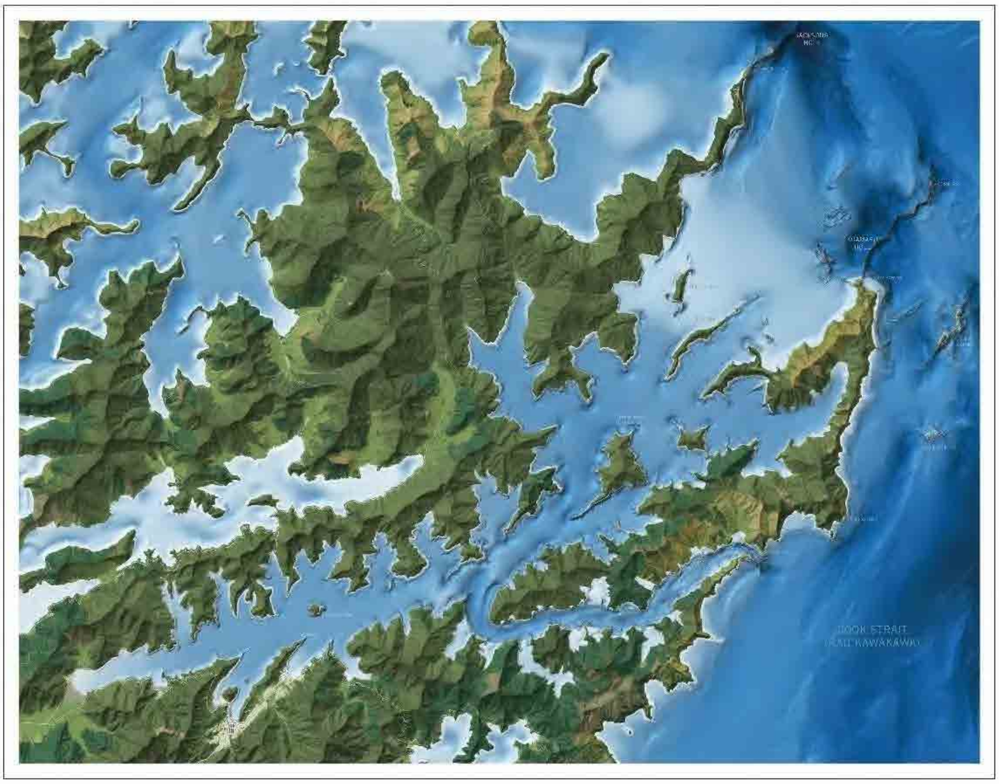
Queen Charlotte Sound / Tōtaranui and

Tory Channel / Kura Te Au (HS51) Survey

What lies beneath?

