds are known from around New Zealand in high current areas. Extensive beds have been reported from the Noises Islands in the Hauraki Gulf (Morrison et al. 2014a; Dewas and O’Shea 2012), on the continental shelf in the South Taranaki Bight (STB) in sloping habitats with high current in water depths of 25–55 m (Beaumont et al. 2015), and in the Rangitoto Channel on the Eastern side of D’Urville Island (Davidson 2017; NIWA, unpublished data). In the STB, *Tucetona* shell debris accumulates down slope in depths of 60–75 m, where it forms a dense multi-layered shell field that has been heavily colonised by a diverse array of sessile species, dominated by reef-forming bryozoans along with mixed invertebrates (e.g. encrusting and erect sponges, foliose bryozoans, colonial and solitary ascidians, brachiopods and epiphytic bivalves) that collectively bind and stabilise the shell (Beaumont et al. 2015, T. Anderson, NIWA pers. obs).

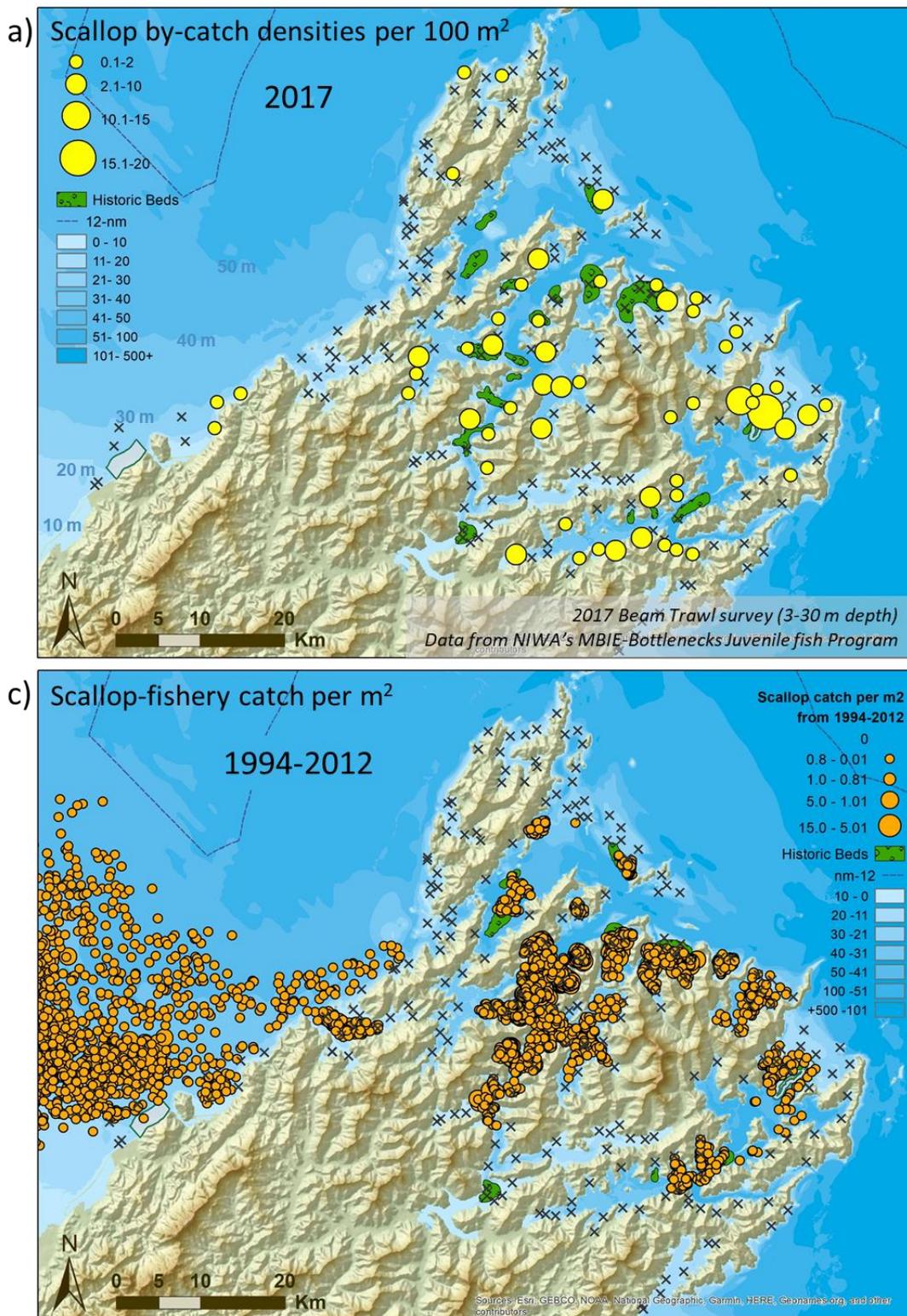
**Horse mussels.** *Atrina* beds are known to occur around New Zealand. Extensive and dense beds have been reported from the Hauraki Gulf (review in Morrison 2014a), Separation Point in Tasman Bay (Davidson 1992), the Bank on the eastern side of Chetwode Islands, and in East Bay in Queen Charlotte Sound (NIWA unpublished data – Bottlenecks survey 2017). Patchy horse mussel beds also occur across the Banks around the Trios and Chetwode Islands, where significant biogenic material (dominated by sponges and reef-forming bryozoans) has become bound together. Sparse horse mussels also occur throughout the Sounds, but many of these show significant signs of shell damage (e.g. Guards Bank, Waitui Bay and Port Gore - where scallop dredge fishing has repeatedly been undertaken: Figure 3-49b), while rare patches of horse mussels are resigned to hollows on the seafloor, that may have provided refuge from past fishing activity.



**Figure 3-47: Distribution and abundance of key bed-forming bivalves.** a) Robust dog cockles, b) Horse mussels, c) scallops, and d) green-lipped mussels. Total abundance (light orange bubble plots); species presence (yellow circles -represents all available datasets combined (OBIS-NZ, TePapa, and NIWA-Inverts); red circles represent research trawl survey catches (green weight; data source: MPI trawl database); dark orange circles represent scallop research dredge survey catches (data source: MPI scallop database and CSEC Ltd.). Abundances and weights are raw/unstandardised values, used here simply to indicate where bivalve beds (rather than isolated individuals) may occur.



**Figure 3-48: Bivalve distribution and abundance for a) scallops and b) horse mussels, within the Hauraki Gulf, New Zealand.** Legend bubbles are described in previous figure, but also shown here are the locations of marine reserves in green.



**Figure 3-49: Scallop distribution and abundance in Marlborough Sounds.** a) yellow bubble plots = densities of scallop bycatch (counts per 100 m<sup>2</sup>) from 3-m wide beam trawl sampling (NIWA Bottlenecks survey 2017), and b) small orange circles = densities of scallops caught in research dredge survey tows in Marlborough Sounds from 1994–2012 (Data source: MPI and CSEC). Green underlying polygons on both maps = depict areas of historical scallop beds (Handley 2017). x indicates sampling sites.

**NZ scallops.** *Pecten* beds are common in Northland, the Hauraki Gulf, Coromandel, Golden and Tasman Bays, the Marlborough Sounds regions and at the Chatham Islands where they have supported significant commercial and recreational fisheries (Tuck et al. 2017; MPI 2017b). Historical scallop beds within the Marlborough Sounds have been delineated based on historical knowledge and scallop fishery data (Handley 2015). Scallop population declines, however, in recent years led to the closure of the SCA 7 fishery (Golden Bay, Tasman Bay, and Marlborough Sounds) (Handley 2015). Large dense scallop beds have been recorded on the western side of Long Island marine reserve, that extends into and is protected by this MPA. This scallop bed has been estimated to cover a 0.17 km<sup>2</sup> area of the seabed (representing 2.6% of the MPA) located in water depths of >30 m along the western boundary of Long Island marine reserve (Haggitt 2017).



**Figure 3-50: The mapped extent of green-lipped mussel bed through time in Ohiwa Harbour** Areal extents are demarked for 2007, 2013 and 2016, and identify a 96% decline in the mussel bed.

**Green-lipped mussels.** *Perna* beds are for the most part ecologically and functionally extinct in areas where they were once a dominant biogenic habitat (e.g. Firth of Thames, Hauraki Gulf, Kaipara Harbour, Tasman Bay, review in Morrison et al. 2014a p45-49). Green-lipped mussels were also historically estimated to cover large areas of the seabed in the inner regions of the Marlborough Sounds (Handley 2015). Many of these mussel beds supported a commercial native harvest, that lead to serious declines (e.g. Firth of Thames, Paul 2012; Kenepuru Sounds, Handley 2015). Nowadays beds of native green lipped mussels growing on the seabed are rare, and likely sourced from vagrants from nearby mussel farms. A recent NIWA video survey (NIWA's MBIE Bottlenecks programme - survey 2017) sampling within Kenepuru Sounds recorded mixed biogenic beds with small isolated clumps of green lipped mussels growing on the seabed on the northern side of Kenepuru Sounds. However, again, it is unclear whether these reflect motile displacement from nearby farms or represent naturally settled patches. Excessive numbers of the predatory 11-armed starfish have been associated with significant losses of green-lipped mussels in Ohiwa Harbour, south of Tauranga. In 2007, an extensive mussel bed occurred along the western side of Ohiwa harbour with mussel abundance estimated at 112 million. Monitoring of this bed through time has identified significant and very rapid declines with ~57 million in 2008, ~16 million in 2009, ~2 million in 2013, and only 485,000 remaining in 2016 - a 96% loss within 9 years (Figure 3-50; Paul-Burke and Burke 2016). In

contrast, in 2009, 1.2 million predatory starfish were estimated to occur within the mussel bed, although other stressors, including increased sedimentation were also recorded (Burke-Paul, 2018).

### 3.9.6 Stressors and threats

- Commercial and recreational harvesting of target species (e.g. scallops, green-lipped mussels), as well as bycatch species (e.g. horse mussels and robust dog cockles).
- Bottom-contact fishing activities (e.g. dredging and bottom trawling) can remove, dislodge and break bivalves, particularly emergent species such as Horse Mussels. Bivalve beds may vary in their exposure and vulnerability to fishing disturbances and damage (review in Michael 2007). For example, species such as the robust dog cockle that lie buried beneath the sediment (with its feeding siphons just coming to the surface) may suffer little impact from gear that does not penetrate the sediment. In contrast, species that emerge above the seabed, such as horse mussels, may be far more vulnerable to being removed, dislodged or broken by dredging and bottom trawling. However, while living infaunal robust dog cockles may be less impacted, the removal of *Tugetona* shell-debris may significantly reduce the biodiversity associated with these relict-shell habitats.
- Many bivalve beds and their communities have been significantly impacted by bottom-contact fishing, which in combination with increased sedimentation, has caused bivalve habitats to be degraded and removed.
- Commercial fishing decimated green-lipped mussel populations in both the Firth of Thames and then subsequently in Kenepuru Sound, and the Marlborough Sounds.
- Bottom-contact fishing activities and gear (e.g. dredging and bottom trawling) can damage or reduce structural biota, especially emergent and fragile species (Rice 2006; Michael et al. 2007; Tuck et al. 2017). While damage may not be uniform, increasing fishing intensity can reduce the density and diversity of benthic communities, especially emergent species and biogenic habitats (MPI 2017b).
- Increased suspended sediments, sedimentation and increased eutrophication can be critical stressors to filter feeding bivalves (Hewitt and Pilditch 2004, Lohrer et al. 2006).
- Outbreaks of predatory starfish may cause local and possibly widespread mortality of bivalves, and maybe responsible for significant declines either in isolation or in combination with other stressors (Burke-Paul, 2018).

### 3.9.7 Condition

- A horse mussel bed has been characterised and mapped within the Long Island Marine reserve (Haggitt 2017) covering 0.3 km<sup>2</sup> (representing 0.4% on the MPA) - located between Long Island and the Kokomohua Islands in water depths of 10 - 20 m. However, little is known about the condition or change in extent of this habitat through time.
- Overfishing of scallops has led to temporary closures of scallop fisheries around the country (e.g. SCA 7 and Kaipara Harbour). Ongoing fisheries research is investigating the resilience and recovery of scallop fisheries (Tuck et al. 2017).
- Green-lipped mussel beds on soft sediments can now be considered a rare biogenic habitat in New Zealand. The Green-lipped mussel bed in Ohiwa Bay has undergone a rapid and significant decline (96% loss) in extent and density.

**Table 3-21: Overall condition status of Beds of large shellfish within New Zealand..**

	<b>Change in coverage</b>	<b>Habitat condition</b>	<b>Ecoservices condition</b>	<b>Likely future trajectory</b>	<b>Evidence/ Confidence</b>
<b>Robust Dog cockles</b>	<b>Unknown<sup>1</sup></b>	<b>Good</b>	<b>Very Good</b>	<b>Stable</b>	<b>Moderate</b>
<b>Horse mussels</b>	<b>Decreased 25-75%</b>	<b>Poor</b>	<b>Poor</b>	<b>Declining</b>	<b>Good/Moderate</b>
<b>Scallops</b>	<b>Decreased 25-75%</b>	<b>Moderate</b>	<b>Poor</b>	<b>Variable??</b>	<b>Good</b>
<b>GL mussels</b>	<b>Decreased 75-100%</b>	<b>Defunct</b>	<b>Defunct</b>	<b>No-recovery<sup>2</sup></b>	<b>Good</b>

<sup>1</sup> National inventory on Robust dog cockles has large gaps, with little known on the spatial extent of beds or changes through time. Beds however are expected to be widespread and extensive, particularly in areas of high current flow on inner and mid-shelf locations.

### Overall condition status within NZ

**Robust Dog Cockle Beds.** As it is unfished and resilient to the effects of bottom trawling and dredging, it is likely that beds of this species remain in overall good condition. However, little is known of its distribution on the continental shelf, particularly along the west coast of both main islands.

**Horse Mussel beds.** Several location may still provide good ecosystem services, however many beds on the shelf have been damaged, reduced in extent or lost due to bottom fishing activities (including scallop dredging).

**NZ scallop beds.** Extensive populations occurred in the mid-outer Marlborough Sounds and in the Haruaki Gulf, where they supported nationally important scallop dredge fisheries. Commercial and recreational fishing has reduced stocks leading to localised loss of distinct scallop habitat in some areas. Sedimentation is also an important threat to scallop habitat in some areas.

**Green-lipped mussels.** Though common on coastal reefs and on mussel farms, Green-lipped mussel beds are ecologically/ functional extinct from its native seabed habitats where it previously formed extensive beds.

### 3.9.8 Knowledge gaps

- Fishery-surveys provide considerable information on densities and biomass for key fishery species and fished areas, however, non-fished species and areas are less well known.
- Loss of large bivalve species can have catastrophic impacts on ecosystem function and environmental health, however little direct information is available for New Zealand bivalve beds. Green-lipped mussel beds from large areas in the Firth of Thames, Tasman Bay, and the Marlborough Sounds show anecdotal information that has led to significant interest by fishers in the restoration of these habitats. However, it is currently unclear what conditions and processes are required to re-establish these once widespread habitats.
- Similar restoration studies are likely to be required for horse mussels. A greater understanding of the importance of horse mussel beds as nurseries for juvenile snapper in the Hauraki Gulf and blue cod in the Marlborough Sounds is also required to accurately determine what may be limiting juvenile recruitment of these two commercial important species.

**Table 3-22: Gap analysis summary for Beds of large shellfish.**

Type	Description
<b>Distribution &amp; function</b>	Fishery-important shellfish beds (e.g. scallops) well documented, but non-fished species (e.g. horse mussels and robust dog cockles) are moderately described for some regions, but poorly documented nationally. Beds known to have often pivotal roles in ecosystem function and health.
<b>Biological &amp; taxonomic</b>	Biology and taxonomy well described for key species.
<b>Management &amp; conservation</b>	Some beds are closed to fishing periodically, and some are represented in relatively low amounts within some Marine Reserves. LEK and anecdotal evidence indicates extensive loss of some bivalve beds has occurred within New Zealand coastal waters. LEK and anecdotal evidence also indicates the loss of some juvenile-fish nursery habitats (e.g. horse mussels for juvenile blue cod) may have occurred, yet little to no protection of these potentially-critical nursery-habitats exists.

## 3.10 Calcareous tubeworm mounds

### 3.10.1 Habitat description and definition

New Zealand serpulids can create “temperate carbonate reefs, the counterpart of tropical coral reefs” (Riedi and Smith 2015). *Galeolaria hystrix* is the largest and most significant aggregating serpulid in New Zealand. *G. hystrix* are suspension feeding tubeworms that have a distinctive bright red branchial crown and live in calcareous tubes. This species can grow as individuals or in colonies that can form complex three-dimensional mounds (or reefs) that can become more than a metre high and several metres in diameter (MacDiarmid et al. 2013). *Galeolaria* mounds may take ~9 years to form, but can be as old as 50 years (Smith et al. 2005; Riedi 2012) with individual worms within these mounds estimated to live for long as 12 years (Riedi 2012). Mounds grow by successive recruitment of worms, likely attracted by chemical cues (based on other congeneric species, Smith et al. 2005, Kupriyanova et al. 2001), with mound height growing up to 6.7 cm/year (Riedi 2012). A mound may contain 4500-8500 living worms/m<sup>2</sup> and is estimated to involve 31 generations of worms to form large 50-year-old mounds (Riedi 2012).

**Definition:** Calcareous Tubeworm Mounds are defined as raised reef-like structure up to 1.5 m high and 1-100 m in diameter encountered at relatively low densities (e.g. 40 per ha); with a thicket deemed present where one or more mounds are seen, or intertwined tubes contribute ≥10% of the catch in dredges or beam trawls, or where intertwined tubes are collected in a single grab sample (MacDiarmid et al. 2013).

### 3.10.2 Key species

*Galeolaria hystrix* is a subtidal calcareous tubeworm (Family: Serpulidae) that is endemic to New Zealand (Hare 1992) and to southern Australia (e.g. New South Wales and South Australia - Day and Hutchings 1979). Serpulidae have calcareous tubes, significant because these mineralised tubes last long after the death of the creators, and abundantly enter the fossil record.

NB: The ‘blue tube worm’ *Spirobranchus cariniferus* is a calcareous species that grows on intertidal rocky shores on near vertical surfaces, and is most prominent in central New Zealand, but throughout the country apart from Chatham Island. Like *G. hystrix*, colonies can be more than 25 years old (Riedi and Smith 2015), but this serpulid tubeworm appears to exclude other species, rather than be habitat creating as are *Galeolaria* reefs.

