Mapping the ecological and biophysical character of seabed habitats of the Paraninihi Marine Reserve, Taranaki, New Zealand.

by

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Abstract

Habitat mapping is important for determining the spatial distribution of biological and physical components of the seabed. Conventional surveying methods, such as diver or drop camera surveys are time consuming and constrained by factors such as depth, water clarity, currents, and weather conditions, which means that is not practical to survey large tracks of sea floor using these methods. Consequently, a substantial proportion of the world's seafloor remains undescribed. In recent years, multibeam sonar (MBES) has revolutionised the way we image, map and understand the marine environment. However, the quantitative characterisation of MBES backscatter imagery for seafloor and habitat mapping remains a developing field. This thesis examines the utility of MBES backscatter imagery as a tool for the characterisation and mapping of biogenic habitats. Pariokariwa Reef, located within Paraninihi Marine Reserve, Northern Taranaki, was chosen as the location for this study because it supports a range of distinct habitats (including sponge gardens of unusually high biomass and diversity) against which to assess our ability to use MBES backscatter imagery to recognise biogenic seabed habitats.

This thesis describes the collection of spatially coincident MBES data (bathymetric and backscatter) within Paraninihi Marine Reserve and outlines techniques used to process and transform this data. Acoustic data was used to generate a predictive habitat map that was linked to the habitat classes derived from observations made on Pariokariwa Reef, over fine spatial scales. Results from the survey, showed MBES successfully produces high resolution bathymetric imagery that revealed the reefs unique morphology. The resolution of the backscatter imagery was fine enough to identify four dominant seabed classes on the reef, but not fine enough to accurately map heterogeneous habitat over small spatial scales. Results from the study suggest that image-based backscatter classification shows promise for the interpretation of MBES backscatter data, for the production of habitat maps. However, this study revealed a new challenge associated with habitat mapping, which is acoustic surveying over complex reef topography. Hence for complex or heterogeneous topographies, MBES data must be generated at a finer resolution in order to acquire the same level of detail that is

available in predictive habitat models created from acoustic surveys conducted over flat, homogenous terrain.

I also examined the distribution of biological assemblages over a smaller spatial scale, to that examined using MBES. The purpose of this exercise was to test whether the reefs complex terrain influences biological community composition and distribution. Visual imagery obtained from drop camera and scuba diver surveys, revealed heterogeneous habitat over small spatial scales, across the morphology of the reef. Community composition and distribution significantly changed with reef aspect, with percentage sponge and biogenic reef appearing to be significantly higher over the vertical face of the reef, and within reef overhangs. Percentage silt was highest below the reef, and appears to be a dominant environmental factor influencing the composition and distribution of sponge communities on the Pariokariwa Reef. The findings from this study suggest multibeam sonar can be used as a tool to map biogenic seabed habitat. However, there are challenges associated with acoustic seabed classification across complex terrain, and therefore requires in situ surveys, conducted over smaller spatial scales.

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Table of Contents

List of Figures

List of Tables

Chapter 1: *General Introduction*

1.1 Benthic Habitat Mapping

Habitat mapping over a range of spatial scales is an important tool for identifying the spatial distribution of biological and physical habitats, which includes bathymetry, sediment type, habitat distribution and species diversity within the region. A greater understanding of the distribution, extent and status of benthic marine habitats is required in order to facilitate the protection of threatened and rare habitats, to assess the general state of the environment (McGonigle *et al*., 2009; Micallef *et al*., 2012) and to map the distribution of resources. Historically, seafloor classification has been based on diver observations and grab-samples collected from the seabed. However, these survey techniques are time consuming, expensive, weather limited, potentially dangerous and can only be implemented at discrete locations on the seabed, and over small spatial scales (Schimel, 2011). To accurately map large areas of seabed alternative methods are needed.

Advancements in subtidal habitat mapping began in the 1940's when high frequency echosounders were developed to indirectly survey the seafloor (Kenny, 2003). Developments in acoustic surveying technology have accelerated over the last 30 years, with demands by humanity to discover and manage resources, and explore unknown territory within our oceans. Acoustic surveying technology such as multibeam sonar and sidescan sonar surveys can be useful in mapping large areas of the seabed and, if ground truthed, can effectively identify habitats that act as 'surrogates' for ecological character and attendant species diversity. Sonar technology, geographical positioning capabilities and computer power have therefore revolutionised the way we image, map and explore the seafloor (Mayer, 2006).

1.2 What is Biogenic habitat?

Habitats are commonly characterized by their discrete physical, chemical and biological attributes, and the biological community of specie assemblages residing within; thus making the area distinctly different from surrounding areas. Animals and plants tend to distribute themselves along environmental gradients (e.g. sediment type), which means community clusters can be defined as distinct habitats (Brown & Blondel, 2009). Community distribution and diversity is often influenced by the physical characteristics of the seabed, such as topographic complexity and substrate type. Thus, benthic habitat maps inform us about the range of important ecological processes likely to exist within the area, and help describe patterns of biodiversity within the marine environment (Brown & Blondel, 2009; Brown *et al.*, 2011; Lucieer *et al.*, 2013).

Habitats within spatial proximity to each other are often connected through species distribution and larval connectivity (Morrison *et al.*, 2009). In New Zealand ecosystems, we only have a rudimentary understanding of such connectivity between spatially discrete habitats. Habitat mapping therefore plays an important role in filling in some of these geographical knowledge gaps, by identifying areas of the seabed that are potentially connected to one another, due to their locality, resemblance in topography, substratum or biology (Morrison et al., 2009).

Biogenic habitats are often three-dimensional structures that can either be a living organism substrate (e.g. coral reefs); or non-living structures such as dissected rock platforms or; substrates generated by a living organism (*e.g.* tubeworm reef structures) (Degraer *et al.*, 2008; Morrison *et al.*, 2014). Acoustic and *in situ* data can be collected for biogenic habitats, and layered as environmental data over the underlying bathymetry, to accurately represent species/habitat distributions (Brooke *et al.*, 2008; Brown et al., 2011; Colquhoun & Heyward, 2007). Biogenic habitats have a diverse range of functions, which include protection from erosion, elevated benthic-pelagic coupling and nutrient cycling, supply of shelter and food for various organisms, and elevation in biodiversity (Morrison *et al.*, 2014). Mapping the distribution of biogenic habitats accurately portrays the distribution of other biological assemblages as well, such as fish populations (Morrison *et al.*, 2014).

1.3 *In situ* and *ex situ* surveying techniques

Habitat mapping technologies can be divided into two groups: *in situ* and *ex situ*. The first group of technologies "*in situ*", includes tools and methods that involve collecting a sample (seabed or marine organism) and analysing it later in the lab;

or optically classifying the seabed or organism from a close range (Schimel, 2011). For example, dive surveying techniques such as underwater visual censuses/ surveys are regularly used over localised regions of the reef to describe the benthic communities, characterise biological assemblages at a species level, and identify boundaries between habitats (Innangi, 2015). This *in situ* technique is non-destructive and requires experienced divers to identify and count fish densities in a defined proximity to the transect line they are swimming along, and sometimes includes the need to estimate fish lengths for demographic purposes. These sampling methods can be implemented at discrete locations (point sampling or stratified random sampling), or along transect lines, but are limited to characterizing the seabed at a small, local scale.

The other sampling method group involves indirect sampling of the seabed and making visual observations based on a bathymetry map created by acoustic data. This second group of methods are classed as "*ex situ*" technologies, and are often labelled as "seabed-mapping techniques"(Schimel, 2011). The following tools are included under this second category: acoustic remote-sensing systems, satellite and airborne remote-sensing systems and modelling tools based on ocean and atmosphere physics (models of bed stress, temperature and salinity etc.).

1.4 Acoustic Seabed-Mapping Systems

Acoustic remote mapping techniques, such as multibeam echosounder (MBES), can be used to map relatively large areas of the seabed. Acoustic waves emitted by multibeam echosounder, can transmit information long distances through the water. Backscatter from the seafloor resembles acoustic "images" of the seabed, at excellent resolution, and is used to detect and locate obstacles and targets, and measures habitat characteristics (seafloor topography, living organisms and hydrological structures) (Schimel, 2011). The backscatter signal is produced by the acoustic signal reflecting off the seafloor or topographical structures. The degree of scattering and the strength of the signal are directed back at the survey vessel. Reflectivity depends on the substrate and the topographic layout of the seabed, including, but not limited to, its subsurface layering, surficial roughness and impedance (Schimel, 2011). The main limitation of this sampling method is related to the complexity and variety of natural seabed environments and the equipment's inability to clearly classify distinct seabed habitats without incorporating ground truth data into the analysis (Schimel, 2011).

1.4.1 Multibeam Echosounder

Multibeam echosounders are acoustic remote-sensing systems that transmit pulses and receive bathymetric (topography) data with high resolution, accuracy and near-complete coverage of the seabed; as well as backscatter data (acoustic strength), from the water column and seafloor (Huang *et al.*, 2011; Schimel, 2011). These complex systems were designed in the 1970's, for the purpose of recovering multiple simultaneous depth measurements across the swathe, and have revolutionised benthic habitat mapping and exploration of the seafloor.

Multibeam sonar has the ability to map areas of the seabed from water depths ranging from a few metres, to thousands of meters; depending on the strength of the signal frequency being emitted from the device. Systems have been developed to record data from a wider range of incident angles, typically from 0 degrees at nadir, to more than 60 degrees for the outer beams. This means that MBES images show a strong along-track banding, which is not seen in sidescan sonar (SSS) images (Schimel, 2011). Multibeam sonar is swathe forming and produces a greater incidence angle compared to SSS because the transducer is positioned on the water's surface rather than being towed close to the seabed. This means MBES receives an insonified footprint (coverage) of the seafloor, that is wider along-track, compared to across-track (Le Bas & Huvenne, 2009). The disadvantage of MBES design is that hull mounted systems, cover a shorter across-track range of the seafloor; and thus require 100% overlap between tracks to accomplish the same level of backscatter imagery resolution as SSS. Without 100% overlap, valuable data is lost as the result of acoustic attenuation throughout the water column, as the signal spreads and is absorbed by particles, thus producing lower resolution imagery if swathe tracks do not overlap (Le Bas & Huvenne, 2009). Nevertheless, MBES is often chosen over sidescan sonar because of its ability to provide surveyors with both bathymetry data (water depth), at a greater coverage and resolution to single beam echosounders (SBES), and backscatter data at a similar resolution to SSS (Le Bas & Huvenne, 2009).

Multibeam echosounders are also preferred over optical and radar remote mapping technologies because MBES can be used in deep, murky waters, whereas other technologies may only be suitable for mapping shallow, clear coastal environments (Huang *et al.*, 2013). Thus MBES sounder technology is the most cost-effective, time efficient method for mapping large areas of the seabed (Huang *et al.*, 2013). Multibeam technology provides high-resolution and near-coverage images of the bathymetry and is commonly used to collect information on the geomorphological characteristics of the seafloor (Brown *et al.*, 2011). Backscatter data is produced by transmitted pulses refracting off the seabed, which results in data, derived from one hundred different beam angles (Huang *et al.*, 2013). Angular response is related to seabed type, which determines the strength of the backscatter, and is a useful tool for identifying various features on the seabed (Schimel, 2011).

1.4.2 *In situ* and *ex situ* data integration

Acoustic backscatter data, produced by MBES, identifies individual habitats by creating a unique acoustic signature for each seabed type (e.g. mud, sand and gravel). Multibeam surveys are a quick process that allows the researcher to identify the substrates physical characteristics over large spatial scales, however, acoustic surveying data *per se* is not usually considered as a predictor variable in biological studies (Lucieer *et al.*, 2013). Previous studies using MBES to map the seabed, have also incorporated 'ground truthing' data into the dataset, to investigate the distribution of benthic biological (biogenic) habitats, and clearly identify rock formations and sediment types (Brown & Blondel, 2009; Che Hasan *et al.*, 2012; Conway *et al.*, 2005; Hamilton & Parnum, 2011; Huang et al., 2013; Jordan *et al.*, 2005; Lucieer et al., 2013; Roberts *et al.*, 2005).

The integration of *in situ* and *ex situ* datasets accurately captures the seabed of interest over a large scale, and describes the benthic habitat that has been mapped at a finer scale. For example, a study by Lucieer *et al.* (2013), expressed the importance of identifying factors that influence sponge distribution at a fine scale, rather than at the scale of the MBES data. During this study, substrate complexity and rugosity were differentiated into classes using acoustic data, and sponge presence was associated with consolidated reef structures. However, these reef structures reflect a stronger signal when compared to sponge communities, which limited the author's ability to separate sponge density from the reef (Lucieer *et al.*, 2013). Ground truth data therefore characterizes acoustically defined areas with associated biotic attributes (Hamilton & Parnum, 2011; Jordan *et al.*, 2005). In a related study by Che Hasan et al. (2012), a combination of MBES and underwater video observations, were used to characterize biogenic habitats in Discovery Bay Marine National Park, Victoria, Australia. Using the classified video data, the authors were able to identify five broad biota classes and three substratum classes; information that could not be obtained if only *ex situ* data was collected.

This combinational method involving acoustic and video data creates a habitat classification method that is reasonably accurate. However, a disparity exists between what can be acoustically discriminated and what is visually observed. This may be attributed to a number of factors including: 1) lack of data available for algorithm models; 2) poor interpretation of the data both acoustically and visually; 3) biotic distribution is affected by a combination of topographical, biotic and abiotic factors; and 4) drop camera data is suitable for characterizing hard substrata types and biogenic structures, but not as good for differentiating between other substrate types (e.g. sand vs. coarse sand) (Huang *et al.*, 2011; Lucieer *et al.*, 2013).

Haywood *et al.* (2008), used a combination of sampling devices to broadly characterize seabed habitats over a large spatial scale. The authors created a map identifying distinct seabed habitats and biota found in Torres Strait, using data from trawl, epibenthic sled surveys and towed video camera surveys. The authors compared the effectiveness of these three tools, and concluded that towed camera surveys were suitable for surveying seabed's too rough to sled or trawl through. However, the taxonomic resolution achieved using a towed video camera was low compared to extractive techniques. Camera surveys are not suitable for sampling very small or highly mobile organisms (Haywood *et al.*, 2008); nevertheless, this technique is preferred over others, because it is non-destructive, cost effective, and easy to deploy.

For the study reported here, multibeam sonar was used to define Pariokariwa Reef's morphology, and produce backscatter imagery that could be used to map and predict habitat composition on the reef. A combination of dive and drop camera surveys was used to investigate the distribution of biogenic habitats across Pariokariwa Reef and be used in conjunction with acoustic data to characterise and map biogenic habitats on the reef. Dive surveys were also performed at discrete locations, to characterise biological assemblages over small spatial scales on the reef, to determine whether biological community composition and distribution in influenced by the reefs distinct morphology. At its inception, the study was going to look for signs of habitat recovery within Parininihi Marine Reserve following nine years of protection from fishing by comparing areas inside and outside the reserve. Waikiekie Reef, located just outside the north-eastern reserve boundary, was chosen as the control site, because of the two reefs been in close proximity of one another, and share similar geology and biology. Waikiekie Reef was mapped using multibeam sonar; however, due to time constraints and survey logistics, we were unable to ground truth the reef system.

1.5 Parininihi Marine Reserve

Parininihi Marine Reserve was established on Pariokariwa Reef, off the coast of North Taranaki, in 2006. A preliminary survey conducted on Pariokariwa Reef by Battershill and Page (1996), indicated the reef system supported an unusually high biomass and diversity of sponges, some endemic to Pariokariwa Reef. An unpublished report (Smith, 2007) studying invertebrate diversity within the reserve, indicated species richness within the reserve is greater than 75% of sites found elsewhere in New Zealand. What is more extraordinary is that data from a global study of species richness patterns observed in similar communities, indicated that species diversity in the Taranaki region is greater or equal to 60% of biological communities found elsewhere in the world; and estimated richness in Taranaki is greater or equal to 70% of communities found elsewhere (Smith, 2007).

Benthic samples and quantitative estimates of biomass were carried out by Battershill (1996) at five dive sites, and photographs were taken of new species found on the reef. Using this data, three distinct habitats were identified on the reef: shallow boulder and rock outcrop reef; shallow boulder and rock outcrop sponge garden; and deep broken rock reef (Battershill & Page, 1996). This preliminary study revealed a unique assemblage of species in terms of its community structure, comprising both warm-water and cold-water/sub-antarctic species located in shallow water conditions (8-10 m). The deeper-reef system (15 m), is subjected to a high energy wave climate; however, despite this area being heavily influenced by swell and sediment erosion, this deeper-reef supports one of the richest biological communities found in New Zealand, and supports a number of un-identified species (41 new species) (Battershill & Page, 1996). The reef is characterized by diverse sponge assemblages, including some species, *Polymastian.sp.(cf crassa)* and *Axinella* spp., that appear to be rare elsewhere in New Zealand (Battershill & Page, 1996).

Bioassay tests carried out on samples (*i.e.* sponge) collected from the study (as part of the original survey), indicate that Pariokariwa Reef can be identified as a potential site for high biodiscovery, because a number of species located on the reef (*e.g..Carmia hentsheli* and *Latrunculia* sp. (cf *brevis*)), exhibited interesting antitumor activity (Battershill & Page, 1996). A significant percentage of the species screened, showed high levels of biological activity, the majority of which were species endemic to the area or remain un-identified. It was clear from the 1995 survey that Pariokariwa Reef should be protected from destructive fishing techniques given its unique character and high endemic biodiversity. There remain many unanswered questions concerning the significance of the reef system to the wider Taranaki region and west coast New Zealand coastal biogeography, not to mention potential opportunity in hosting future biodiscovery research. It is crucial that unique species are not lost from the system, by bottom trawling and ghost fishing, before being identified as a biologically active species, useful to humans.

Prior to study by Battershill (1996), there had been few biodiversity surveys done along the coast of north Taranaki (Hayward *et al.*, 1999). Furthermore the biogeographic distribution of marine invertebrates along the west coast of the North Island has been poorly recorded, because of the unpredictable surf conditions along this coast which limits the level of accomplishable research in these exposed conditions. This study will provide insight into the dynamics of New Zealand's north-western coastline in a region that supports important habitat (including Maui's dolphin ecosystem), important fisheries (e.g. Kahawai), and is subject to increasing developmental pressure (offshore seabed mining and petrochemical development).

1.6 Objectives of this study

The overall objective of this study was test whether multibeam sonar imagery can be used as an effective tool for habitat mapping, using Pariokariwa Reef, within Paraninihi Marine Reserve as a test case. This goal was to be met by achieving via following specific objectives.

(1) Produce a bathymetry map of Pariokariwa Reef
(2) Produce a backscatter mosaic of Pariokariwa Reef and see if it suggests different habitats
(3) Investigate the effectivity of combining acoustic and *in situ* survey techniques to map habitats on Pariokariwa Reef.
(4) Examine the distribution of biodiversity across distinct topographical features across Pariokariwa Reef.
(5) Consider the usefulness backscatter imagery is as a habitat mapping tool.

1.7 Structure of the study

In order to achieve the objectives listed above, the study was carried out in 3 main phases, leading to three core chapters (2-4).

Chapter 2:

Benthic Habitat Mapping: Acoustic Surveying using Multibeam Echosounders.

Chapter two presents a simple methodology for extracting high resolution bathymetry data from MBES, and its application over Pariokariwa Reef, located within Paraninihi Marine Reserve. Therefore this chapter relates to objective (1) of the thesis. This chapter discusses the role bathymetry plays in benthic habitat distribution, and how bathymetric imagery can be used in conjunction with backscatter imagery, to map biogenic habitats on the seabed. Following the results of the MBES survey on Pariokariwa Reef, this chapter investigates what survey parameters influence imagery resolution, and how the resolution of the imagery can significantly influences the level of detail in habitat maps.

Chapter 3:

Benthic Habitat Mapping: *Acoustic Seabed Classification*

Chapter three presents a methodology for extracting backscatter imagery from MBES, and classifying the backscatter imagery, using a combination of acoustic and in situ survey techniques. The benefits and limitations of this technique are explored through their application MBES data set, acquired over Pariokariwa Reef in December, 2014. This chapter, therefore, relates to objectives (2) and (3) of the thesis.

Chapter 4:

Characterisation of biological communities on Pariokariwa Reef

Chapter four investigates what influences the reefs unique morphology, and heterogeneous substrate has on biological community composition and distribution across the reef. This chapter studies the structure of biological community at a finer spatial scale, to the acoustic survey conducted over the entire reef system and investigates what environmental factor are influencing sponge community composition and distribution over the reef. This chapter, therefore, relates to objective (4) of this thesis.

Chapter 5:

General Discussion: *Combining acoustic and in situ survey techniques*

Chapter six concludes the thesis by summarising the major findings from the research, and outlining how these findings met the major objectives, made in the introduction. This Chapter discusses the pros and cons of this combined survey technique and provides suggestions for refining the survey technique and for further research within the marine reserve. This chapter, therefore, relates to objective (5) of this thesis.

Chapter 2: *Benthic Habitat Mapping: Acoustic Surveying using Multibeam Echosounders*

2.1 Introduction:

Over the past 15 years anthropogenic activity such as destructive fishing, dredging and oil extraction, have had a significant influence on the marine environment. Sudden declines in marine ecosystem health has raised awareness of an urgent need to improve the management of marine living resources, and understand the spatial and temporal distribution of marine benthic habitats, in order to classify and protect them (Brown *et al.*, 2011; Freitas *et al.*, 2011; McGonigle *et al.*, 2009; Schimel *et al.*, 2010). Understanding of the spatial distribution of benthic habitats over a large spatial scale is vital for assessing impact of human activities (Brown & Blondel, 2009; Freitas et al., 2011; Ierodiaconou *et al.*, 2007); placement of marine reserves (Jordan *et al.*, 2005); and appointing areas of the seabed suitable for biodiscovery surveys and resource extraction (Anderson *et al.*, 2011; Przeslawski *et al.*, 2013). However, our knowledge on the scope, geographical range and ecological functioning of benthic habitats is limited as a result of survey methods that have traditionally been used in the past. Conventional survey methods such as grab samples, cores, video, and photography are time consuming and restricted to characterising localized areas of the seabed, and as a result it has been estimated that only 5-10% of the world's seafloor has been mapped to a resolution as detailed as those produced on land (Brown et al., 2011; Wright & Heyman, 2008).

2.1.1 'Habitat' - an ecological definition

The term "habitat" is a fundamental concept in ecology; however, the definition of "habitat" is vague and often misused (Mitchell, 2005). The concept "habitat" is loosely described in formal dictionary as:

Habitat: the natural home or environment of an animal, plant, or other organism (Simpson *et al.*, 1989).

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However, confusion develops when this definition is put to practical use, because the term “habitat” is often associated with a group of individuals of the same species, or population, rather than a single organism (Schimel, 2011). Furthermore, within ecology it is often uncertain whether the concept of “habitat” refers specifically to the area where the population is found, or the physical parameters that characterise their locality (Mitchell, 2005; Schimel, 2011). It has been proven through various ecological studies within both terrestrial and marine origin, that an environment’s physical parameters (e.g. sediment-type, complexity, temperature, salinity, oxygen concentration and light availability), influence population dynamics and species distribution; however, by focusing on the physical environment to map or describe a habitat, we are limited to making predictions at a species/population level and not at a community level. It is important to consider biotic factors (e.g. competition, predation, food supply and disease) as well as collect measurable environmental parameters, as biotic factors play a crucial role in mapping community patterns. (Mitchell, 2005). Thus the term “habitat” ideally incorporates two common understandings: (1) the term “habitat” is associated with the physical and biological components of the ecosystem, and (2) the community itself (Dauvin *et al.*, 2008).

2.1.2 Benthic Habitat Mapping

Benthic habitat mapping involves a singular or series of surveys that determine the spatial distribution of “benthic habitats” within the marine environment; based on spatially discontinuous environmental data sets, which are represented as a map. There are currently no standardized objectives or methods for benthic habitat mapping, which is attributed to the absence of a consistent and universal definition this activity (Schimel, 2011). Marine habitat mapping in the past involved dividing the survey area into distinct boundaries, which were used to represent the distribution of divided habitats. However, biological assemblages are not separated by discrete boundaries but are distributed in a rather continuous or discontinuous manner (Brown et al., 2011). Whilst distinct boundaries do exist between some habitats (e.g. the interface between the edge of a bedrock reef and surrounding sediment), there is more likely to be a gradual shift between benthic communities, in association with changes in seafloor rugosity, topographic position, reef relief and aspect (Holmes *et al.*, 2008). Thus, seafloor characteristics and biological assemblages are now represented in a more gradual manner in maps, rather than appointing discreet boundaries between benthic communities (Brown et al., 2011).

2.1.3 The revolution of remote sensing technology

2.1.3.1 Introduction to underwater acoustics

Advancements in habitat mapping have been occurring for last 30 years as a result of developments in acoustic surveying technology. Data collection and processing has revolutionised the way we are able to image, map, and understand marine systems, over large spatial scales (McGonigle et al., 2009). More specifically, development in multibeam echosounder technology is beginning to supersede other acoustic technologies such as SSS and SBES, as a result of MBES being capable of capturing high resolution imagery over a large spatial scale (Brown & Blondel, 2009). High resolution bathymetry provides marine scientists with information on the seafloor's topography, which has been proven to provide insight on the spatial variation of benthic habitats.