Guide to Survey Results and Graphical Portfolio

Part One



Surveyed for Land Information New Zealand and Marlborough District Council

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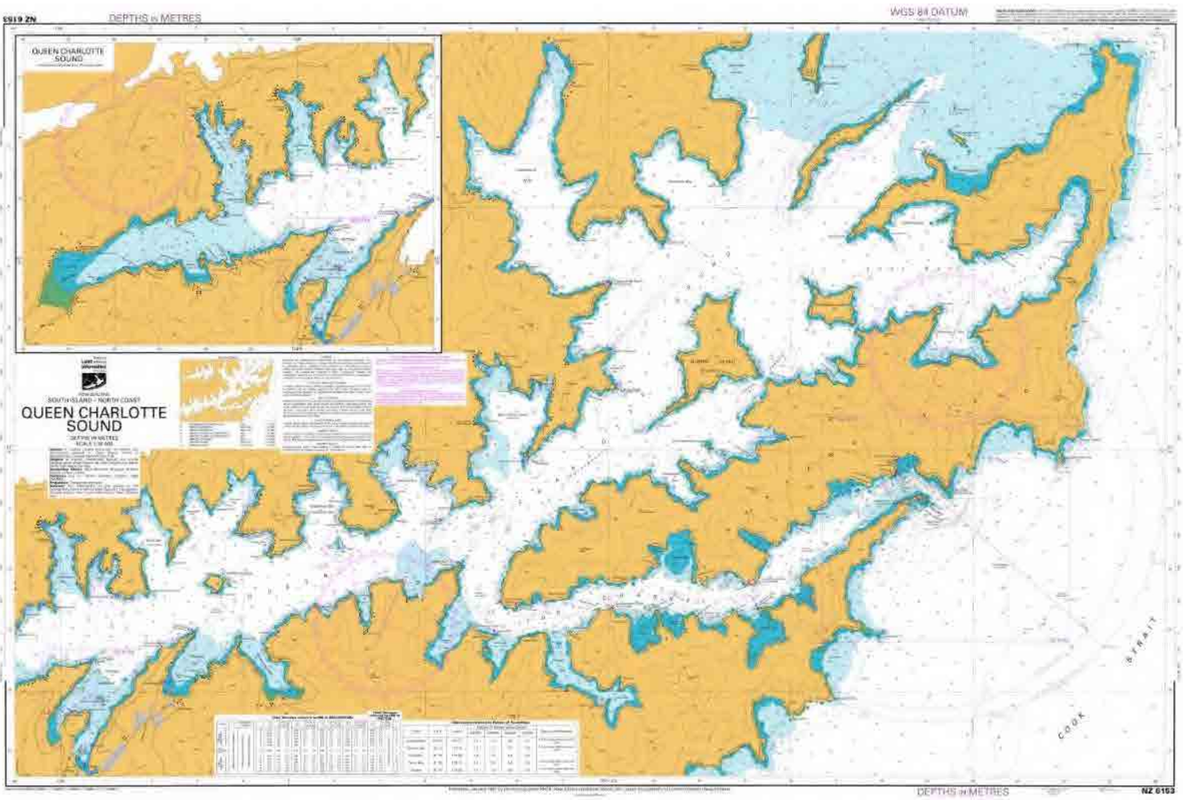
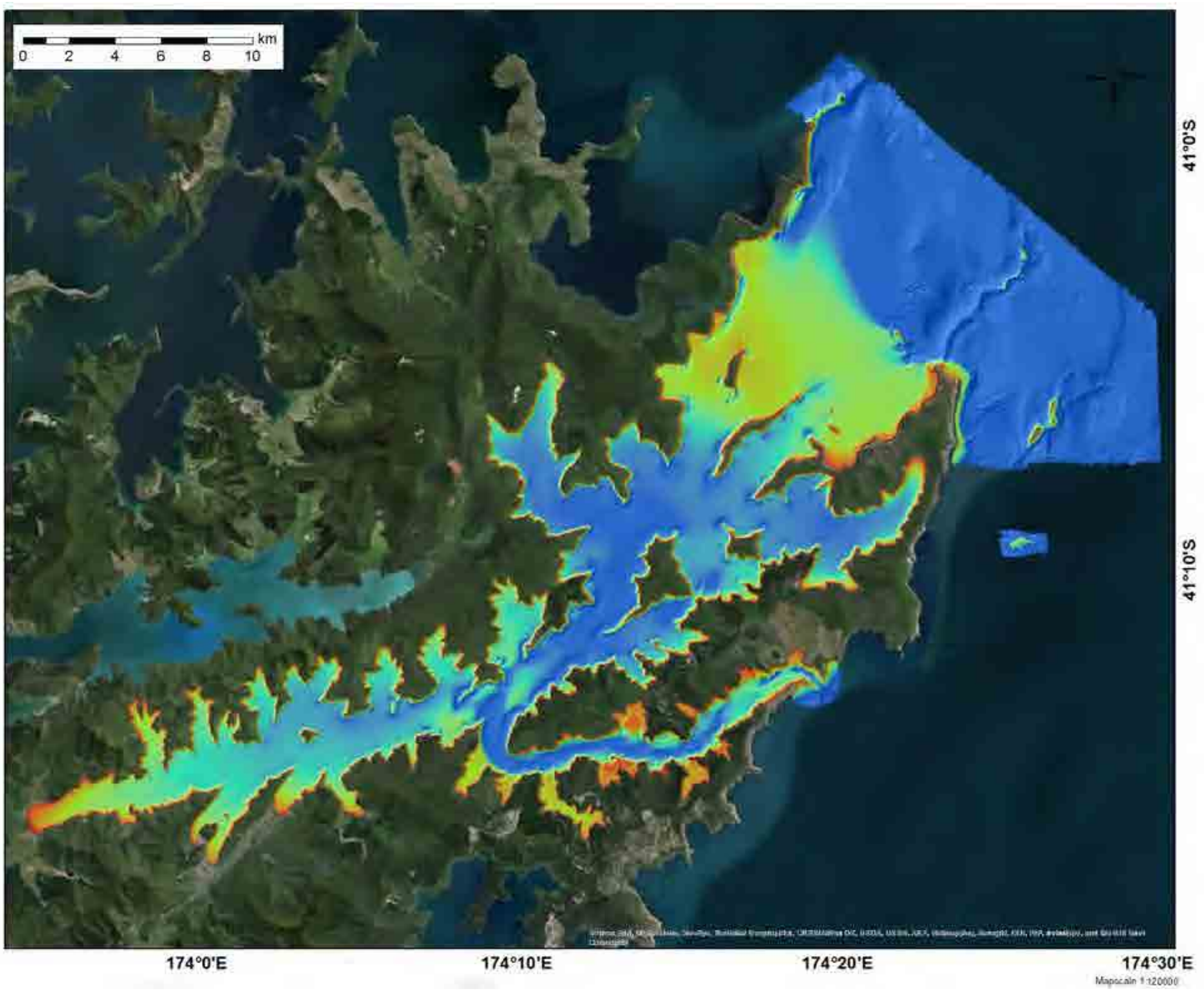
Front cover image: Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au. NIWA Chart, Miscellaneous Series 101. Neil H.L., Mackay K., Mackay E.J., Wilcox S., Smith R. 2018.