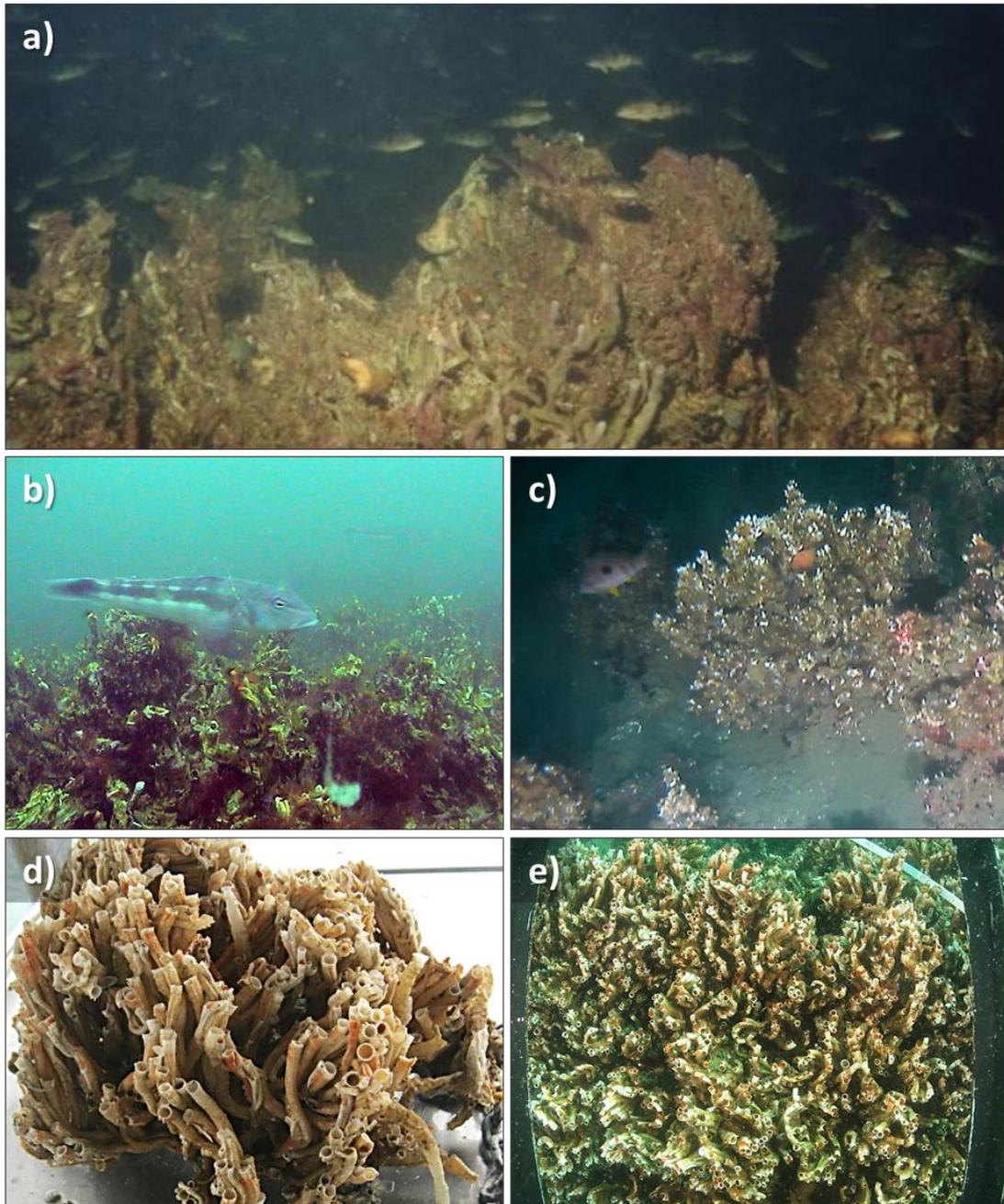
### 3.10.3 Data sources

- Although *G. hystrix* is known to occur around New Zealand, represented by individual or small clusters of specimens, only sporadic records are present and only in some collections (partly due to preservation issues), but include little to no mention of habitat forming structure. Collections data were extracted and examined, but provided little to no information on where mounds formed by this species might occur, and so are not plotted here (Table 2-1).
- Regional data and examples come from published reports and unpublished data (NIWA’s-MBIE Bottlenecks programme (C01X1618)).

### 3.10.4 Provision of ecosystem service

- Habitat-formers providing localised hotspots in biodiversity.
- Large *Galeolaria* mounds provide habitat structure for diverse sessile and motile fauna, including “Christmas tree” polychaete worms (*Spirobranchus laticarpus*), burrowing anemones (*Cerianthus* sp.), octopus, blue cod, tarakihi, spotted wrasse, blue moki, pigfish, red cod, butterfly perch and triple fins (Smith et al. 2005; Davidson et al. 2010; MacDiarmid et al. 2013).

Skate and shark egg cases were also commonly found attached to *Galeolaria* mounds in Big Glory Bay (Smith et al. 2005).



**Figure 3-51: *Galeolaria hystrix* mounds (reefs).** a) ~50-yr old *Galeolaria* mound in Big Glory Bay, Stewart Island, with associated sponges, ascidians, and school of spotties (Source: A. Smith, University of Otago); b-c) extensive mounds occurring across the top and upper slope (respectively) of Perano Shoals in Marlborough Sounds - with associated blue cod (b - source: R. Davidson, Davidson Consulting Ltd) and spotties, sponges and ascidians (c - Source: NIWA's CBedcam imagery 2017); d) large *Galeolaria* mound collected from East Waikehe Island, Hauraki Gulf (NIWA's MBIE Bottlenecks survey, 2017); and e) *Galeolaria* tubeworms in 0.25m<sup>2</sup> photoquadrats from a mound in Whataroa Bay, Port Underwood 2016 (photograph provided by Mike Page, NIWA).

### 3.10.5 Biogeographic distribution

#### National scale

In New Zealand, *Galeolaria* specimens have been collected from as north as the Hauraki Gulf (NIWA Bottlenecks Surveys 2107 - unpublished data) down to Stewart Island from depths of 6 to 30 m (MacDiarmid et al. 2013) (Figure 3-51). The colonies are best known from sightings of large mounds in the Marlborough Sounds (e.g. Davidson and Richards 2015; Page 2017), and in Big Glory Bay / Paterson Inlet in Stewart Island (Smith et al. 2005), but are expected to be widely present in enclosed waters at modest depths, and in smaller clumps (G. Read pers. comm.). For example, significant sporadic clumps of less than 1 m diam. occur in Wellington Harbour (G. Read pers. obs.). *Galeolaria* can occur as individuals or colonises comprising many individuals, however, the presence of biogenic mounds is likely to be rare in New Zealand (MacDiarmid et al. 2013).

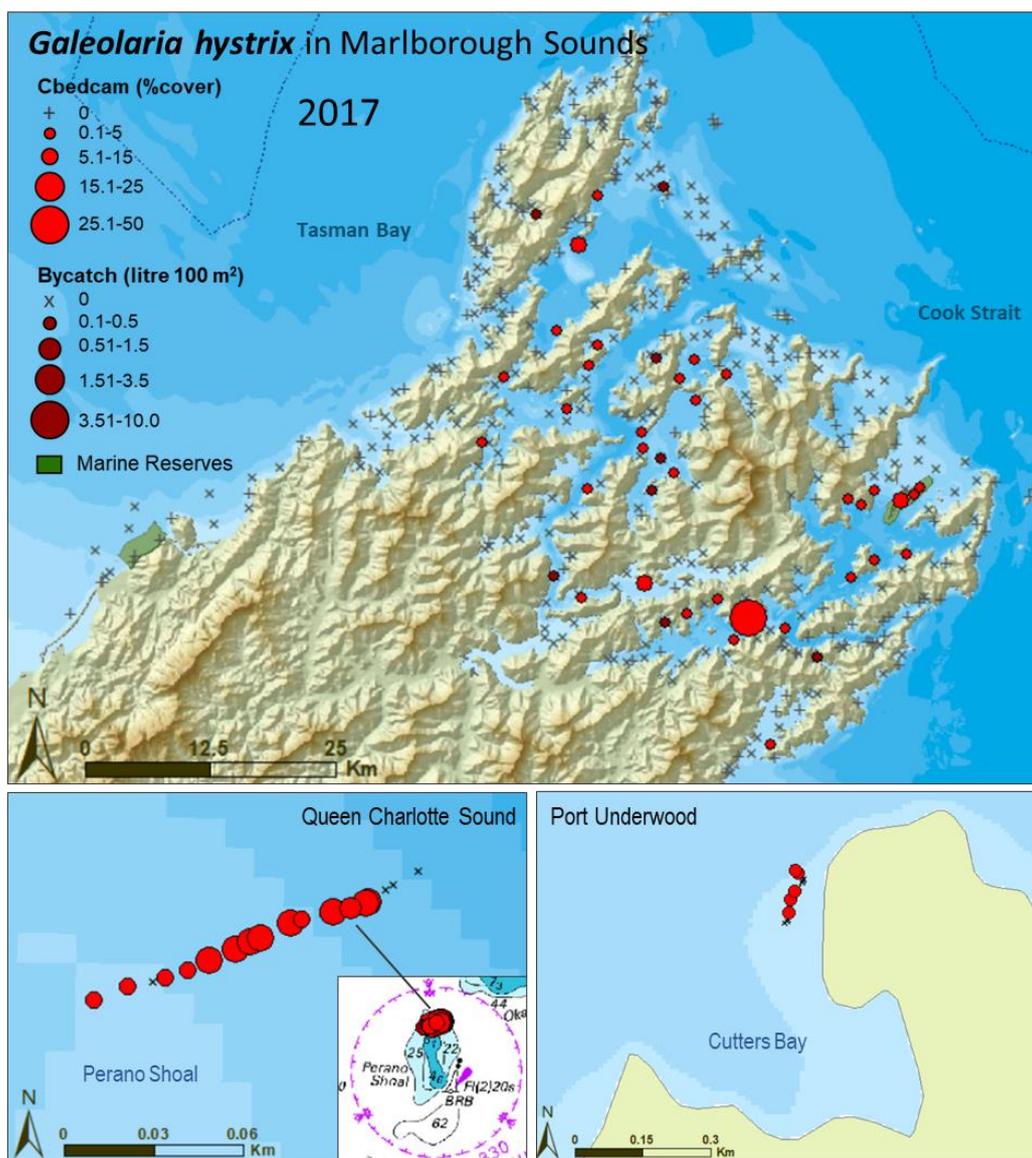
#### Regional scale/case studies

**Big Glory Bay:** *Galeolaria hystrix* mounds were found in numerous locations within Big Glory Bay, Paterson Inlet, Stewart Island in water depths of 9-16 m (Smith et al. 2005; Figure 3-51a). A total of 114 mounds were recorded within a 28-ha area. Mounds were patchy in distribution within the Bay, with most mounds standing 1.5 m in height and 1-5 m in diameter. Radiocarbon dating found these reefs to be less than 50 years old (Smith et al. 2005).

**Marlborough Sounds:** *Galeolaria hystrix* occurs throughout sheltered areas of the Marlborough Sounds, but only forms significant mounds in a few locations (Davidson 2011, Davidson et al. 2017; Davidson and Richards 2015; Page 2017). The most prominent mounds occur on Perano Shoal in Queen Charlotte Sounds covering an area of ~ 5.5 ha on the upper slope of the shoal (this is the largest *Galeolaria* mound known in Marlborough, Figure 3-51b-c); and on two headlands on the eastern side of Port Underwood - the Knobbies covering 3.4 ha in 3-12 m water depth and Whataroa Bay (e.g. Figure 3-51e) covering 0.9 ha in 3-15 m (Davidson 2010; MacDiarmid et al. 2013; Mike Page pers. comm.).

### 3.10.6 Stressors and threats

- Physical damage: Tubeworms are highly vulnerable to physical disturbance. *Galeolaria* reefs are very fragile and easily broken by disturbance from boat anchors (Elliot 1995), dredging, and benthic trawling (Rosenberg et al. 2003; Davidson and Richards 2015).
- Sedimentation: *Galeolaria* are suspension-feeders that are susceptible to increased suspended sediments that can block feeding appendages and affect respiration (Kupriyanova et al. 2001) and sedimentation that can smother and kill colonies.
- Mortality of a *Galeolaria* reef in Tennyson Inlet occurred following a filamentous diatom bloom in the Marlborough Sounds (M. Page, pers. comm.). Blooms (possibly toxic) are known to cause mortality by smothering benthic macroinvertebrates (Kroger et al. 2006; Chang 1999). It is possible that such events occur elsewhere in the Marlborough Sounds and may cause mortality events (M. Page, pers. comm.).
- Aquaculture effects. *Galeolaria* reefs are often found near mussel and salmon farms (e.g. Port Underwood and Big Glory Bay).



**Figure 3-52: Distribution and abundance of the calcareous mound-building tubeworm, *Galeolaria hystrix*, a) across the Marlborough Sounds. b) along a single video transect at Perano Shoal, in Queen Charlotte Sounds, and c) alongshore of the headland adjacent to Cutters Bay in Port Underwood. Red bubbles = ranked % cover from underwater towed video (CBedcam) observation (Apr-May 2017); burgundy bubble = volume in litres of bycatch collected from 3-m wide beam trawl towed for 300 m (coll. Mar-Apr 2017). Data presented are from NIWA's MBIE-Bottlenecks Juvenile fish program - 2017 Beam Trawl and CBed-camera survey. All samples were collected in 3-30 m depth.**

### 3.10.7 Condition

- *Galeolaria* mounds in Big Glory Bay (also referred to as reefs) that were surveyed in 2002 found 36% of *G. hystrix* mounds were broken or dead, while the remaining 64% were intact. Of those intact, 65% of the serpulid tubes were occupied by living *G. hystrix* (Smith et al. 2005). *Galeolaria* mounds near the entrance on the western side of Glory Bay had the highest proportion of dead mounds, while inner Glory Bay mounds were considered to be in ‘Excellent’ condition. However, it was noted that these mounds had a ‘great deal of sediment on them’, and that sponges and ascidians were generally absent. No evidence of farm impacts on *Galeolaria* mounds, that were adjacent to farms, were observed (Smith et al. 2005).
- Anchor drag marks were observed running off the high point into deeper water off the Perano Shoals in Queen Charlotte Sound (Davidson and Richards 2015).
- *Galeolaria* reefs on the headland of Whataroa Bay in Port Underwood include a discrete area encompassing multiple large mounds that vary in height approximately 5-9 m. The size and extent of the mound habitat has remained consistent between 2011 and 2017, although the health of some patches on the outer boundary have declined, while new patches have grown within the central regions of the habitat (Mike Page pers. obs.), it is unclear what is driving these patterns.

**Table 3-23: Overall condition status of Calcareous tubeworm mounds within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Stable <sup>1</sup> (with some loss)	Unknown-Moderate <sup>1</sup>	Very Good <sup>2</sup>	Stable-Declining <sup>3</sup>	Good

<sup>1</sup> Mounds in several areas have been re-surveyed, with most showing similar extents, but with localised loss and some anchor damage (Davidson et al. 2011).

<sup>2</sup> Biodiversity high in and around Mounds (e.g. Davidson et al. 2011; Smith et al. 2015; Anderson pers. obs.).

<sup>3</sup> Expected to be stable where sedimentation is low and benthic fishing and boat-anchoring activities are absent, but likely to undergo significant decline/loss where these stressors and activities occur.

#### Overall condition status within NZ

Only a few mound locations known. Slow growing and very long lived (~50 years old). Highly vulnerable to any physical disturbance or damage. Important species for benthic protection.

### 3.10.8 Knowledge gaps

- Calcareous tubeworm mounds are rare in extent (Big Glory Bay and Marlborough Sounds) and are extremely fragile to even small disturbances (e.g. a single boat anchor can decimate a mound). Currently no protection exists for this rare and fragile habitat. While some initial mapping has been undertaken on mounds near aquaculture farms, the extent of large mounds is still largely unknown. Mapping and monitoring these fragile habitats should be prioritised.
- Small-scale monitoring of some *Galeolaria* mounds has been undertaken (e.g. in relation to marine farm resource consents and activities - Whataroa Bay in Port Underwood e.g. Davidson 2011; Mike Page Pers. comm.), however the area and abundance of other mounds is unknown.
- Little is known about the biology and ecology behind mound formation, specifically what triggers colonial growth and subsequent mound formation relative to isolated clumps or individuals, or what may inhibit mounds.

**Table 3-24: Gap analysis summary for Calcareous tubeworm mounds.**

Type	Description
<b>Distribution &amp; function</b>	Calcareous tubeworm mounds are known to occur in discrete locations within Big Glory Bay and Marlborough Sounds, but the distribution beyond these regions is poorly known.
<b>Biological &amp; taxonomic</b>	<i>Galeolaria hystrix</i> is the dominant calcareous mound-forming species, but other undescribed species may occur. Some basic biology is known, but little to nothing is known about how, where and under what conditions <i>G. hystrix</i> forms mounds.
<b>Management &amp; conservation</b>	Currently no protection exists for this rare and fragile habitat, but mounds are incredibly fragile and extremely vulnerable to even small physical disturbance.

## 3.11 Non-calcareous tubeworm fields

### 3.11.1 Habitat description and definition

Polychaete tubeworms are marine worms that live in permanent tubes that are buried (to some degree) in marine sediments. Some tubeworm species occur in high densities over extensive areas, with their emergent tubes (that part of the tube sticking out above the ground) providing 'low-relief' structure for other species (e.g. Stoner et al. 2007; Morrison et al. 2014a; Jones et al. 2016). The biogenic habitat-forming polychaetes in New Zealand are in the annelid families Serpulidae, Chaetopteridae, Sabellidae, and Sabellariidae. Species within these families usually live in permanent tubes and are filter feeding tube-dwellers, with the chaetopterids also selectively deposit-feeding.