There is a growing body of literature that suggests environmental gradients, identified by geophysical data (e.g. water depth, substrate type, reef aspect and relief), have a strong influence on the distribution and composition of sessile biological communities (Cutter *et al.*, 2003; Ierodiaconou et al., 2007; Kostylev *et al.*, 2001). It is clear from previous studies that the underlying substrate and geomorphology of the seafloor, influences biological community composition and distribution, which is why most methods of acoustic sampling and imaging of the seafloor are designed to describe the substrate (Brown & Blondel, 2009; Diaz *et al.*, 2004; McGonigle et al., 2009; Wright & Heyman, 2008). High resolution bathymetric data reveals previously unrecognised seafloor morphological and substrate attributes, which provide the framework for mapping benthic communities (Kostylev *et al.*, 2001). However, substrate is not the only component influencing the distribution of benthic communities; biogenic structures (e.g. sponge) also influence community composition and are often associated with marine fauna that inhabit them (Holmes et al., 2008). Scientists are now programming MBES to collect high resolution bathymetry and backscatter data simultaneously which, when ground truthed, can be used to characterise the seabed and generate habitat maps (Cutter et al., 2003; Le Bas & Huvenne, 2009; Schimel et al., 2010).

2.1.3.2 Comparison between the acoustic systems

Single-beam echosounders (SBES) are the oldest and simplest habitat mapping technology. They emit a single, large beam directly below the ship and measure the return time for the beam. This simple technology is used to measure water depth, seabed hardness and roughness, which are then linked to specific seabed habitat characteristics (Colquhoun & Heyward, 2007; Schimel, 2011). The two main features extracted from SBES acoustic data for habitat classification are the first (E1) and second echo (E2). The first echo is a characteristic of seabed roughness, and the second echo reflects the hardness of the bottom substrate (Colquhoun & Heyward, 2007). The major shortcoming in using SBES systems is that they produce low resolution acoustic "imagery", and are unable to produce a contiguous output. This is because this system does not produce a wide swathe across the track and therefore cannot produce an acoustic image of the seafloor like sidescan and multibeam sonar (Schimel, 2011).

Single beam echosounders technology has largely been replaced by sidescan and multibeam sonar, because these SSS and MBES produce a swathe, which produces a continuous data layer of the seabed. A continuous data layer ensures full coverage of the seafloor, as all swathe tracks overlap. The only downside to swathe systems is the complex interaction of the off-axis backscatter with the seafloor, which makes acoustic seafloor classification ("segmentation" of acoustic signal into discrete "spatial unit") challenging (Brown *et al.*, 2011). A pseudo-calibration curve is often produced to process the backscatter data and its purpose is to compensate for transducer directivity (angular), acoustic attenuation and dispersion though the water-column (range) and seafloor incidence (angular) (Le Bas & Huvenne, 2009)

Sidescan sonar (SSS) was designed in the 1950s to allow acoustic scientists to identify general seabed geomorphology, by studying the variation in acoustic shadows in the stacked backscatter (Schimel, 2011). The disadvantage of this traditional system is being unable to identify the angle of the reflected backscatter, which means the bathymetry is not measured. Measuring the water depth and thus the seabed's bathymetry is an important feature for habitat mapping, because it correlates with physical variables in the water column such as temperature, light and oxygen availability. These physical parameters must be considered when habitat mapping, because they influence the distribution of biota (Schimel, 2011).

Sidescan sonar was initially preferred over MBES, because raw images produced by SSS systems, show reduced banding and distinctive shadows, which are interpreted to represent distinct morphological features on the seafloor. This is mainly due to a narrow along-tract resolution of sidescan sonar (<1° grazing angle) compared to MBES systems (1-3°grazing angle) (Brown & Blondel, 2009). However, MBES imagery is improving to the point where their quality is approaching that of SSS (Schimel, 2011). This is because MBES backscatter is co-registered with the bathymetric data, which helps assist with interpretation and processing (Brown & Blondel, 2009; Schimel, 2011).

2.1.3.3 Multibeam Echosounder:

Early multibeam systems emitted 16 beams, which cover the seafloor in the along-track direction as well as across-track. The swathe width between each beam was 45 degrees, to ensure the system captured an accurate image of the seafloor. Today's systems emit more beams (100-240), and generate a wider swathe (120-150 degrees), compared to earlier models thus increasing the resolution of the imagery (Mayer, 2006). The transducer records the strength, direction, and the time it takes for an acoustic signal to return, after an encounter with the seafloor. Transducer technology is evolving towards a wider bandwidth (approaching 50% of their center frequency) which will benefit the resolution of bathymetric imagery, and thus expand our abilities to classify and map benthic marine habitats (Mayer, 2006; Schimel, 2011). By increasing, bandwidth which is the range of frequencies used to transmit a signal; these systems have the ability to increase the spatial and temporal resolution of the acoustic data recorded, as well as provide a multispectral look at the seafloor (Mayer, 2006). Broad-band multibeam systems record acoustic data faster, and receive a greater spatial density of soundings along the track, because they have the ability to transmit multiple pings into the water column at one time. This increases the resolution and accuracy of the acoustic data.

2.1.3.4 Bathymetry measurement by MBES:

Bathymetric data produced by MBES systems provide us with geophysical information (substrate rugosity, water depth, reef relief and aspect), which plays a crucial role in defining benthic habitats and mapping the distribution of benthic communities (Ierodiaconou et al., 2007). Water depth information is computed by measuring the time it takes for the signal to return to the transducer. Substrate composition and spatial arrangement, along with water depth influence the distribution of biological communities through influence of exposure to wave and current energy, sediment stability and light availability (Holmes et al., 2008).

This chapter reports the hydrographic survey undertaken on Pariokariwa Reef, on the 6th of December 2014, and the processing methodology that followed. The multibeam echosounder survey was performed on Pariokariwa Reef, within Paraninihi Marine Reserve, prior to the ground truthing operations discussed in the following chapter. A background to benthic habitat mapping, using various *in-situ* and remote sensing techniques is first reviewed, followed by a discussion on how different remote-sensing techniques influence imagery resolution.

The following hypothesis will be tested in this chapter:

> Multibeam technology has the ability to map large regions of the seabed at a resolution, high enough to identify distinct morphological features on the seabed.

2.2 Methods

2.2.1 Survey site

A multibeam survey was carried out within Paraninihi Marine Reserve, off the Northern Taranaki coast, on the 2nd of December 2014. Paraninihi Marine Reserve is 1800 hectares in size and extends alongshore 5.5 km of the Whitecliffs coastline (McComb, 2007). The seaward boundary is 3.7 km out from Pukearuhe Beach, but excludes an area between Pariokariwa Point and 200 m north of Waipingau Stream mouth, out to 750 m (McComb, 2007). This exclusion zone acts as a corridor for surfcasters, small boat fisherman and kayakers to fish in. The boundaries of the reserve and their coordinates are noted in Fig. 2.1.

The multibeam survey was carried out over Pariokariwa Reef located within the marine reserve and Waikiekie Reef, a control site located outside the reserve. Pariokariwa Reef is 4.6 km in length and 1.5 km in width, with ~70% of the reef system protected by the marine reserve. The reef system Pariokariwa Reef was mapped with nearly 100% coverage, ensured by consecutive tracks running parallel to one another. One area of the reef however was not covered in the survey: the southern end points of the reef (points 5, 6, 7 on Fig. 2.1) where waters were too shallow for survey. Pariokariwa Reef is the second largest marine reserve on the west coast of New Zealand and accounts for ~2% of the total length of the west coast of the North Island (McComb, 2007). The location is predominantly exposed to southwesterly weather, and high energy wave action.

A decision was made to focus the MBES survey over Pariokariwa and Waikiekie reef, and not the entire marine reserve, because of limited time to carry out the exercise due to the exposed conditions on the west coast. There two reefs took presidency over reef habitat elsewhere in the reserve because the Department of Conservation (DOC) and MetOcean Solutions (2007) have collected visual imagery of the both reefs using drop camera and bait remote underwater video (BRUV) technology.

It was anticipated when setting up the surveys that biological community composition would be similar between the two reef systems (reserve and outside unprotected control) as they are adjacent to one another, and therefore would likely be connected through larval drift. Waikiekie Reef's morphology was expected to be similar to Pariokariwa, as both systems have been subjected to the same tectonic and hydrological processes, making Waikiekie Reef a suitable control site for the study.

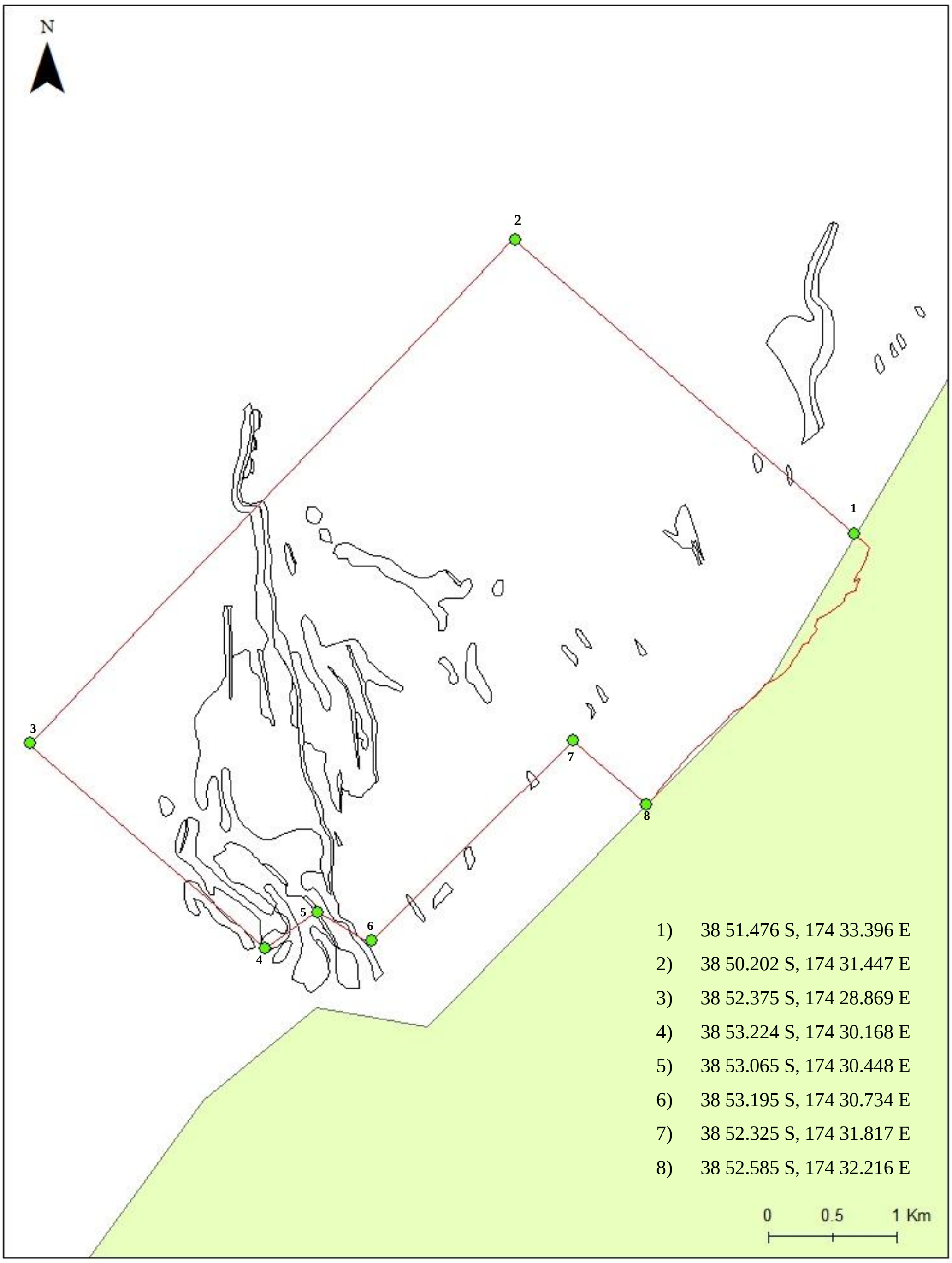

Figure 2.1: Charted map of Pariokariwa Reef, within Paraninihi Marine Reserve, Produced through a sidescan survey, by MetOcean Solutions Ltd. The reef systems are outlined in blacks, and the reserve boundaries, red.

2.2.2 Multibeam echosounder survey

2.2.2.1 Method

The Reson 7125 SV2 Dual Frequency multibeam echosounder was operated from Discovery Marine Limited's (DML) 7.0m Senator built pontoon vessel PANDORA (Fig. 2.2); at a travelling speed of 5-6 knots. This acoustic device transmits a pulse at a frequency between 400-200 kHz, with a depth range between 0.5 m – 150 m (400 kHz), and 0.5 m – 400 m (200 kHz) below the transducer, and a swathe angle of 165° (across-track). The device's maximum ping rate is 50 Hz and receives a maximum 512 soundings per ping in shallow water. A VALEPORT MINI SVS (sound velocity sensor) was lowered into the water before the MBES survey commenced. The sensor emits a single pulse down into the water column and allows accurate measurement of temperature, pressure and sound velocity in one cast. The sound velocity sensor thus provides the highest accuracy, lowest sound and best resolution acoustic data. PANDORA was also fitted with a Trimble SPS855 WADGNSS positioning system, and an Applanix POS MV 320 WaveMaster motion sensor, which was used to compensate for heave, pitch, roll and yaw. Tidal variation during the survey operation was accounted for by applying tidal data from tide gauge readings from within the Taranaki Inner Port to the data set using the Quality Integrated Navigation System software (QINSy).

Figure 2.2: Discovery Marine Limited survey vessel PANDORA (A & B); fitted with a Reson 7125 SV2 Dual Frequency Multibeam echosounder at the hull of the boat on the starboard side (A & C).

2.2.2.2 Processing and analysis

All survey sites were logged into the hydrographic software package QINSy. This is the standard software for marine surveying and is used for a wide range of applications, including bathymetric chart and electronic navigation chart production. QINSy software is integrated with a navigation system that stamps all incoming data with a UTC (coordinated universal time) time label. The software is programmed to label data with a time stamp within 1 sec of a ping being recorded. All computations for this software are calculated in 3D. To process the bathymetry data, QINSy was used to make necessary corrections for the sounding position, and compensate for differences for tidal phase and amplitude between Port Taranaki and the survey site. Fledermaus was then used to manually filter through the raw data, and to remove noisy artefacts (v.741d).

Bathymetry data was then exported as a Geotiff in ArcMap v10.2.2. A 0.27m mesh bathymetry chart was produced in ArcMap using New Zealand Transverse Mercator projection.

2.3 Results and Discussion

2.3.1 Description of the survey

The multibeam survey, performed on the 6th of December, 2014, took 8 hours to execute. The survey covered 3.2 km of the length of Pariokariwa Reef, and 1.5 km of the width, as well as 1.1 km of the length of Waikiekie Reef. The area of Pariokariwa Reef prioritised for survey, runs out from Pariokariwa Point, which lines up with points 6 and 7 of the marine reserve boundaries, and carries on all the way out to the seaward boundary of Paraninihi Marine Reserve, almost halfway between points 1 and 8 (Fig. 2.1). It took a total of 26 survey tracks to cover Pariokariwa Reef, with the average track running 1.9 km in length, and taking ~20 min to complete (Fig. 2.3). Over 30 survey tracks, or a total of 3 ½ Km^2 (350 ha) of Paraninihi Marine Reserve (1800 ha) was insonified during the survey, which is ~19% of the area within the reserve.

In addition to multibeaming Pariokariwa Reef, the sonar system continued to log data on the run out to Waikiekie Reef. This adjacent reef is 3.9 km from Pariokariwa Reef, and took 41 min to reach, travelling at a speed of 6 knots.

Waikiekie Reef runs in a northward direction, similar to Pariokariwa Reef. It was clear from the survey that Waikiekie Reef runs quite a distance adjacent to the shoreline; however, due to the finite time to survey, only 1.1 km of the reef was multibeamed. Ten survey tracks were run in the area of the reef, with the average survey track measuring 0.8 km in length (Fig. 2.3).

The result of the multibeam survey and processing of the bathymetric data in Fledermaus was a high definition bathymetric map of Pariokariwa (Fig 2.4) and Waikiekie Reef (Fig. 2.5). The bathymetric maps produced from this survey are the most detailed maps of the reefs to date. The only charted map available of Pariokariwa Reef, prior to the MBES survey, was a charted map of the reef produced through a sidescan survey by MetOcean Solutions Ltd (Fig. 2.1).

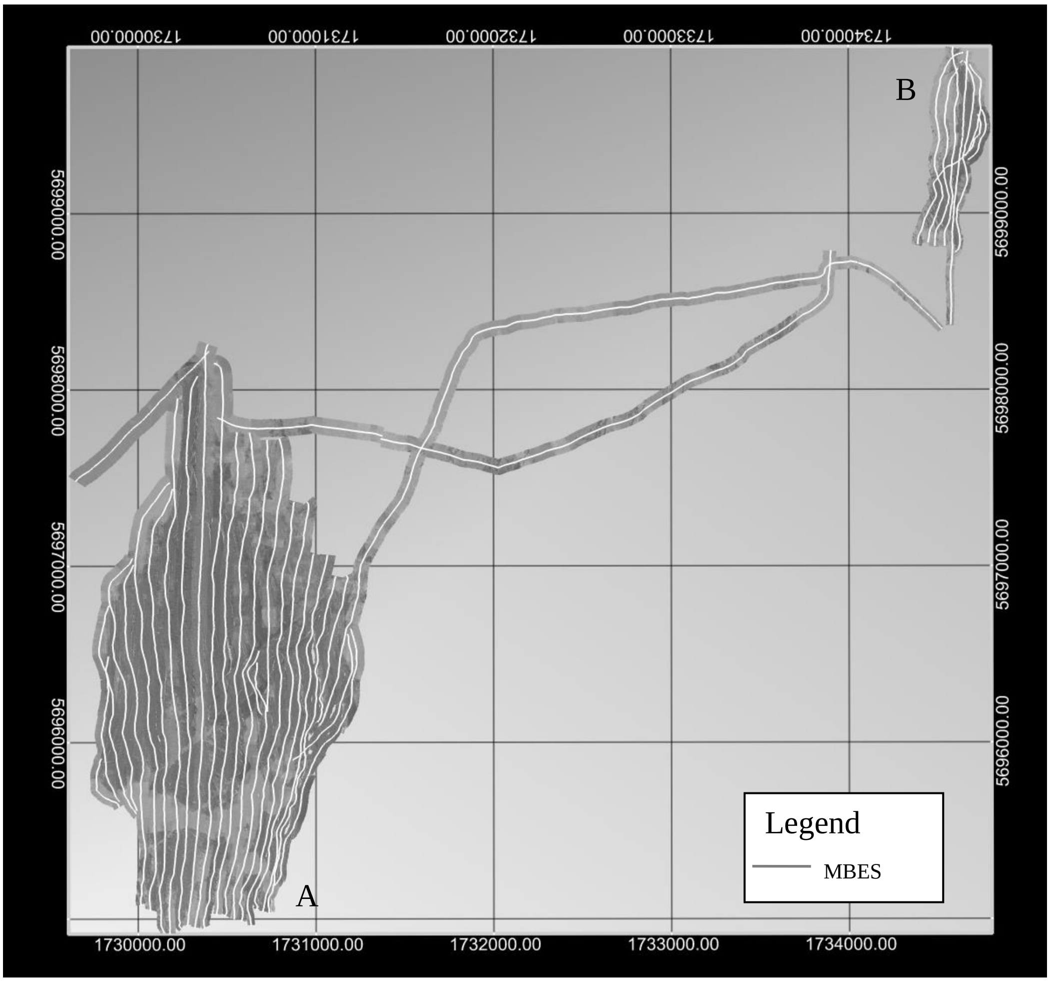

Figure 2.3: Multibeam echosounder (Reson 7125 SV2 Duel Frequency) survey coverage of Pariokariwa (A) and Waikiekie Reef (B) (December 2014), displayed on a km² grid.

2.3.2 Description of the seabed

The high-resolution bathymetry map of Pariokariwa Reef varies in water depths between 4 – 20 m (Fig. 2.4). This large reef system, measuring ~4.8 km in length, and 1.5 km in width, runs out from the coastline in a north-east direction. Shallow regions of the reef are characterised by complex seabed features, including ridges, overhangs and saw-tooth reef forms. Three distinct benthic habitats were identified based on the bathymetric data: Sediment inundated reef (Fig. 2.5A); bedrock reef characterised by ridge tops, over hangs and under hangs (Fig. 2.5B); and mud and siltstone habitat (Fig. 2.5C).

Four fault lines cross though Pariokariwa Reef at varying angles in a south-west direction (Fig. 2.6). Techtronic faulting has caused certain regions of the reef to be pushed up, while other areas have remained low profile, or have been worn away, if made from a finer material (e.g. silt stone). The saw-tooth structures which are a prominent topographical feature on the reef are made up of a sequence of hard and soft layers, known as a flysch sequence. A flysch sequence consists of alternating bands of sandstone and siltstone, which is similar to the geology of the nearby Whitecliffs. The ridge tops and top layer of the reef is made up of a hard material, while the layers beneath are of a finer material (silt stone and mudstone). Ocean currents, wave action (abrasion and erosion) and normal weathering processes wear down, and undercut regions of the reef that are made of finer material. These oceanographic processes have influenced the unique geomorphology of Pariokariwa Reef and will continue to influence it, due to the reef being made up of erodible materials. Sediment has built up within troughs and low profile areas, especially in areas where tectonic faulting has caused large gaps to form between areas of the reef (Fig. 2.5A). Deeper regions of Pariokariwa Reef are characterised by lower profile, saw-tooth structures, which are warped through tectonic processes. Regions of the reef influenced by the fault lines have shifted in a north-east direction. This process is most obvious at the northern point of the reef, where a predominant ridge line, running halfway along the reef, has fractured and broken away (Fig. 2.5B).

Waikiekie Reef is likely to share a similar geology to Pariokariwa Reef, because the sediment sequences that build the foundation of both reef, originate from the Whitecliffs. Waikiekie Reef is similar in morphology to Waikiekie Reef, because it's been influence by the same weathering and coastal processes. However, Waikiekie Reef is characterised by a single ridge top, with a deep overhang running the length of the reef on the landward side. This means that in comparison to Pariokariwa Reef, this reef system has simpler morphology (Fig. 2.7). Waikiekie Reef is also orientated at a slight angle (45°) to Pariokariwa Reef, which may influence the coastal process that shapes the reef (Fig. 2.3).

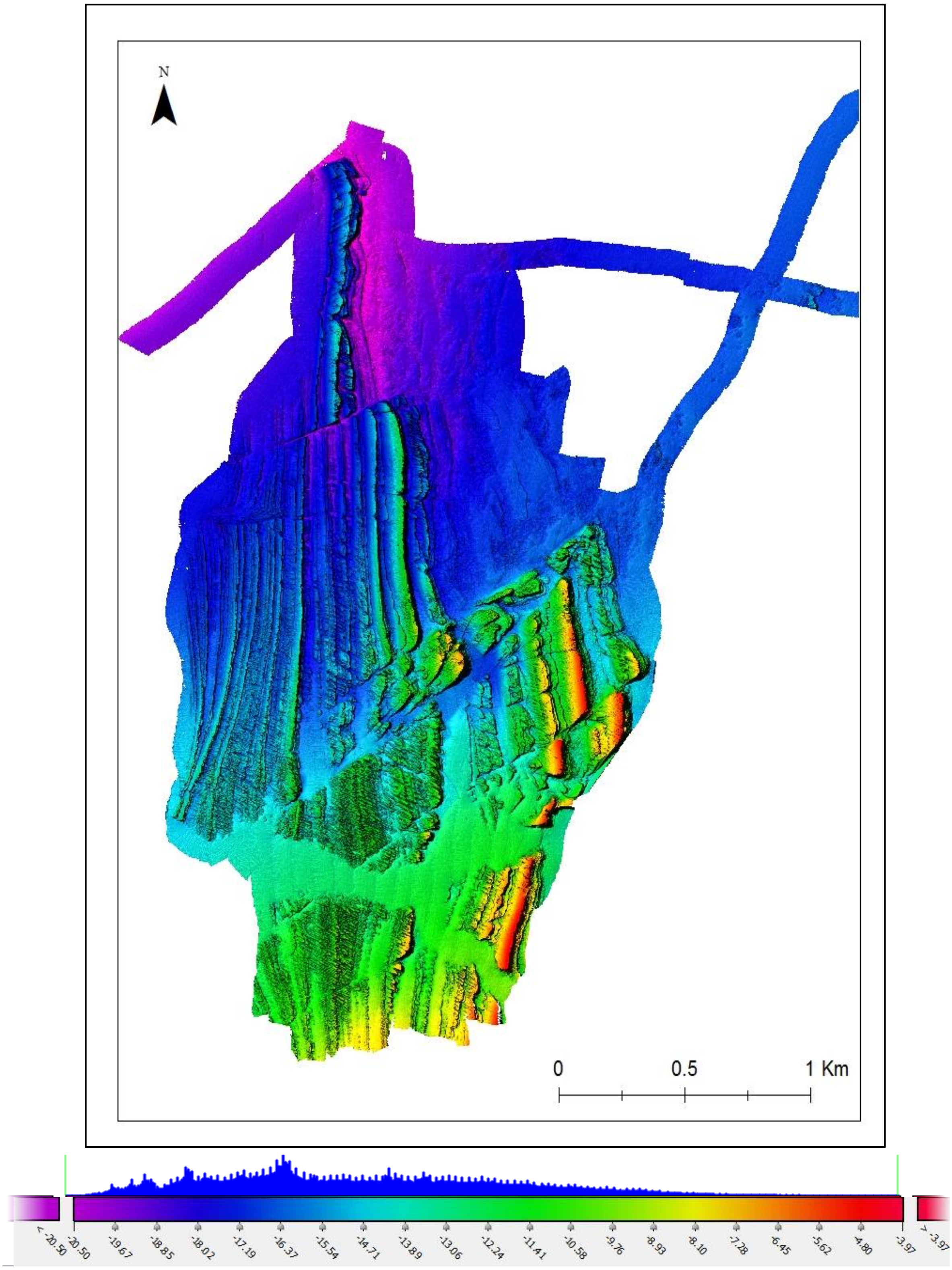

Figure 2.4: Bathymetry of Pariokariwa Reef based on the multibeam echosounder survey performed in December 2014.