Frontispiece Figure 1: Chart NZ6153 – Queen Charlotte Sound.



Frontispiece Figure 2: Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au Hydrographic Survey (HS51) Survey Coverage. (2 m sun-illuminated digital elevation model)

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Executive summary

The National Institute of Water and Atmospheric Research Ltd (NIWA) was contracted in October 2016 by Land Information New Zealand (LINZ) to undertake hydrographic surveying services for the Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au Hydrographic Survey (HS51). This work was commissioned by a partnership between LINZ and the Marlborough District Council (MDC).

The commissioned survey comprises both hydrographic (LINZ) and habitat mapping (MDC), requirements which are met by a NIWA-led partnership with Discovery Marine Limited (DML) under LINZ project HYD-2016/17-01 (HS51) Contract No 20058.

This Guide to Survey Results and Graphical Portfolio accompanies the final deliverables and is submitted in accordance with the HS51 Services Agreement Contract and MDC Specifications for Science Component.

The seafloor mapping campaign for HS51 comprised 280 days on the water. On 224 days soundings were acquired using two vessel platforms. An additional 67 days were completed for observational (coastal, seabed, and navigation aids) and tide gauge installation. This survey has gathered more than 30 terabytes (Tb) of digital information, with an estimated 5,549,300,000 depth-data points collected by the multibeam systems across a coverage of 433 km^2. The portfolios and this accompanying guide to the science encompass the entirety of the datasets collected, including over 15 Tb of water column soundings. Additionally, these documents are in support of a substantial digital-data delivery that captures all the field and value-added products.

Two NIWA vessels were used in the survey: the RV *Ikatere* for all but the shallowest extents of the sounds; and the smaller RV *Rukuwai* for shoals, embayments and shorelines. The RV *Ikatere* was fitted with a multibeam survey system that gives seafloor coverage of up to 5-times the water depth. It produces a fan-shaped array of 800 acoustic beams that result in a very high-density of soundings. It also logs water column and backscatter data. The smaller RV *Rukuwai* was fitted with a new specialist shallow-water system which allows bottom coverage of up to 12 times in water depth <5 m. It was used along coastline areas not surveyed by the larger vessel.