Tubeworm species can form dense colonies that consolidate sediments over expansive areas (1-10s kms), which in turn modifies water flow and sediment transport over the seabed (Levin 1982; Kostylev et al. 2001). In high energy environments, differential flow over the seabed relative to patchy tubeworm densities can result in raised bed forms, as sediment is scoured away from low density or barren tubeworm areas. The tubeworm communities may vary considerably in their morphology, with some species having long sections of their tubes exposed at the surface (e.g. the Chaetopterid, *Phyllochaetopterus socialis*, commonly known as wireweed or tarakihi-weed) while other species are mostly buried with almost no emergent tube (e.g. the Sabellid tubeworms, *Euchone* spp.). Dense tubeworm colonies can support diverse infaunal and epifaunal communities, and in high densities may result in other biogenic habitats growing on top of them (e.g. sponges on wireweed [e.g. Figure 3-53a], algal meadows on the Oweniid tubeworm, *Owenia petersenae* [e.g. Figure 3-58a,c]).

**Definition:** Tubeworm Fields are defined as areas of contiguous cover or mosaics of higher density tubeworm patches interspersed by bare sediment, where tubeworms (and any attached epifauna) cover >500 m<sup>2</sup> of seafloor, or contribute at least 25% of the weight or volume of the catch from towed sample gear, or occur in two successive samples collected by point sampling gear (MacDiarmid et al. 2013).

### 3.11.2 Key species

- Wire-weed/Tarakihi-weed, *Spiochaetopterus* and *Phyllochaetopterus* spp (Family: Chaetopteridae).
- *Acromegalomma* worms, *Acromegalomma suspiciens* (Family: Sabellidae).
- *Euchone* spp. (Family: Sabellidae)
- *Owenia petersenae* (Family: Oweniidae)

### 3.11.3 Data sources

- Lack of specimens in collections (due to preservation issues) and the lack of taxonomic nomenclature for this group meant that Museum specimen identification datasets (OBIS-NZ, NIWA-Inverts and Te Papa) provided little information (Table 2-1).
- Regional data and examples come from published reports and unpublished data (NIWA's-MBIE Bottlenecks programme (C01X1618)).

### 3.11.4 Provision of ecosystem service

- Soft-sediment bioengineers; consolidate and stabilises sediments indirectly by altering the hydrodynamic flows patterns and amount of suspended matter in the system.

- Support significantly higher infaunal and epifaunal diversity and abundance than adjacent soft-sediment, by providing regular inputs of labile organic material through their break-down of deposited algal carbon (Hutchings 1998). Higher biodiversity in, on and around wormfields.
- Dense tubeworm colonies may form consolidated and raised mounds that epibenthic flora and fauna colonise, including a wide variety of invertebrates and fishes (Morrison et al. 2014a). Some tubeworm species may provide exposed tubes that epibionts attach to (e.g. sponges on the wireweed, *P. socialis*). However, while epifauna may increase with increasing tubeworm densities, infaunal diversity and abundance of non-generic species may decrease as space becomes limited.
- It is also likely that some species are an important food source to some fish species.
- No quantitative information on the value of tubeworm habitats to fisheries productivity is available.

### 3.11.5 Biogeographic distribution

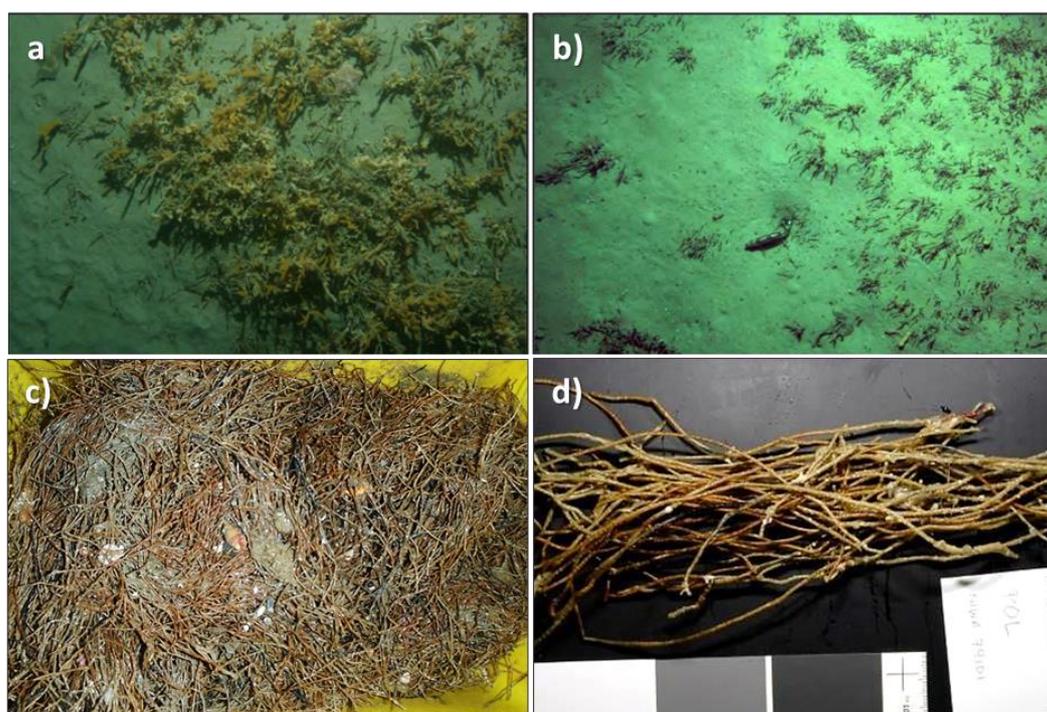
#### National scale

Little is known about the occurrence of tubeworms as biogenic habitats around New Zealand, except for the meadow-forming species-complex *Spiochaetopterus* and *Phyllochaetopterus socialis* (wireweed) (MacDiarmid et al. 2013; Morrison et al. 2014a; Jones et al. 2016). However, low-relief tubeworm fields (similar to those in the wireweed complex) are wide spread in many areas (Morrison et al. 2014a; Jones et al. 2016; 2018). The lack of distribution knowledge, in part stems from the lack of identified specimens in museum collections. In this review, no matches were found in the museum databases, as many of these worms do not preserve well and species have not been described, so cannot be distinguished from all non-habitat-forming species. The tough tubes of many tubeworm species protect them from preservation, so are often rare or absent from museum collections (G. Read pers. comm.). Little is known about geographic extents and distributions, or if newly discovered species are endemic crypto-species (G. Read pers. comm.). Many tubeworm fields, even those that encompass very large areas, are often unnamed and undescribed (e.g. *Euchone*-like species A [unnamed species, termed sp A by G. Read] forms one of the densest tubeworm beds in New Zealand and covers an extensive (est. 400 km<sup>2</sup>) area of seabed across the mid-to-north shelf of the South Taranaki Bight (Beaumont et al. 2015). The recent discovery of several extensive tubeworm fields on the continental shelf of New Zealand (see examples below), indicates that tubeworm fields are likely to be widespread but vastly under-represented in national and regional datasets. Some tubeworm fields are also known to support commercially important fishery species (e.g. the wireweed or 'Tarakihi-weed' fields where tarakihi are commonly caught and have been observed sheltering in-amongst the wireweed fields (Jones et al. 2016; and review in Morrison et al. 2014a).

#### Regional scale/case studies

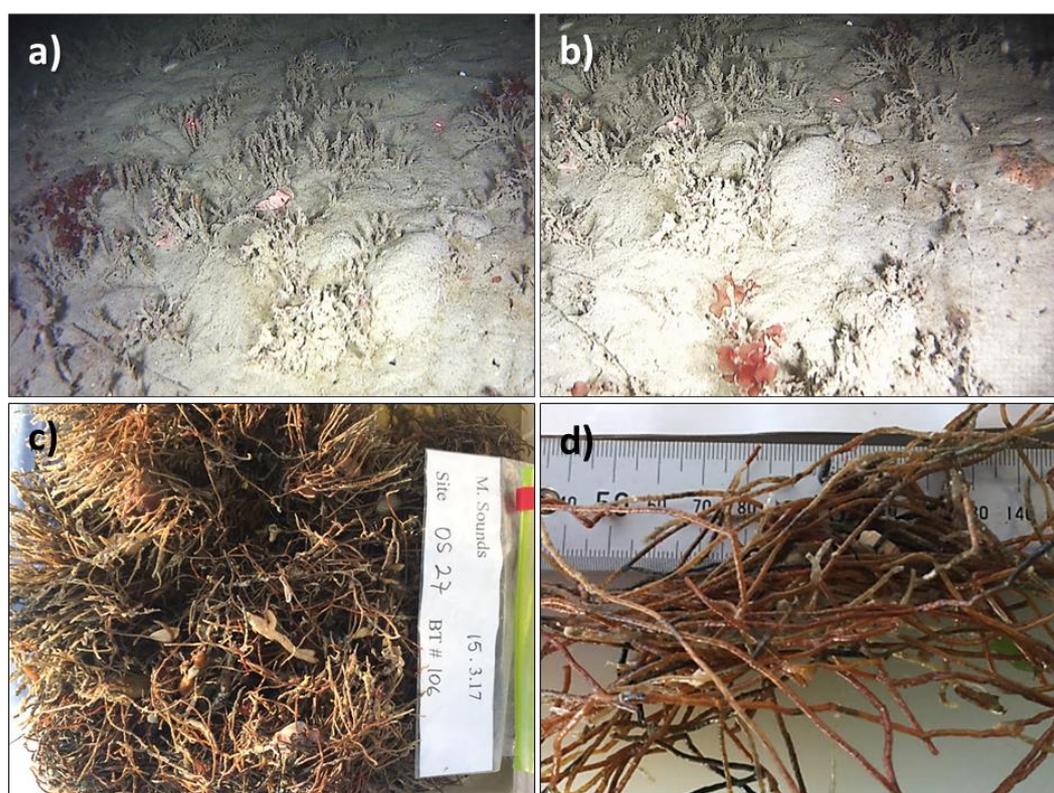
Localised studies have identified a variety of non-calcareous tubeworm fields (also termed beds or meadows) in a variety of soft-sediment habitats; some occurring in remarkably high densities (e.g. >120 individual Chaetopterids per 0.02 m<sup>2</sup> in northeast New Zealand (R. Creese unpublished data, cited in Tricklebank et al. 2001) and up to 216 individual Sabellids per 0.02 m<sup>2</sup> off the South Taranaki Bight (Beaumont et al. 2015). We present several examples below.

**Otago Shelf Wire-weed (Tarakihi-weed) Fields:** Offshore species of the genera *Spiochaetopterus* and *Phyllochaetopterus* form biogenic structures collected in bottom trawls, and are known to fishers as ‘wireweed’ or ‘tarakihi weed’ as they are extremely tough and hard to cut or break (Morrison et al. 2014a; Jones, et al. 2016). These grow partly buried in sediments and can occur as extensive (10s of km’s) dense fields. The tubes of this species occur in small entangled clumps, are horny, often regularly transversely banded, and only 2-3 mm in diameter, but 400 mm or more in length (G. Read pers. obs.). The most extensive wireweed fields occur off ‘the Hay Paddock’ an area 140 km<sup>2</sup> (based on Local Ecological Knowledge (LEK) interviews of long-time fishers) on the North Otago Shelf, off Oamaru in 50–110 m water depths (review in Morrison et al. 2014a; Jones et al. 2016). Surveys undertaken by NIWA in 2011 multibeam mapped and surveyed 7 km<sup>2</sup> of the Hay paddocks, using towed-video and benthic collections. These surveys found extensive wire-weed meadows in 70-110 m water depths – with low-relief sponge cover growing on the wireweed, but only occasional low-quality patches further inshore in depths of 50-70 m in muddier sediments, but where LEK interviews had indicated one of the largest wire-weed areas.



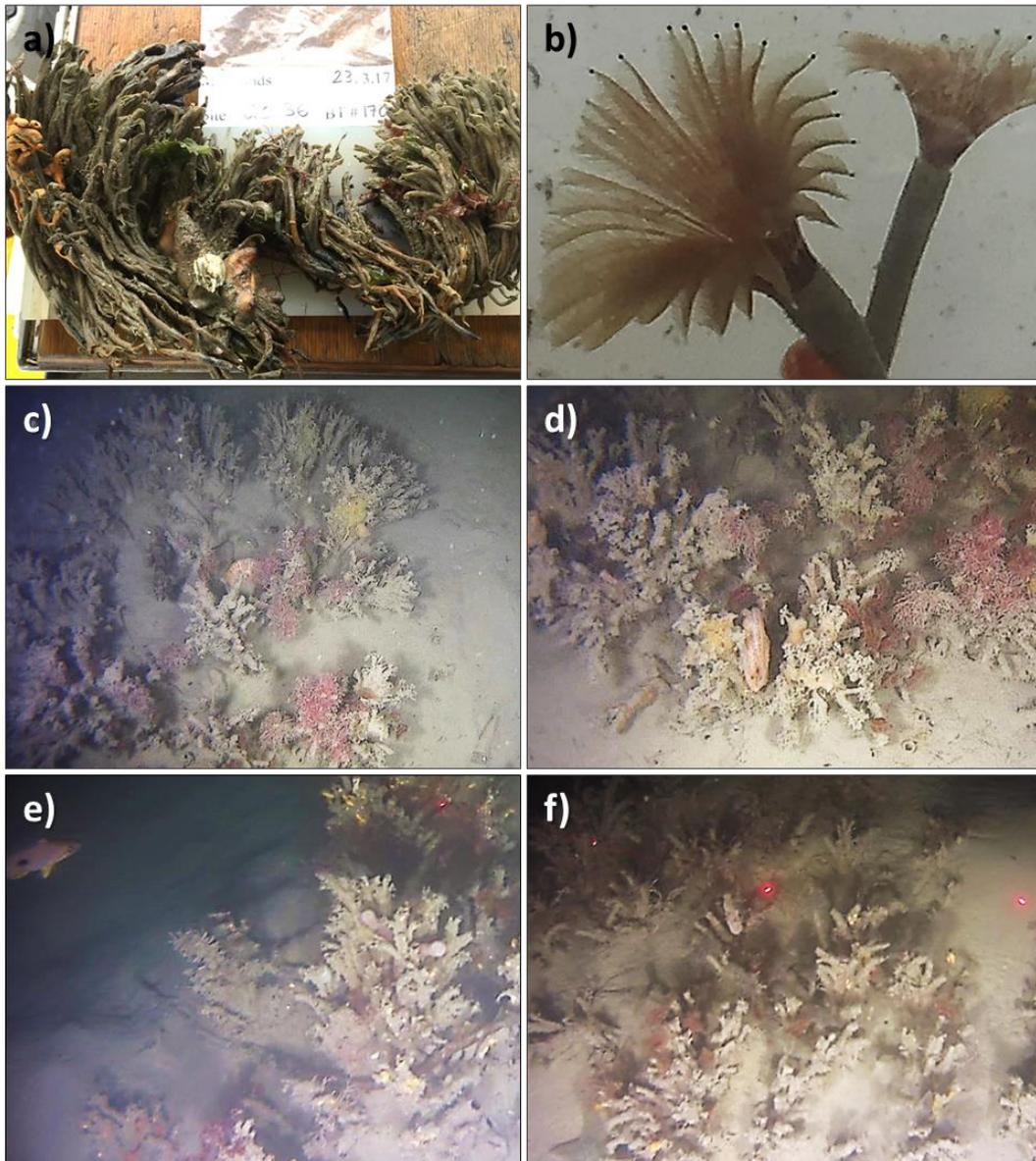
**Figure 3-53: Wire-weed tubeworm fields from the Hay Paddocks on the North Otago Shelf, off Oamaru.** a) wireweed patch with substantial sponge assemblage; b) low-density wireweed field off North Canterbury, with sleeping tarakihi. (Figure 30, from Morrison et al. 2014a). c-d Examples of wireweed specimens collected from these habitats

**Marlborough Sounds (Wire-weed like) tubeworm fields.** In the Marlborough Sounds, a tubeworm similar in appearance to the wire-weed defined from the Hay Paddocks (see example above), but not as tough (i.e. can be easily cut) has been recorded in soft-sediment bays throughout the Marlborough Sounds (e.g. Figure 3-54; Figure 3-57; NIWA’s MBIE Bottlenecks surveys, 2017 - unpublished data). These tubeworms have been initially described as *Spiochaetopterus* spp (Geoff Read, pers. comm. to T. Anderson) and occur in patchy to moderate density fields and were often intertwined within *A suspiciens*. *Spiochaetopterus* spp. densities were found to be highly variable within and between bays, but supported a wide range of flora (most red algal species) and fauna (5-armed starfish, holothurians, ophiuroids, and small fishes, such as triplefins and spotties) (NIWA’s MBIE Bottlenecks surveys, 2017 - unpublished data).



**Figure 3-54: Wire-weed like Chaetopterid tubeworm beds, *Spiochaetopterus* spp.** This habitat is common throughout the Marlborough Sounds as mono-specific beds, and intertwined within *Acromegalomma* fields. a-b) Port Gore, Marlborough Sounds; c-d) Guards Bank, Marlborough Sounds. Images (a-b) taken during NIWA’s MBIE Bottlenecks programme (C01X1618) using NIWA’s CBedcam (END17101-MSCB17 survey).

**Marlborough Sounds *Acromegalomma* wormfields:** Dense fields and localised patches of raised tubeworms, comprised of *Acromegalomma suspiciens* (formerly *Megalomma suspiciens*) were recently collected or observed growing in soft-sediments in > 10 sheltered embayments across the Marlborough Sounds (Figure 3-55 and Figure 3-57), during NIWA’s MBIE Bottlenecks fish-habitat surveys, 2017 (NIWA, unpublished data). The most extensive and dense *A. suspiciens* fields (e.g. Figure 3-55a-f) were recorded from Nikau Bay in the inner Pelorus Sounds, Maraetai, Hitaua and Onapua Bays in Tory Channel, Croisilles Harbour (MSCB17 site TC-C06) and the Knobbies in Port Underwood (MSBT17: site EC22).



**Figure 3-55: *Acromegalomma suspiciens* tubeworm beds from the Marlborough Sounds.** a) fanworm bundles of *A. suspiciens* collected from Hitaua Bay, Tory Channel (site QC36); b) image showing the branchial crown out feeding; c-d) dense clumps (or clusters) of *A. suspiciens* in Onapua Bay, Tory Channel (site QC-C50); e) raised mound in Hitaua Bay, Tory Channel – and spotty; dense field in Nikau Bay – red branchial crowns can be seen feeding (site PS-C50). Images from NIWA’s-MBIE Bottlenecks programme (C01X1618) (c-f) using NIWA’s CBedcam (END17101-MSCB17).