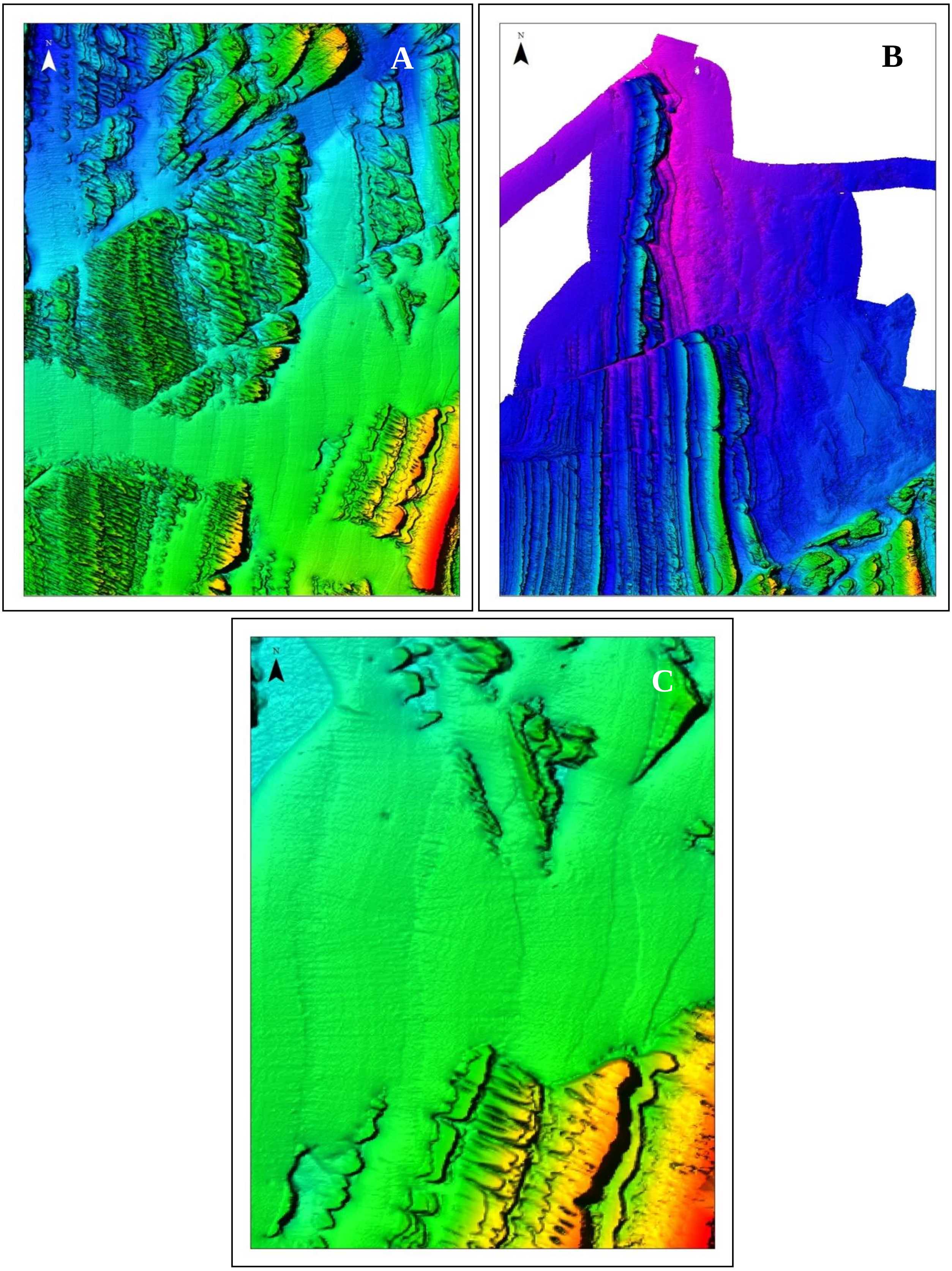

Figure 2.5: Three established habitat classes: Sediment inundated reef (A); bedrock reef characterised by ridge tops, over hangs and underhang (B); and mud and siltstone habitat (C).

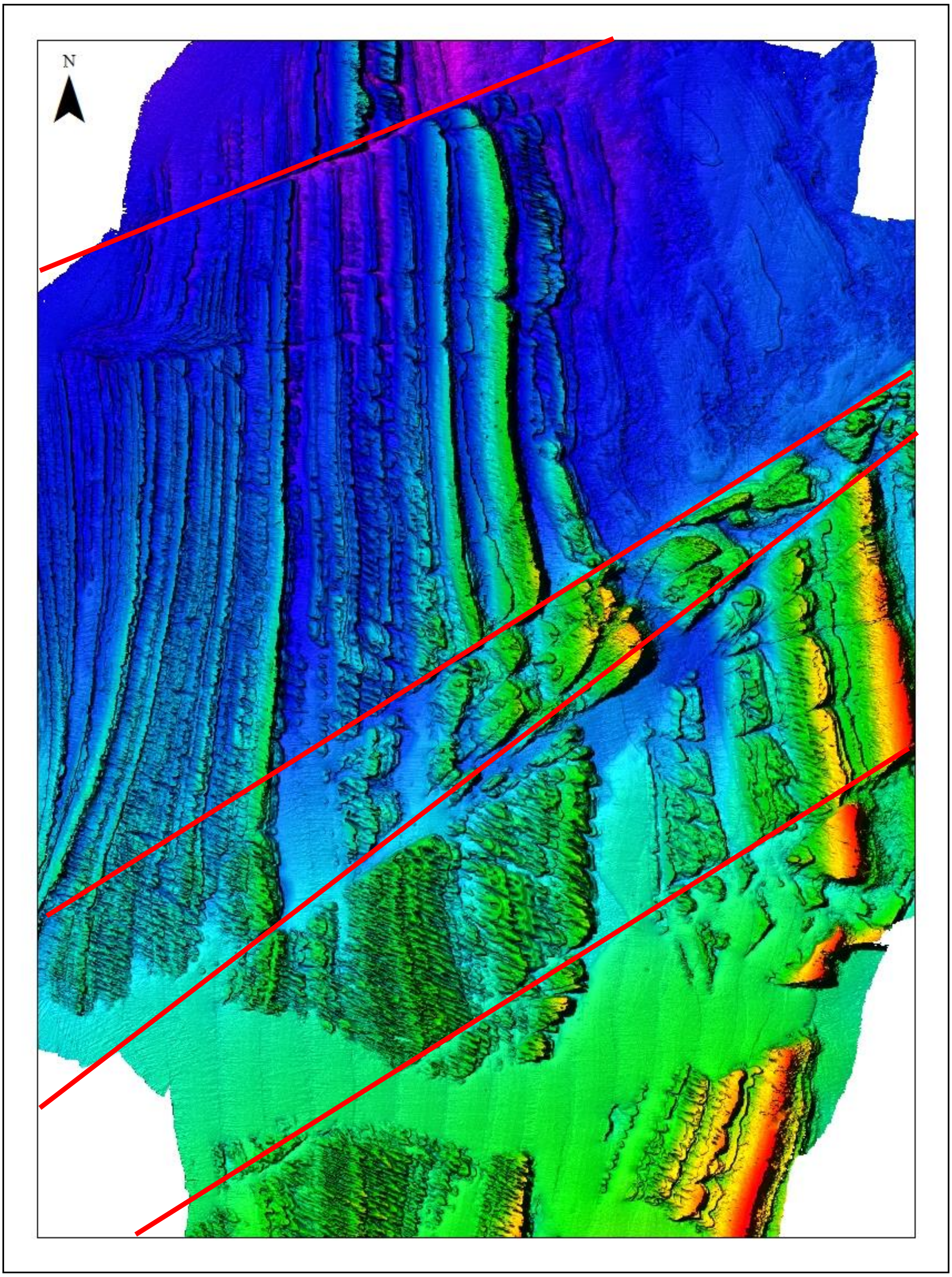

Figure 2.6: Bathymetry of Pariokariwa Reef, identifying fault line intersection through the reef system (red lines 1 - 4).

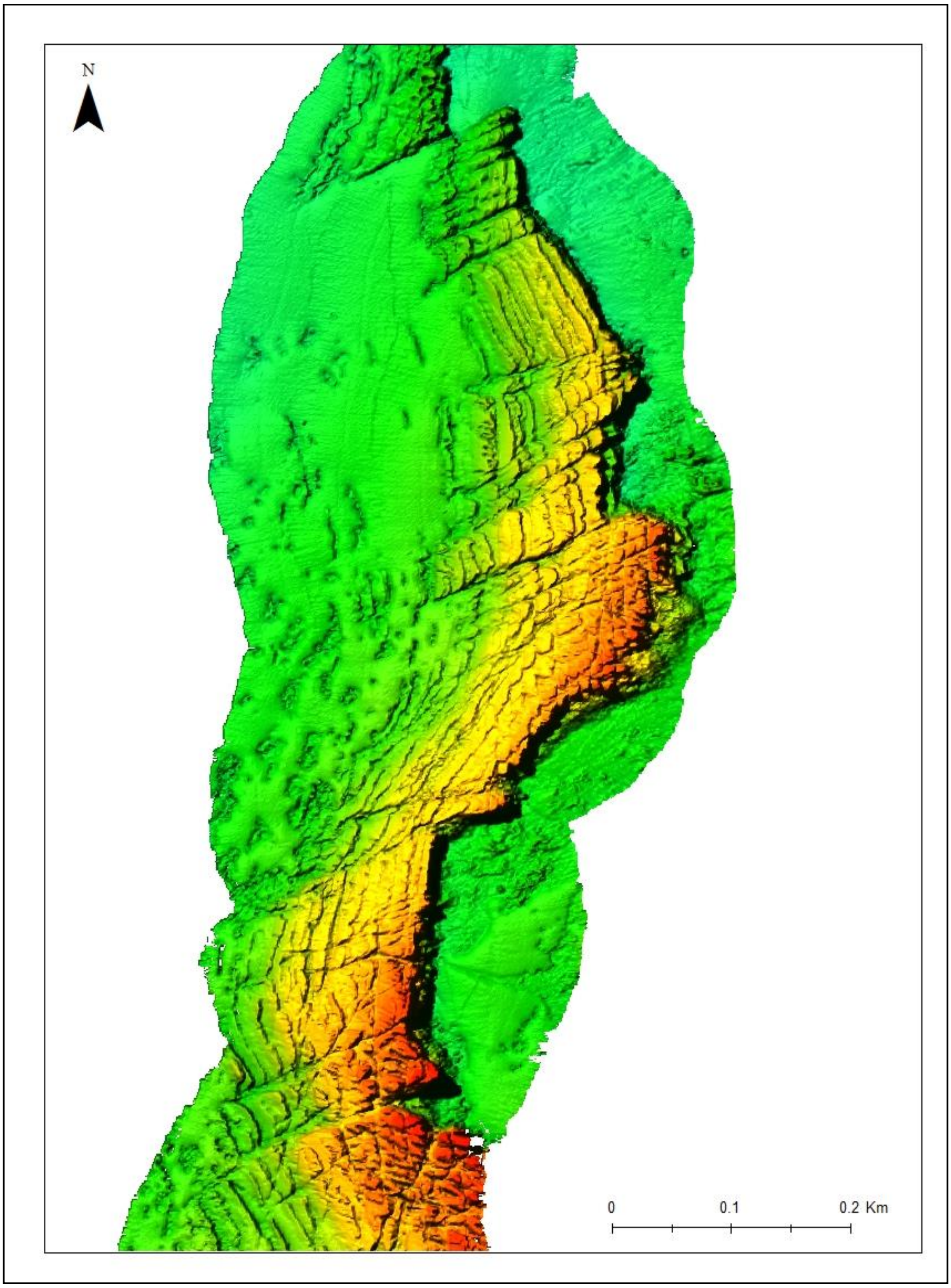

Figure 2.7: Bathymetry of Waikiekie Reef based on the multibeam echosounder survey performed in December 2014.

2.3.3 Use of bathymetry map for habitat mapping

A high resolution bathymetry map, overlain by a habitat map, acts as a good physical surrogate for marine biodiversity (Kostylev et al., 2001). The rocky morphology of Pariokariwa Reef provides important diverse habitats for reef fish and benthic species, while the sediment below the reef houses infaunal species. Processed bathymetric data of Pariokariwa Reef provides valuable information on the reef's morphology and is a crucial feature to use for habitat mapping, because water depth correlates with physical variables in the water column such as temperature and light availability. These physical parameters must considered for habitat mapping because they influence the distribution of biota (Schimel, 2011). Characteristics of seafloor bathymetry such as roughness, slope and reef aspect also influence species distribution (Nichol *et al.*, 2012). Fundamentally, if habitat classes are identified, and their distribution confirmed through ground truth survey, then the bathymetry map can help predict species relationships in other areas (Kostylev et al., 2001; Le Bas & Huvenne, 2009). When bathymetric data is used in conjunction with classified backscatter data for the purpose of habitat mapping, marine surveyors have the ability to classify the seafloor into habitat classes. These habitat classes are often associated with a known substrate type, such as bedrock, sand or mud. Substrate type can, to a degree, be identified from bathymetric data which allows broad habitat types to be associated with identified substrates, and thus make predictions on habitat distribution in neighbouring areas (Huang *et al.*, 2013; Le Bas & Huvenne, 2009).

2.3.4 Parameters influencing bathymetry resolution

It is clear from the literature that there are a number of parameters influencing the precision and resolution of bathymetric data. These parameters can be divided into four characteristic groups: Transducer design, towing and mounting, water-column, and survey track configuration.

1) Transducer Design: The design of the transducer influences the ping rate (which is usually fixed for a particular device and depth), and beam width which has a significant influence on the precision and resolution of the bathymetric data. Transmission frequency influences the range of useful signal received by the transducer. The accuracy with which a sonar device detects the

seabed and objects suspended in the water column, is determined by the transmission frequency, selected for the water depth being surveyed. For the purpose of this survey the Reson Dual Frequency Multibeam Echosounder was set to transmitting a high frequency pulse (400 kHz - 200 kHz) and ping rate (50 kHz), due to the survey being conducted within shallow coastal waters (4-20 m). High frequencies (>50 kHz) are best used in shallow waters, and when travelling at a faster speed, because the transducer will receive return pings at a faster rate and can transmit the next wave faster again, thus increasing the resolution of the bathymetric data. Echosounders transmitting at a high frequency produce higher resolution imagery, but only of a localized area of the seabed. The higher the frequency of the sonar, the shorter the slant-range, which means that devices transmitting at a high frequency, should be towed close to the seabed rather than hull mounted (Dufek, 2012; Le Bas & Huvenne, 2009). In contrast to using high frequencies to survey shallow waters, low frequencies (12 kHz - 30 kHz) should be used for survey deeper waters, because low frequency sound waves are absorbed slower by water and therefore can travel further though the water column. Low frequency signals travel through the water at an angle that is more perpendicular to the seabed. It is best to travel at a slower speed and reduce the swathe angle when surveying in deeper regions because this will reduce the slant-range and increase the resolution of the imagery (Ocean Explorer, 2015).

The precision of bathymetry data increases as the number of impact points being received by the transducers increase. The literature recommends that the width between consecutive beams along the swathe can be wider when surveying over flat terrain, because regardless of where the beams hit the seabed, the reflecting echoes will accurately represent the flat terrain. The maximal beam width suggested for surveying over flat surfaces is 130°-150°, and 110°-130° for surveying over complex terrain (Maleika, 2013). A study by Maleika (2013) investigated what influence varying MBES parameters have on image accuracy, and reported that a beam width >150°, over changing terrain, will increase the level of error in the bathymetric dataset by 20-30 cm (at a 99% confidence interval). This means that as the terrain increases in irregularity, the level of error between each beam increases, along with the level of lost data; thus reducing the accuracy of the imagery (Maleika, 2013). A wide swathe is often favoured for surveying over large regions of the seabed, because the wider the swathe, the more area covered per track, which means less tracks are travelled over the same area of seabed, and therefore less time is required to conduct the survey. It is therefore beneficial for surveyors to have background knowledge on the terrain being surveyed, to ensure the transducer is set, to recording data at the highest possible resolution, and within an efficient space of time. In this study, the beam angle of the Reson Duel Frequency Multibeam Echosounder was set at 165°, which means the width of the swathe is quite wide considering the complexity of the terrain being surveyed. The beam width was set at 165° because a wider swath allowed us to cover more ground with each track, thus reducing the time needed to perform the survey.

2) Towing and mounting: The speed travelled while surveying depends on the signal frequency and water depth. The vessel used for the multibeam survey over Pariokariwa Reef, travelled between 5 and 6 knots while surveying, which was an appropriate speed for logging data, based on the shallow depths of the site and high frequency of the sonar. The sonar system used for the survey was hull mounted, which means the position of the imagery is very precise; however, the resolution of the acoustic data may have been reduced slightly as the result of the transducer being higher up from the seafloor. The higher the transducer is above the seafloor, the greater the width of the swathe, which means a larger area of the seabed is insonified with every track, thus reducing the number of track needed to survey the entire area.

3) Water Column: Characteristics of the water column such as water temperature, salinity, and the pressure profile of the water column, influences the spreading and absorption of each ping (Le Bas & Huvenne, 2009). Refraction of the sound wave as it moves through the water column can influence the resolution of the imagery, but generally at a minor extent. Sound refraction off suspended particles and objects (e.g. pelagic fish) in the water column is interpreted as noise within the data, and must be removed from the imagery in order to ensure accurate interpretation (Le Bas & Huvenne, 2009).

4) Survey track configuration: The resolution of the bathymetric map increases with increasing overlap between survey tracks (Le Bas & Huvenne, 2009; Maleika, 2013); however, the expense and duration of the survey also increases with the number of tracks travelled. Survey vessels tend to travel in a straight line and at a constant speed while performing an acoustic survey; with consecutive tracks running parallel to one another to ensure 100% coverage of the seabed. Survey tracks travelled over Pariokariwa Reef, in December 2014, ran parallel to one another with little to no overlap. Previous studies suggest survey tracks that overlap one another by 20-50%, increase the number of impact points they receive, and will therefore produce higher resolution imagery (Le Bas & Huvenne, 2009; Maleika, 2013). Additional cross-tracks, covering the same area, have also proven to increase the resolution of bathymetric imagery, especially when surveying over complex seabed features, similar to the reef overhangs and steep ridges characteristic of Pariokariwa Reef.

The bathymetry map of Pariokariwa Reef reveals the reef's unusual topography, which includes saw-tooth structures, ridge tops, overhangs, fault lines and crevices. Scuba dive observations on the reef indicate habitat type changes over small spatial scales, especially across the vertical faces and reef overhangs where biological communities are paramount. There is likely to be a challenge associated with characterising habitats in areas of the reef associated with complex topography (e.g. ridge tops, and overhangs), and heterogeneous habitat composition. This is because topographically complex features on the reef will not be described as well by the MBES imagery. These imagery issues associated with Pariokariwa Reefs complex topography are likely to be minor when used to characterise Waikiekie Reef. This is because Waikiekie Reef's topography is simpler compared to Pariokariwa Reef, as this reef system only has one ridge top.

2.4 Conclusions

The outcome of the multibeam survey over Pariokariwa Reef in December 2014 was the production of a high resolution bathymetry map, which provided detail on the reef's morphology, relief, aspect, and rugosity (bedrock reef and sediment). The bathymetry map produced during this study provides valuable information on Pariokariwa Reef morphology, and is therefore a crucial feature for habitat mapping. Therefore, the hypothesis investigating the ability for multibeam technology to map large regions of the seabed, at a resolution high enough to identify distinct morphological features on the reef, was accepted.

The sonar device was set for surveying shallow waters, and the vessel travelled no faster than 6 knots while logging data, to ensure high resolution imagery. However, no overlap between survey tracks meant that obscured areas of the reef such as the overhangs were often missing data points, which led to gaps in the imagery. There areas of the reef not represented by data are likely to be misinterpreted when automated classification is attempted on the backscatter imagery, in the following chapter. Based on the results of this study, I recommend that future acoustic surveys within the region should follow a survey style that achieves enough overlap between tracks to increase the resolution of the imagery, and cross-track coverage should be achieved over regions of the reef that are considered to be of interest.

Chapter 3: *Benthic Habitat Mapping: Acoustic Seabed Classification*

3.1 Introduction

Seabed classification involves partitioning of the seafloor into geologically defined classes, based upon the physical characteristics of the seabed and its influence on acoustic signal (Boulay, 2012; Brown *et al.*, 2011; Che Hasan *et al.*, 2012; Huang *et al.*, 2011; Ierodiaconou *et al.*, 2007; Schimel, 2011). The resolution of multibeam sonar technology and backscatter imagery has increased over the past 30 years revolutionising the way we are able to image, map and understand the seabed environment. Multibeam systems are now sophisticated instruments that emit multiple beams (>500 for some instruments) down towards the seabed, and produce a swathe that is wide across-track. These instrument advancements mean that MBES imagery achieves near complete coverage of the seafloor (Le Bas & Huvenne, 2009). The acoustic data collected by these modern MBES systems provides baseline data for habitat maps of the seabed, as these data sets provide surveyors with information on seabed geology and morphology. Strong links have been made between acoustic signatures and surficial sediment characteristics (De Falco *et al.*, 2010; Freitas *et al.*, 2011), biogenic habitat characteristics (Brown et al., 2011; Che Hasan et al., 2012; Collier & Humber, 2007; Kostylev *et al.*, 2001; McGonigle *et al.*, 2009), and archaeological components (Mayer *et al.*, 2003) on the seabed environment. However, backscatter imagery must be interpreted in conjunction with *in-situ* data in order to provide any accurate information on the distribution of biological assemblages (Brown et al., 2011; Kostylev et al., 2001).

An acoustic response or 'backscatter' is the result of the acoustic signal intersecting the seabed at an angle, and being reflected, absorbed and scattered in multiple directions based on the acoustic impedance (hardness) contrast between sediment and water, seafloor roughness and sediment characteristics (sediment type, and grain size) (Boulay, 2012; Fonseca & Mayer, 2007; Le Bas & Huvenne, 2009; Schimel, 2011). The shape or intensity of the returning echo provides two types of information for seafloor characterisation. The strength of the first returning echo (E1) provides information on the roughness of the seabed and is dependent on the level of energy being scattered by heterogeneities on the sediment, topography and seabed attenuation. The second-order echo return (E2) carries information on seabed hardness and is the result of complex scattering of the sound wave when it makes contact with the seabed (Boulay, 2012). For example, fine sediments generally produce a lower backscatter intensity compared to coarser sediments and bedrock due to their increased porosity, lower density and sound velocity. The results of a study by De Falco et al. (2010), indicated that backscatter intensity is strongly influenced by sediment grain size, and that backscatter intensity increases significantly at the $p<0.01$ level as grain size increases (in the range of 1-16 mm). Coarser sediments are likely to generate a higher backscatter intensity due to scattering increasing when a signal makes contact with a rough sediment-water interface as a result of coarser particles, lower porosity, higher density and sound velocity (Ferrini & Flood, 2006).

Backscatter classification is often done using computer generated models, which involve the use of pattern-recognition techniques to extract spatial information from georeferenced backscatter imagery. *In situ* data (ground truth data) is often collected from areas of the seabed, represented by distinct geophysical properties. The integration of *ex-situ* and *in-situ* datasets accurately captures the seabed area of interest over a large spatial scale and describes benthic habitats that have been mapped. Habitat maps provide detailed information on biophysical habitat distribution across the seafloor and can be used as models to predict habitat and species relationships in other regions of the seabed that contain similar physical and climatic conditions (Kostylev et al., 2001). Habitat maps are often created for marine biological applications, such as assessing rhodolith and seagrass species distribution (Che Hasan et al., 2012), mapping coral reef communities (Collier & Humber, 2007), and modelling fish-reef relationships (Bax *et al.*, 1999).

3.1.1 Backscatter processing

Whilst it is possible for experienced users to interpret and make seafloor predictions from raw backscatter, it is not recommended because unprocessed backscatter data contains speckle noise and a range of incidence angles, which compromises the resolution of the imagery. Speckle noise can often be mistaken from morphological and physical properties on the seabed which make interpreting the raw backscatter a challenge (Fonseca & Mayer, 2007).