Collectively, the deliverables comprise the following documents and digital data:

- A guide document that summarises the acoustic dataset and identified features, which are illustrated in detail in the accompanying portfolio set. Part 1 of the guide summarises essential results and field interpretations arising from the survey, and briefly highlights how these data could be used in future benthic surveys and resource planning. For the most part, Part 1 can be read independently of Part 2, sufficient for the end user that does not require specific details around acquisition and post-processing methodologies.

  Part 2 of the guide (separate document) includes post-processing methodologies, as well as technical information and specifications already provided to LINZ and MDC for HS51 which was included within the following documents and datasets: Report of Survey (RoS), Tidal Data Pack (TDP), Quality Assurance Data Pack (QADP), Mobilisation Report, Geodetic Data Pack (GDP), 23 standard and ancillary sheets as well as digital contours and coastline and 13 Tb of Raw Multi-Beam Echo Sounder (MBES) data, 1.7 Tb of processed GSF and ASCII data, 1.7 Mb of plotted depth ASCII.

- A set of thirteen A2 portfolios, each comprising 28 map sets. Each map set portrays a full suite of data visualisations, including: bathymetry, backscatter, benthic-terrain class outputs, seafloor classification, water-column features, modelled-benthic habitats, and marine farm subsets where applicable.

- Six new NIWA Miscellaneous Chart Series: – maps of the region that illustrate the bathymetry and are produced primarily for the purposes of public engagement.

- Digital delivery – ESRI feature database (fgdb and accompanying mxd's), that includes all processed datasets and tabulated data.

This final package of deliverables provides MDC with NIWA's appraisal of the coastal marine area, which will assist MDC, industry and the community to better understand, sustainably manage and protect resources and important coastal marine ecosystems of the Queen Charlotte Sound/ Tōtaranui and Tory Channel / Kura Te Au region. It provides a data-rich foundation and point of reference that will support future initiatives across a range of spatial, logistical, social, and resourcing scales.

Key outcomes

- A total coverage of 433 km^2 of bathymetric data were acquired and these data collectively illustrate the seafloor complexity of Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au. Bathymetry is illustrated as a sun-illuminated digital elevation model (DEM), produced from a 2-m resolution dataset.

- Four notable features are: (a) the sill in outer Queen Charlotte Sound that separates the relatively quiescent inner Queen Charlotte Sounds from the tidally dominated deeper Cook Strait; (b) the seafloor depression/scour that occurs throughout Tory Channel and is flanked by shallow bays; (c) the extensive rocky ridges extending into Cook Strait, and the extensive flat areas of seafloor plains; (d) the marginal bays and inlets of Queen Charlotte Sound, that, while shoaling at their heads, are similar depths to those of central Queen Charlotte Sound. In contrast, the marginal bays of Tory Channel are shallower than central Tory Channel.

- Eight terrain attributes were produced from the new bathymetric data to aid in defining the geomorphic complexity (shape and depth), including: Depth; Depth range; Standard deviation of depth; Slope; Standard deviation of Slope; Curvature; Aspect; and Rugosity. In the benthic environment, ecological diversity can generally be correlated with the complexity of the physical environment, and can help identify areas where high biodiversity may exist on the seafloor.

- The backscatter intensity is a measure of the reflected-sound signal returned from the seafloor. The intensity of the backscatter signal provides a semi-quantitative indication of the nature of the seabed substrate. Seafloor backscatter (for >5 m water depth) was segmented into four classes representative of the substrate or sediment types. The resultant classification indicates: ~49% of the area comprises low reflectivity mud, ~36% of the area comprises high reflectivity coarse sand or gravel, 8% of the area low-medium reflectivity fine sand, and ~6% of the area is medium-high reflectivity medium sand.