*A. suspiciens* is a large endemic sabellid tubeworm normally seen as solitary individuals, but in the recent NIWA video surveys were seen in habitat-forming clusters, that in places formed raised mounds or extensive fields (Nikau Bay, Pelorus Sound) in soft sediment embayments. The type locality for *A. suspiciens* is from French Pass, between D’Urville Island and north end of South Island, New Zealand (-40.922°, 173.837; estimated geolocation). As far as is known this is the same species that occurs non-grouped, but no molecular studies confirming this have been done, and the worms have yet to be carefully compared morphologically. Colour variants of this species are known but colour is not necessarily an indication of cryptic species.

The tubeworm clusters collected have a robust sponge-like texture and grow together in fused colonies in soft-sediments. Tubes are up to about 150 mm long, with part of the tube below the

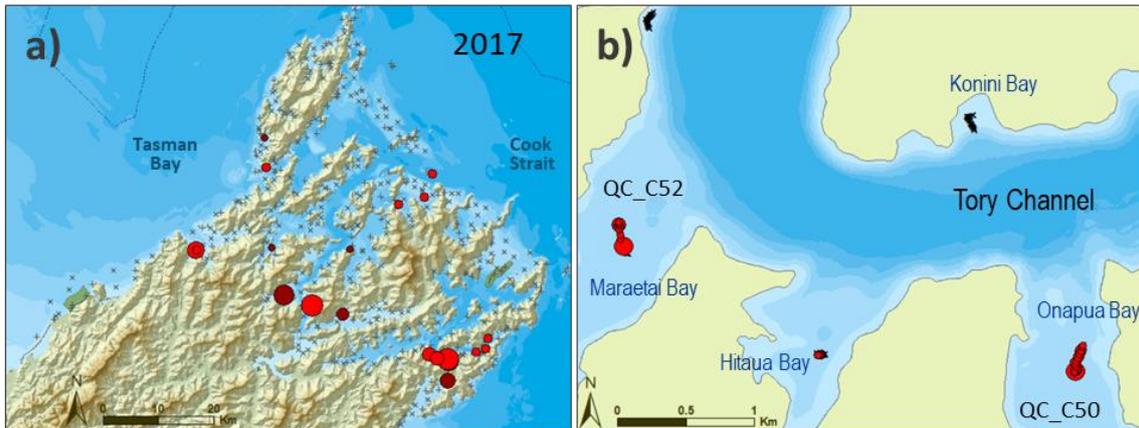
sediment, while the exposed part of the tube stands ~30-100 cm above seabed, providing physical structure and complexity for a wide variety of sessile fauna and flora to colonise- including encrusting and erect sponges, colonial and solitary ascidians, bladed and filamentous red algae, an unknown thick red biofilm (inner part of Nikau Bay only), and epiphytic bivalves. It also provides complex 3-dimensional structure that provides refuge to a range of fish, including subadult tarakihi, spotties and triplefins. *A. suspiciens* tubeworm mounds and fields appear to be an important biogenic habitat within expansive soft-sediment embayments in the Marlborough Sounds, but appears to have gone largely unnoticed – possibly because it occurs in inner bays out in open flat muddy areas where divers rarely go.

**South Taranaki Bight *Euchone* Tubeworm fields:** Extensive tubeworm fields comprising dense populations of the surface-living tubeworm, *Euchone* sp. A, have also been recorded across the northern mid-shelf region of the South Taranaki Bight in water depths of 20-70 m, with densities highest in depths of 30-50 m (Figure 3-56 and Figure 3-32a; Beaumont et al. 2015 – referred to as wormfields). *Euchone* sp A is a small undescribed suspension-feeding worm that lives within vertical tubes (often 4 x longer than the worm itself) that it constructs by cementing sand grain together (Geoff Read, NIWA pers. obs.). This species is associated with fine-medium grained sediments, where they can occur in extremely high densities (up to 10.8 thousand per m<sup>2</sup>; mean 1,137.52 ± 180.95 SE per m<sup>2</sup> - Beaumont et al. 2015 and NIWA, unpublished data), making them important habitat stabilisers in these high-energy west-coast environments.

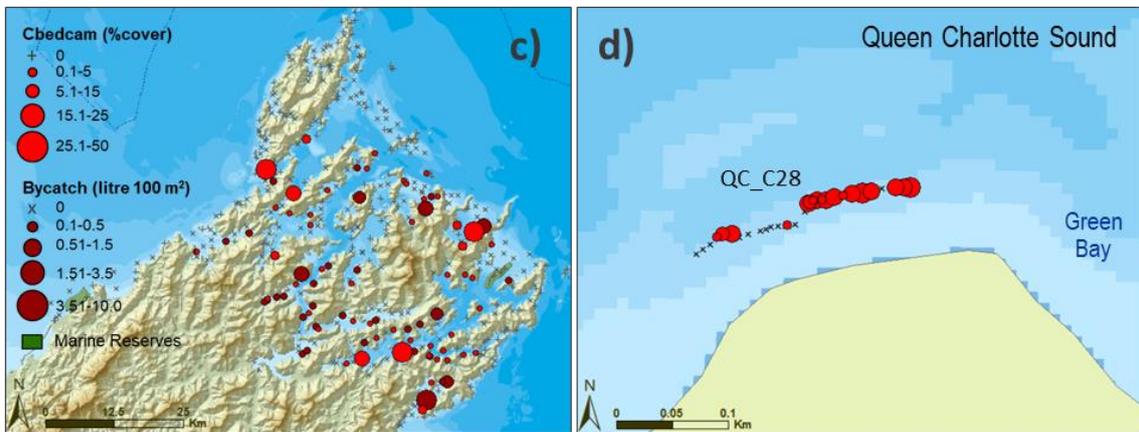


**Figure 3-56: *Euchone* wormfields from Patea shoals on the South Taranaki Bight.** a) A dense wormfield habitat, b) Collection of *Euchone* sp A within cemented sand grain tubes (many only partially intact due to collection (stained in Rose bengal)); c) sediment core with *Euchone* sp A worms; d) two whole specimens: One fully encased in its sand-grained tube with only its crown (feeding appendages) exposed, the other removed from its sand grain tube [scale bar is 10 mm]; e) whole specimen with only some sand grains still attached around posterior region [scale bar is 5 mm] (Source: Images from Beaumont et al. 2015).

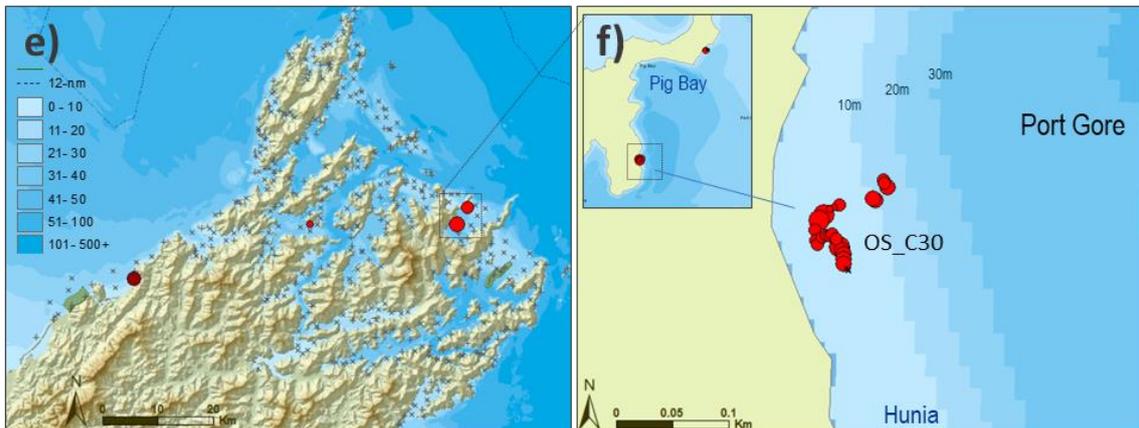
*Acromegalomma suspiciens*



*Spiochaetopterus* spp

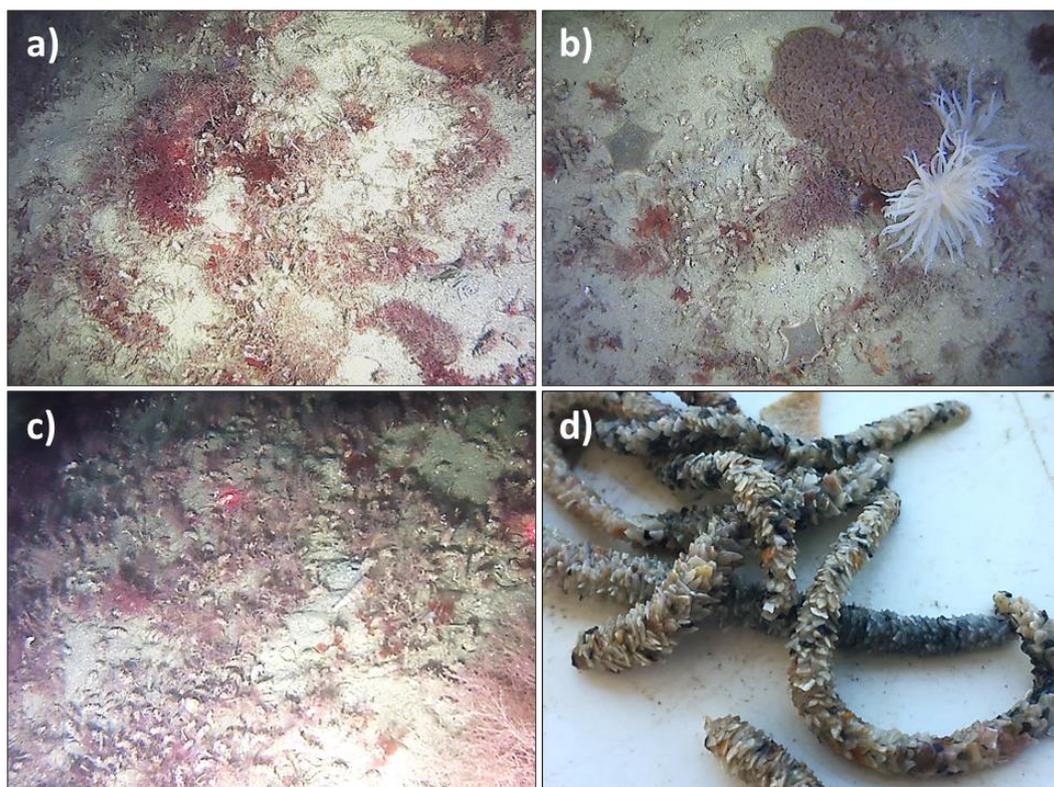


*Owenia petersenae*



**Figure 3-57: Tubeworm fields distribution and abundance within the Marlborough Sounds.** a,c,e = Regional scale/case studies distribution for three key tubeworm taxa; b, d, and f present a finer scale example of their distribution and abundance. Red bubbles = % cover from underwater towed video (CBedcam) observation (Apr-May 2017); burgundy bubble = volume in litres of bycatch collected from 3-m wide beam trawl towed for 300m (coll. Mar-Apr 2017). Data presented are from NIWA’s MBIE-Bottlenecks Juvenile fish program - 2017 Beam Trawl and CBed-camera survey. All samples were collected in 3-30 m depth.

**Owenia wormfields:** An extensive tubeworm field, comprised of *Owenia petersenae* occurs at Gannet Point on the western side of Port Gore 110-150 m offshore in 10-20 m water depth (Davidson et al. 2010; and NIWA video imagery from MBIE bottlenecks survey, April 2017 - Figure 3-58 and Figure 3-57). *Owenia* tubeworms live in the surface sediments, and when present in high densities form slightly raised mounds (T. Anderson, NIWA pers. obs. NIWA's CBedcam video surveys; site OS\_C30). These habitats support a variety of red algae, *Patiriella regularis* starfish and wandering anemones (Figure 3-58a-d), and in places provide an underlying base for algal meadows dominated by *Stenogramma* (T. Anderson, NIWA pers. obs. NIWA's CBedcam video surveys; site OS\_C30).



**Figure 3-58: *Owenia petersenae* tubeworm beds off Gannet Point on the western side of Port Gore, Marlborough Sounds.** Species associated with *Owenia* beds include: mixed red algal, dominated by the red algae *Stenogramma* (a-c); the five-armed starfish, *Patiriella regularis* and the wandering anemone, *Phlyctenactis tuberculosa* (b); d) *Owenia* specimens collected from NE-side of Delaware Bay (MSBT17-TB07). Images (a-c) taken during NIWA's-MBIE Bottlenecks programme (C01X1618) using NIWA's CBedcam (MSCB17-OS-C30).

### 3.11.6 Stressors and threats

- Physical destruction or disturbance of the seabed, due to bottom-fishing activities (Rosenberg et al. 2003), maintenance dredging of channels and harbours, or coastal development.
- Invasive species
- demersal trawling on marine sedimentary habitats

### 3.11.7 Condition

- Little if anything known.
- Beaumont et al. (2015) found that *Euchone* sp A fields had undergone little change in nearly three decades. *Euchone* sp A in the South Taranaki Bight were recorded in 1992 (Page et al. 1992 - cited in Beaumont et al. 2015) during a survey of the proposed 'Kupe pipeline' where they were described as the most abundant infaunal species in the soft-sediments around the pipeline (densities of 233.4 - 908.5 per 0.01 m<sup>3</sup>). NIWA surveys within the same region undertaken in 2011-12 found comparable densities (mean 374.19 ± 80.36 SE per 0.01 m<sup>3</sup>), indicating little change. However, these wormfields are located on the mid-shelf of Patea Shoal an area recently licenced to mine for IronSands by New Zealand EPA. Little is known about the biology of this species or its post-disturbance recovery potential, or even its distribution beyond the Patea Shoals region (Beaumont et al. 2015).
- Wireweed fields within the 'Haystacks' off Oamaru were depicted as polygons by long-time fishers, subsequent NIWA surveys in 2012 recorded lower density fields inshore than interviewees maps would indicate, suggesting that some reduction in density and extent may have occurred along the inshore zone of these wireweed/Tarakihi-fields (Jones et al. 2016).

**Table 3-25: Overall condition status of Non-calcareous tubeworm fields within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Unknown/ Decreased <sup>1</sup>	Unknown- Moderate <sup>1</sup>	Good <sup>2</sup>	Stable-Declining <sup>3</sup>	Moderate

<sup>1</sup> Some tubeworm fields (e.g. Wireweed fields off Oamaru) were found to occur in much lower densities than the thick field depicted by fishermen (Jones et al. 2016), indicating a possible decline in these areas.

<sup>2</sup> Tubeworm fields support diverse and often abundant epibionts and epifloral, and provide structure for fishery species, but little is known about these habitats prior to 2011 (Jones et al. 2016; Jones et al. 2018).

<sup>3</sup> Expected to be stable where sedimentation is low and benthic fishing activities are absent, but Tubeworm fields often occur in areas targeted by benthic fishing activities and are likely to undergo significant decline/loss where these stressors and activities continue.

### Overall condition status within NZ

Tubeworm fields are poorly represented in the Museum collections due to poor preservation, so the distribution, and even the taxonomy, of these species are very poorly known.

Recent surveys across the Marlborough Sounds found tubeworm fields to be an important and abundant biogenic-habitat, but many of these tubeworm fields had not be recorded previous, suggesting that they are likely to be more widespread around NZ than reflected in the currently known distribution.

Tubeworms fields in soft-sediment are vulnerable to disturbance from natural and anthropogenic disturbance.

#### 3.11.8 Knowledge gaps

- Many species of tubeworms that create dense and extensive fields/beds or mounds, remain unnamed and undescribed (G. Read pers. comm.).
- Little if anything is known about their biology and ecology, other than by general conspecific/congeneric inference.
- Recent biogenic habitat and fish-habitat surveys around coastal and continental shelf regions of New Zealand have greatly enhanced our knowledge on these previously little known biogenic habitats. Considerable work is still required to understand, manage, and conserve these habitats.

**Table 3-26: Gap analysis summary for Non-calcareous tubeworm mounds.**

Type	Description
<b>Distribution &amp; function</b>	Distribution and function of Non-calcareous tubeworms fields on soft-sediments is poorly documented, but some tubeworm fields are known to occur over extensive areas, but little to no spatial mapping exists around most of New Zealand.
<b>Biological &amp; taxonomic</b>	Fields often comprise more than one species, but the taxonomy of this biogenic group is poorly known, with most key/dominant species remaining undescribed. Biology is also poorly known for most taxa.
<b>Management &amp; conservation</b>	Biogenic habitats over soft-sediments, especially extensive tubeworm field, are poorly represented in marine reserves. Some tubeworm fields have been identified by fishers as important habitat for fishery species, yet little is known about their resilience or recovery following benthic fishing impacts.

## 3.12 Deep-sea chemoautotrophic tubeworm patches

### 3.12.1 Habitat description and definition

A group of deep-sea tubeworms (known as “beardworms”) are found in chemosynthetic environments, associated with hydrothermal vents and cold seeps. They used to be in separate phyla, Vestimentifera, and Pogonophora, but have recently been placed within the Phylum Annelida, Class Polychaeta, and most are in the Family Siboglinidae. These worms have no gut, and are adapted to absorb nutrients from the surrounding seawater and from symbiotic bacteria that live in a specialised organ, the trophosome, where they utilise hydrogen sulphide (vents) or methane (seeps). The worm provides the bacteria with oxygen and sulphide/methane through its circulatory system, and in return gains a source of food and energy. Hence, they are very different ecologically from other worms.

Hydrothermal vent habitats around New Zealand mainly occur on active seamounts along the Kermadec Arc. Here the seafloor is volcanic rock, with venting often creating small mound or chimney features. The worms occur in rock crevices or patches of sediment where they can take root, near but not in the direct venting. Tubeworms can tolerate temperatures up to about 60°C, whereas some of the vents along the Kermadec Arc can emit fluids at 300–400°C. These vent habitats range from 200 m to 1800 m in depth.

Seep sites in the EEZ are mainly known from the east coast of the North Island, and are associated with authigenic carbonate rock structures. These are areas where hydrocarbon-rich fluids seep or flare up through the seabed, typically occurring at depths around 700 m to 1000 m.

Tubeworm patches are typically not very dense or extensive in New Zealand habitats, compared with classic overseas situations, such as hydrothermal vents on the East Pacific Rise or seeps in the Gulf of Mexico. Nevertheless, they can form patchy thicket formations or loose aggregations that create a habitat and host other fauna.