Processing backscatter data can increase the resolution of the data set and ensure accurate interpretation of seabed features (Blondel & Sichi, 2008; Le Bas & Huvenne, 2009; Lucieer *et al.*, 2013; Schimel *et al.*, 2010). Processed backscatter imagery is more suitable for implementing automated classification techniques producing habitat maps at a higher resolution and in less time. Backscatter processing is often done using computer software programs, such as Fledermaus Geocoder Toolbox (FMGT), and QINSy. These have been designed to compensate for radiometric and geometric corrections in the backscatter data as well as making corrections for slope and removing speckle noise (Fonseca & Mayer, 2007; Le Bas & Huvenne, 2009; Schimel, 2011). Radiometric and geometric corrections are made to the backscatter to ensure that remaining signal variations represent the seafloor, which is essential for accurately characterizing the seafloor and producing habitat maps.

Variation in backscatter strength is related to the incidence angle, commonly known as the angular response. Backscatter angular information is often overlooked during standard backscatter processing and mosaicking; however, variation of backscatter intensity with angle of incidence is an intrinsic property of the seafloor that can aid its characterization (Fonseca & Mayer, 2007). Processed raw backscatter data can be presented in two forms, angular response curves and backscatter mosaics. Backscatter mosaic data is produced by normalising a range of backscatter intensities at a chosen incidence angle. However, the backscatter mosaic, normalised to one incidence angle, does not accurately show the spatial range of backscatter intensities available on the seabed, which reduces the accuracy of the imagery. In comparison angular response curves maintain backscatter information at a full range of incidence angles (Huang *et al.*, 2013).

3.1.2 Classification design

The discrimination (or classification) of acoustic data into intensity classes can follow two approaches, supervised or unsupervised. Supervised classification is used when the classes are known and the acoustic data is partitioned with the help of *in-situ* data. Unsupervised classification is used when there is no prior knowledge of seabed type before classification. Consequently, unsupervised classification involves clustering pixels together into classes that are acoustically similar (Boulay, 2012). *In-situ* data is used following unsupervised classification, to identify the substrate and habitat types associated with the backscatter signatures identified within the imagery.

Seabed classification methodologies can also be separated into “top-down” and “bottom-up” approaches. The top-down approach involves prior interpretation and segmentation of the backscatter data prior to characterizing the seabed with ground truthed datasets (e.g. sample or video footage) (Schimel, 2011). The bottom-up approach involves the collection of *in-situ* data over a large spatial scale prior to collecting acoustic data. A statistical relationship is then generated between the *in-situ* and acoustic data to identify relationships between the two. This method of seabed classification exercises the use of *in situ* data to discriminate between acoustic classes, rather than make assumptions (Boulay, 2012; LaFrance *et al.*, 2014; Schimel, 2011).

The aim of this chapter was to test whether the MBES backscatter imagery was suitable for classification of habitats. There are two components to this, the first being whether backscatter data is of sufficient sensitivity to be able to characterise more than the geology of the seabed: can biogenic community character be visualised in some form? Secondly, most MBES campaigns generate non overlapping profiles; hence there are data gaps in the imagery.

The following hypothesis is tested in this chapter: Acoustic properties can be linked to biogenic habitat structure and therefore can be used to map their distribution.

3.2 Methods:

3.2.1 Study area

Ground truth site locations were chosen by layering the backscatter imagery over the bathymetry and selecting areas of the reef where a range of backscatter intensities were present. Fledermaus and ArcGIS were used to identify the following geomorphological parameters for each site: water depth, coarse substrate type (bedrock/sediment), reef slope and height (m) (Table 3.1). Water depths at selected sites varied between 12-21 m, with the average depth measuring 15 m.

Table 3.1: Description of ground truth Sites 1-3 (photo-quadrat) and 5-7 (dive and drop camera). Surveys conducted in February 2015.

Site number	Max depth (m)	Corse substrate type's	slope (°)	Reef height (m)
1	12m	Bedrock/sand	6.33	7m
2	11.5m	Bedrock/sand	5.12	5.3m
3	15m	Bedrock/sand	5.49	4m
5	15m	Bedrock	6.29	7m
6	12.1m	Bedrock/sand	6.56	3.2m
7	12.6m	Bedrock	4.86	0.7m

3.2.2 Mosaic creation

Raw backscatter data was processed using the geo-spatial processing software, Fledermaus Geocoder Toolbox v.741d (FMGT). The raw backscatter data was processed to increase the resolution imagery (0.27m pixel size). FMGT was used manipulated the spatial variation of acoustic responses across the reef and was used to correct any geometric and radiometric distortions within the data set. A "Trend" Angle Varying Gain (AVG) filter was applied to the dataset to compensate for the angular dependence of the backscatter. The "trend" AVG filter was used in preference to other filters, for example "flat" and "adaptive" filters, because it has been proven to clean artefacts more efficiently. The backscatter mosaic was saved as an .SD file and opened in Fledermaus where it was then saved as a Geotiff. The Geotiff was opened as a greyscale raster in ArcMap 10.2.2 (Fig. 3.1). The backscatter imagery of Pariokariwa Reef ranges between -6.0 dB to -56.7 dB in backscatter intensity. The adjusted geo-referenced backscatter mosaic was created on a New Zealand Transverse Mercator spatial projection. The backscatter mosaic was layered overtop of the bathymetry map to help identify areas of the reef, characterised by heterogeneous habitat patterns (Fig. 3.2).

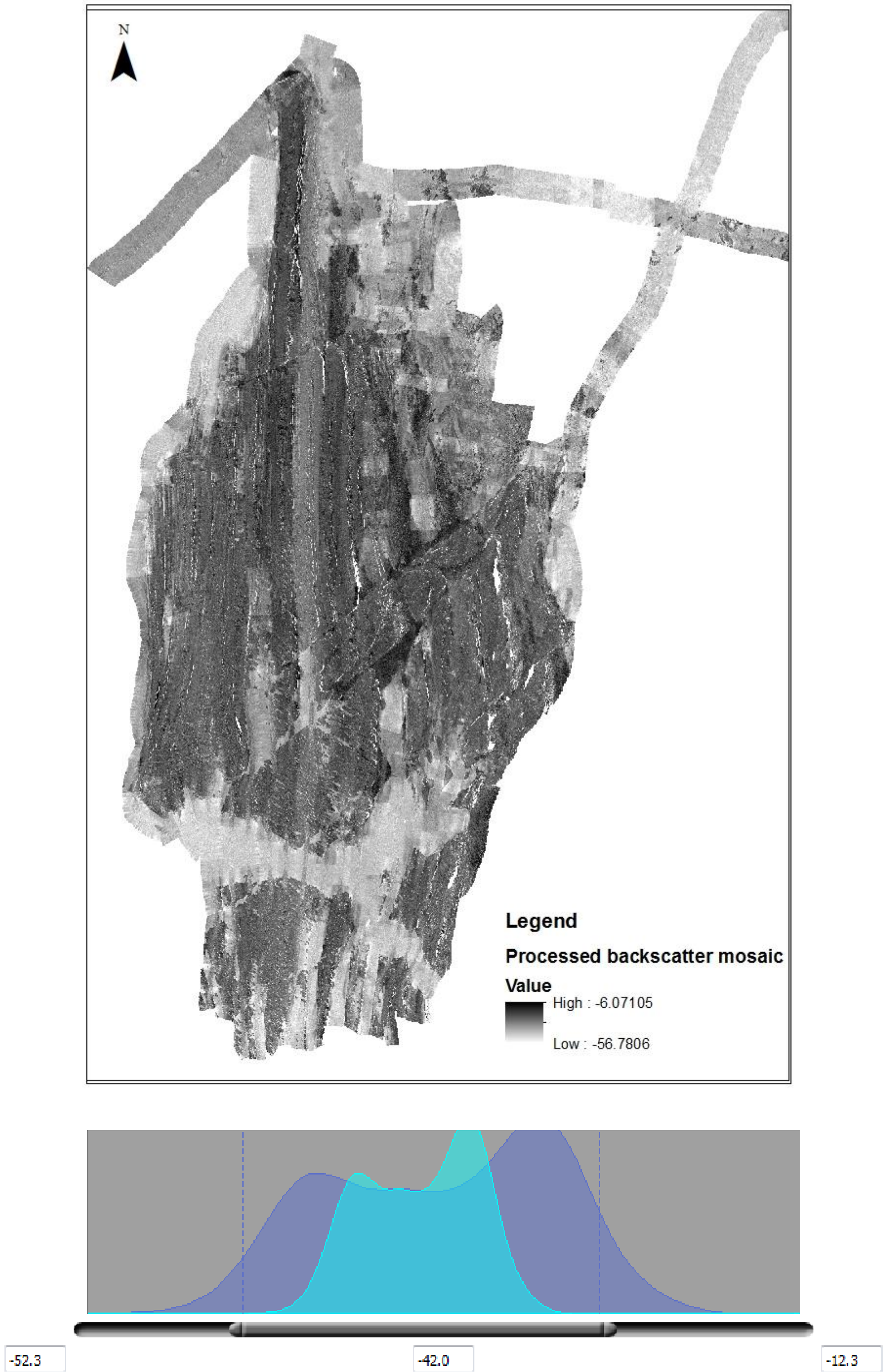

Figure 3.1: Multibeam echosounder backscatter mosaic of Pariokariwa Reef, based on the survey performed in December 2014. Multibeam backscatter distribution (dB) over Pariokariwa Reef.

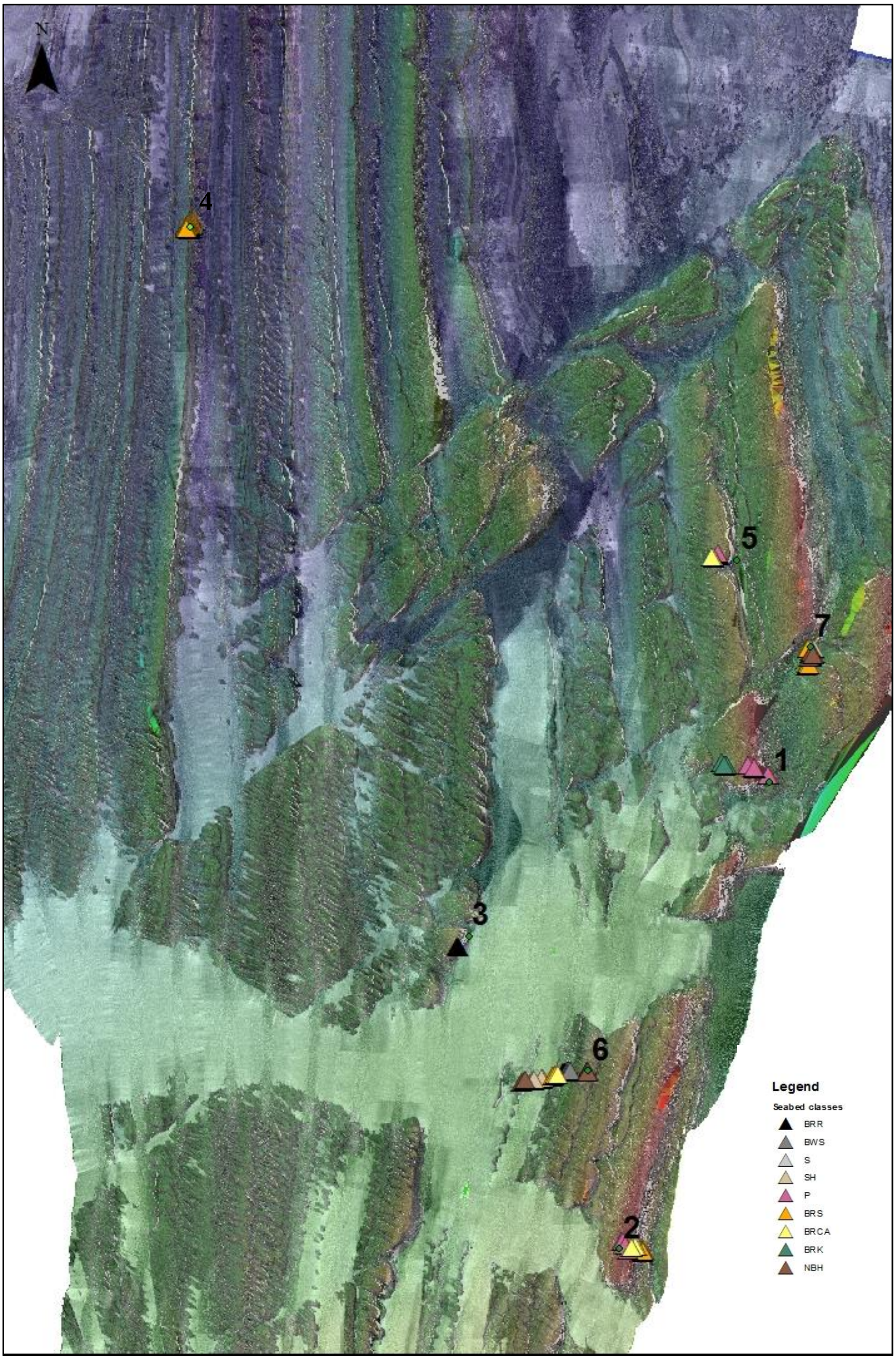

Figure 3.2: Backscatter imagery layered over top of bathymetric map with the position of ground truth stations classified on the bases of seabed type. Numbers 1-7 represent areas of the reef surveyed.

3.2.3 *In situ* surveying

Drop camera and scuba observational surveys were executed to aid in the interpretation and classification of the backscatter (Fig. 3.2). Photo quadrat surveys were carried out at four sites on the reef (1-4), drop camera at two sites (6 & 7), and an additional observational scuba survey at one (5). In addition to the ground truth data collected during this study, historical drop camera (2006) and bait remote underwater video (BRUV) footage collected by DOC and MetOcean Solutions (2012 & 2014) was also analysed, to identify dominant seafloor classes on the reef and confirm substrate classes identified at ground truth sites. Historical video footage was available for the entire reef, which made it possible to characterise acoustically defined areas with broad substrate and biota classes.

3.2.4 Drop camera survey

Georeferenced drop camera surveys were conducted from a 3.4m, rigid hulled inflatable boat on the 30th of January, 2015. Two transects were run across areas of the reef that were represented by heterogeneous backscatter responses. The first transect was run at site 1, and the second a site 2 (table 1). For the purpose of this survey two GoPro cameras were fixed to a steel tripod frame, and were lowered into the water from the boat, until the frame made contact with the seafloor. The drop camera was then pulled out of the water prior to the boat progressed forward, to prevent the frame hitting the reef and damaging biological habitat and our equipment while the boat was in motion. After each camera deployment the boat would move forward along the transect for 10-15 seconds and then the camera would be deployed again. The first camera sampled at a frame rate of 1 still, every 10 seconds, and was positioned so that the lens looked down the frame, into the quadrate attached to the end. The second camera filmed the entire survey, and was positioned so that the lens was looking in the direction the boat was moving. A hand held GPS, kept on board the boat, tracked the entire survey, and images captured during the survey were time stamped to ensure that the location of seabed classes identified during the survey, could be identified on a georeferenced map. Track one (site 1), ran for 44m, and was a test run, while track two (site 2), was 115m. Of the 88 stills recorded, only 79 were suitable for image analysis, owing to problems of exposure, focus, and field of view.

3.2.5 Scuba observational survey

An extensive scuba survey was executed on the north eastern section of Pariokariwa reef (174.509336, -38.872914; Site 5; Fig. 3.2). The location of this site was chosen based on the seabed's interesting morphology and mixed array of backscatter intensities. A shot line and float was used to pinpoint the location of the coordinates chosen for this survey. Two divers descend down the shot line and ran a 36 m transect reel along the profile of the reef. Diver 1 carried a slate and water proof paper with the outline of the reef printed on it, while diver two carried the transect reel, tape measure and a float line with a hand held GPS attached to it. A tape measure was used to measure the distance biological communities protruded from topographical feature on the reef bed, and also the size of the community in metres.

The purpose of this exercise was to produce a habitat map of the site, clearly identifying habitat boundaries across the morphology of the reef, at a finer taxonomic resolution to the drop camera surveys. The final habitat map was layered over the backscatter mosaic associated with that site which allowed affiliation of environmental data (geological and biological) collected at a local scale, with backscatter signatures collected over a large spatial scale.

3.3 Data Analysis

3.3.1 Video data

Approximately 18.3 minutes of video footage was classified into 10s segments. Dominant substrate and biological habitat classes were identified within each segment, and assigned independent codes. The segment length was determined based upon camera 1's 10 s frame rate, which meant that each video segment was matched up with a time stamped image. Each video/image set was coded on the basis of prominent substrate and biogenic habitat type: S (sand), SH (sand and shell hash), BWS (bedrock reef with sand), BRR (bedrock reef), P (*Polysiphonia* bed), SG (sponge garden), BR (biogenic reef), BRK (biogenic reef dominated by kelp), BRMA (Biogenic reef dominated by mixed algae), BRS (Biogenic reef dominated by sponge), BRCA (Biogenic reef dominated by colonial ascidians) and NBH (No biogenic habitat). The results of video analysis informed the majority of seabed class validation, because it represented the most abundant and spatially complete coverage of the classified area.

3.3.2 ArcGIS Spatial Analysis

Segmentation of the backscatter mosaic was done using the Spatial Analysis extension in ArcGIS 10.2.2. The Spatial Analysis extension offers an image classification toolbar, which identifies patterns in the backscatter imagery, and produces a raster, comprising of training classes used for thematic maps (ESRI ArcGIS, 2015). The spatial analysis tool classified the backscatter data using ground truth data (Table 3.1), and converted the backscatter imagery into a raster map. Spectral signatures identified through ground truthing the backscatter were used to classify the entire image using a supervised classification algorithm. Four substrate classes were identified through *in-situ* observations: S (sand), SH (sand and shell hash), BWS (bedrock reef with sand) and BRR (bedrock reef). In addition to the substrate classes, biogenic habitat classes were also identified through *in-situ* survey: P (*Polysiphonia* bed), SG (sponge garden), BR (biogenic reef), BRK (biogenic reef dominated by kelp), BRMA (Biogenic reef dominated by mixed algae), BRS (Biogenic reef dominated by sponge), BRCA (Biogenic reef dominated by colonial ascidians) and NBH (No biogenic habitat).

Ground truth data was collected from six of the seven sites chosen for survey. Backscatter values, associated with each seabed class were randomly collected from georeferenced marks identified within the ground truth sites. Backscatter values were randomly chosen within a 10 m radius of each ground truth mark, to reduce the level of error associated with the positioning of the tracking GPS system (<1m), and the resolution of the grid (0.27 m). It has been recommended by Sutherland *et al.* (2007) that ground truth data should be collected within an 8-20m radius of the station in order to achieve a strong correlation between ground truth information and the acoustic data. Consequently 20 backscatter intensities for each seafloor class (12) were chosen randomly from the 6 ground truth sites. The mean, standard deviation and standard error values were calculated for each seabed class, and were presented as a box and whisker plot (Fig. 3.3). A one-way analysis of variance (ANOVA) was used to test the null hypothesis: relative backscatter intensity does not vary with seafloor type, (Underwood, 1997). The

ANOVA was followed by a Duncan's Post Hoc test, to test for any similarity between the various seabed classes (Table 3.2). The aim of statistical analysis was to determine whether the internal texture of individual seabed class were statistically significant from one another, and to identify any statistical link between biogenic habitat and backscatter response.

3.4 Results

3.4.1 Map of backscatter intensity

The processed backscatter was displayed as an image with backscatter values ranging from -6.0 dB to -56.7 dB (Fig. 3.1). The substrate class BRR was characterized by backscatter intensities ranging between -36.6 dB and -31.5 dB (μ = -25 dB); and the SH dominated seabed, surrounding the reef, was associated with a backscatter intensity ranging between -41.6 dB and -23.8 dB (μ = -31 dB).

3.4.2 Ground truth data

Ground truth stations were set up to collect information on the geological and biological makeup of the seabed, across areas of Pariokariwa Reef, represented by unique morphology, and heterogeneous backscatter intensities. Ground truth locations are shown in Fig. 3.2 where the backscatter mosaic has been layered over the top of the bathymetry. The location of the drop camera sites (6 & 7) were chosen based on the smooth transition from bedrock - sand habitat at these sites.

Analysis of the video footage is based on 111, 10 s segments of footage. Twelve seabed classes were identified through analysis of the video segments and were used to classify the backscatter data. The following seabed classes were used to characterize the seabed: S, SH, BWS, BRR, P, SG, BR, BRK, BRMA, BRS, BRCA and NBH. The drop camera footage and imagery was good for characterizing different types of hard-substrata and broad habitat classes (e.g. P vs. SG); however, it was not good for discriminating between different sediment types (e.g. S vs. SH), or classifying biology at a high taxonomic level.

Direct observations by divers at Site 5 showed biogenic reef, especially sponge habitat, dominated the vertical face of the reef and overhangs, while the seabed surrounding the reef was largely associated with mixed turf, sand and shell hash or no biogenic habitat.

3.4.3 Relationships between seabed type and acoustic response

Analysis of variance (ANOVA) was used to test for differences in relative backscatter intensity between the 12 seabed types identified through ground truth surveys. The ANOVA showed significant differences in backscatter intensity between the 12 seabed classes (Table 3.3) ($p<0.01$). This means that the null hypothesis indicating no significant difference in backscatter intensity, between seabed classes, was rejected. The one-way ANOVA test was followed by Duncan's post hoc test to examine any differences in relative backscatter intensity between the 12 seabed classes. Table 3.2 shows the results of the Duncan's test and indicates that 9 of the 12 seabed classes produced a backscatter response that was significantly different for at least one other class. Duncan's test indicated BBR, BRS and BRK produced a significantly higher backscatter intensity compared to S, SH, NBH and P ($p<0.05$). Backscatter intensity significantly decreased from -25 dB to -31 dB with the transition from BBR and BR to S ($p<0.05$). However, the two substrate classes S and SH were associated with similar backscatter intensities which meant that classification analysis of the backscatter mosaic could not tell these two class apart ($p=.62$).

To produce thematic maps using the acoustic data, a threshold value was established, in order to identify spatial boundaries between seabed classes (sedimentary seabed and biogenic habitat typologies). The box and whisker plot showing mean and standard error ranges, identified a single threshold value (-29 dB), as indicated in Figure 3.3. Seabed typologies associated with an acoustic response above -29 dB were characterized by high backscatter values, while seabed classes below the threshold were characterized by low backscatter values. The threshold value separated the seabed classes into two broad groups, (1) BBR, BWS, BRS, BRK and BRCA (>-29 dB, μ = -25 dB), (2) S, SH, NBH, and P (< -29 dB, μ = -31 dB) (Fig. 3.3). Results from Duncan's post hoc test showed certain seabed classes shared similar backscatter intensities, and therefore could not be differentiated from one another. It is clear from looking at Fig. 3.4 that biogenic habitat classes (BRS, P, BRM and BRCA), commonly associated with the vertical face of the reef and overhangs, produce an acoustic response similar to bare bedrock reef. The results of the post hoc test, identified in Table 3.2, indicate that some of the biogenic habitat classes, associated with BBR (SG, BR, & BRMA), coincide with other seabed classes and therefore could not be used to classify the backscatter imagery.

Table 3.2: Summary table of analysis of variance for backscatter intensity.

Variable	F	P
Backscatter intensity	**3.34**	**0.00**

Table 3.3: Summary table of Duncan's test of comparison between seabed classes and their associated backscatter intensities.