- Thirteen significant seafloor features are highlighted in the new bathymetry data, including:

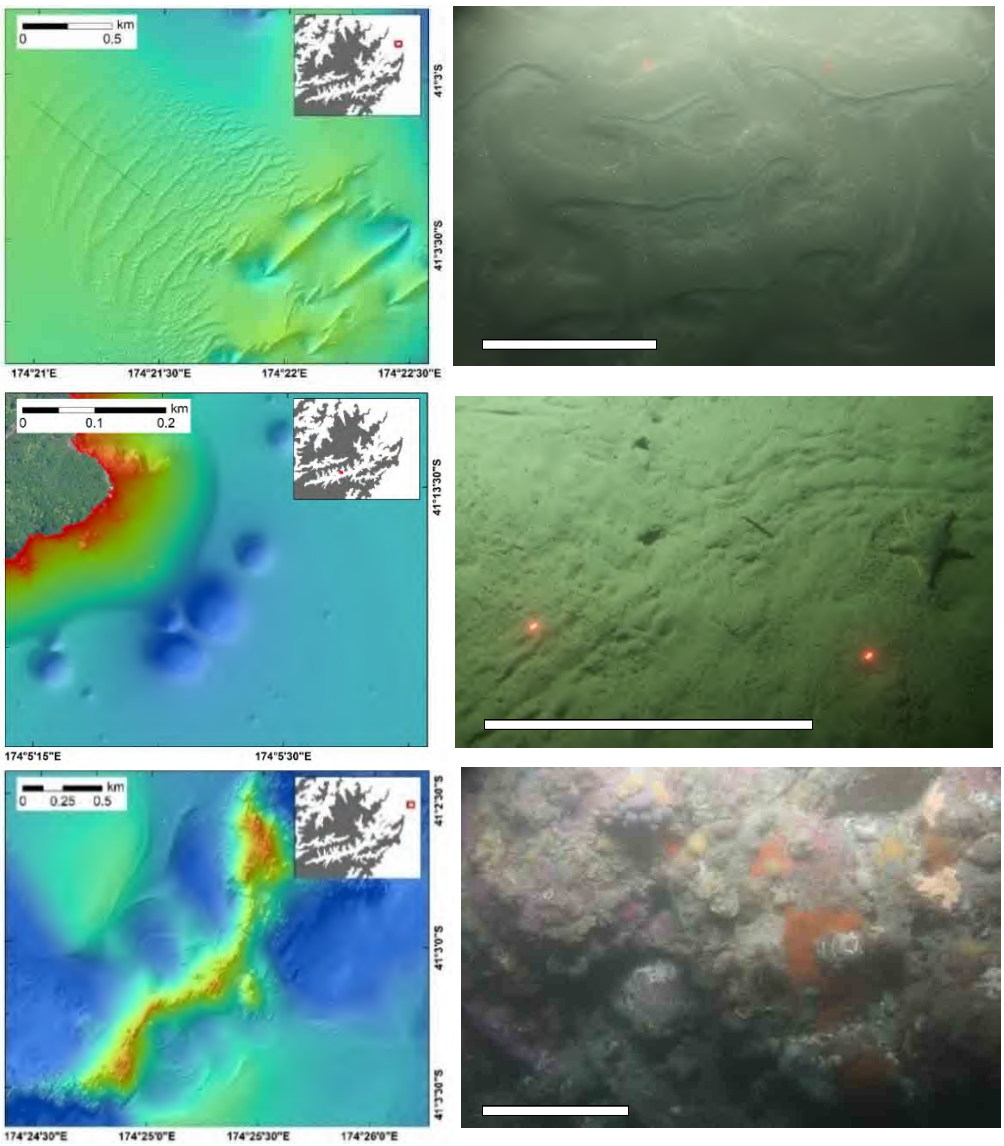
  - Prominent sediment wave fields comprising coarse sand and gravel linear ridges, up to 20 m high and 300 m apart; often associated with fine-scaled rippled sands;
  - Seafloor depressions: (a) small pockmarks 0.5–1 m deep and 2–15 m wide attributed to freshwater seeps, (b) large scours along the coastline and headlands, and (c) deep-water scours tens of metres deep and kilometres long with gravel- to cobble-sized substrates;
  - Anthropogenic seafloor structures captured distinctly in the bathymetry including: mooring blocks, pipelines, propeller wash, anchor drag marks and seabed cable features;
  - Significant areas of rocky reefs and ridges occuring in outer Queen Charlotte Sound and Tory Channel. These steep-sided features rise above the surrounding seafloor and exhibit complex topography;
  - Flat seafloor plains dominating the middle and inner Queen Charlotte Sound. Here, the seafloor is generally featureless with bioturbated fine-grained mud, low backscatter reflectivity, rugosity, and slope. The sill at the outer Queen Charlotte Sound, which separates the relatively quiescent inner Queen Charlotte Sounds from the tidally dominated deeper Cook Strait, is a significant flat plain within the survey area. The axis of Tory Channel has many sections with low slopes and rugosity, although the substrate is generally coarse sand and gravels.