**Definition:** Tubeworm patches are defined by structure-forming chemoautotrophic species associated with hydrothermal vent and cold seep habitats. Indicative species as per Schedule 6 of the EEZ Act are *Siboglinum* spp., *Oasisia fujikurai*, *Lamellibrachia juni*, and *Lamellibrachia* spp. A patch exists if:

- One or more aggregations of multiple tubeworms are visible in a seabed imaging survey of an active vent or cold seep (typically a scale of about 100m<sup>2</sup>).
- Two or more specimens of a chemoautotrophic species are found in a point sample.
- Two or more specimens of a chemoautotrophic species are found in a sample collected using towed gear.

### 3.12.2 Key species

There are three main species of chemoautotrophic tubeworms known in New Zealand waters:

- *Lamellibrachia juni*
- *Lamellibrachia columna*
- *Oasisia fujikurai*

These species are the larger-bodied taxa, and are from the old Vestimentifera phylum group. It should be noted that the taxonomy of the siboglinids is difficult, and many New Zealand records are currently only identified to the genus level.

More species possibly occur-*Lamellibrachia juni* and *Oasisia fujikurai* were both described as new species from collections in 2004 from Brothers Seamount (Miura and Kujima 2006). With further exploration of vents and seeps, more new discoveries are likely to occur.

Smaller-bodied species may also be common, such as *Siboglinum vinculatum* and ampharetid polychaetes, which can be locally abundant in cold seep areas.

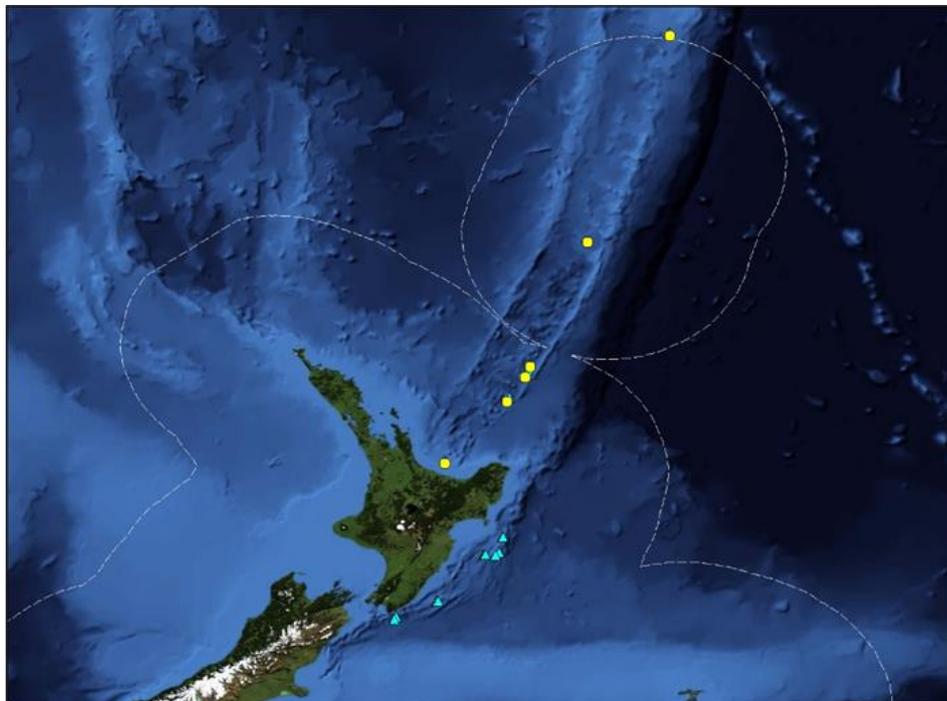
### 3.12.3 Data sources

- NIWA-Inverts data records extracted for Family 'Siboglinidae' and then by key species (as defined in section 3.12.2 Key species) within New Zealand waters (n=100 records, Table 2-1).

### 3.12.4 Provision of ecosystem services

Deep-sea tubeworm patches can perform several ecosystem services:

- Worm tubes can act like root structures to consolidate and stabilise sediment.
- Aggregations of worms can support higher epifaunal diversity and abundance by creating three-dimensional biogenic habitat: this can provide shelter and refuge for smaller mobile animals (e.g., shrimps), as well as an attachment surface for other fauna such as hydroids and sponges which grow on older exposed parts of the polychaete tubes.
- The symbiotic relationship with chemosynthetic bacteria provides the basis for an energy cycle that is not founded on the normal carbon-based source. The ecosystem is hence fundamentally different from most other deep-sea environments. There can be high density of a small number of species able to adapt to such extremes of chemical composition and high temperature, and high levels of endemism driven by the combination of depth (pressure), temperature, and chemical composition of the vent or seep.



**Figure 3-59: Confirmed records of chemosynthetic siboglinid tubeworms.** Yellow circles represent those associated with hydrothermal vents, blue triangles represent cold seeps.

### 3.12.5 Biogeographic distribution

#### National scale

Aggregations of vent and seep tubeworms are known from Cook Strait northwards to the extent of the EEZ and ECS (Figure 3-59). The distribution of these habitats is not fully known. The extent of cold seep sites beyond the Hikurangi margin is unknown. Even for active volcanoes along the Kermadec Arc, many have not been surveyed for their seabed biology, and so there is a likelihood that communities exist in between the known locations in Figure 3-59.

Densities for this habitat are typically not high, in comparison with tubeworm aggregations known in other countries, and vary considerably in their extent between sites (e.g., seeps, Bowden et al. 2013). In venting areas along the Kermadec Arc, tubeworms are generally in small clusters, although become more extensive and dense at Monowai and further north in the Lau Basin.

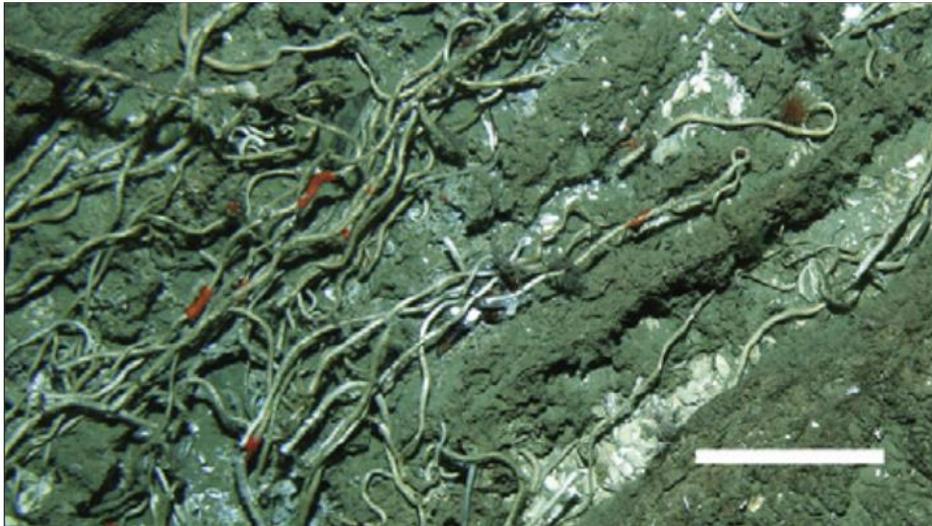
#### Regional scale/Case studies

The vent and seep habitats split readily into two main regions- seamounts of the Kermadec Arc northeast of the North island, and cold seep areas on the Hikurangi Margin off the southeast coast of the North Island.

**Kermadec Arc vent sites:** The New Zealand section of the Kermadec Arc is recognised as a separate biogeographic region for hydrothermal vent communities (e.g., Rogers et al. 2012, Rowden et al. 2016). Biogeography is mainly driven by the dominance of mussel and stalked barnacle fauna on the southern Kermadec Arc, but the limited distribution of New Zealand *Lamellibrachia* and *Oasisia* species also contribute as they only occur at the deeper volcanoes at depths of 1100-1200 m. These tubeworms form small clump-like thickets in places at Brothers and Monowai seamounts (Figure 3-60), covering no more than 1-2 m<sup>2</sup>, and having a discontinuous distribution over the extent of venting. The clumps, especially at Monowai, are associated with bathymodiolid mussels, lithodid crabs, alvinocarid shrimps, and vent fishes. However, at Rumble III, Healy and Wright volcanoes their distribution is very scattered, densities are low, and there are few other invertebrates (Rowden and Clark 2005).



**Figure 3-60: Tubeworms as part of a hydrothermal vent community on Monowai Seamount-at about 1200 m.** Tubeworms seen here together with bathymodiolid mussels, alvinocarid shrimps, and lithodid crabs (image courtesy NOAA-NIWA-GNS).



**Figure 3-61: An aggregation of *Lamellibrachia* sp. on the “Hihi” carbonate platform.** Tubeworms seen here in moderate density at ~750m depth (image from Baco et al. 2010).

### 3.12.6 Stressors and threats

- Bottom trawling is the main threat to this faunal group. Tubeworms in New Zealand waters often form a flattened almost creeping tube structure, and so will not be cut down by trawl nets, but will be crushed and damaged by the ground gear used in deep-water fisheries (such as in orange roughy fisheries). Bowden et al. (2013) showed that increasing trawl intensity at seep sites was associated with decreased levels of live fauna. On seamounts, the effects of bottom trawling are well documented (see review by Clark et al. 2016) and the effects of heavy ground gear on sessile benthic invertebrates can be severe.

Several seamounts on the Kermadec Arc are protected from bottom trawling by the Tectonic Reach Benthic Protection Area, and there is currently no bottom trawling activity in the northern parts of the area in the EEZ around the Kermadec Islands. There are no protected areas off the southeast coast of the North Island, and hence seep worm fields are at greater risk than vent communities.

- Seabed mining is a clear threat. On seamounts with hydrothermal venting (either black smoker or diffuse vent environments) the target resource is polymetallic sulphides (also known as seafloor massive sulphides or SMS), and in seep environments there is potential for exploitation of gas hydrates. The former is a short-medium term threat, as SMS mining is already planned and permitted off Papua New Guinea and there are numerous exploration licences throughout the SW Pacific (including lapsed ones in the Kermadec and Colville Ridge areas) and in international waters. Gas hydrate development is likely to be more long term.
- The effects of climate change, and ocean acidification are unclear, although tube-building animals may be affected by changes in various chemical saturation horizon depths.

### 3.12.7 Condition

- There is little known about the overall condition of deep-sea tubeworm fields around New Zealand.
- Some areas have been observed to be affected by bottom trawling (“Rock Garden” area due to orange roughy fishing).
- Whereas tubeworms in some vent habitats may be relatively fast growing, cold seep species are reported to be slow growing (up to several hundred years). Almost nothing is known about the biology of *Lamellibrachia* and *Oasisia* species in New Zealand.

**Table 3-27: Overall condition status of Non-calcareous tubeworm fields within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Unknown-Stable- Decreased <sup>1</sup>	Good-Poor <sup>2</sup>	Unknown	Stable-Declining <sup>3</sup>	Moderate-Good

<sup>1</sup> Known areas of habitat display a range from stable to decreasing condition, but a number of sites may already have been affected historically that we cannot assess.

<sup>2</sup> Some areas show clear signs of poor habitat condition, others are good. Hence a range is given here to reflect the variability.

<sup>3</sup> Several known habitats are closed to fishing, and they are expected to remain stable. Where fishing continues, there is expected to be a further decline.

#### Overall condition status within NZ

Seep and some vent areas overlap with areas and depths of deepwater trawl fisheries (e.g., orange roughy). They are highly vulnerable to any physical disturbance or damage.

Biology is poorly known (incl. distribution, abundance, age and growth), and hence there is insufficient information to assess the status of populations.

### 3.12.8 Knowledge gaps

- The distribution of tubeworm beds on cold seeps off the Hikurangi Margin is relatively well mapped, but worm distribution on seamounts of the Kermadec Arc, and other seep areas, is not well known.
- Almost nothing is known about the biology of *Lamellibrachia* and *Oasisia* species in New Zealand. Hence their resilience to human activities or climate change is not understood.
- Taxonomy is an ongoing problem, with limited samples in New Zealand institute and museum collections. Research on these communities relies heavily on international collaboration, such as between US and NZ for vent environments, and Germany-US-NZ for seep habitats.

**Table 3-28: Gap analysis summary for Deep-sea chemoautotrophic tubeworm patches.**

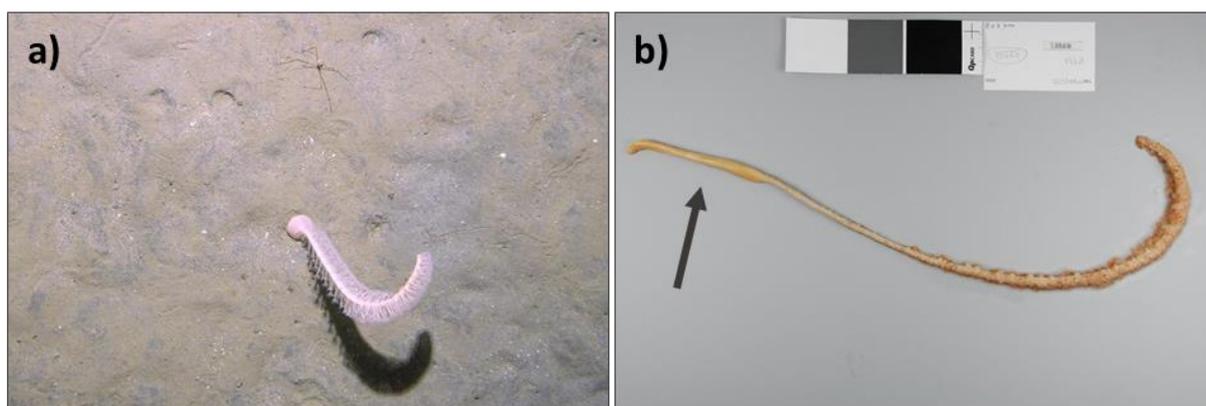
Type	Description
<b>Distribution &amp; function</b>	Distribution and ecosystem function of deep-sea sibloglinids tubeworms is not well known. Aggregations of vent and seep tubeworms are known in some areas, and support higher epifaunal diversity.
<b>Biological &amp; taxonomic</b>	Three main species known for New Zealand, but the taxonomy of the sibloglinids is difficult. Little is known about the biology of these species, although some information about their symbiotic relationship with bacteria is known.
<b>Management &amp; conservation</b>	Deep-sea sibloglinids tubeworms are classified as sensitive environments under the EEZ Act, but the species are not currently protected. Some hydrothermal vent habitats where they could occur are protected within New Zealand's Tectonic reach and Kermadec Benthic Protection Areas. Resilience to human activities is believed to be low.

## 3.13 Sea pen and whip fields

### 3.13.1 Habitat description and definition

Sea pens are colonial marine cnidarians (other cnidarians include sea anemones, corals, and jellyfish) in the order Pennatulacean. They belong to the octocoral group with 8 tentacles to each of their polyps but are specialized and morphologically distinct. Except for rare “rock pens” that attach to deep sea rocky outcrops, the great majority of sea pens anchor in soft sediments with a root-like bulbous peduncle and carry feeding polyps on a flexible erect stalk up to about 1 m in height (e.g. Figure 3-62). They occur on soft sediments (fine gravels, soft sand, mud or abyssal ooze) in the waters where turbulence is unlikely to dislodge them and where there is a current to ensure a flow of plankton across their feeding polyps (e.g. Figure 3-63). They have mostly been observed as isolated individuals and in a few places in densities of up to 6 per m<sup>2</sup> although this may reflect the limited exploration of New Zealand’s EEZ. Because the area of suitable sediments on slope and abyssal seafloors is vast this biogenic habitat could be very widespread.

**Definition:** Sea pen fields (or Sea whip fields) are defined by two or more individuals per m<sup>2</sup> in seabed imaging surveys or two or more specimens collected using towed gear is sufficient to indicate the presence of a Sea pen field (MacDiarmid et al. 2013).



**Figure 3-62: Flower Sea pen, *Anthoptilum grandiflorum*, from the Bay of Islands, New Zealand. a) *in situ* on a sandy seafloor, and b) specimen viewed through a macro camera lens, arrow depicts the long slender and muscular peduncle that it can inflate, anchoring it into the soft sediment to stop it from floating away in the current [Photographs taken by Peter Marriott, NIWA. Oceans Survey 20/20 Bay of Islands].**

### 3.13.2 Key species

- Flower sea pen, *Anthoptilum grandiflorum* (Anthoptilidae)
- Rock pen, *Anthoptilum gowlettholmesae* (Anthoptilidae)
- Club sea pen, *Kophobelemnion stelliferum* (Kophobelemnidae)
- Rope-like sea pen, *Funiculina quadrangularis* (Funiculinidae)
- Two-toothed sea pen or sea whip *Halipterus willemoesi* (Halipteridae)
- Purple sea pen, *Pennatula cf. phosphorea* (Pennatulidae)
- Feathery sea pens, *Pennatula* spp. (Pennatulidae)
- Armoured sea feather, *Pteroeides* sp. (Pennatulidae)

### 3.13.3 Data sources

- VME surveys, compiled from Museum Collections (incl. NIWA-Inverts, Te Papa, VME surveys) and MPI fishery surveys (MPI-COD and MPI-Trawl) for key species within New Zealand waters (Table 2-1) for water depth  $\geq 200$  m. To cover areas of the seafloor  $< 200$  m, OBIS-NZ, NIWA-Inverts and Te Papa records extracted for Order 'Pennatulacean' were also included.  
NB: In the sections below, all available data are presented, except where VME models are presented, here observed VME-samples only are presented to provide valid comparison.

### 3.13.4 Provision of ecosystem service

As this habitat remains largely unstudied the services they provide are poorly known and those described below are rather speculative.

- Because they form an emergent three-dimensional structure with a buried bulb it is likely that in areas where they are common sea pens help to stabilise the sediment and contribute to a distinct sea floor boundary layer of slower currents.
- The erect structures may also provide refuge to small fish and invertebrates. Baillon et al. (2012) found fish larvae to consistently associated with five species of sea pen on the Grand Banks off eastern Canada - including *A. grandiflorum* which is also found in New Zealand (e.g. in the Bay of Islands and the Fordland).
- It is also likely that some species are an important food source to specialised nudibranch and ophiuroid predators.