Seabed type	BRR	S	SH	BWS	BRS	NBH	P	BRK	BRCA
BRR		**0.00**	**0.01**	0.38	0.87	**0.01**	**0.04**	0.70	0.70
S	**0.00**		0.62	**0.02**	**0.00**	0.61	0.26	**0.00**	**0.00**
SH	**0.01**	0.62		0.07	**0.00**	0.97	0.48	**0.02**	**0.02**
BWS	0.38	**0.02**	0.07		0.32	0.06	0.22	0.58	0.58
BRS	0.87	**0.00**	**0.00**	0.32		**0.00**	**0.03**	0.61	0.60
NBH	**0.01**	0.61	0.97	0.06	**0.00**		0.49	**0.02**	**0.02**
P	**0.04**	0.26	0.48	0.22	**0.03**	0.49		0.09	0.09
BRK	0.70	**0.00**	**0.02**	0.58	0.61	**0.02**	0.09		0.97
BRCA	0.70	**0.00**	**0.02**	0.58	0.60	**0.02**	0.09	0.97	

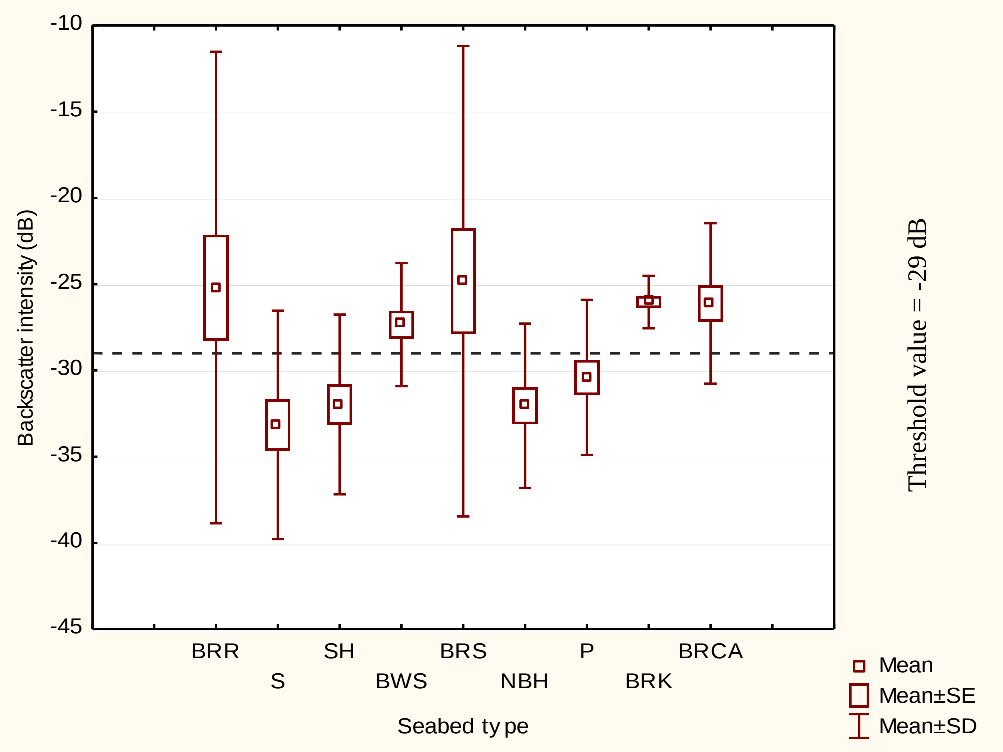

Figure 3.3: Whiskers plot of backscatter intensity for different seabed typologies (threshold value is indicated on the right hand side of the plot). High backscatter values are associated with bedrock reef (BRR), bedrock reef with sand (BWS), Biogenic reef dominated by sponge (BRS), biogenic reef dominated by kelp (BRK) and biogenic reef dominated by colonial ascidians (BRCA). Low values correspond to sand (S), sand and shell hash (SH), no biogenic habitat (NBH), and *Polysiphonia* beds (P).

Figure 3.4: Relative backscatter intensity and position of the ground truth stations classified in relation to various seabed classes. Average backscatter above and below the threshold (-29 dB) were used as the two relative backscatter classes.

3.4.4 Supervised Classification

Thematic maps of the seabed cover types are displayed in Figures 3.5-3.6. Figure 3.5 illustrates the results of supervised classification and identifies SH, BWS, BRS and P as the dominant training classes. P produced the strongest backscatter return out of the 5 habitat classes (μ = -29.8 dB), followed by BRS (μ = -30.5 dB). BWS produced the strongest acoustic return out of the two dominant substrate classes (μ = -25 dB), followed by SH, which produced the weakest backscatter return (-35.3 dB).

BRS was the dominant habitat class on Pariokariwa Reef, with this class covering 22.5% of the surveyed region. The second dominant habitat class on the reef was P, which covered 13.6% of the survey area. The predominant substrate class was SH, which covered 51.3% of the survey area, followed by BWS 12.4% (Fig. 3.6). Confusion arose when attempting to differentiate between the following seabed classes, in backscatter imagery: S with SH, NBH and P, and BBR with BWS, BRS, BRK and BRCA. S was confused acoustically with the classes SH (p = 0.62), and NBH (p = 0.61). SH was largely associated with backscatter values below the threshold value (-29 dB), and successfully trained the backscatter imagery (Fig. 3.5). The seabed typology, BRR, was confused acoustically with biogenic habitat classes residing on bedrock reef, and therefore acts as the main source of scattered acoustic energy. Poor classification results were also obtained between the classes BRK and BRCA, because these classes shared some overlap with dominant seabed typologies.

Figure 3.5: Class distribution resulting from the supervised Classification of the MBES backscatter data in ArcGIS. Supervised classification was performed on a grey-scale mosaic of the MBES backscatter, retrieved from Pariokariwa Reef, Northern Taranaki in December 2014. Where BRCA = biogenic reef dominated by colonial ascidians, BRK = biogenic reef dominated by kelp, BRR = bedrock reef, BRS = biogenic reef dominated by sponge, BWS = bedrock reef with sand, NBH = no biogenic habitat, P = *Polysiphonia* beds, S = sand, and SH = sand and shell hash.

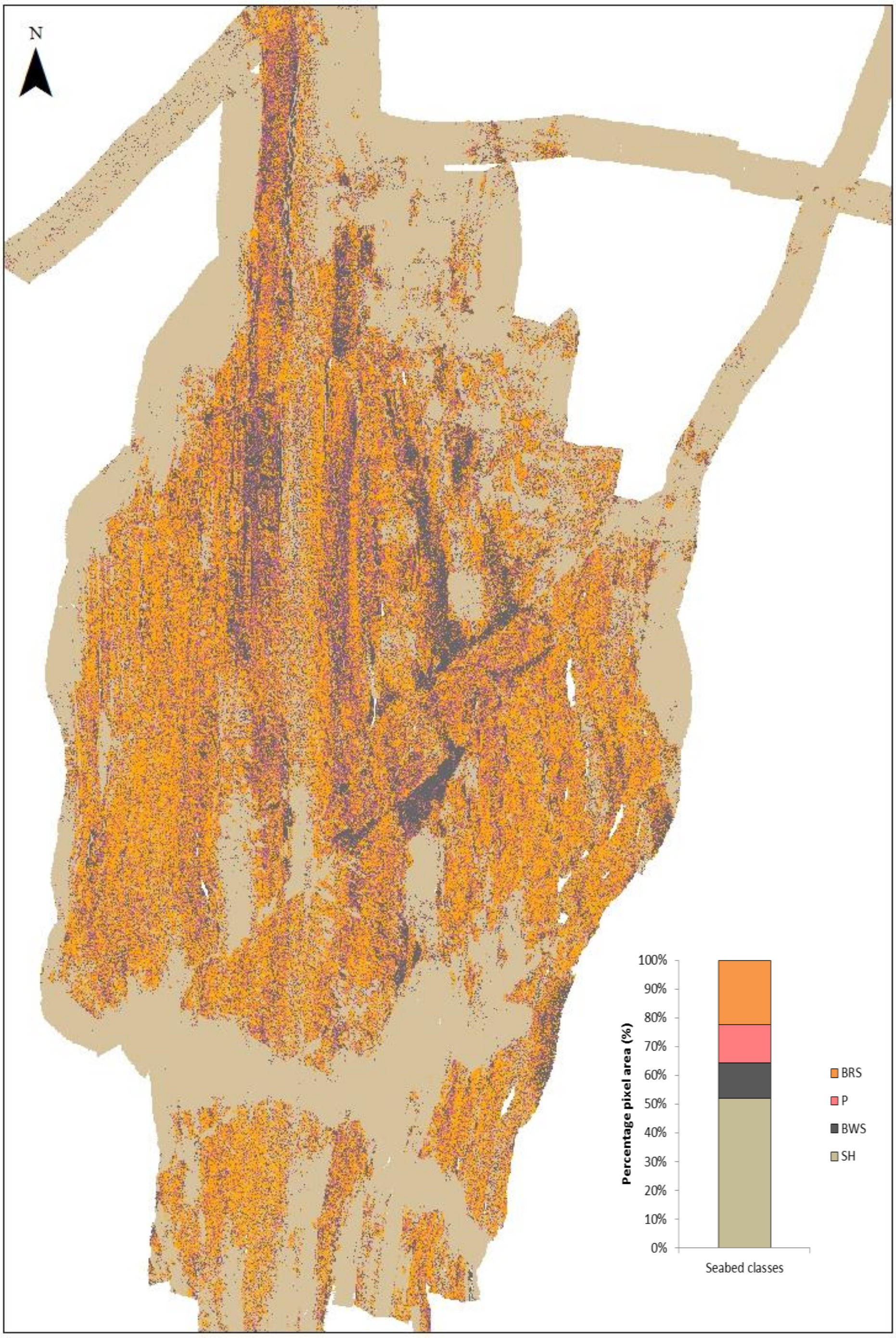

Figure 3.6: Class distribution resulting from the supervised Classification of the MBES backscatter data in ArcGIS. Supervised classification was performed on a grey-scale mosaic of the MBES backscatter, retrieved from Pariokariwa Reef, Northern Taranaki in December 2014. Where BWS = bedrock reef with sand, SH = sand and shell hash, P = *Polysiphonia* beds, S = sand, and BRS = biogenic reef dominated by sponge

3.5 Discussion

3.5.1 Acoustic seafloor classification

Seabed cover types could not be distinguished from backscatter intensity alone. Therefore the acoustic data was segmented using ground truth data collected from Pariokariwa, in order to produce a thematic map. Supervised classification of the backscatter data indicated textual variation within the backscatter mosaic, which was related to micro-scale roundness (e.g. biogenic habitat zonation on bedrock reef, and sand, and shell hash within troughs), and impedance of the seafloor; thus supporting the finding of other studies (De Falco et al., 2010; Ferrini & Flood, 2006; Huang et al., 2013).

Statistical analysis of the ground truth and acoustic data sets indicated a significant difference in acoustic response between 9 of the 12 seabed classes identified. However, supervised classification only matched up 4 of the 9 seabed classes, with acoustic classes in the mosaic. Two of the substrate classes, BBR and S, that appeared dominant through observational surveys, overlapped with other seabed classes in the model (Fig. 3.6), and therefore have no predictive ability. This means that the resolution of the backscatter mosaic is weak, which has led to acoustic confusion when attempting to differentiate between image, derived acoustic classes. Bedrock has a stronger acoustic return to other substrates, because of its high acoustic impedance contrast (Huang *et al.*, 2013). However, this substrate class overlapped with classes P and BRS, which means the consolidated reef structure below the sponge habitat is generating a stronger acoustic signal than the overlying habitat and is therefore influencing the return signal as found in work by Lucieer et al. (2013). Biogenic structures, especially sponges, are not prone to producing such a strong acoustic response because the thin walled, siliceous skeleton of these organisms, allows them to absorb some of the acoustic energy (Conway *et al.*, 2005).

The seabed class SH produced a stronger backscatter return compared to S and finer sediments. This is attributed to the substrates higher acoustic impedance contrast and relative surface roughness, which causes stronger surface scattering (Huang et al., 2013). Sand is more homogenous in particle size compared to coarser sediments (sand + gravel, or sand + shell hash), which is why the acoustic return of sand is lower (De Falco *et al.*, 2010; Huang et al., 2013). Based on previous studies and the results of the ground truth survey associated with this study, S should have produced the lowest acoustic return in this study area; however, statistical analysis indicated this substrate class did not significantly differ in acoustic intensity to SH.

There were areas of the backscatter imagery that appeared to be incorrectly classified as sand and shell hash, while ground truth surveys indicated this was not the case. Observational scuba and drop camera surveys on the seafloor surrounding Pariokariwa Reef, classified the sediment as being coarse sand and shell hash mounds, with fine-grained sand/silt built up in the troughs (Fig. 3.7A – 3.7B). The supervised classification model also failed to predict classes BRCA, BRK, SG, and BRR which were misclassified into the classes P and BRS.

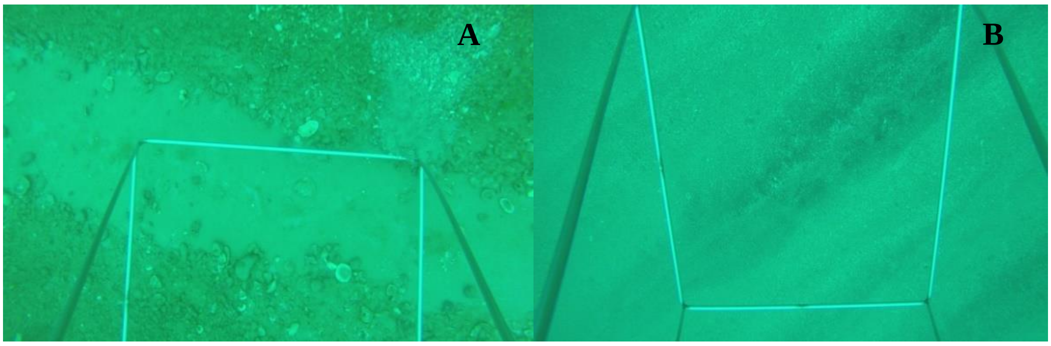

Figure 3.7: Sand and shell hash mounds with organic build up within trough (A), and sand with fine silt infused within it (B).

The results of this study are encouraging, considering only a day of acoustic survey was allocated to Pariokariwa Reef and a limited number of sites were ground truthed. The results of the MBES survey suggest that further developmental research within Paraninihi Marine Reserve is necessary in order to increase the resolution of the backscatter imagery, and thus increase the accuracy of seabed classification. The technique described here demonstrates how reliable classes defined through ground truthing can be used to partition acoustic classes into attributes with known predictive power. However, the ability of this model to identify acoustic signatures that act as surrogates for ecological character and attendant species is limited without further statistical analysis and modelling as indicated by (Lucieer et al., 2013).

Acoustic surveying technology has been adapted as a standard tool for survey reef systems, however, previous studies report the production of accurate imagery over sediment areas but only mixed success over reef systems (Collier & Humber, 2007). Backscatter imagery over reefs is often compromised due to the reduced amplitude of the multiple returns as a result of loss of energy and scattering when making contact with rough reef surfaces. The grazing angle (angle at which the acoustic wave intersects the seabed) modulates the backscatter response, and is responsible for acoustic shadowing within imagery. Acoustic shadowing occurs when the bathymetric wavelength is shorter than the swathe width, and is making track over high relief regions of the reef (Collier & Humber, 2007). Shadowing in the imagery is a common attribute of SSS because these systems are often towed close to the seabed (Schimel, 2011).

The presence of dense, highly diverse sponge communities within the reef overhangs failed to be picked up by the sonar. These regions of the backscatter imagery are represented by no data as a result of acoustic waves scattering over complex terrain and energy being lost within concave reef areas. A solution to reduce the level of shadowing within imagery is to achieve 20-50% overlap between parallel survey tracks. Overlap between tracks prevents minor errors in navigation and allows for the correction and confirmation of detailed seabed features from one track to the next (Le Bas & Huvenne, 2009). The quality of backscatter imagery can be assessed based on the consistency of features in overlapped regions, and the absence of acoustic class boarders parallel to the survey track (Preston, 2009).

However, working with overlap between tracks still makes seabed classification a challenge because it is difficult to know which data should be used in the final map (Le Bas & Huvenne, 2009). The easiest method for sorting through overlapping regions of the data set is to use a code where, for example, the latest data points overwrite previously logged imagery. One issue associated with this method is the uncertainty that the latest acquired data is superior to the older data. Another option is to cut a line halfway between the overlapping tracks, and only use the imagery closest to the track. A variation of this method is for the user to manually appoint where the line is to be cut, and therefore particularly good imagery (distinct features), or noisy artefacts can be selected or cut around. An advantage of using this method is that the user can target any features (e.g. pinnacle, overhang) that have been insonified from two directions. One final method is to average the overlap of the two acoustic data sets around the halfway line, cut between the overlapped tracks. The disadvantage of this method is that features may be insonified from multiple directions and therefore data collected within the overlap may be from different angles of the same feature. Detail on the morphology of the seabed would consequently be lost as a result of averaging the overlapping imagery (Le Bas & Huvenne, 2009).

It is also plausible that the MBES backscatter imagery produced for this survey was compromised, and only a handful of seafloor classes detected, as a result of the multibeam device being hull mounted rather than towed closer to the seafloor like SSS. When the system is hull mounted, the transducers receives data from a constant height above the seabed and therefore recording incidence angles at varying heights and angles. Sidescan sonar produces superior backscatter imagery to MBES because the transducer is towed closer to the seabed; therefore, these instruments insonify a wide swath of seabed, and continuously log a range low, near grazing incident angles (Blondel & Sichi, 2008; Boulay, 2012; Le Bas & Huvenne, 2009). As a result of these low, near grazing incidence angles, SSS provides valuable information on bottom morphology and lithology which increases the resolution of seabed imagery. However, SSS provides no information on bathymetry which makes its imagery complex to understand (Le Bas & Huvenne, 2009). The identification of morphological features on a bathymetry map, such as sand megaripples, provides a valuable clue as to the expected seabed morphology and therefore assists with acoustic seabed classification and the production of feature-rich habitat maps. To increase the resolution of the reef imagery, and produce a more detailed thematic map of Pariokariwa Reef, it would be beneficial to use SSS alongside MBES to ensure interpretation of high resolution bathymetric data is assisted by high resolution backscatter imagery (Blondel & Sichi, 2008; Le Bas & Huvenne, 2009).

3.6 Conclusions

This research provides an unrefined technique for processing and interpreting acoustic data, into spatially explicit habitat maps. The study involved an acoustic survey, conducted over Pariokariwa and Waikiekie Reef, using the Reason 7125 SV2 Dual Frequency Multibeam Echosounder. Results from the study showed that conjoined bathymetry and backscatter data sets provide a robust means of producing thematic maps of the reef. With refinement this technique could be used as a tool to predict habitat-species relationships elsewhere in the region. The resolution of the acoustic data compiled for this study was high enough to identify four dominant seabed classes (SH, BWS, BRS and P) within the backscatter, which means the hypothesis investigating the ability to match up habitat types with acoustic signatures in the backscatter, was accepted. However, the imagery was not detailed enough to differentiate between overlapping seabed classes, that appeared to be statistically different from one another, based on multivariate analysis (BRR, NBH, S, BRK and BRCA). Therefore, the resolution of the imagery needs to be improved to increase the accuracy of seabed classification. Nevertheless the MBES survey performed within Paraninihi Marine Reserve, and the processing and classification methodologies that followed, were novel advances in benthic habitat mapping for the Taranaki Region, and have laid down strong foundations for future research within the reserve and elsewhere in the region.

Classification of the backscatter imagery would improve by collecting higher resolution backscatter imagery and partitioning the imagery, using ground-truth data collected from a wider range of sites on Pariokariwa Reef. Ultimately, this method, when fully refined, will allow users to produce spatially accurate habitat maps that allow us to predict habitat-species relationships across Pariokariwa Reef and other regions of the seabed in the Taranaki Region. Predictive habitat models are a highly desirable tools, because they provide a means by which researchers, managers and stakeholders can characterise and map the extent of habitat types across the seabed, an in this case within an established marine reserve. A habitat map of Pariokariwa Reef, within Paraninihi Marine Reserve, would therefore generate a better understanding of the habitats afforded protection within the MPA, and how they may be responding to removal of human abstractive impacts.

Chapter 4: *Characterisation of biological communities on Pariokariwa Reef*

4.1 Introduction

A central issue in benthic community ecology is determining what physical and biological factors are influencing spatial variation in community structure. The distribution of benthic communities is strongly correlated with seabed topography, hydrodynamic and sedimentary processes (Tecchiato *et al.,* 2015). An important topographical feature of reef systems is aspect, because the “exposure” or position of the reef platform to prevailing swell conditions, sunlight levels or suspended sediment deposition, influences benthic habitat distribution (Guichard *et al.,* 2001; Lucieer *et al.,* 2013). Hydrodynamic processes play a major role in structuring benthic communities by the influence on propagule and larval dispersal, food supply and transport of sediments (Bourget *et al.*, 1994). Such physical factors indirectly influence benthic communities by modifying or regulating local scale factors (e.g. competition for space); but can also directly influence population structure and distribution (Menge & Olson, 1990).

Declining water clarity and increased turbidity, associated with suspended sediments, is closely linked to the declining health of benthic marine ecosystems, and their associated biota, including sponge reefs. Terrigenous sediment deposition in marine ecosystems is recognised as an influential disturbance agent, because fine-grained sediments are prone to smothering and killing small marine infauna and settling propagules (Lohrer *et al.*, 2013; Stubler *et al.*, 2015; Battershill & Bergquist, 1990). Sediment depth and grain size predominantly influence sponge distribution. Most species can tolerate fine to medium grained sediments, if the sediment layer is <1.0 cm in depth (Battershill, 1987, Battershill & Bergquist, 1990). Topographic features such as trenches, cracks and crevices accumulate more sediment, compared to flat, low sloping areas, or reef overhangs (Tecchiato et al., 2015). Areas of the seabed that accumulates more sediment tend not to accommodate adult sponge communities, because sponge propagule establishment is low in areas with overlying sediments >0.5mm (Battershill & Bergquist, 1990.).

4.1.1 Influence of disturbance regimes on population structure

Sediment scour, transport and deposition through wave action and storm disturbances can directly influence sponge habitat; even the smallest perturbation can free up bare space on the reef, in a manner which perhaps influences the orientation of sponge communities (Battershill, 1987). Propagule settlement and recruitment in established sponge populations increase, with the increasing level of disturbance in the area. Settlement rates increase after a disturbance because primary space has been freed up for a finite period of time (Battershill & Bergquist, 1990). Substrate selection by recruiting benthic marine invertebrates and successful establishment, has been proven to influence the spatial distribution of adult populations (Battershill & Bergquist, 1990). When there is limited bare space for propagules to settle on the reef, propagules tend to anchor themselves to rock and shell fragments within the trough of sand megaripples (Battershill, 1987).

Microenvrionmental conditions (e.g. light availability), and substrate type play an important role in settlement success and propagule survivorship, which suggest these variables influence marine invertebrate substrate selection. Bergquist *et al.* (1970) discovered that sponge propagules are capable of settling on a variety of surfaces, and later Battershill and Bergquist (1990), proved the use of settlement cues (e.g. chemical, light, gravity and turbulence) by propagules. The results of this study showed that sponge propagules selectively orientated themselves towards rock fragments ranging in grain size between 0.4 and 0.7mm in diameter. Ninety-five percent of propagules allocated to mixed shell/rock fragment and gravel/rock fragment sites settled exclusively on rock fragments (Battershill & Bergquist, 1990). These results are evidence that sponge propagules and larvae use chemical cues to select a substrate to settle and establish on. Settled propagule survivorship rates increase with increasing grain size and sediment depth (Battershill, 1987).

The aims of this chapter were to trace the origin of suspended sediment loads, entering and settling in Paraninihi Marine Reserve; and determine whether Pariokariwa Reef’s unique morphology influences suspended sediment deposition and thus the characterising sponge community composition and distribution on the reef. This chapter first explores what physical and biological disturbances influence patterns of distribution, abundance and diversity in sponge communities across the seabed. This will be followed by a review of studies investigating what influence natural disturbances (e.g. storms) have had on community structure, through the mediation of generating bare space for larval recruitment. The final section discusses whether any physical cues influence which substrate sponge propagules choose to settle on.

The following hypotheses were tested in this chapter: 1) The Whitecliffs area is one of the main sources of sediment into Paraninihi Marine Reserve. 2) Pariokariwa Reef's unique geomorphology influences sponge community composition and distribution.

4.1 Methods

4.1.1 Photo quadrat survey

Georeferenced photo quadrat surveys were executed at 4 sites on Pariokariwa Reef on the 18th and 19th of February, 2015. Sites were chosen for survey based on their unique bathymetry and heterogeneous backscatter, and were located by x and y coordinates. The coordinates for each site are available in the table below (Table 4.1). Two divers descended down the anchor line at each site, carrying with them 1 GoPro camera fitted to a 1 m^2 quadrat frame. The photo quadrat was randomly placed on varying faces of the reef and a photo was taken with every placement in order to capture any variation in community composition across the morphology of the reef (as seen in Figure 4.1). Each face of the reef (bottom, vertical, overhang and top) was represented by 10 photo samples. The location of each photo was recorded by hand held GPS attached to a surface float, which in turn was attached to the BCD (buoyancy control device) of one of the divers. At each site one of the divers would hold the float line taut over the photo quadrat as a photo was taken, to ensure the location of each photo was tracked from the water's surface. The coordinate location was recorded for every photo quadrat captured on the reef; so that the exact location of each substrate and habitat type identified by these images can be accuracy mapped and lined up with the acoustic data. Water depth (m) was also recorded along the profile of the reef to determine at what depth, reef profile changes (Table 4.2).

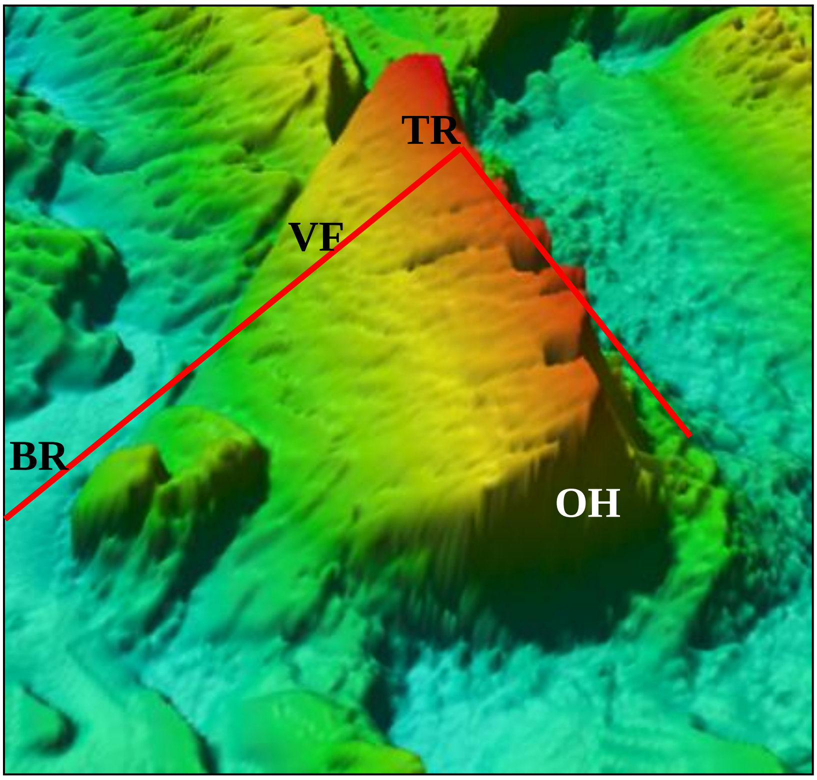

Figure 4.1: Bathymetric diagram showing the reef aspects used for the photo quadrat surveys. Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

Table 4.1: Coordinates of Pariokariwa Reef dive survey sites.