- Various objects through the water column can scatter the emitted sound, and this acoustic-backscatter echo from the water column was recorded. These data were used to image features such as: seeps, kelp beds, mooring lines, marine farms, wharf structures, and submerged shipwrecks. Seep plumes were identified within the water column at numerous locations throughout the survey area, and were more active following periods of heavy rain, after which they diminished. Kelp features identified in the water column were classified according to their height above the seafloor. Kelp observed in the water column data generally occurred over, or proximal to, rocky shoals and ridges with high occurrences in Tory Channel, as well around Pickersgill Island, Arapawa Island and Cape Jackson.

- Using aerial imagery, the seafloor was successfully classified to provide coverage across areas of water depths <5 m not included in the backscatter seafloor classification. Three seafloor classes occur within the survey area: vegetated seafloor, which is either seagrass or algae; hardbottom; and unconsolidated sediment. Of particular interest are the areas of vegetated seafloor which correspond to records of kelp and algae from water-column data and from coastal observations.

- The information from the depth, slope, rugosity and other measures of shape are used to create a classification scheme for the benthic terrain. The resultant classification suggests that Queen Charlotte Sound and Tory Channel have the following proportion of geomorphic habitats: 63% flat plains, 17% broad slopes, 7% broad platforms or depressions, and 4% narrow slopes and rock outcrop highs. This classification scheme underpins a benthic-habitat map, with each class predicted to have distinct environmental conditions, and can inform future targeted photographic and bottom-sampling programmes.

- The co-collection of bathymetric and water-column data allows the three-dimensional investigation of features that extend from the seabed into the water column. The utility of this dataset allows characterisation of marine farms and their relationship with physical habitats, such as rocky reefs. This survey programme offered the opportunity to undertake a regionally integrated and relatively cost-effective assessment of these at a bay- and sound-wide scale which can inform the consenting process for marine farms by providing fundamental environmental data.
- HS51 survey followed established international best practise for scientific-data acquisition and processing and will provide a valuable baseline record for future reference. This full-scale coverage of combined and processed datasets provides a wealth of information that will underpin future management of the survey area, and lends itself to further resource evaluation and development of applied products. This guide provides a list of suggestions.



Frontispiece Figure 3: Bathymetry illustrating sediment waves (upper), pockmarks (middle) and rocky ridges (lower) in Queen Charlotte Sound / Tōtaranui and Tory Channel / Ku. Representative seafloor images for each feature are illustrated to the right. Seafloor images, white scale = 20 cm.

Part 1 – Guide to Survey Results and Graphical Portfolio

1 Introduction

1.1 Background to HS51 survey

Land Information New Zealand (LINZ) partnered with Marlborough District Council (MDC) to commission a comprehensive seabed survey (Sounds Survey – HS51) of Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au.

LINZ will use the information gathered to update its nautical charts, making it safer for the increasing number of vessels – from dinghies to cruise liners – that use these waterways. The survey will also provide MDC with an appraisal of the coastal marine area, to assist MDC, industry and the community to better understand, sustainably manage and protect resources and important coastal marine ecosystems.