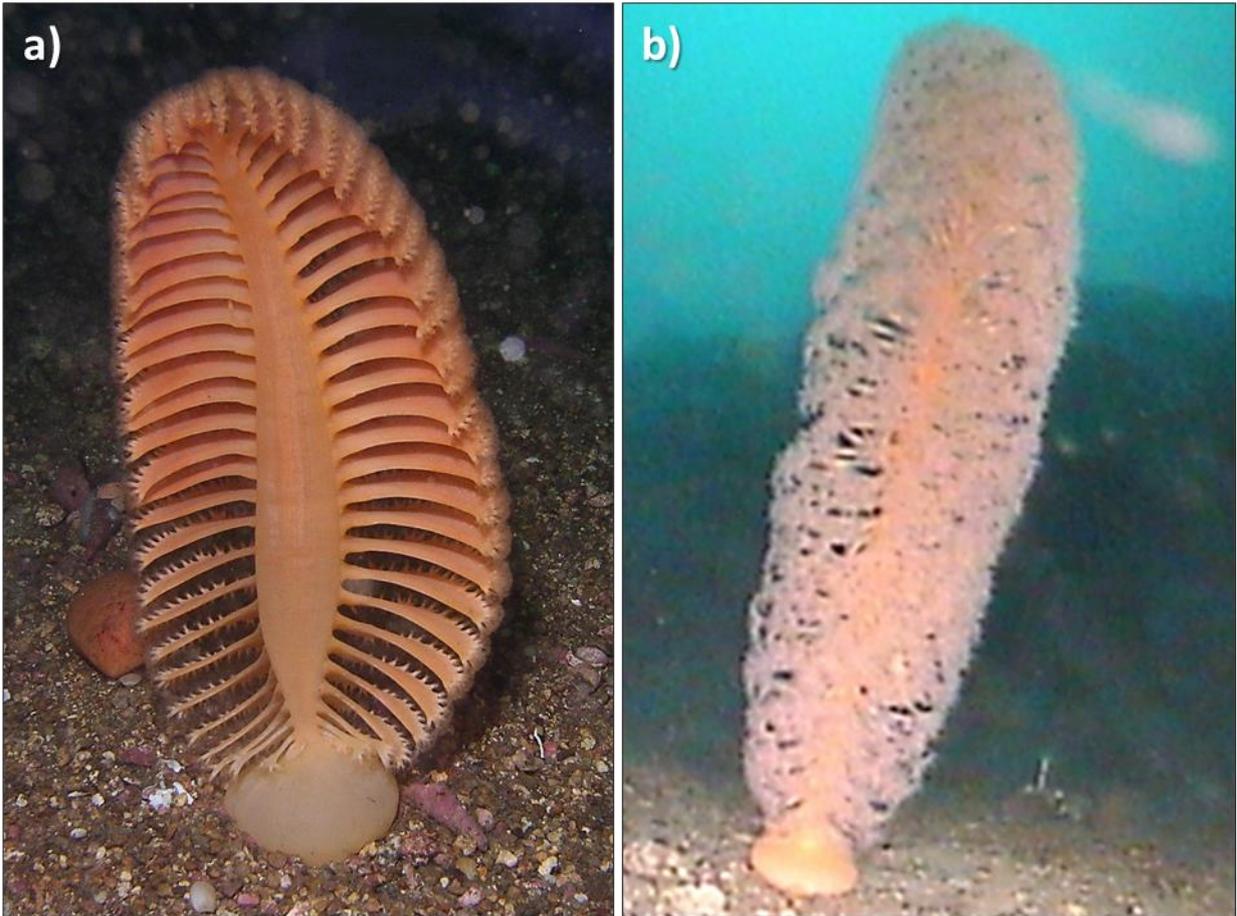
### 3.13.5 Biogeographic distribution

#### National scale

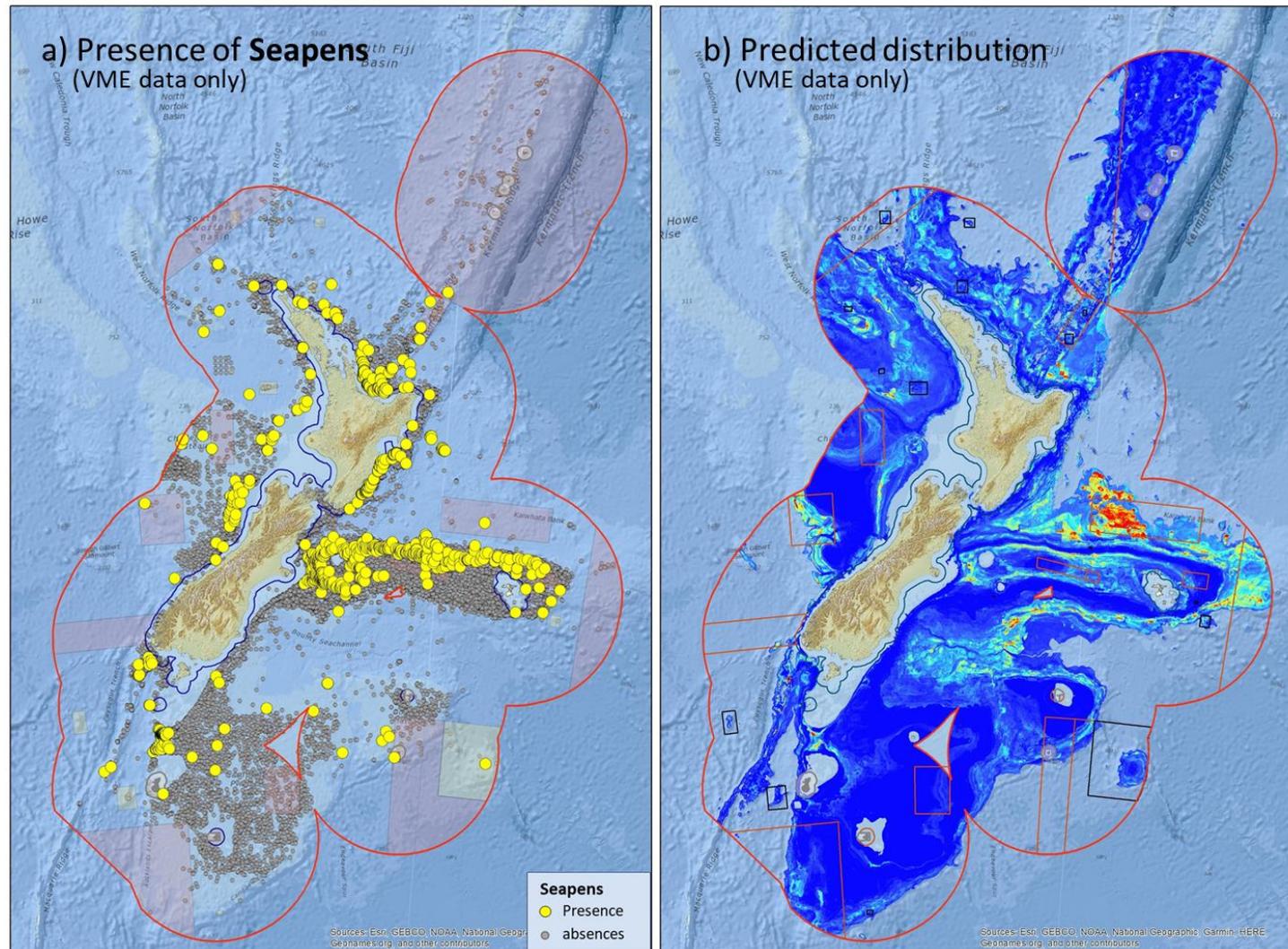
There are currently 31 species of sea pens known from New Zealand waters (about 15% of the global fauna), although 19 (now 16) of those have not been formally described (Cairns et al. 2009 p61). Williams et al. (2014) describe nine sea pen families from New Zealand comprising 15 commonly collected species. Sea pens are found around New Zealand from shallows to the abyssal plain but are uncommon at depths of less than 50 m except where there is protection from strong waves and currents as they are vulnerable to being uprooted from the soft muds where they typical occur. Sea pens are classified as Vulnerable Marine Ecosystem (VME) species - defined as any ecosystem or habitat that is highly vulnerable to one or more kinds of fishing activity or other disturbance.

#### Regional scale/case studies

Seafloor sampling and habitat modelling from depths  $> 200$  m, suggests that sea pens most commonly occur at slope depths off the east and western coasts of northern New Zealand, on the Chatham Rise and around its northern and southern flanks, in the Great South Basin between the Chatham Rise and the Campbell Plateau, and on the southern flank of the Challenger Plateau (see Figure 3-64 and Figure 3-65). A large area in abyssal depths north of the Chatham Rise is predicted to be particularly favourable for sea pens. Sea pens are also an important species in soft-sediment and sill communities in Fiordland (S. Handley, NIWA, pers. comm.).

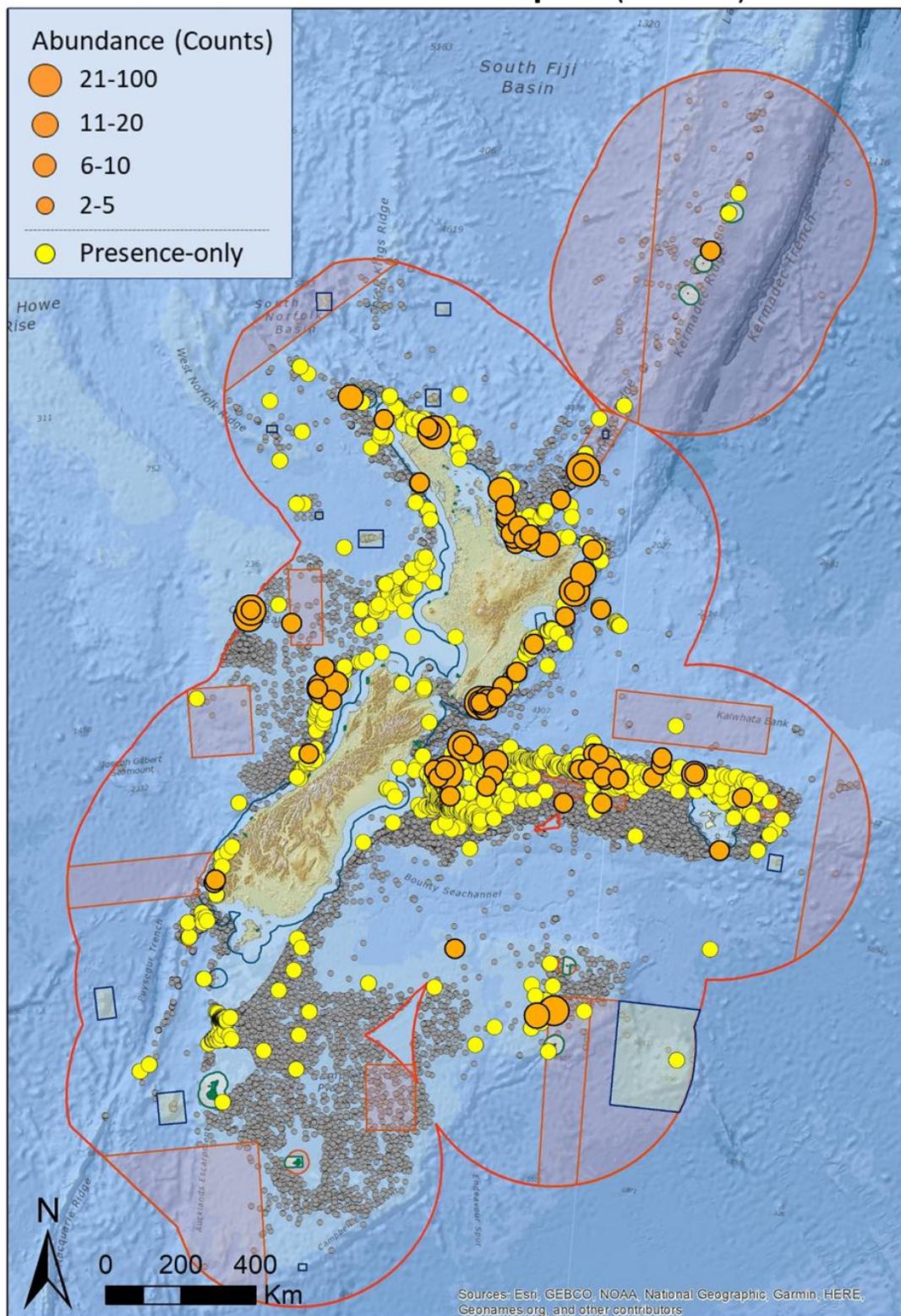


**Figure 3-63: Sea pens from in Fiordland, Southland.** a) Sea pen *Pteroeides bollonsi* at 25 m depth in Preservation Inlet; b) Sea pen, *Anthoptilum grandiflorum* found in soft sediment at 102 m depth. Photographs provided by Sean Handley, NIWA

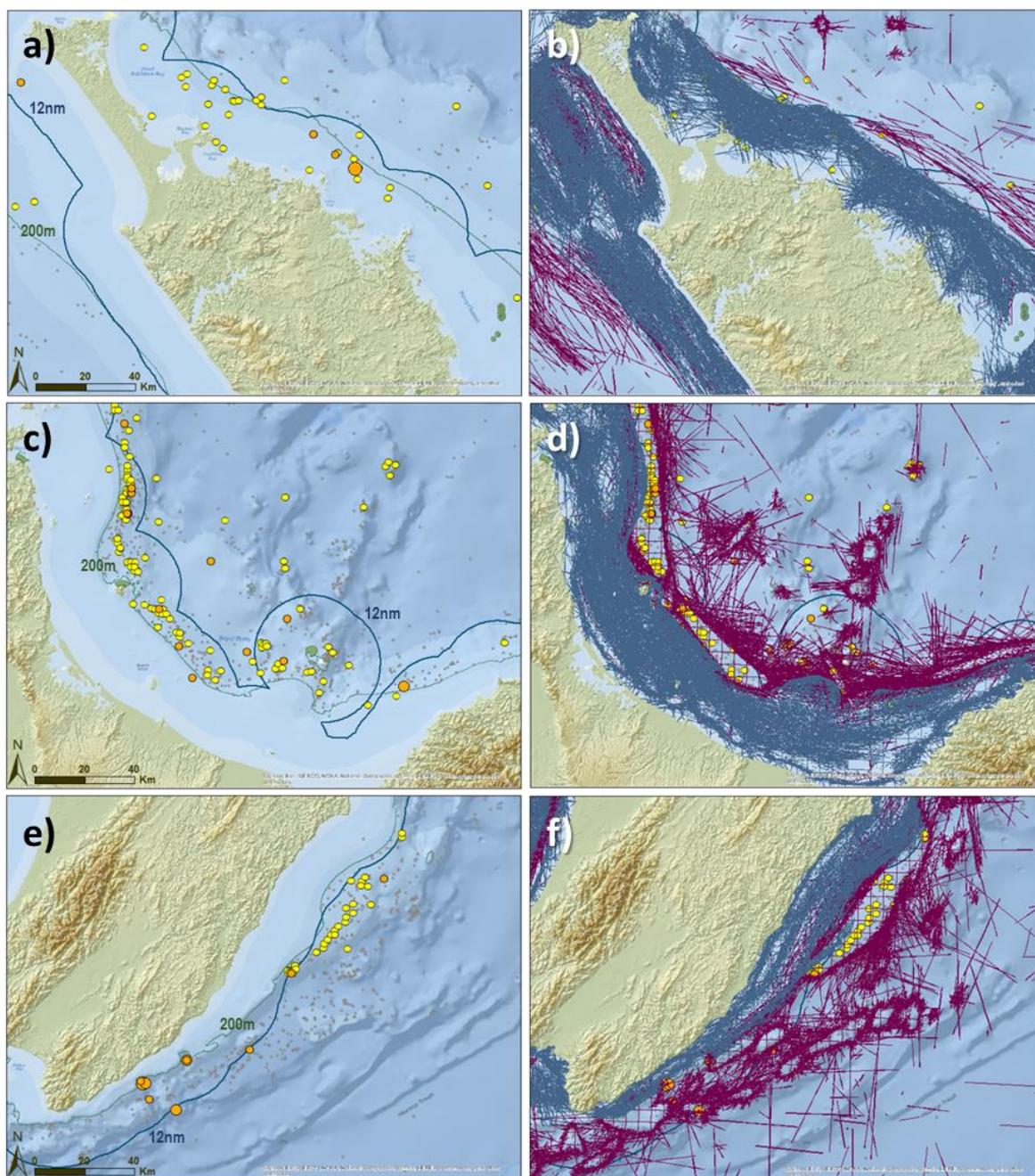


**Figure 3-64: Distribution of sea pens within New Zealand waters, from VME data (>200m water depth).** a) presence of sea pen (VME-data only, based on specimen collections), b) predicted distribution of sea pens based on VME data. Red, orange and yellow colours depict areas of high, medium and low probability of occurrence, blue= likely absences (image recreated from GIS layers from Anderson et al. 2014), with observed and predicted layers cropped to New Zealand’s EEZ (details of modelling provided in Anderson et al. 2014).

## Distribution and abundance of **Seapens** (all data)



**Figure 3-65: Distribution and abundance of sea pens within New Zealand waters (all available data).** Total abundance (orange bubble plots) of all sea pens from OBIS-NZ and NIWA's Specify data, and their presence (yellow circles) from all available datasets (OBIS-NZ, NIWA-Inverts and VME datasets). Abundance = raw/unstandardized counts and are used here simply to determine where sea pen fields (rather than isolated individuals) may occur.



**Figure 3-66: Distribution and abundance of sea pens relative to benthic fishing activity (fishing effort) for three coastal regions in New Zealand.** a-b) Northern New Zealand, c-d) Bay of Plenty, e-f) south Wairapa. Left images: Colour circles depict total abundance (orange) and their presence (yellow) of all sea pens (as per Figure 3-65); right images: show fishing effort from the coastal trawl fishery (data from 2008 to 2016 in water depth of 0-250 m) – depicted by grey-blue lines, and the deep-water trawl fishery (data from 1990-2016 mostly in water depths >200 m-1600 m) - depicted by burgundy lines (as per legend in Figure 3-34). Green line = 200 m depth contour, thick blue line = 12 nm.

### 3.13.6 Stressors and threats and Condition

- Bottom trawling is the main threat to this group. Although their flexible stalk provides some resilience to the passage of ground gear, the whole colony may be uprooted from the soft muds where they typically live. It is possible that before the advent of widespread bottom trawling sea pens were formerly much more common on the continental shelf at depths between 50-200 m. The distribution of bottom trawling on the shelf and slope and the present distribution of sea pens (Figure 3-66) strongly suggests that sea pens are largely absent from areas intensely fished and potentially are indicators for bottom trawling occurrence and recovery.
- Seabed mining also poses a highly localised threat.
- Increased sea temperature and/or change in current strength due to global climate change.