Site number:	Latitude (x)	Longitude (y)	Depth (z)
1	174.510914	-38.874171	12 m
2	174.506362	-38.879599	11.5 m
3	174.509742	-38.868544	15 m
4	174.400675	-38.868541	21 m

Table 4.2: Description of photo quadrat survey sites, conducted in February 2015.

Site number	Max depth (m)	Coarse substrate types	Slope (°)	Reef height (m)
1	12 m	Bedrock/sand	6.33	7 m
2	11.5 m	Bedrock/sand	5.12	5.3 m
3	15 m	Bedrock/sand	5.49	4 m
4	21 m	Bedrock/sand	3.44	3 m

4.1.2 Sediment samples

Sediment samples were collected at Site 3 and from the cliff face, bordering the landward (eastern) edge of the Paraninihi Marine Reserve. Samples were bagged in individual zip lock bags. Wet sediment samples were preserved in the fridge to stop traces of organic matter from breaking down, then analysed for grain-size distribution using the Malvern Laser Particle Sizer.

4.1 Data Analysis

4.1.1 Photographic data

Georeferenced photographs (137) were analysed using the software, ImageJ. Each image was reduced down to the outline of the 1 m^2 quadrat and the area of pixels within the quadrate was calculated for each image using the measure pixel area tool. An average quadrat area was calculated from the 137 measurements, and was used to calculate percentage solitary organisms (e.g. sponge), colonial organisms (e.g. jewel anemones), mixed turf, biogenic reef and silt deposit within each quadrat. The percentage area of species and habitat type within each image was then used as the basis for Permutational Multivariate Analysis of Variance (PERMANOVA), and Canonical Analysis of Principle Coordinates (CAP) in Primer-E v7 (McGonigle *et al.*, 2009).

4.1.2 Grain size analysis

The sandstone collected from the cliff face, onshore from Paraninihi Marine Reserve (Pukearuhe Beach), was crushed and dried before being weighed and run through the Malvern Laser Particle Sizer. Percentage volume of clay, silt, sand, and gravel (>2 mm) were calculated for each sample, along with median and mean grain size. Once all samples had been run through the laser particle sizer, organic matter (i.e. shell) in the samples was removed using hydrogen pyroxide (H_2O_2). Subsamples were then run through the laser particle sizer to calculate what percentage of the sample was made up of organic matter.

Mineralogical analysis was also run on the samples using x-ray diffraction mineral analysis (XRD), to determine what minerals made up each sample.

Sediment samples collected on Pariokariwa Reef were then compared to the sandstone sample collected from Whitecliffs, to determine the silts from Pariokariwa Reef are sourced from the local cliffs. If the samples share the same mineral signatures then it is likely that sediments deposition on the reef is mainly originating from local cliffs.

4.1.3 Multivariate analysis using Primer-E v7

4.1.3.1 PERMANOVA+ and CAP Analysis

Raw data sets were modified by removing any taxa from the data set that appeared in less than 1% of the photo quadrat samples, prior to transformation, to avoid modelling rarer taxa, and thus only targeting species that might discriminate across the reefs morphology (Anderson, 2008). Analysis was based on Bray-Curtis dissimilarities, calculated for square-root transformed abundance data using PRIMER-E v7. Square root transformation is an intermediate transformation that is often used on abundance data sets to reduce the skewness of the data and ensure that all species, dominant and rare, are accounted for in the Bray-Curtis Similarity Matrix (Quinn & Keough, 2002; Anderson *et al.*, 2008; Clarke *et al.*, 2014). The criteria is that variables should not show marked skewness across the samples, enabling meaningful normalisation, and that the relationships between these variables should be linear, to increase the definition of the Bray-Curtis dissimilarity for the biological data (Clarke & Ainsworth, 1994; Clarke et al., 2014). Draftsman plots were compute for each data set, and indicated that square-root transformations were suitable for all three data sets (habitat, phyla and sponge species).

PERMANOVA was used to detect differences in habitat type, community composition and sponge assemblages, and between reef aspects. Statistical analysis consisted of a single factor: reef aspect, which was fixed with four levels (bottom of reef, vertical face, overhang and top of reef), and the following variables: habitat type, phyla and sponge species richness. Multivariate analysis was performed using Bray-Curtis dissimilarities on square root transformed data (transformed to down-weigh the right skewness caused by numerous zero counts and abundant cover types and sponge species).

Canonical analysis of principle coordinates (CAP) was performed on the same variable groups to model changes in habitat distribution and community composition, across the different aspects of the reef. CAP was used to model the changes in assemblage structure occurring over the different reef aspects. Three data sets were analysed separately with the four dominant habitats (sponge garden, biogenic reef, turfing reef and no biogenic habitat (silt)), with Phyla (Porifera, Cnidaria, Bryozoa and seaweed), and the 20 most dominant sponge species occurring in the data sets. CAP draws an axis through the multivariate cloud of points, to indicate which samples are strongly correlated to one another, and are thus grouped together, because they are associated with the same biotic variables (Anderson et al., 2008). Interest lay in distinguishing whether percentage habitat, phylum or sponge community composition changed across the morphology of the reef; and more specifically was there any distinct grouping between samples collected from the overhangs, and those collected below the reef.

4.1.3.2 Univariate analysis:

Single factor ANOVA models were used to test for a significant difference in percentage habitat cover, for four distinct habitat classes (sponge garden, biogenic reef, turfing reef and silt), against reef aspect (factor). Another single factor ANOVA was employed to examine differences in percentage cover of four phyla groups (Porifera, Cnidaria, Bryozoa and seaweed) against reef aspect; and a third was employed to examine differences in sponge species abundance (20 species) against reef aspect. All three data sets were square-root transformed to meet the assumptions of ANOVA (Underwood, 1981).

4.1 Results

4.1.1 Photographic data

Image analysis using ImageJ, identified 66 distinct taxa across 5 Phyla. Rhodophyta (red algae) was the most common Phylum, contributing to 6.45% of all digitised percentage cover, followed by; Chlorophyta (4.10%), Porifera (3.97%), Cnidaria (1.08%), and Bryozoa (0.31%). Percentage cover of unidentifiable biogenic reef contributed to 8.35% of the overall total, and silt deposit 69.83%.

4.1.2 Sediment analysis

The Laser Particle Sizer classifies the sediment by calculating what fractions of the sampled volume were clay, silt and sand, and helps determine the origin of the sediment by comparing it with samples from various origins. The particle distribution diagram showed a peak between 0 - 4 phi units, in both samples; indicating both samples predominantly contained sand (Fig. 4.2). Median particle size for sample A was 59.9µm which is coarse silt, while the median particle size for sample B was 20.7µm which classified as medium silt.

Seventy three percent of sample A, collected from Site 3, consisted of sand, while 84.1% of sample B, collected from the same site, and was sand. Sample A, collected from the reef tops, contained a higher proportion of finer sediments compared to sample B, collected below the reef. Fig. 4.2 indicates sample A's particle size distribution was trimodal, with peaks of sand (74%), silt (14.8%) and clay (12.5%) in the sample. Sample B's particle size distribution was unimodal; with a single peak indicating sand (84.1%) is the dominant size class (Table 4.2). Sample B is positively skewed to the right, indicating this sample is predominantly made up of sand, with a long tail of fine sediment occurring at far lower volumes (15.8%).

X-ray diffraction mineral analysis (XRD) was performed on the two sediment samples and a sandstone sample, collected from Whitecliffs, to try and trace the origin of the samples backs to this iconic cliff face. XRD analysis on the sandstone sample indicated the sample was predominantly made up of the following clay minerals: vermiculite, montmorillonite, and illite. There were also peaks in falspar and quartz, which means a proportion of the sample, collected from Whitecliffs, is sand (Fig. 4.5). Traces of montmorillonite and illite were also detected in samples A and B; however, the peak in montmorillonite had evidently diminished, leaving illite as the dominant clay mineral within the samples (Fig. 4.3 & 4.4). The ratio of montmorillonite/illite in the sandstone sample collected from Whitecliffs was 12:28, which was significantly higher when compared to the sediment samples collected from Pariokariwa reef (2A = 5:1; 3B = 6:13) (Fig. 4.3 & 4.4). Both sediment samples contained peaks in quartz and falspar which is consistent with the results from the Laser Particle Sizer; identifying sand as the dominant particle size.

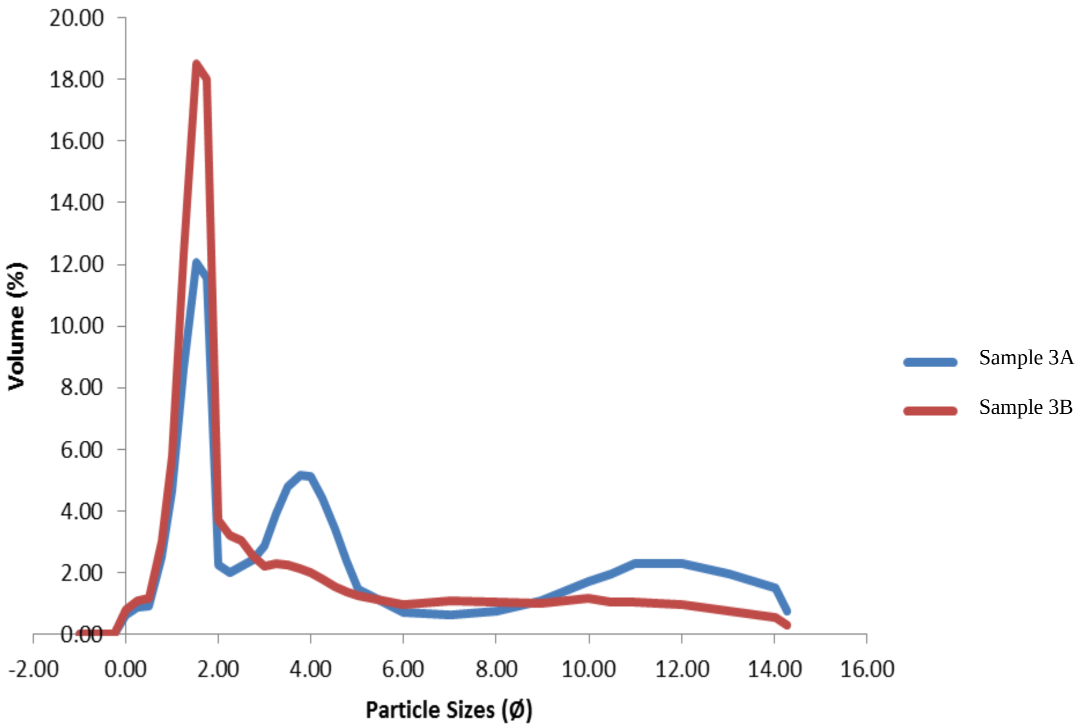

Figure 4.2: Overall laser diffraction particle size distribution of the sediment samples collected from site 3 on Pariokariwa Reef.

Table 4.3: Summary table for the results of the Laser Particle Sizer, showing the proportion of sand, silt and clay within each sample, and mean grain size for each sample.

Sample	Sand	Fines	Silt	Clay	Mean (Mz)	Sorting (SI)	Skewness (SkI)	Kurtosis (KG)	Mean (mm)
Sample 3A	72.62	27.38	14.82	12.56	3.12	2.66	0.52	1.63	0.115
Sample 3B	84.11	15.89	10.07	5.83	2.33	2.13	0.80	2.47	0.199

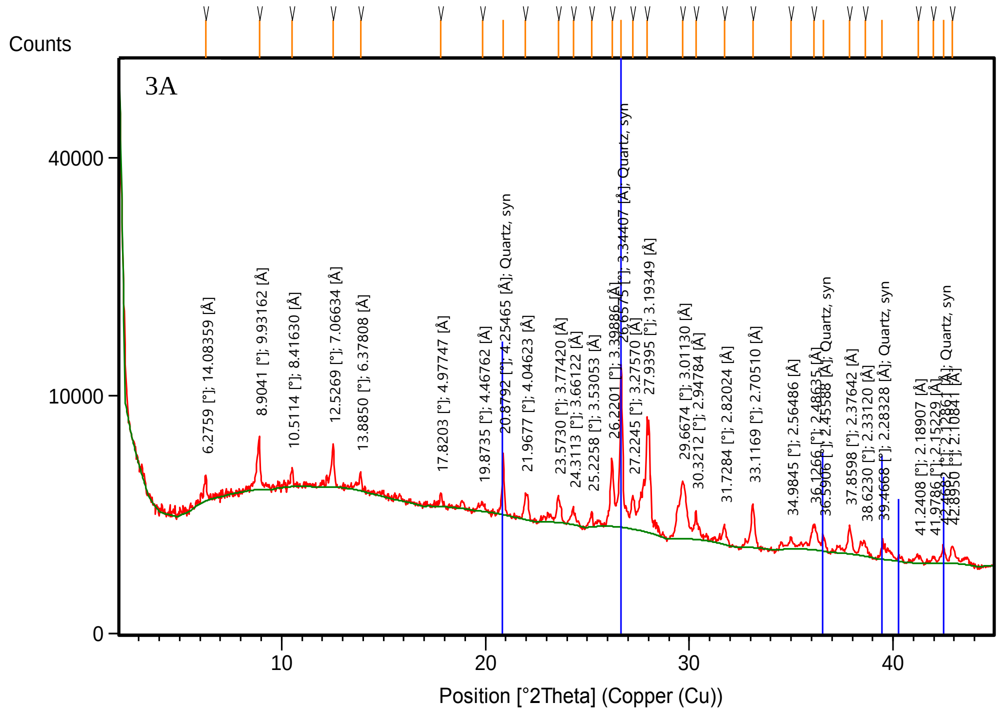

Figure 4.3: Overall laser diffraction particle size distribution of Sample A from site 3 of Pariokariwa Reef collected on 19 February 2015. The predominant minerals found in the sample were: montmorillonites, illites, chamosito, quartz, falspar, pyrophyllite and cronotedtite.

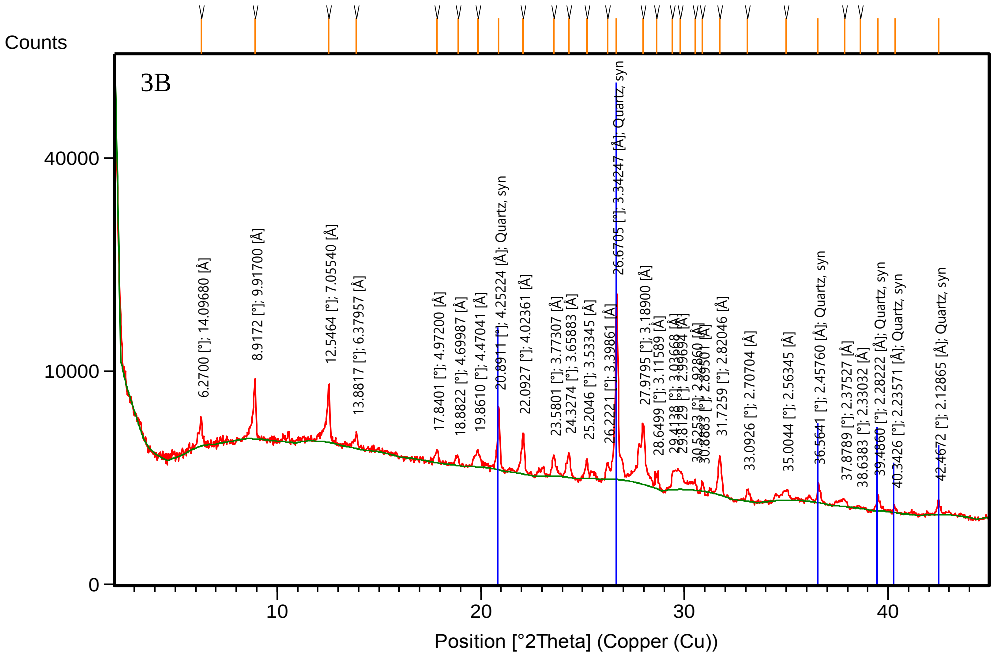

Figure 4.4: Overall laser diffraction particle size distribution of Sample B from Site 3 of Pariokariwa Reef, collected on 19 February 2015. The predominant minerals found in the sample were: montmorillonites, illites, chamosito, palygorskite, quartz, falspar, and chlorites.

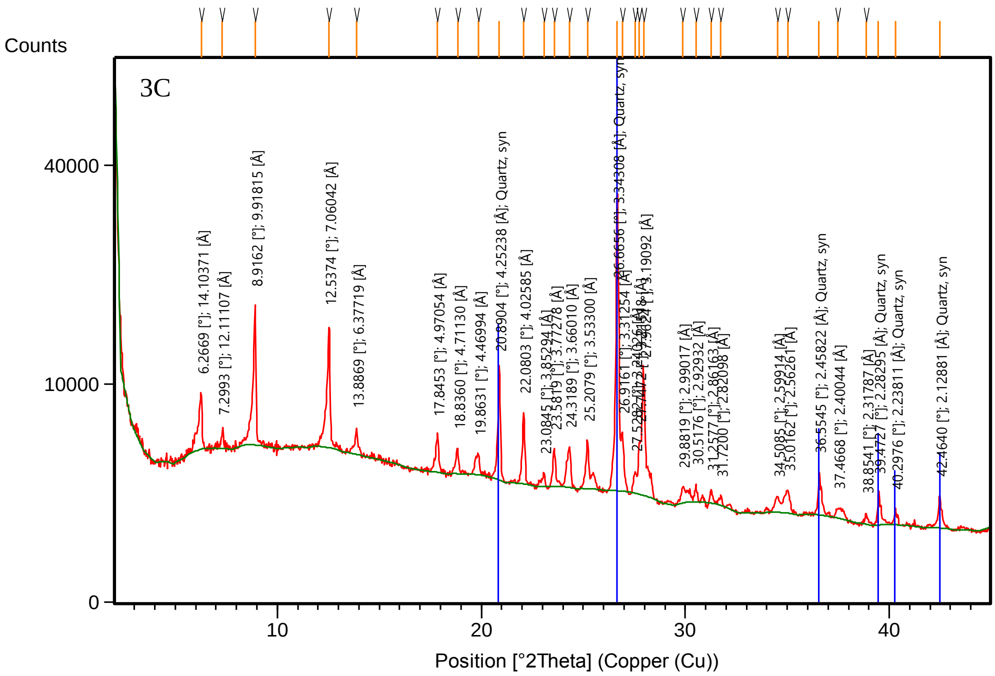

Figure 4.5: Overall laser diffraction particle size distribution of sample C, collected from Whitecliffs, collected on 19 February 2015. The predominant minerals found in the sample were: vermiculites, montmorillonites, illites, chamosito, quartz and falspar.

4.1.3 Analysis of biological community composition

PERMANOVA calculated the correlation strength between reef aspect and biological variables, associated with reef community composition. P-values produced by PERMANOVA were all significant (p=0.01), which indicates a highly significant difference in habitat, community composition, and sponge species richness, across the morphology of the reef. The resulting pseudo-F statistic from the first PERMANOVA (Table 4.4), calculated for the first data set (percentage habitat) was 51.1, which means habitat distribution and domination is strongly dependent on reef aspect. The second and third pseudo-F statistics as seen in Table 4.4 were the product of the PERMANOVA tests to follow. Both pseudo-F statistics were lower than the first (pseudo-F = 20.7, 7.1), which indicates that community structure and sponge species richness, were dependent on reef aspect, but not as strongly as large scale habitat types. This is because patterns, and processes (abiotic and biotic) vary in a scale-dependent manner; and therefore abiotic processes (e.g. reef aspect), that have an apparent influence on habitat distribution, will not influence community structure in the same way (Thrush & Lohrer, 2012). The results from the PERMANOVA tests indicate the null hypothesis, stating no difference in habitat type or community composition across the morphology of the reef, was rejected (p<0.01).

Table 4.4: Multivariate PERMANOVA results displaying the significance of interactions between habitat, distribution community composition, sponge species relative abundance and dominant species relative abundance (SQRT transformed), in response to reef aspect, using 999 permutations. (F = pseudo-F and P = p(perm).

Source	*df*	Percentage habitat			Percentage phyla			Sponge species (RA)			Dominant sponge species		
		MS	F	P	MS	F	P	MS	F	P	MS	F	P
Reef aspect	3	13291	51.15	p<.01	4055.8	20.7	p<.01	10742	6.7	p<.01	13083	28.5	p<.01
Total	136												

Figures 4.5 to 4.9 show the sample configurations from CAP analysis, based on habitat, phyla and species presence (square-root transformed data and Bray-Curtis dissimilarities), and reef aspect. CAP constrains the analysis to emphasise differences in community composition, between the different reef aspects. These data consist of four aspects of the reef (TR, VF, OH, and BR), and the following variables (habitat type, community composition and sponge species richness), which influenced data divisibility within the ordination. There is clearly grouping

in the multivariate cloud of points, which corresponds to changes in community composition on different faces of the reef. There is clear evidence of grouping and separation of the data along the CAP1 axis, which is attributed to environmental variables influencing their distribution. The first ordination investigated what habitats are commonly associated with different faces of the reef. Figure 4.5 is a graphical representation of the results of this analysis. It illustrates that sponge garden and biogenic habitats are the two variables influencing horizontal variation along the CAP1 axis. These two habitat classes appear to have a strong relationship with the reef overhangs. Sponge garden communities dominated the overhangs and were also recorded in high densities along vertical reef faces. It is evident from the mixed clustering of data collected from the reef OH, VF and TR, that vertical faces of the reef are not associated with overly distinct habitat classes. It is unclear for the ordination, whether sponge or biogenic habitat has the strongest correlation with this reef aspect. Areas associated with no biogenic habitat cover and a high percentage cover of silt appears to be located predominantly below the reef edge. The dominant substrate cover below the reef is sand and shell hash, rather than bedrock. Turfing reef (mixed seaweeds) appears to be commonly associated with both and the top and bottom of the reef; but is most strongly correlated with the reef tops. Percentage cover of *Polysiphonia* and mixed turf beds were significantly greater on the top of the reef compared to the bottom, where silt and organic deposit was prevalent.

Any associations between dominant phyla type and reef aspect were investigated using CAP. Biological communities on the reef predominantly consisted of taxa from the phylum Porifera and Cnidaria (Fig. 4.7). These two phyla were the predominate variables influencing data grouping and distribution along the CAP1 axis. Overhang communities were dominated by taxa from the phylum Porifera (e.g. *Ancorina alata*), and Cnidaria (e.g. *Corynactis australis,* jewel anemone). Taxa identified as being in the phylum Bryozoa, only contributed to a small percentage of reef community composition, and were predominantly recorded on the vertical face of the reef. Mixed turf (Phaeophyta and Chlorophyta) and *Polysiphonia* beds (Rhodophyta) were largely associated with reef tops, where in some areas these phyla (mixed turf), would take up 80-100% of the 1m^2 quadrat.