1.2 Data acquisition

The survey was carried out by the National Institute of Water & Atmospheric Research Limited (NIWA) and Discovery Marine Limited (DML), both experts in environmental science and hydrographic surveying, respectively. NIWA has been heavily involved in the mapping of more than 1,500,000 km^2 of New Zealand's seafloor using multibeam echosounder equipment.

A suite of digital systems was used to acquire and process the multibeam MBES data, which includes bathymetry, seafloor backscatter, and water column data. Multibeam data can be used to assess the type of substrate and bedforms, along with other seafloor features such as dredge marks, wrecks and pockmarks. More specifically, backscatter intensity can help identify the type of seafloor substrate; whether it is hard rock or soft mud, or sediments are coarse- or fine-grained. Various objects through the water column can also scatter the emitted sound pulse from the MBES, and this acoustic backscatter echo from the water column was recorded and analysed. Examples include kelp beds, marine farms, pipelines, and freshwater seeps.

Two NIWA vessels were used in the survey: the RV *Ikatere* for all but the shallowest extents of the sounds; and the smaller RV *Rukuwai* for shoals, embayments and shorelines. The RV *Ikatere* was fitted with a Kongsberg EM2040 MBES, which gives seafloor coverage of up to 5-times the water depth. It produces a fan-shaped array of 800 acoustic beams that result in a very high-density of soundings. The EM2040 MBES also logs water column and backscatter data. The RV *Rukuwai* was fitted with a Kongsberg Geoswath Plus system to acquire geo-referenced side scan and bathymetric information in water depths less than 5 m, as well as along coastline areas not surveyed by the EM2040 multibeam. The Geoswath system is an interferometric multibeam which allows bottom coverage of up to 12 times the water depth.

In addition, these acoustic data are supported by ground-truth data obtained during the survey, which includes seabed substrate samples, bottom video and photographs, and aerial photographs.

1.3 Purpose of this guide and portfolio

This guide provides an overview of the acoustic dataset and identified features, illustrated in detail in the accompanying portfolio. It is accompanied by 3D visualisations which can be viewed with iView4D software and data used to generate the portfolio images are supplied as an ESRI file geodatabase. This guide also summarises essential results and field interpretations arising from the survey. Finally, the guide highlights how these data could be used in future benthic surveys and resource planning. The portfolio comprises 28 map sets as shown on the portfolio index map (Figure 1-1), with localities shown on Figure 1-2. Each map set comprises a full suite of visualisations of bathymetry, backscatter, benthic terrain class outputs, seafloor classification, water column features, modelled benthic habitats, and where applicable marine farm subsets.

Overarching location descriptors used in this report follow the portfolio map set nomenclature, namely: inner Queen Charlotte Sound extends from Grove Arm to Dieffenbach Point; middle Queen Charlotte Sound covers the region from Bay of Many Coves to East Bay; and the outer Queen Charlotte Sound covers north of Resolution Bay to The Brothers and open ocean Cook Strait. The Tory Channel map covers the full extent of Tory Channel, and the three isolated areas of Witts Rock, McManaway Rock, and Awash rock.

1.4 HS51 survey objectives

- Hydrographic objectives:
  - Bathymetry for the HS51 survey area, from the drying line to the measured maximum depth of 380 m;
  - The delineation of all low water drying rocks and islets; and
  - Full area search to locate and determine the least depths over significant bathymetric features, known shoals/reef areas and any listed dangers.
- Science objectives:
  - Characterisation and mapping of seabed features, derived from bathymetry;
  - Seafloor and benthic terrain classifications to identify habitats; and
  - Identification of potential biological habitats important for biodiversity.

1.5 Science specifications and required outcomes

- MBES full seafloor bathymetric coverage in depths greater than 5 m;
- MBES-backscatter coverage in depths greater than 5 m;
- Minimum of SBES bathymetry and side-scan data in depths less than 5 m;
- A multibeam solution to characterise marine-farm infrastructure and underlying seabed;
- MBES water-column data of significant features to be collected; and
- Provision of a guide of the factual results and interpretations arising from the completed survey and data processing.