**Table 3-29: Overall condition status of Sea pen fields within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Unknown <sup>1</sup>	Unknown <sup>1</sup>	Unknown <sup>1</sup>	Stable-Declining <sup>2</sup>	Poor <sup>1</sup>

<sup>1</sup> There is little direct information available to assess the overall condition status of sea pens in New Zealand. Most collection records are based on one or a few specimens, with little to no information on spatial extents, densities or the health of this biogenic habitat.

<sup>2</sup> Expected to be very stable where benthic fishing activities are absent, but likely to decline or disappear from areas where benthic fishing activities are ongoing.

#### Overall condition status within NZ

There is little direct information available to assess the overall condition status of sea pens in New Zealand. Sea pens have a wide distribution with many species occurring at depths infrequently trawled. It is possible that before the advent of widespread bottom trawling sea pens were formerly much more common on the continental shelf at depths between 50-200 m. The distribution of bottom trawling on the shelf and slope and the present distribution of sea pens strongly suggests that sea pens are largely absent from areas intensely fished and potentially are indicators for bottom trawling occurrence and recovery.

### 3.13.7 Knowledge gaps

- The distribution of most species of sea pens in New Zealand is poorly known, a consequence of insufficient exploration of slope and abyssal seafloors where most species occur.
- The association of fish and invertebrates with sea pens in New Zealand waters is unknown.
- The negative association between sea pens and bottom trawling requires further investigation.

**Table 3-30: Gap analysis summary for Sea pen and whip fields.**

Type	Description
<b>Distribution &amp; function</b>	Distribution and function of sea pen fields is poorly known. Although sea pens are widely distributed within New Zealand waters (albeit rarely sampled especially across the continental shelf), fields have rarely been described or documented.
<b>Biological &amp; taxonomic</b>	Little is known about the biology of these species, and while 31 species are known from New Zealand waters, 19 remain undescribed.
<b>Management &amp; conservation</b>	Unlike hard corals, sea pens are not protected under the wildlife Act. Some protection is provided to sea pens within some Fiordland Marine Reserves (e.g. Te Awaatu Channel and The Long Sound Marine Reserve, Te Tapuwae o Hua, in Preservation Inlet), and offshore and in the deep-sea within Seamount Closures and BPAs. However, the known distribution of sea pens lies mostly outside these protection zones (see distribution maps above). Sea pen fields are therefore not well represented within protection zones. Little is known about their resilience or recovery following benthic fishing impacts, but their absence from heavily fished areas suggests they may be good indicators of benthic disturbance/recovery.

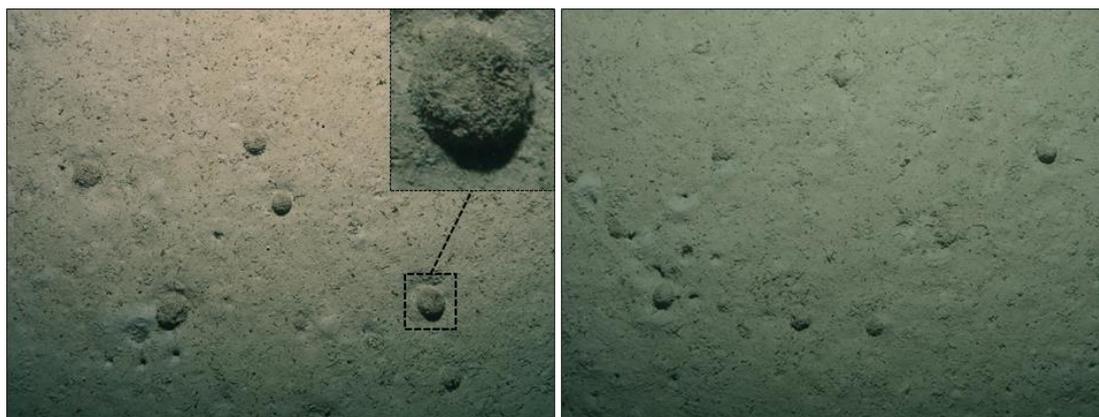
## 3.14 Xenophyophore beds

### 3.14.1 Habitat description and definition

Xenophyophores are very large, single celled protozoans belonging to the Foraminifera (suborder Astrorhizina) and the Xenophyophorea. Individual organisms form roughly spherical mineral tests ca. 5-20 cm in diameter - made up of mineral grains, sponge spicule fragments and organic debris, and are sparsely distributed across muddy sediment substrata in depths deeper than ca. 500 m, where they are conspicuous, often dominant faunal elements of the deep-sea benthos. Where abundant, they provide significant spatial complexity at the scale of tests (cms) and patches (kms) (Levin and Gooday 1992).

Xenophyophores are associated with higher infaunal densities. Xenophyophores are particularly abundant below areas of high surface productivity and are, themselves, fast growing. They feed on fine particles, such as bacteria, from the seabed or the water column. Most of any xenophyophore is dead matter - living plasma makes up less than 5% of the clump volume. They may be easily mistaken for broken and decayed parts of other animals or for inorganic concretions.

**Definition:** Xenophyophore Beds are defined by one or more individuals per m<sup>2</sup> using any sampling method (MacDiarmid et al. 2013).



**Figure 3-67: Xenophyophores on the eastern flank of Chatham Rise at ca. 600 m depth.** Image is from NIWA's DTIS towed underwater camera (survey TAN1701; image number 143-039). Image width is 1.9 m.

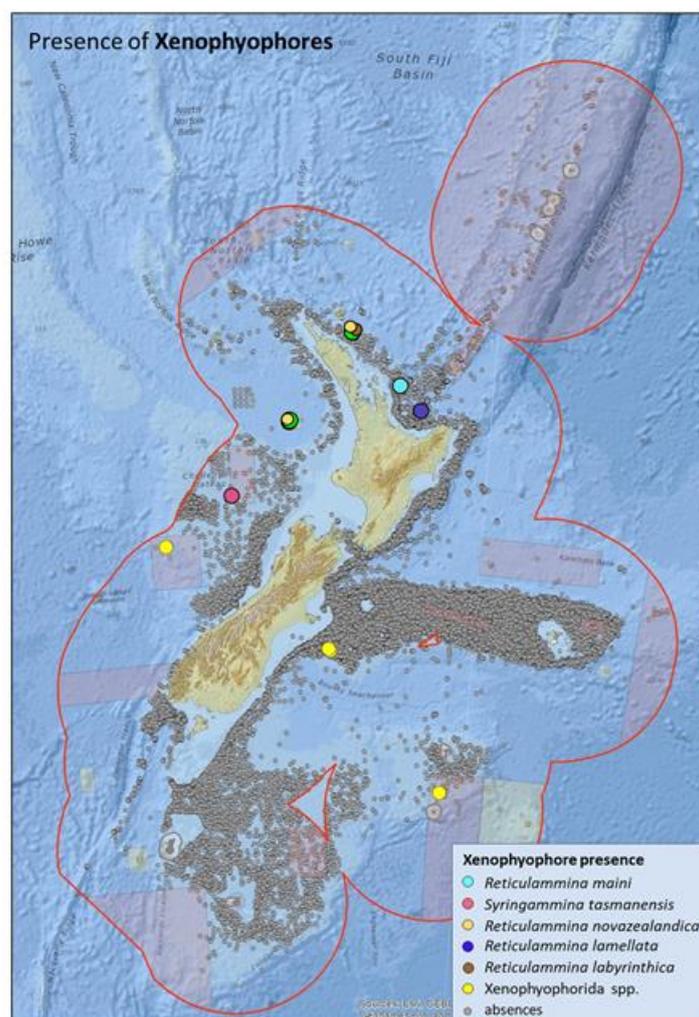
### 3.14.2 Provision of ecosystem service

Xenophyophores provide conspicuous structure in otherwise low-dimensional soft sediment deep-sea environments. Very little known about their ecosystem role of in New Zealand waters but a global review undertaken by Levin (1991) is relevant and worth repeating here. She found “a potentially significant role for the protozoans in structuring deep-sea metazoan assemblages. Direct interactions include provision to metazoans of (a) hard or stable substratum, (b) refuge from predators or physical disturbance, and (c) access to enhanced dietary resources. In some instances, rhizopod tests may provide a nursery function. Xenophyophore modification of flow regimes, particle flux, bottom skin friction and sediment characteristics appear likely and are believed to account for altered composition and abundance of meiofauna and macrofauna in the vicinity of rhizopod tests. Some analogous interactions are observed between metazoans and biogenic sediment structures in shallow water. However, metazoan-rhizopod associations are hypothesized to be more highly developed and complex in the deep sea than are comparable shallow-water associations, due to rhizopod abilities to enhance scarce food resources and to low rates of disturbance in much of the

deep sea. Agglutinating rhizopods appear to be a significant source of heterogeneity on the deep-sea floor and large tests often represent ‘hotspots’ of metazoan activity. As such, they are hypothesized to have contributed to the origin and maintenance of metazoan diversity in the deep sea by providing distinct microenvironments in which species can specialize.”

### 3.14.3 Data sources

- Xenophyophore specimens were only available from a few NIWA-Inverts specimen records (specifically: 20 specimens from 16 records), ranging in collection depths of 752-1760 m.



**Figure 3-68: Distribution of Xenophyophores within New Zealand waters, based on presence-only data of identified specimens in NIWA-Inverts.** Xenophyophore species included in these plots are shown in the legend.

### 3.14.4 Biogeographic distribution

Seven species have been recorded in New Zealand, three of which are endemic. It is expected that more species will be recorded. Xenophyophores have been located on the eastern, northern and western continental slopes of New Zealand and on the Chatham Rise at depths of 500-1300 m. But they are likely to be grossly under-sampled because of the difficulties in collecting whole specimens and the lack of targeted image surveys.

### 3.14.5 Stressors and threats

- Fragile test: susceptible to physical contact (rarely sampled intact using scientific trawls and dredges), so expansion of bottom-contact trawl fisheries into deeper waters of the EEZ would impact these organisms adversely.
- Sedimentation from bottom-trawling or minerals extraction is also likely to affect these organisms adversely.

### 3.14.6 Condition

- Expansion of anthropogenic extractive activities (fishing, minerals) into deeper waters will impact these habitats.

**Table 3-31: Overall condition status of Xenophyophore beds within New Zealand.**

Change in coverage	Habitat condition	Ecoservices Condition	Likely future trajectory	Evidence/confidence
Unknown <sup>1</sup>	Unknown <sup>1</sup>	Unknown <sup>1</sup>	Stable-Declining <sup>2</sup>	Poor

<sup>1</sup> There is little information available to determine where Xenophyophore beds occur, and almost no information to assess the overall condition status of Xenophyophores in New Zealand. Most collections records are based on one or a few specimens, with little to no information exists on spatial extents, densities or the health of this biogenic habitat.

<sup>2</sup> Expected to be very stable in depths >1,600 m where benthic fishing activities are absent, but likely to decline or disappear from areas where benthic fishing activities are ongoing.

#### Overall condition status within NZ

Potential impacts from expansion of trawl fisheries into deeper water, and potential development of seabed mining/mineral extraction.

### 3.14.7 Knowledge gaps

- Very little is known about this habitat, or how common it is. Deep sea surveys rarely collect Xenophyophore specimens, while underwater video footage has rarely quantified them.

**Table 3-32: Gap analysis summary for Xenophyophore beds.**

Type	Description
<b>Distribution &amp; function</b>	Distribution and function of Xenophyophore beds is poorly known in New Zealand waters.
<b>Biological &amp; taxonomic</b>	Seven species have been recorded from within New Zealand waters, but more species expected with further exploration. Little is known about the biology of these species.
<b>Management &amp; conservation</b>	Xenophyophore beds are not currently protected, and their resilience to human activities or climate change is not known.

## 4 Discussion

Biogenic habitats are living homes for diverse marine fauna. They provide living three-dimensional structure that provides shelter, protection and resources (i.e. homes and food) for diverse communities of marine plants and animals. These structural habitats can often occur over extensive areas of the seafloor, and support hotspots of marine biodiversity (MacDiarmid et al. 2013; Morrison et al. 2014a; Thrush et al. 2001). These extensive living habitats also provide important, and often essential roles in the marine environment, by stabilising coastal sediments, filtering water, recycling nutrients, mitigating coastal erosion and inundation, and through the provision of ecosystem productivity (reviews in: MacDiarmid et al. 2013; Morrison et al. 2014a; Jones et al. 2016, 2018). They also provide refuge for crucial life stages (nurseries and spawning grounds) of many commercial, recreational and taonga species (e.g. snapper, blue cod, tarakihi) and as such bestow important economic and social values to human society (Morrison et al. 2014a; Thrush et al. 2001).

While there is a large amount of literature, both nationally and internationally, identifying the importance of biogenic habitats, this review has identified that there are very few national inventories for New Zealand's biogenic habitats. The best data available exist for the two coastal fringe species: seagrass meadows and mangrove forests. However, while inventories for these two species are compiled from the best available data, they do not yet represent a full or systematic survey of New Zealand coastlines (e.g. some key estuaries are missing known data). Kelp forests on shallow subtidal reefs are also relatively well documented in the published literature (e.g. Shears and Babcock 2007), however there is currently no national data inventory on the abundance or extent of kelp forest habitats around New Zealand. In contrast, most other biogenic habitats had relatively poor coverage of samples at the national scale that were reliant on Museums and Collections databases of presence-only data, with large data gaps.

Most data available for this review was sourced from Museum and Collections databases (>92%). These contain presence-only data (no absences). These types of data have some inherent bias. For example, Collections records for macroalgal used in this review were mostly from intertidal areas (~>80% of the data available), with much fewer records from subtidal areas that comprise more area<sup>26</sup>. In addition, well known-species such as *Ecklonia radiata* (an easily identifiable and commonly occurring kelp species), were missing from collections made at many locations where they are known to occur – reflecting a bias in Collections databases towards rare or unusual species. Similarly, sea pens and corals have deep-sea distributions, however the data presented from VME studies represents a variety of targeted research studies from specific offshore and deep-sea locations, many of which are targeting unique and vulnerable marine ecosystems (e.g. seamounts, canyons, vents and methane seeps), or are part of baseline surveys in areas where oil, gas and minerals are also present (e.g. extensive sampling surveys in the South Taranaki Bight, Chatham Rise and Kermadec Trench). While these data provide an extremely rich source of presence, abundance and absence data for many species, they are inherently biased towards these ecosystems. These gaps and biases in national data make it difficult to draw firm conclusions on the state of these biogenic habitats at a national level, or the likely ecological impacts of threats and stressors. For example, it is unclear whether the absence of sea pens across the continental shelf is a true ecological absence, an artefact of low sampling effort across much of New Zealand's continental shelf, or an indication of high fishing by-catch of this vulnerable group.

Existing knowledge of biogenic habitats is also biased by physical habitat type. Most research undertaken on biogenic habitats within New Zealand, has to date, been undertaken on rocky outcrops either nearshore (e.g. kelp forests) or on outcrops associated with raised or complex

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<sup>26</sup> Depth was determined from underlying bathymetry grids using specimens GPS positions, as depth records were not provided in the seaweeds datasets.

bathymetric features (e.g. seamounts, canyons, vents and seeps), while comparatively little research has been undertaken on habitat-forming species that grow over or on soft-sediments.

Some habitat-forming species are poorly represented or mostly absent in Collections databases. This was most apparent for those species that do not preserve well (e.g. most tubeworm species); are traditionally not retained during surveys (e.g. rhodoliths); or are rarely collected in benthic samples (e.g. Xenophyophores). Many of these habitat-forming species have been described as forming extensive habitats in some areas, but remain poorly represented and are often undescribed, with little known about their national (or regional) distribution, abundance and condition.

While presence-only data over national-scales (i.e. occurrence of collected specimens) does provide value information on biogeographic distributions and the range extents of species (e.g. Anderson et al. 2014; Wood et al. 2012), it is not a quantitative measure of biogenic habitat occurrence (i.e. one tree may not depict a forest). Data for this review were also sourced from quantitative research surveys (recorded as numbers of individuals, weight, or volume of a species collected at a site) to depict areas where aggregated individuals occur. OBIS-NZ contains the highest number of records, including counts, weights or volumes (depending on the type of species) for some sites, however no information is available to standardise these values by effort. Presently, there is no national quantitative effort-adjusted database to house project specific data. OBIS-NZ has the potential to include and standardise by effort, but does not do so presently. A very large number of marine benthic studies have been undertaken within New Zealand waters, but the majority of these have not been collated. These datasets if combined would provide an extremely rich source of information for both national and regional scale management and conservation across a very wide range of topics (including biogenic habitats, as well as numerous other objectives and national data modelling exercises - e.g. national risk assessments, habitat suitability and ecosystem modelling, etc). This is a critical data gap, that could with a little effort be filled. Collating these datasets would not be without its difficulties, but would we believe provide a rich source of information, and would establish a database framework for determining data gaps, housing future studies, and importantly, if undertaken, would be considerably cheaper than collecting a single large-scale field survey.

Temporal studies have been undertaken on a range of coastal communities, however, most estimate spatial and temporal densities using 'within-habitat' survey methods (providing grand mean [summary statistic] comparisons between locations and habitats), and occur only for a limited number of locations and biogenic habitats, such as macroalgal communities (including kelp forests), sponge communities (including a few sponge gardens), seagrasses and mangroves. While this is an excellent method to capture changes in species densities in space and time, it does not capture large-scale changes in spatial extent of habitat-forming species. For example, biogenic habitats are likely to expand or contract along the edges of beds (thickets, meadows, fields etc.), which rarely get captured in traditional sampling methods. In contrast, only a very limited number of surveys have mapped and/or spatially-explicitly monitored biogenic habitats within New Zealand (e.g. several discrete marine reserves - DOC unpublished maps; and some seagrass and mangrove habitats – DOC's SeaSketch project). Limited temporal surveys have also been undertaken on several seamounts to examine the effect on fishing intensity on coral resilience and recovery. Apart from these few studies, almost no temporal data exists to determine spatial and temporal change in the extent and health of other biogenic habitats. Due to this paucity of data, this report is unable to produce a comprehensive direct-assessment on the health of these habitats or the relative change in condition attributes. However, information on threats and stressors provides valuable insight into the likely impacts and trajectories of these habitats.