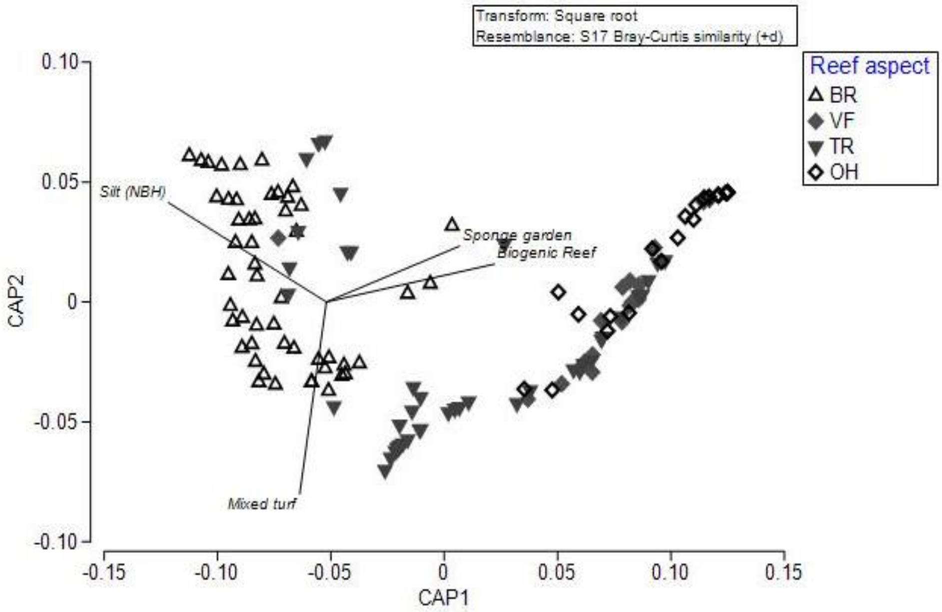

Figure 4.6: Showing habitat distribution of 4 dominant habitat types in relation to reef aspect. Two habitat types (sponge garden and biogenic reef) explain the majority of the variation in the data cloud, along the CAP1 axis. Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

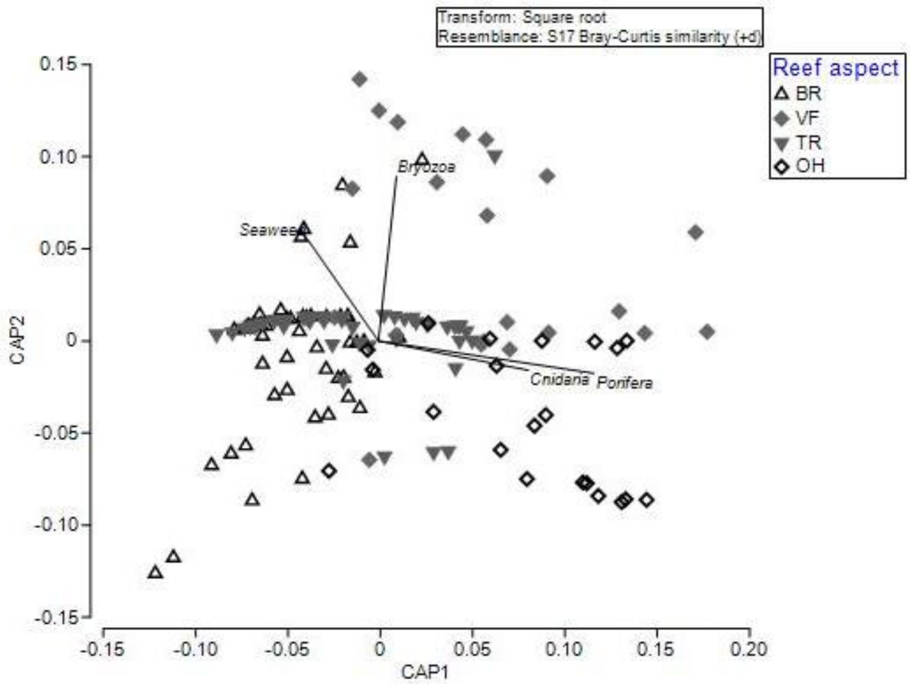

Figure 4.7: Showing community composition of 4 dominant phylum's in relation to reef aspect. Two dominant phyla (Porifera and Cnidaria) explain the majority of the variation in the data cloud, along the CAP1 axis. Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

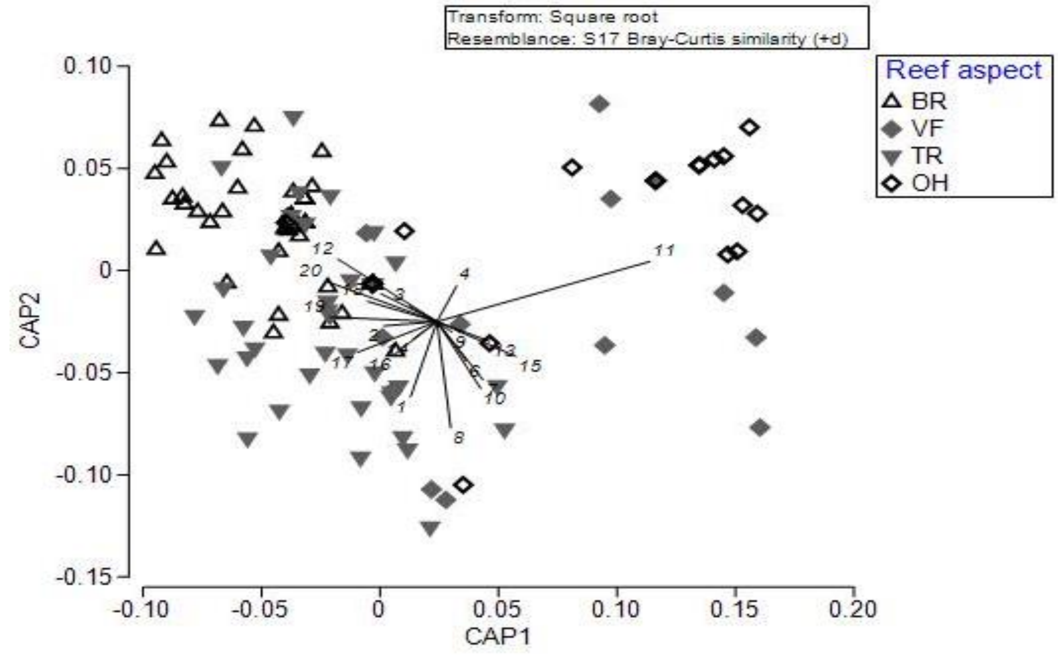

Figure 4.8: Showing assemblage of 20 species in relation to reef aspect. 1 species (11 = *Ancorina alata*) explains the majority of the variation in the data cloud, along the CAP1 axis. The following numbers denotes dominant sponge species on the reef: 1 = *Aaptos globosum*, 2 = *Callyspongia conica*, 3 = *Psammocinia perforodorsa*, 4 = *Polymastia pepo*, 5 = *Polymastia croceus*, 6 = *Tethya burtoni*, 7 = *Tedania sp*., 8 = *Stelletta conulosa*, 9 = *Crella incrustans*, 10 = *Mycale Sp*., 11= *Ancorina alata*, 12 = *Ciocalypta polymastia*, 13 = *Haliclona heterofibrosa*, 14 = *Clathria macrotoxa*, 15 = *Cliona celata*, 16 = *Pararhaphoxya pulchra*, 17 = *Raspailia topsenti*, 18 = *Axinella sp*, and 19 = *Callyspongia ramosa*. Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

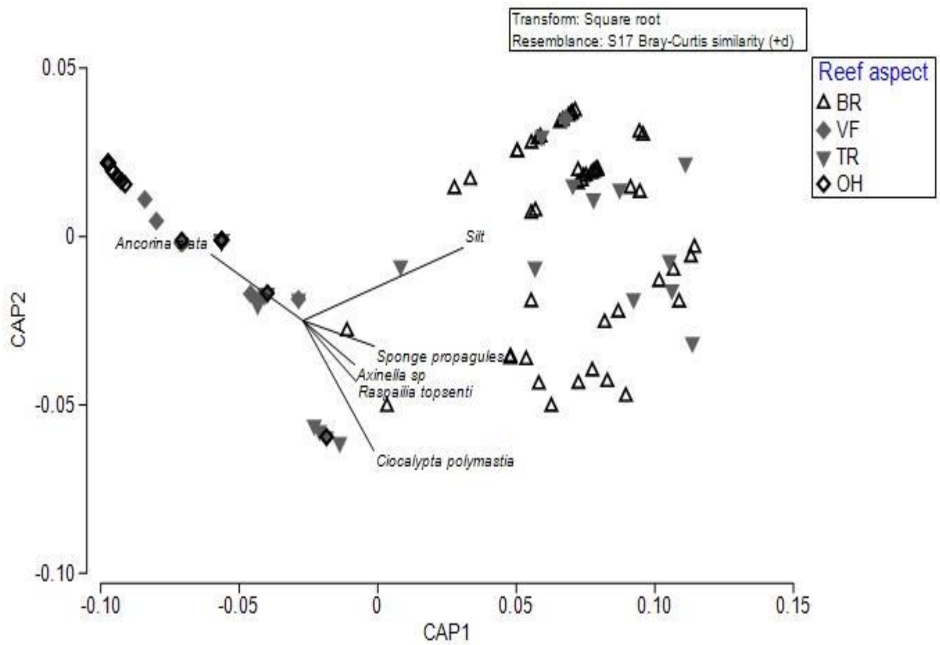

Figure 4.9: Showing the distribution of four dominant sponge species and sponge propagules and silt build up in relation to reef aspect. Distribution of silt on the reef explains the majority of the variation in the data cloud, along the CAP1 axis. Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

Sponge species richness differed significantly with reef aspect (PERMANOVA, Pseudo-F = 0.01) (Table 4.3). Therefore the null hypothesis stating no significant difference in sponge community composition and distribution, across the morphology of the reef, was rejected ($p<0.01$).The associations between sponge community composition and reef aspect were investigated using CAP. The CAP test indicated the following sponge species were strongly associated with the overhangs and vertical face of the reef: *Ancorina alata*, *Haliclona heterofibrosa, Polymastia pepo* and *Tethya burtoni. Aaptos globosum, Clathria macrotoxa*, *Callyspongia sp*., *Pararhaphoxya pulchra and Stelletta conulosa* are sponge species, commonly found on the top of the reef, while the following species were commonly identified in communities associated with the top and bottom of the reef: *Callyspongia conica, Callyspongia ramosa, Ciocalypta polymastia, Mycale spp.*, *Polymastia croceus,* and *Raspailia topsenti* (Fig. 4.8).

Finally, CAP was used to visualise differences in the sponge assemblages and to identify trends in dominant species and sponge propagule distribution, over reef aspect (Fig. 4.9). Results of this CAP analysis showed the BR was characteristically associated with 3 of the 4 dominant sponge species (*C. polymastia*, *R. topsenti*, and *Axinella* sp.). *Ancorina alata* was characteristically affiliated with the vertical face and overhangs, where the overlaying sediment layer is significantly thinner (Fig. 4.9). Sponge propagules were also associated more with the bottom of the reef, where the overlying sediment layer is thicker.

4.1.4 Univariate analysis

Bar graphs clearly showed a relationship between sponge percentage cover and reef aspect. Sponge percentage cover significantly varied with reef aspect ($p<0.01$). Percentage sponge per 1 m^2 quadrat was significantly higher within reef overhangs ($\mu = 59.4 \pm 5.0\%$ S.E.), compared to anywhere else on the reef (Fig. 4.10). Percentage sponge significantly decreased across flat areas of the reef, prone to sediment build up (TR = 26.8 ± 2.4% S.E. and BR = 14.3 ± 1.3% SE). Percentage cover of unidentifiable biogenic reef varied significantly over the morphology of the reef ($p<0.01$), and was the dominant habitat type utilizing space on the reef. On average, photo quadrates taken on the VF and within the OH, contained 64.5 ± 5.3% (mean ± S.E.) and 63.6±6% (mean ± S.E.) biogenic reef, which was significantly higher compared to the TR ($\mu = 23 \pm 5.1\%$ S.E.) and BR ($\mu = 1.6 \pm 1.6\%$ S.E.) (Fig. 4.9). Percentage composition of dominant phyla within the $1m^2$ quadrat varied significantly over reef aspect (Table 4.6). Percentage Porifera was significantly higher within reef overhangs ($\mu = 59.1 \pm 5.0\%$ S.E.), and the vertical faces ($\mu = 41.5 \pm 4.2\%$ S.E.) compared to the top ($\mu = 26.87 \pm 2.3\%$ S.E.) and bottom ($\mu = 14.4 \pm 3.2\%$ S.E.) of the reef ($p<0.01$). Percentage Cnidaria per square meter was highest along the vertical faces of the reef ($\mu = 22.1 \pm 7.1\%$ S.E.) and was recorded in minuscule amounts below the reef ($\mu = 1.2 \pm 3.2\%$ S.E.) (Fig. 4.11).

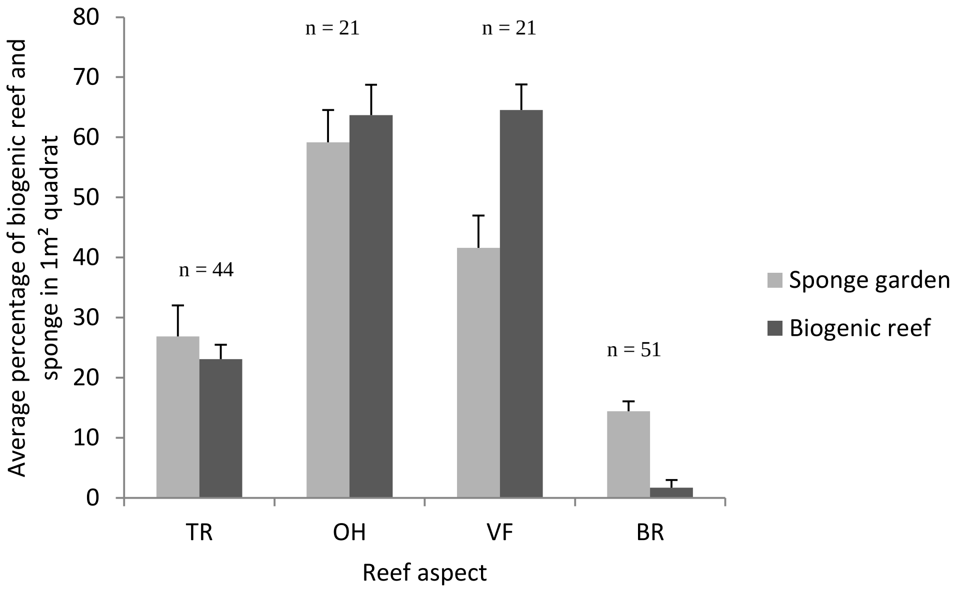

Figure 4.10: Comparing percentage cover of the two dominant habitat classes, between the four reef aspects. Values are means with standard error bars. Sample size was given above each column (total n = 137). Significant differences in percentage sponge and biogenic habitat were evident across the morphology of the reef (ANOVA test, p<0.01). Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

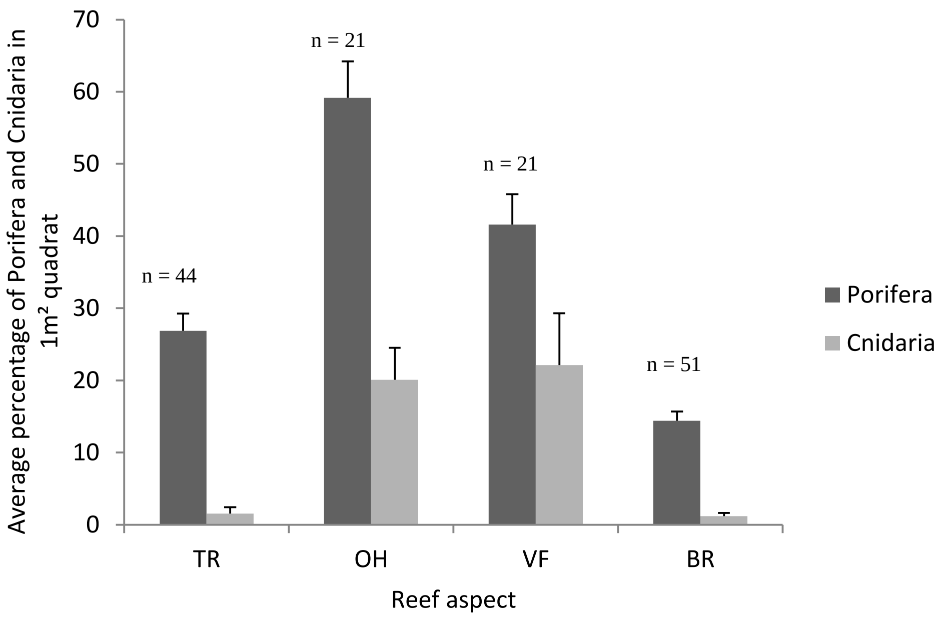

Figure 4.11: Comparing percentage cover of the two dominant phyla, between the four reef aspects. Values are means with standard error bars. Sample size was given above each column (total n = 137). Significant differences in percentage Porifera and Cnidaria were evident across the morphology of the reef (ANOVA test, p<0.01). Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

Table 4.5: Single factor ANOVA models for SQRT transformed percentage sponge and biogenic reef, Porifera and Cnidaira, recorded across reef aspect. SQRT transformed total *C. polymastia*, *R. topsenti*, *Axinella sp*., and *A. alata* were also tested for a significant difference across the different faces of the reef

Habitat		Sponge garden			Biogenic reef		
Source	*df*	MS	F	P	MS	F	P
Reef aspect	3	0.5	24.1	0.00	3.03	49.5	0.00

Phyla		Porifera			Cnidaria		
Source	*df*	MS	F	P	MS	F	P
Reef aspect	3	1.12	44.39	0.00	0.38	15.92	0.00

Sponge species		*Ciocalypta polymastia*			*Raspailia topsenti*			*Axinella sp.*			*Ancorina alata*		
Source	*df*	MS	F	P	MS	F	P	MS	F	P	MS	F	P
Reef aspect	3	1.38	5.61	0.00	0.70	2.64	0.05	0.44	3.01	0.03	3.46	34.73	0.00

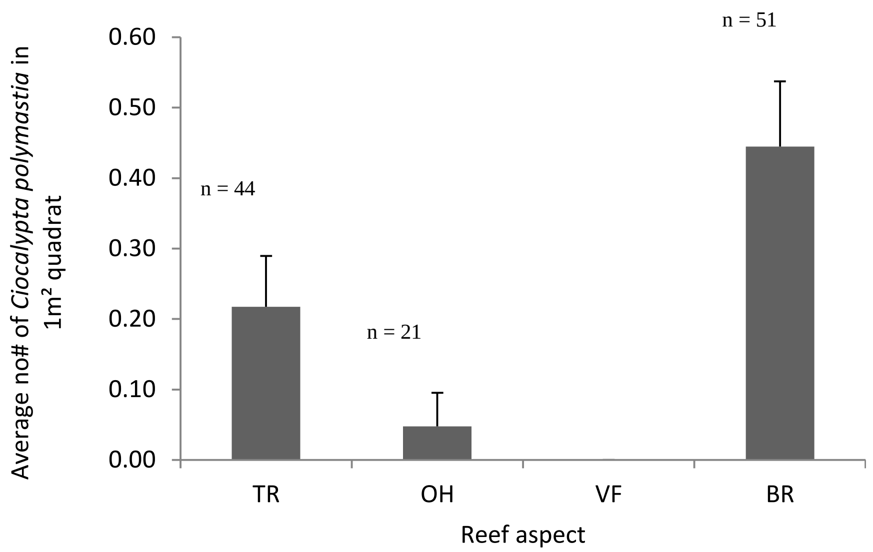

Figure 4.12: Comparing number of Ciocalypta polymastia within a 1 m² quadrat, between the four reef aspects. Values are means with standard error bars. Sample size was given above each column (total n = 137). Significant differences in percentage sponge and biogenic habitat were evident across the morphology of the reef (ANOVA test, $p<0.01$). Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

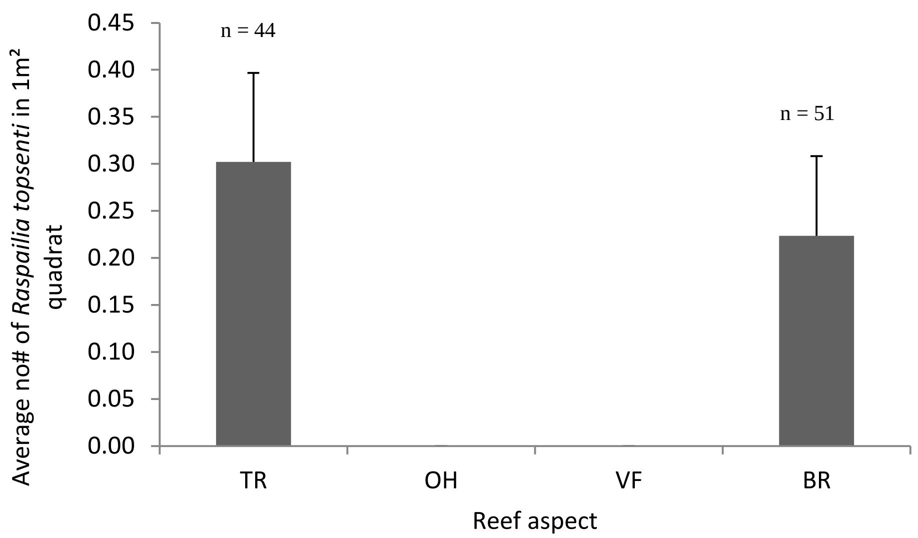

Figure 4.13: Comparing number of *Raspailia topsenti* within a 1 m² quadrat, between the four reef aspects. Values are means with standard error bars. Sample size was given above each column (total n = 137). Significant differences in percentage sponge and biogenic habitat were evident across the morphology of the reef (ANOVA test, $p<0.05$). Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

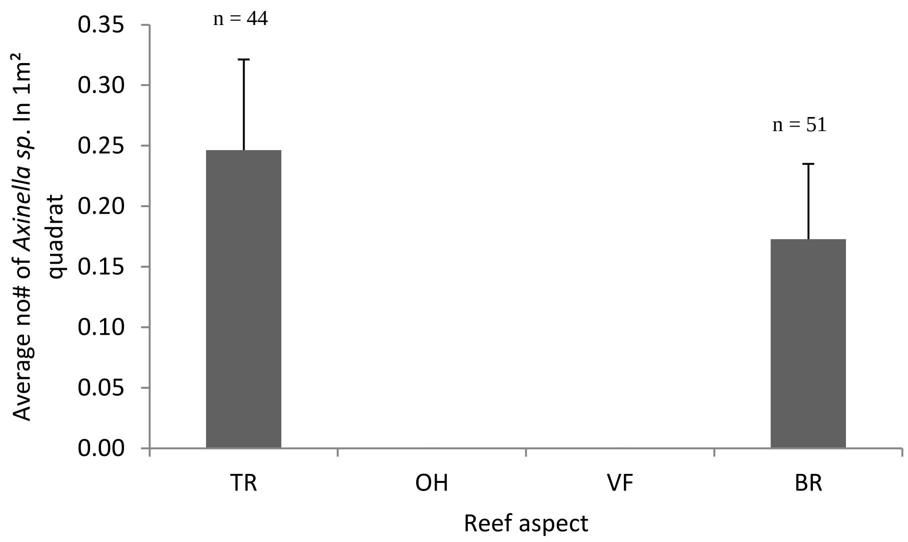

Figure 4.14: Comparing number of *Axinella sp* within a 1 m² quadrat, between the four reef aspects. Values are means with standard error bars. Sample size was given above each column (total n = 137). Significant differences in percentage sponge and biogenic habitat were evident across the morphology of the reef (ANOVA test, $p<0.05$). Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

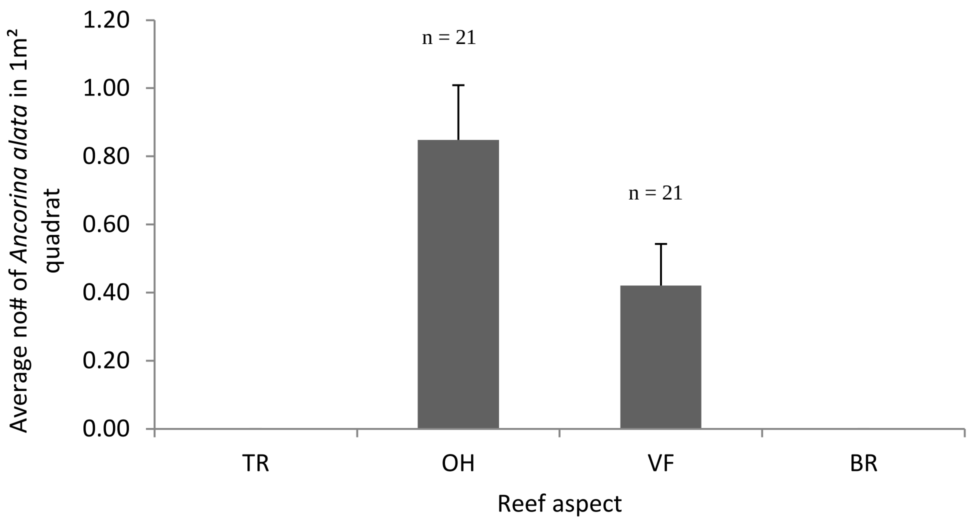

Figure 4.15: Comparing number of *Ancorina alata* within a 1 m² quadrat, between the four reef aspects. Values are means with standard error bars. Sample size was given above each column (total n = 137). Significant differences in percentage sponge and biogenic habitat were evident across the morphology of the reef (ANOVA test, $p<0.01$). Reef aspects: Bottom of reef (BR), vertical face (VF), top of reef (TR) and overhangs (OH).

Four common sponge species were identified as being the main contributors to primary space utilization on the reef tops. These species were: *Ciocalypta polymastia*, *Raspailia topsenti*, *Axinella sp*., and *Ancorina alata*. *C. polymastia* was recorded as present across 3 of the 4 reef aspects (Fig. 4.12). An average photo quadrat taken below the reef contained 0.5 ± 0.09 (mean ± S.E.) of an individual, while the top of the reef contained 0.22 ± 0.07 (mean ± S.E.) of an individual, and 0.05 ± 0.04 (mean ± S.E.), within the overhangs (Fig. 4.12). *Ciocalypta polymasita* abundance varied significantly with reef aspect, and was the dominant species of sponge below the reef, on the sediment. *Raspailia topsenti* was the second most abundant species of sponge on the reef, but was recorded solely at sites along the reef tops where it averaged 0.3 ± 0.09 individuals per square meter (mean ± S.E.), and 0.22 ± 0.08 below the reef (Fig. 4.13) *Axinella sp* was also exclusively found along reef tops and below the reef and, similar to *R. topsenti*, was most abundant along reef tops (µ = 0.25 ± 0.07 S.E.) (Fig. 4.14).