Although specific threats and stressors varied for each biogenic habitat, the overall importance of threats and stressors appears to vary with distance offshore. Biogenic habitats growing along the coast (e.g. seagrass meadows, mangrove forests and kelp forests) especially those close to urban areas, face a range of threats and stresses associated with increased sedimentation, benthic

disturbance through coastal development (infrastructure) and coastal maintenance (e.g. channel dredging), along with declines in water quality (e.g. increased suspended sediments, nutrification and pollution) associated with these activities. Although some biogenic habitats occur within Marine reserves, and there are afforded protection against direct physical disturbance (e.g. benthic fishing activities), they do safeguard them against key threats from land-based issues such as sediment and nutrient run-off. The combination and possible synergistic effect of multiple stressors may also be important, but has not been examined.

A gradient response offshore is likely, whereby biogenic habitats growing further offshore on the mid-outer continental shelf and upper continental slope (e.g. bryozoan thickets, sponge gardens, tubeworm fields and beds of large shellfish) are likely to be impacted less by coastal development, and more by benthic fishing disturbances, which is highest on the mid-shelf and upper continental slopes around New Zealand (Tuck et al. 2017). Although evidence of increased sedimentation out across the shelf is becoming evident in some locations (Morrison et al. 2014a). Historical accounts of fishing activity (e.g. bycatch, fishing-footprint and historical fisher-interviews), indicate that biogenic habitats on the mid to outer shelf are either the target of high fishing activity (e.g. bryozoan thickets for dredge oysters, wire-weed fields for tarakihi), or have been moderately to heavily fished on or around the edges of these habitats (e.g. bryozoan thickets from Separation Point, and Otago shelf that support commercial fish species) due to their association with commercial fish species. For those biogenic habitats that are susceptible to breakage (e.g. Horse mussel beds, bryozoan thickets) loss and damage of habitat is likely to have occurred due to on-going fishing activities (e.g. Batson and Probert 2000; Morrison et al. 2014a). However, little baseline or monitoring data exists to validate these impacts. In this desk-top study, fishing activities overlaid on observed and LEK-depicted habitat distributions, identify intensive and often targeted fishing activity on or around these habitats. This demonstrates that biogenic habitats on New Zealand's mid to outer shelf are highly vulnerable to the effects of benthic fishing activity, with extensive areas already indicative of damage and loss (e.g. broken bryozoan fields off Patea Shoals, Otago shelf, and Foveaux Strait; extensive breakage and loss of horse mussel beds on outer banks of the Marlborough Sounds; and absence of wireweed fields inshore of the Haystacks). Some biogenic habitats may also co-exist (and possibly critically rely) on early-colonising species, such as tubeworm fields, horse mussels or the robust dog cockle (and their relict shells). The removal or fishing-down of these successional habitats (Batson and Probert 2000; Hewitt et al. 2005; Handley et al. 2014; Morrison et al. 2014a; Beaumont et al. 2015), may therefore have cascading effects. However, little is known about the ecology or successional dynamics in these ecosystems.

In deeper offshore regions of New Zealand, slow growing stony and branching corals that comprise coral thickets and fields are highly vulnerable to physical damage from benthic fishing gear (Miller et al 2012; Clark et al. 2018). Coral thickets are particularly vulnerable on raised bathymetric features in water depths < 1600 m where bottom trawl fishing occurs, such as seamounts that have historically been targeted for commercial species, such as orange roughy (Clark et al. 2018). Significant loss of coral habitat and associated biodiversity has been recorded on heavily fished seamounts compared to unfished ones (Clark et al. 2018). Deep-water corals are very slow growing and very long-lived (Tracey et al. 2007; 2018). Impacted coral communities on heavily fished seamounts show no evidence of recovery, even after nearly two-decades of protection (e.g. Morgue seamount, closed to fishing in 2001). These studies indicate that benthic fishing activities can have long-lasting impacts on vulnerable biogenic habitats. At depths >1600 m, biogenic habitats - such as some stony corals, sponges, xenophyophores, deep-water tubeworms and sea pens - are likely to be protected from fishing activity disturbance (by depth alone) and, in the absence of other anthropogenic impacts (e.g. deep-sea mining activities), are predicted to be stable through time.

Some biogenic habitats once damaged and lost may not recover, but rather may shift to an alternate ecosystem state (Airoldi and Beck 2007). Large scale historical losses of biogenic habitats have been

documented in New Zealand's history. For example, the loss of ~500 km<sup>2</sup> of green-lipped mussel beds within the Firth of Thames has coincided with large declines in water quality, increased sedimentation and resuspension of sediments (described in Morrison et al. 2014a). Large-scale losses of green-lipped mussels within Kenepuru Sounds and horse mussel beds from across the outer Marlborough Sounds are also described by long-time fishers and residents (Handley 2015 and NIWA unpublished data), with similar declines in water quality, increased sedimentation and resuspension of sediments (Handley 2015 and NIWA unpublished data). Historic accounts of these waterways mentioned clear blue waters where one could see the seabed clearly beneath the vessel, but are now characterised as muddy, turbid and opaque, with a significant loss in aesthetic value. Significant and on-going loss of biogenic habitats is still occurring. The rapid decline in green-lipped mussel bed on the western side of Okiwa Harbour, has led to the collapse and near-complete loss of this prized Taonga bed, with an estimated loss of 107 million benthic mussels within <10 years. Coastal development and land-use practices have resulted in higher sedimentation around much of New Zealand's coastal waterways. While increased levels of sedimentation appear to be promoting mangrove expansion seaward over tidal flats, increased sedimentation levels may have strongly negative impacts on other biogenic habitats (e.g. seagrass meadows and rhodolith beds).

Due to large gaps in our knowledge, current estimates of biogenic habitats are likely to greatly under-represent the real extent and location of biogenic habitats. This is highlighted by the massive discrepancy between early estimates of national seagrass cover 44 km<sup>2</sup> (Green and Short, 2003 – based on limited availability of data) compared to 242 km<sup>2</sup> calculated following a national inventory (value provided by DOC August 2018, but still excludes some known data gaps). With the advancement of remote sensing multibeam technology more locations and larger areas of the seabed are being mapped (e.g. Oceans 20/20 Bay of Islands (Morrison et al. 2010); Kapiti Island Marine Reserve, Queen Charlotte Sounds and Tory Channel projects)). Multibeam derived habitat maps and broad-scale spatial sampling surveys are revealing critical biogenic habitats where previously no records of biogenic habitats were known (e.g. DOC and MPI 2011, NIWA unpublished data). For example, NIWA's MBIE Bottlenecks surveys have documented critical blue cod nursery grounds comprised of bryozoan thickets/sponge gardens, horse mussel beds and relict biogenic rubble fields, as well as other key biogenic habitats, such as algal meadows and tubeworm fields, in areas not previously documented. The extent of knowledge gaps on the distribution of biogenic habitat is expected to be large. This was recently highlighted by the fact that one of the key habitat forming tubeworms recorded as 'common' within the Marlborough Sounds during the 2017 Bottleneck surveys, had never been documented as a habitat-forming species before. Given most soft-sediment shelf habitats have been poorly sampled, it is likely that tubeworm fields along with a range of other biogenic habitats occur more extensively than is currently known.

Technological advancements in remote sensing is providing new avenues to map a wide range of benthic marine habitats. Remote sensing methods (e.g. multibeam bathymetry, sidescan sonar) can now be used to map biogenic habitats that have vertical structure (e.g. tubeworm mounds, stony-coral thickets, bryozoan thickets) or reflective acoustic properties (e.g. bryozoan thickets, dense bivalve beds) (e.g. Morrison et al. 2014a; Jones et al. 2018). The advent of drones, is providing a cost-effective approach to mapping shallow coastal habitats along the coastal fringe (e.g. seagrass meadows and mangrove forests) or in shallow clear water areas (e.g. kelp forests). Mapping and monitoring biogenic habitat will be an essential component to managing and conserving these ecosystem- essential habitats.

Recommendations for future research:

- 1) Compile existing quantitative data into a national database. Abundance data from sampling surveys and seafloor characterisations from underwater video surveys are currently housed in project-specific databases, that are inaccessible, compiling these would provide a valuable national-scale data source to address many data gaps.

- 2) Improved methods and approaches for species not well represented in New Zealand's Collections databases (e.g. Tubeworms, rhodoliths and Xenophyophores), with collections of these habitats prioritised in future surveys
- 3) Prioritise mapping and monitoring surveys of key biogenic habitats and areas where threats and stressors are high (e.g. fragile and productive habitats targeted by benthic fishing activities),
- 4) Future surveys to incorporate measures of biogenic habitat extent and condition,
- 5) Existing fine-scale data and maps need to be included in a national data inventory (similar to seagrasses and mangroves within the SeaSketch project) to ensure that disparate datasets are available for national examination.

## 5 Summary

Biogenic habitats provide three-dimension structure that afford shelter, protection and resources (i.e. homes and food) for a wide range of marine flora and fauna. These habitats can often occur over extensive areas of the seafloor and support higher biodiversity than adjacent habitats.

Biogenic habitats are of commercial, recreational, and aesthetic value to society, for tourism (e.g. kelp forests, Fiordland black corals); commercially and recreationally for shellfish harvesting (e.g. scallops, green-lipped mussels); and indirectly by providing crucial habitat for commercial, recreational and taonga species (e.g. snapper, blue cod, tarakihi), especially during crucial life stages (e.g. nursery and spawning grounds).

Biogenic habitats also provide a wide range of essential ecosystem services that keep the marine environment healthy. These include, stabilising coastal sediments, filtering marine waters, recycling nutrients and mitigating coastal erosion and inundation. Without these services, rapid degradation of ecosystems can occur with cascading effects and significant loss of aesthetic, commercial and recreational values.

This review identified very few national inventories for biogenic habitats. Of the 15 key biogenic habitats examined, national inventories albeit incomplete ones, were only available for 2 habitats (seagrass and mangroves), with inventories not yet representing a full or systematic survey of New Zealand coastlines (e.g. some estuaries are missing known data). An additional two habitats have well described national distributions (e.g. kelp forests and deep-water corals), while no national scale inventories are available for the remaining 11 habitats, which have very limited national descriptions based on some presence-only data with data biases, limitations and extensive gaps. Due to these large gaps in our knowledge, current estimates of biogenic habitats are likely to greatly under-represent the real extent and location of these habitats.

Three biogenic habitats were poorly represented or mostly absent in Collections databases, but have been described as forming extensive habitats in some areas. These habitats remain poorly represented and are often undescribed due to poor preservation (e.g. most tubeworm species); poor sample retention (e.g. rhodoliths); or are rarely collected in benthic samples (e.g. Xenophyophores).

Very few temporal studies exist on biogenic habitat within New Zealand. Those that have been undertaken are mostly on nearshore coastal species, such as kelp forests, seagrass meadows and mangrove forests. Monitoring studies have mostly recorded changes in densities within these habitats rather than documenting large-scale changes in spatial extents or the health and productivity of these habitats. Where mapping studies have been undertaken, large changes in spatial extent have been recorded (e.g. seagrass, mangroves, and kelp forests), reflecting both natural dynamics (e.g. within marine reserves) and changes in threats and stressors.

The large data gaps in New Zealand's spatial inventories for biogenic habitats and lack of original baseline assessments for all but a few biogenic habitats, however, makes it problematic to assess whether habitat loss has occurred (*i.e. hard to know how much you've lost if you don't know how much you had originally, or even how much we have now*). Assessments of threats and stressors provide valuable information on the likely condition and trajectory of some habitats, but these assessments rely heavily on expert opinion and qualitative descriptions for the most part, rather than quantitative published studies.

The top three threats to biogenic habitats are climate change (particularly increasing water temperatures), sedimentation (particularly for inner shelf habitats), and benthic fishing activity (particularly for inshore and mid-outer shelf habitats), but the relative importance of threats and stressors varied with distance offshore.

Coastal fringe habitats (e.g. seagrass meadows, mangrove forests and kelp forests), especially those growing close to urban areas, are stressed and threatened by increased sedimentation, declines in water quality, and benthic disturbance from coastal activities and development.

Inshore habitats (e.g. horse mussel beds, calcareous tubeworm mounds and rhodolith beds) are likely to be impacted by combinations of coastal pressures and benthic fishing activities.

Mid-outer shelf habitats (e.g. wireweed fields, bryozoan thickets, sponge gardens) are threatened less by coastal effects and more by benthic fishing disturbances, which are highest on the mid-shelf and upper continental slopes around New Zealand – often in and around these biogenic habitats (as indicated by fishing effort relative to the LEK-maps in this review).

Deep-sea coral thickets and fields exposed to fishing activities (*i.e.* depths <1600 m), especially those on seamounts targeted by fishing, have undergone substantial damage and community loss – with no evidence of recovery observed even a decade after fishing activity has been removed.

Habitats in depth beyond those fished (e.g. depths > 1600 m) where no other human activities (e.g. oil, gas and mineral exploration) occur are unimpacted and predicted to be stable.

Biogenic habitats not only offer complex structure that support elevated levels of biodiversity, many of the habitats reviewed in this report also have particular significance for fisheries management, as adult, nursery or spawning habitats (e.g. wireweed fields, bryozoan thickets, horse mussel beds). Consequently, protection of these habitats may be vital for not only the habitats themselves, but also for sustaining or even enhancing fishery numbers, but this would require new approaches to fishing these habitats.

This review identified significant data gaps for most key biogenic habitats, and the absence of national inventories for 13 of the 15 biogenic habitats, with the two national inventories (for seagrass and mangroves) having recognised gaps.

Recommendations to fill these data gaps include i) compiling existing quantitative data from single project-specific surveys into a national dataset; ii) improved methods and approaches for species not well represented in New Zealand's Collections databases (e.g. tubeworms, rhodoliths and Xenophyophores), with collections of these habitats prioritised in future surveys; iii) prioritise mapping and monitoring surveys of key biogenic habitats and areas where threats and stressors are high (e.g. fragile and productive habitats targeted by benthic fishing activities), iv) future surveys to incorporate measures of biogenic habitat condition; and v) we recommend that existing fine-scale maps be included in a national data inventory (such as DOC's SeaSketch project) to ensure that disparate datasets are available for national examination.

## 6 Acknowledgements

We acknowledge the contributions of data and advice from many sources including: the National Institute of Water and Atmospheric Research (NIWA) for Collections data, spatial data layers, predicted species distributions, physical and biological data layers; the Ministry of Fisheries for the provision and permission to use benthic fishing effort and fishery research data; the Department of Conservation for spatial data layers; Land Information New Zealand (LINZ) for national topographic and land-classification databases; NIWA LEK researchers and the commercial fishers they interviewed for spatial data layers on biogenic shelf habitats; with specific thanks to Bruce Marshall, Rick Webber and Carol Stevenson (Te Papa Museum); Severine Hannam and Tom Trnski (Auckland Museum); Emma Hill (DOC Wellington); Steve Ulrich (Marlborough District Council); Chris Battershill (Waikato University); Jeffrey Robinson (Otago University); Emma Jones, James Williams, Ian Tuck and Michelle Kelly (NIWA Auckland); Carolyn Lundquist (NIWA Hamilton); David Bowden, Suze Baird and Kate Neill (NIWA Wellington). We also thank workshop attendees for their expert input into this programme and assistance sourcing and providing data. We thank Ashley Rowden and Reyn Naylor (NIWA Wellington) who both provided comments on earlier sections of this report, and Ian Tuck for reviewing this report.

## 7 Glossary of abbreviations and terms

Biodiversity	The variability among living organisms from all sources; this includes diversity within species, between species and of ecosystems.
Biogenic	<i>“produced or brought about by living organism”</i> The Oxford English Dictionary (2018).
Biogenic Habitat	<i>“Habitats created or brought about by living organisms (i.e. Trees, coral reefs, kelp forests, etc.) That support other animals, plants and organisms”.</i> These may be emergent above ground structures, or those created beneath the surface. Only the former is examined in this review.
BOMECE	Benthic Optimised Marine Environmental classification. Described in detail in the methods of this review.
BPA	Benthic protection areas (BPAs) are areas of seabed in New Zealand where some fishing activity is illegal
Danish Seine	A fishing method in which a net is operated by surrounding the fish and being drawn over the seabed toward one or more vessels.
DOC	Department of Conservation (New Zealand)
Dredging	Towing a device over the seabed primarily for the collection of shellfish.
Ecosystem	An interacting system of living and non-living parts.
Emergent (habitat/structure)	Above ground structure that is higher than neighbouring habitats.
Estuary	A partially enclosed coastal body of water that is either permanently or periodically open to the sea in which the aquatic ecosystem is affected by the physical and chemical characteristics of both runoff from the land and inflow from the sea.
Exclusive Economic Zone (EEZ):	The area of ocean from the outside edge of the territorial sea (12 nautical miles off the coast of New Zealand) out to 200 nautical miles from the coast.

GIS	Geographic Information System. Computer software for the handling of spatial data, and advanced data manipulations and analysis
Habitat	<i>“the natural home or environment of an animal, plant, or other organism”</i> The Oxford English Dictionary (2018)
Intertidal	The region between the high tide mark and the low tide mark.
Iwi	Māori group descended from a common ancestor and associated with a distinct territory
LEK	Local Ecological Knowledge; ‘anecdotal’ observations and knowledge of local individuals and communities that sits outside formal science
Mātauranga	The knowledge, comprehension, or understanding of everything visible and invisible existing in the universe’ synonymous with wisdom.
MfE	Ministry for the Environment (New Zealand)
Monospecific	Consisting of only one species.
MPA	Marine Protected Area, an area of the marine environment protected from some forms of human activity. 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 (DOC and MPI 2011).
MPI	Ministry for Primary Industry (New Zealand)
Obligate	By necessity.
Polygon	An area fully encompassed by a series of connected lines. In this review depicting (or predicting) an area where a habitat occurs within.
Sedentary (of animals)	Are those fixed to one spot (e.g. Barnacle, sponges, hydroids, and coral), including animals that live in tubes (e.g. Polychaete worms)
Sessile	Fixed in one position, immobile.
Substratum (seafloor)	A physical substance or layer that underlies something (e.g. Rocky substratum).
Subtidal	The benthic ocean environment below low tide that is always covered by water.
Taonga	Tangible and intangible treasures of Māori
Territorial sea	The area of sea from the coastline of New Zealand out to 12 nautical miles.

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