Ancorina alata was the most abundant species within reef overhangs where an average quadrat contained 0.85±0.2 of an individual (Fig. 4.15) and across the vertical faces of the reef. This species of sponge was not recorded on the reef tops and below the reef, where sediment was prone to build up. .

4.1 Discussion

4.1.1 Dominant sources of sediment on Pariokariwa Reef

Mineral analysis on sediment samples collected from Pariokariwa Reef and Whitecliffs indicated that Whitecliffs, bordering the landward (eastern) side of Paraninihi Marine Reserve, is a source for clay mineral loading in this marine environment. Pariokariwa Reef is dominated by fine grained sediments consisting of both terrigenous (clay and quartz) and biogenic material (carbonates), with grain size < 60 µm. Both sediment samples contained a relatively high proportion of fine sediments (>5%) which characterises the sediment on the reef as being a cohesive mud/sand. Sample A contained a higher proportion of fine particles (27.3%) compared to Sample B (15.8%), consistent with its collection from on top of the reef. Sediment that accumulates within the cracks and crevices on the reef, are generally finer-grained compared to sediments surrounding the reef, or on top of the reef. This is because hydrodynamic forces are strongest around the margins of the reef, and reduce in energy as impinging waves refract in various patterns according to reef shape, orientation, and surface morphology (Flood & Scoffin, 1978). The water levels on the reef during high tide are not shallow enough for surface currents to reach the reef bed and agitate fine-grained sediments. However, during low tide and storms, surface currents reach the reef bed and uplift sediment, transporting it to the leeward side of the reef. As a current's energy reduces as it moves over the reef, coarse sediments drop out of the water column first, followed by fine-grained sediments (Flood & Scoffin, 1978). Site 3 is located near the centre of Pariokariwa Reef, in the southern region of the reef. The site is fringing a scoured out channel of the reef which is inundated with sediment. The prevailing wind and wave direction within the Taranaki region are south-westerly (McComb, 2007). Wave energy transports terrigenous sediments in a north-easterly direction, dropping sediments out of the water column with distance travelled over the reef. By chance, Sample A collected from on top of the reef contained shell hash, which explains why average particle size was slightly larger in this sample ($\mu = 3.12$ Mz), compared to Sample B ($\mu = 2.33$ Mz) (Table 4.4).

XRD results revealed sediment samples collected from the reef (3A & 3B), shared similar mineralogy to the sandstone sample collected from Whitecliffs. However, the sediment samples only contain trace levels of clay mineral, while there were significantly higher levels of clay in the sandstone sample from Whitecliffs (Fig. 4.3 – 4.5). It is likely that the clay minerals are being washed away during sediment transport and when re-suspended within the water column, during major storm events. Clay mineral is very fine in particle size, and remains suspended within the water column for several days following a major disturbance. Turbid conditions often persist, near the seabed, long after terrigenous sediments settle from the water column, as a result of these fine-grained sediments being re-suspended by wave and tidal movement (Lohrer et al., 2013).

4.1.2 The effects of reef aspect, encrusting biota and sediment on sponge community composition and propagule recruitment

Sponge habitat, inhabiting bedrock reef, was largely dominated by fine-grained sediment (μ = 3.12 Mz), consisting of both terrigenous and biogenic material, with a median grain size of 59.9 μm. The sediments, surrounding Pariokariwa Reef, or within scoured out regions of the reef, were predominantly fine-grained sediments, with a median grain size of 20.7 μm (Table 4.4). Observations made by divers, suggest mean sediment particle size is coarser below the reef, compared to on top of the reef, which is attributed to a build-up of shell hash and coarse sediments within troughs. PERMANOVA tests revealed there was a significant difference in sponge abundance and species richness between the different faces of Pariokariwa Reef (Pseudo-F< 0.01) (Table 4.3). Adult sponge habitat was sparse below the reef, with percentage sponge being significantly lower on BR compared to the VF and OH reef aspects $p<0.01$ (Table 4.5). This is because excessive sediment loads and frequent sedimentation events tend to influence the structure, density and diversity of sponge assemblages, which is in turn attributed to suspended and deposited sediment loads impacting sponge recruitment, reproduction, and establishment (Bannister *et al.*, 2011; Powell *et al.*, 2014). Smothering is less likely to occur for individuals extending 5-15 cm above the sediment – water interface. However, plumes of suspended sediment still impact the condition and growth of large suspension feeders, because fine-grained sediment tends to clog sponge inhalant canals and filtering apparatus, thus reducing their pumping activity (Bannister et al., 2011; Lohrer et al., 2013).

Sponge propagules were more abundant on unstable substrates within scoured regions of the reef, and surrounding sediments, compared to the VF and OH aspects, where percentage sponge habitat and biogenic reef was highest (Fig. 4.9). It has been shown in Battershill and Bergquist (1990), that sponge propagules are most likely to settle on bare surfaces, where there is a higher chance of settlement (even if these are only temporarily bare during storms). It is plausible then, that recruitment of sponge propagules is highest on unstable grounds, where there is space available for settlement, compared to stable substrates dominated by biogenic reef. There is the suggestion that sponge propagules are prone to anchoring themselves to cobble, gravel and broken shell which accumulates in the troughs of sand megaripples (Battershill, 1987; Battershill & Bergquist, 1990). Some sponge species are known for gravitating to scoured out regions of bedrock reef or into the trough of megaripples; however, settlement and survivorship on unstable substrate is dependent on the species, ambient sediment depth and quality (e.g. grain size) (Battershill, 1987). The probability of propagule establishment and survivorship on unstable substrates is low, and propagules often end up being transported elsewhere. These natural processes explain why a high abundance of propagules were found on unstable sediments below Pariokariwa Reef, but not on areas of the reef heavily covered by biogenic habitat. Adult sponge abundance was significantly lower below the reef compared to the other reef aspects, which possibly corresponds to propagules moving on from their site of initial settlement and settling on a stable substrate when space becomes available (Battershill & Bergquist, 1990).

It was evident from diver observations and still images, that regardless of reef aspect, sponge individuals were exposed to suspended sediment (Fig. 4.16). Numerous photos were taken of sponge individuals being heavily covered in fine-grain sediments, which are known to influence the pumping activity of sponges due to the inhalant canals and filtering apparatus of the sponge being clogged with fine-grained sediment. This pumping activity is fundamental to a sponge’s well-being, because it is necessary for filter feeding, respiration and the release of sexual products (Gerrodette & Flechsig, 1997; Tompkins-MacDonald & Leys, 2008; Bannister et al., 2011; Stubler et al., 2015). A study by Lohrer et al. (2013) reported that the filtering rate (clearance rate) of *Aaptos* spp. (golf ball sponges), significantly decreased with increasing sediment deposit. The study concluded that animals exposed to suspended fine-grained sediments lose condition due to impaired feeding capacities. Therefore, sediment disturbance around sponge communities is an important factor controlling community dynamics (Ayling, 1978; Battershill, 1987).

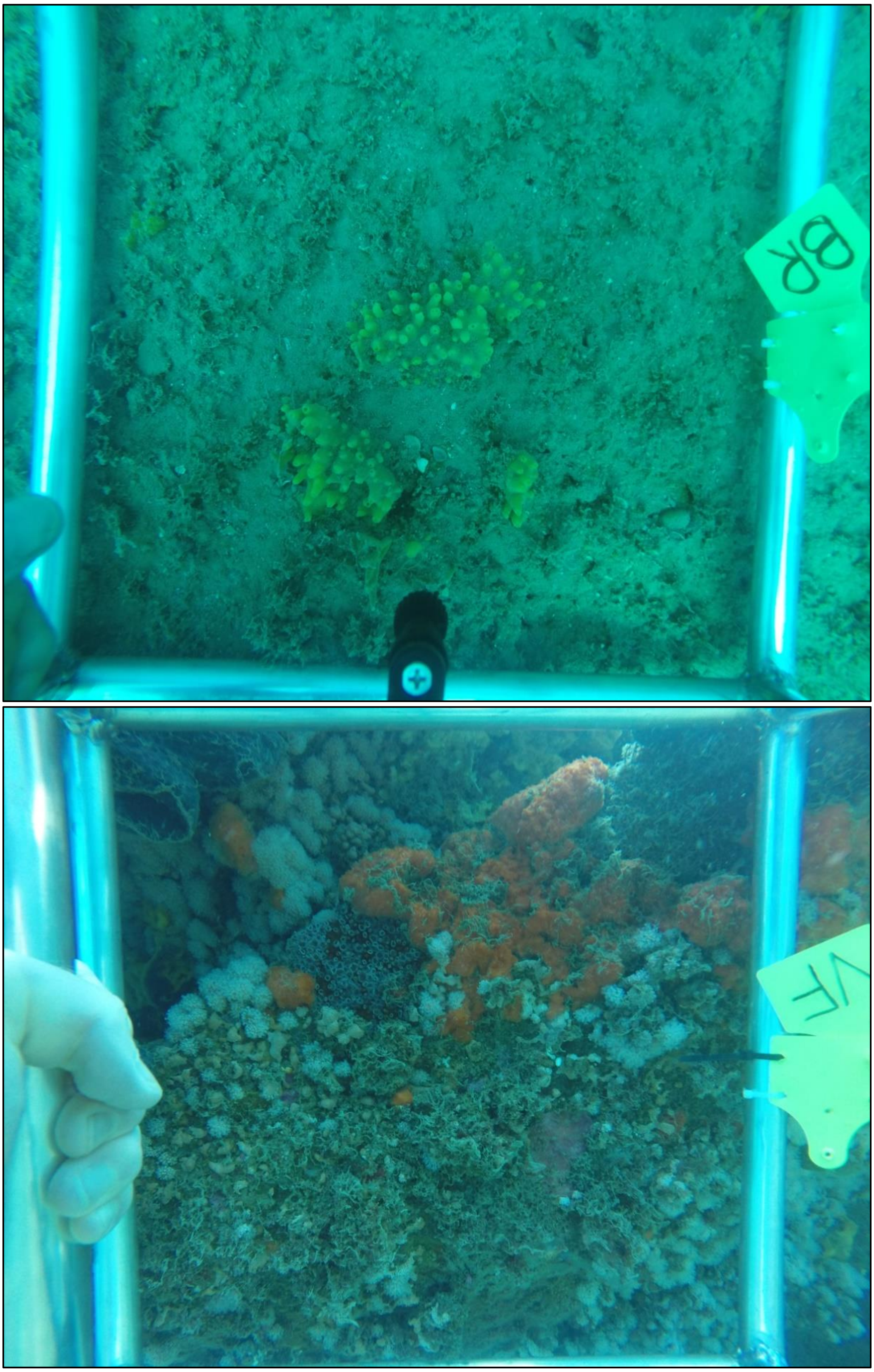

Figure 4.16: Still images taken from below the reef (A) and the vertical face (B), showing that suspended sediment is capable of settling anywhere. The overlying sediment below the reef is deeper compared to the vertical face of the reef.

However, the response sponge communities have to elevated sediment levels is influenced by the environmental history of the region and the ability for some species to adapt to high sedimentary conditions (Lohrer et al., 2013). Results from this study confirm Whitecliffs as a known source for sediment loading offshore. Whitecliffs is made of various layers of sandstone and mudstone that for centuries has been eroded by coastal processes (erosion, scour and attrition) (King *et al.*, 1993; Rotzien *et al.*, 2014). However, there was not enough evidence from this study to confirm the Whitecliffs as a fundamental source from sediment on the reef. Additional samples and further mineral analysis would need to be conducted to make such conclusions. Historical turbidity values (2002 – 2006) collected by McComb (2007), within Paraninihi, suggests silts on the reef do not solely originate from local cliffs, but also from fluvial inputs from various river mouths, including: Mokau, Tongaporutu, Mimi, Urenui and Waitata (McComb, 2007). Historical sediment data collected offshore from Paraninihi (20 – 40 m), shows traces of terrigenous silts and muds which are likely to have been transported offshore, via coastal currents, strong enough to advect suspended river borne sediments kilometres offshore (McComb, 2007).

Local sponge communities, containing species endemic to the region will theoretically have adapted to surviving in these turbid conditions, and are therefore likely to continue to survive in this environment. In contrast to reports discussing the negative effects of sediment on sponge communities, other studies report the presence of highly abundant sponge communities living in heavily sedimented environments (Bell & Barnes, 2000; Bell & Smith, 2004). These studies suggest that various physiological and morphological adaptions allow some sponges to cope with short-term increases in settled or suspended sediment levels (Bell *et al.*, 2015). However, if turbid conditions persist, species diversity decreases as a result of less tolerant species failing to establish and being removed from the community. Benthic community patterns observed on Pariokariwa Reef are similar to patterns observed in the previous studies of Battershill and Page (1996) and Smith (2007). Results from this study suggest that high sedimentation rates within these waters have significantly influenced sponge community composition and distribution on Pariokariwa Reef. Sponge abundance and species diversity significantly varies with reef aspect, which means the null hypothesis stating reef aspect does not influence community composition can be rejected ($p<0.01$). Aspects of the reef with high sediment accumulation contained sparse sponge individuals with no distinct communities, while the vertical face of the reef and overhangs contained highly diverse and abundant communities. *Ciocalypta polymastia*, *Axinella sp.* and *R. topsenti* were the dominant species found in areas with high sediment cover; however, many of these individuals appeared to be unhealthy, with most individuals appearing dull in colour, often deformed in shape and largely covered in silt.

4.1 Conclusions

Reef systems, such as Pariokariwa Reef, that are continuously exposed to terrigenous sediments events, tend to provide sub-optimal conditions for local temperate water sponge species. Biological community composition and sponge species distribution significantly varied with reef aspect ($p<0.01$). Therefore, the null hypothesis stating reef aspect does not influence biological community composition, was rejected. Terrigenous sediments, originating from Whitecliffs and Local River mouths (e.g. Mokau, Urenui and Tongaporutu appear to have a significant impact on the structure, abundance and diversity of sponge assemblages on Pariokariwa Reef, as a result of propagule establishment and maturation being stumped in areas with high sediment accumulation.

General Discussion and Conclusions: *Combining acoustic and in situ survey techniques*

5.1.1 Introduction

Understanding of the spatial distribution of benthic habitats over a large spatial scale is vital for assessing impact of human activities (Brown & Blondel, 2009; Freitas *et al.*, 2011; Ierodiaconou *et al.*, 2007), placement of marine reserves (Jordan *et al.*, 2005), and appointing areas of the seabed suitable for biodiscovery surveys and resource extraction (Anderson *et al.*, 2011; Przeslawski *et al.*, 2013). Benthic habitat mapping involves a singular or series of surveys that determine the spatial distribution of "benthic habitats" within the marine environment, based on spatially discontinuous environmental data sets, represented as a map. Advancements in habitat mapping have been occurring for the last 30 years as a result of developments in acoustic surveying technology. Developments in acoustic data collection and processing has revolutionised the way we image, map, and understand marine systems, over large spatial scales (McGonigle *et al.*, 2009). More specifically, development in multibeam echosounder technology is beginning to match or supersede other acoustic technologies (e.g. SSS and SBES) as a result of MBES being capable of capturing high resolution bathymetric and backscatter data simultaneously over a large spatial scale (Brown & Blondel, 2009; Brown *et al.*, 2011; Micallef *et al.*, 2012). High resolution bathymetry provides marine scientists with information on the seafloor's topography including insights on the spatial variation of benthic habitats.

In this thesis I review recent studies that have explored methods of automated classification of MBES data for the delineation of seafloor habitats (Brown & Blondel, 2009; Che Hasan *et al.*, 2012; Cutter *et al.*, 2003; Hamilton & Parnum, 2011; Ierodiaconou et al., 2007; Lucieer *et al.*, 2013; Preston, 2009). I then conducted a MBES survey aiming to formally characterize and map the distribution of biological habitats on Pariokariwa Reef, within Paraninihi Marine Reserve, Northern Taranaki; using multibeam sonar and a combination of *in situ* survey techniques. The aim was met by achieving the following objectives.

5.1.2 Objective (1)

Objective (1) was defined as:

(1) *Produce a bathymetry map of Pariokariwa Reef.*

The acquisition and processing of multibeam (MBES) data was described in Chapter 2. The objective associated with this chapter was to test whether the Reson Duel Frequency MBES could map Pariokariwa Reef's unique bathymetry at a resolution high enough to identify unique topographical features on the seabed. One of the main outcomes of the MBES survey was the production of high resolution bathymetry maps of Pariokariwa Reef and Waikiekie Reef. The resolution of the bathymetry map was detailed enough to show the reefs unique topographical features, such as the four fault lines running through the reef, caused by tectonic processes. The bathymetry map acquired during the MBES survey provided detailed information on water depth, substrate rugosity, reef relief and reef aspect. It shows Pariokariwa Reef's unique morphology, distinct for this region and also for New Zealand because the reef system has been shaped by tectonic stresses, which has tilted and broken areas of the reef into blocks by faulting. The underlying bedrock is a flysch sequence, which means the reef is comprised of a series of alternating bands of siltstone and sandstone, which easily erode with weathering and erosion. Ground-truthing stations were chosen by identifying unique topographical features in the bathymetry map. This selection process was required to involve a representative number of sites (4), from 1 of 2 rugosity classes (rough and smooth).

One complication associated with the MBES bathymetry data set, was that obscure areas of the reef (e.g. overhangs) were often missing data points, which led to gaps in the imagery. In chapter 2 of my thesis I reviewed a number of studies that used MBES bathymetry to map the seafloor (Dufek, 2012; Le Bas & Huvenne, 2009; Maleika, 2013). High resolution bathymetry maps are formed by MBES systems measuring depth observations in a near continuous and automatic way over surveyed areas of the seabed. The result of these studies indicate the resolution and accuracy of MBES data (bathymetry and backscatter) is largely influenced by transducer design, towing and mounting, signal attenuation in the water-column, and survey track configuration. The results of these studies indicate that the accuracy of bathymetry data is predominantly influenced by transducer design. In this study I feel confident that the beam width and the frequency to which the device was set was appropriate for the shallow waters being surveyed. I believe one way to increase the resolution of a MBES data set is to sample with 20-50% overlap between survey tracks in future runs. Overlap between parallel survey tracks and additional crosswise tracks over complex regions of the reef has been proven to increase image accuracy by 50% and ensure 100% coverage in obscure regions of the reef (Maleika, 2013).

5.1.3 Objective's (2) & (3)

Objective (2) was defined as:

(2) Produce a backscatter mosaic of Pariokariwa Reef.

Objective (3) was defined as:

(3) Investigate the effectivity of combining acoustic and in situ survey techniques to map habitats on Pariokariwa Reef.

Chapter 3 of this thesis examined the ability of MBES technology to record backscatter data at a resolution, high enough to characterise the seabed. The MBES backscatter imagery collected within Paraninihi Marine Reserve was processed using Fledermaus Geocoder, and classified using the Spatial Analysis extension in ArcGIS. Supervised classification was used in this chapter to produce a thematic map of Pariokariwa Reef. The fundamental results of Chapter 3 indicate backscatter data is an asset to seabed classification with the right automated classification method and training data sets. Supervised classification analysed the seafloor classes and used these classes to segment the MBES backscatter imagery and into smaller image objects, containing similar intensity classes (texture analysis). This method of classification, also known as the 'bottom-up approach', identified four dominant seabed classes within the backscatter imagery: sand and shell hash (SH), bedrock reef with sand (BWS), biogenic reef dominated by sponge (BRS) and *Polysiphonia* beds (P). Four of the six classes associated with bedrock reef (bedrock reef, biogenic reef dominated by kelp, biogenic reef dominated by colonial ascidians, and biogenic reef dominated by sponge) overlapped with other seabed classes in the backscatter imagery.

Bedrock reef dominated by sponge was the dominant habitat class on Pariokariwa reef with this class covering 22.5% of the surveyed region. Based on these results, the high intensity backscatter classes, identified in the imagery, are largely associated with bedrock reef, covered in biogenic habitat and dominant by sponge. There was also clear overlap between the substrate classes (sand, no biogenic habitat and shell hash), resulting with the sand and shell hash classes contributing to most of the textures in the smooth zones (sediment) in the backscatter mosaic. There is a great deal of literature suggesting that sidescan sonar (SSS) produces superior backscatter imagery to MBES and should be used in conjunction with MBES. Combined acoustic imagery, through a joint MBES-SSS operation, will increase the resolution of the imagery, and is therefore recommended future acoustic surveys in the region.

5.1.4 Objective (4)

Objective (4) was defined as:

(4) Examine the distribution of biodiversity across distinct topographical features on the reef.

The aim of Chapter 4 was to determine whether reef aspect significantly influenced the composition and distribution of biological assemblages across Pariokariwa Reef. Multivariate analysis using PERMANOVA, and CAP, showed that habitat distribution and biological community composition, varied significantly over the morphology of the reef ($p<0.01$). Percentage silt within a 1 m^2 quadrat varied significantly varied with reef aspect ($p<0.01$) and appears to accumulate most densely within scoured out regions of the reef. Sponge community composition was significantly lower in sediment inundated areas of the reef (bottom and top of reef), compared to the vertical face and overhangs. This is because the vertical faces of the reef and overhang structures are at an angle that is not prone to accumulating sediment.

Mineralogical analysis of the sediment samples, collected from Pariokariwa Reef and Whitecliffs, suggest sediments accumulating on the reef are originating from Whitecliffs. This is because the reef samples contained traces of the same clay mineral (montmorillonite and illite) detected in the sandstone sample collected from the Whitecliffs. However, the sandstone sample showed a peak in the clay mineral montmorillonite which was not detected in the sediment samples. This indicates this clay mineral dissipates from the sediment load with distance from its source. These results suggest Whitecliffs, bordering the Northern Taranaki coastline, are the dominant sediment source for clay mineral entering Paraninihi Marine Reserve.

5.1.5 Concluding remarks and recommendations for future research

Prior to performing this multibeam survey on Pariokariwa Reef in December 2014, the only map available of the reef was a charted map, produced by MetOcean Solutions in (1997). The charted map of Pariokariwa Reef provides insight into the size and shape of the reef system but no information on water depth, substrate rugosity, reef relief, or aspect. Following the multibeam survey on Pariokariwa and Waikiekie reef, visual insights have been gained into the morphology of these reef systems as well as a general idea of their geological and biological composition; which allows us to generate hypotheses regarding the origin and dynamic processes influencing larval recruitment on Pariokariwa Reef, and the resultant effects of these biological processes on community composition. This study performed within Paraninihi Marine Reserve, involved novel advances in benthic habitat mapping for the Taranaki Region, and has laid down strong foundations for future research within the reserve and elsewhere in the region.

The backscatter imagery was segmented into acoustic classes and classified using the seabed classes, identified through ground truth surveys, following the MBES survey. The acoustic classes identified within the imagery were matched up with four dominant seafloor classes identified on Pariokariwa Reef. These four classes were SH, BWS, BRS and P.

The spatial detail of this methodology depends on the resolution of the multibeam imagery. I therefore recommend that prior to executing another multibeam survey in these waters, the multibeam survey procedures, processing, and classification methods must be refined to increase the resolution and accuracy of the multibeam imagery. This habitat mapping technique can be refined by a) running two sonar systems (MBES and SSS) in tandem, to increase the resolution of the backscatter imagery, whilst maintaining high resolution bathymetry; and b) confirming the accuracy of the habitat map identified through Acoustic Seabed Classification by executing a more extensive ground-truth survey on the reef, and studying the reef geology through the collection of sediment grab sample.

Following the MBES survey and the production of a thematic map of the reef, the photo quadrat surveys, executed at various sites on the reef, were used to formally characterise the biological assemblages, identified in the backscatter imagery. Sponge habitat appeared to be the dominant habitat class in the thematic map which is why sponge classification took precedence over other phyla. Sponge community composition and distribution significantly changed with reef aspect ($p<0.01$). Sponge specie distribution is largely influenced by sediment transport and accumulation on the reef which is indirectly influenced by the reefs morphology. Therefore, by understanding the geomorphological and biological composition of Pariokariwa Reef, it is possible to predict sponge species distribution over the reef and potentially elsewhere in the region.

There are still many unknowns associated with Pariokariwa Reef and Paraninihi Marine Reserve. My research has been vital in highlighting the following knowledge gaps, and it is important to continue further investigation into the following aspects, in order to grasp a better understanding of the quality, quantity and spatial distribution of habitats residing within Paraninihi Marine Reserve.

1. Further data (acoustic and ground truth) needs to be collected from Pariokariwa Reef to generate higher resolution MBES imagery of the reef and thematic maps that better represent the reef's unique habitat composition.

2. Which coastal processes are influencing the reef and how are these processes influencing sediment transport around Pariokariwa Reef.

3. Based on Pariokariwa and Waikiekie Reefs' similar morphology, and the biological communities associated with these systems which are similar in structure and richness; it raises the question whether there are other reef systems in the area connected via larval dispersal.

4. A large proportion of taxonomy remains to be done, which means an extensive biodiversity survey needs to be carried out within Paraninihi Marine Reserve. This biodiversity survey should include the collection of sponge specimens for the purpose of species classification.

5. Following a biodiversity survey, it would be interesting to carry out an extensive biodiscovery survey within the reserve to see if the indicated species richness corresponds in terms to unique compounds of potential marine natural products.

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