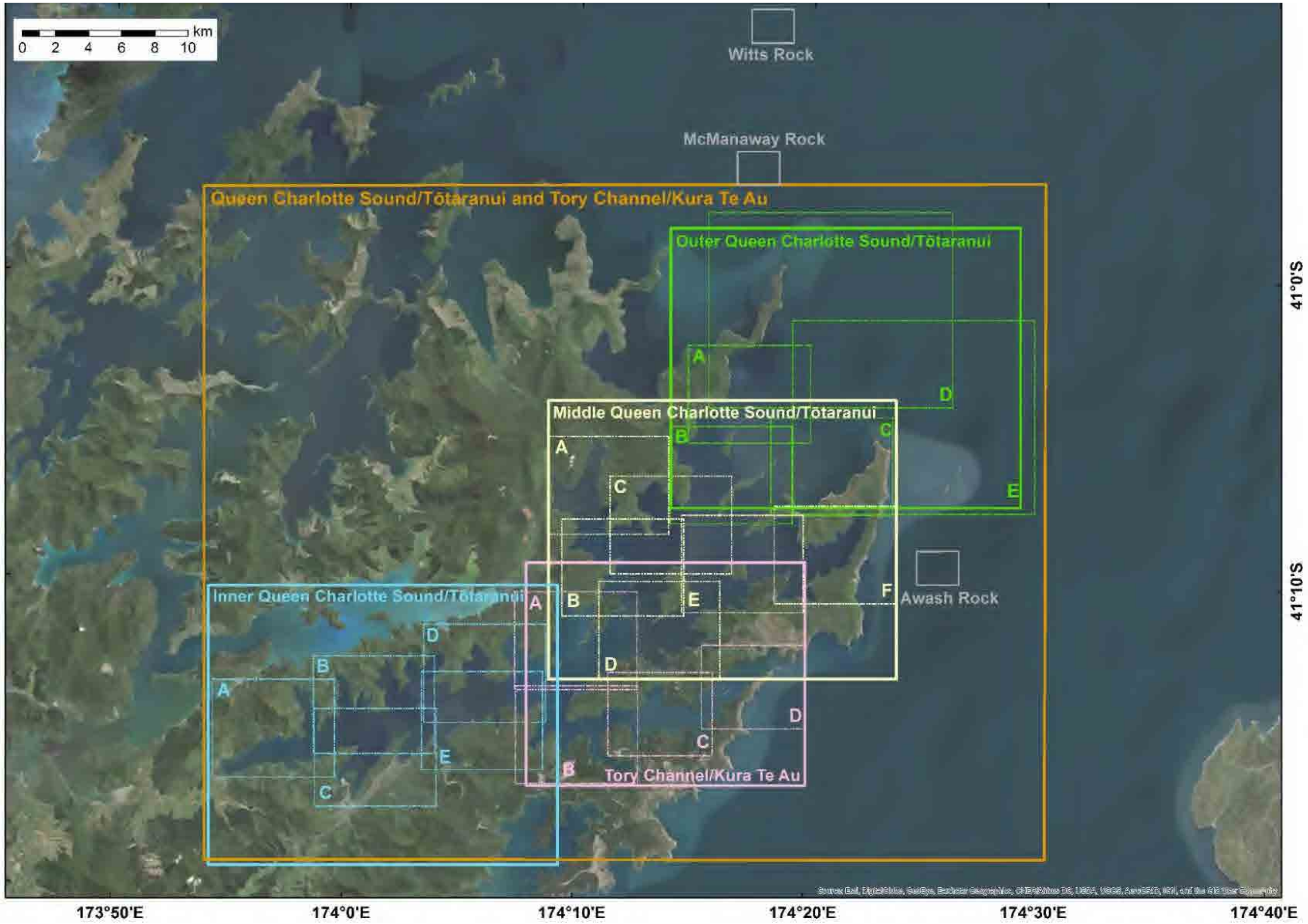


Figure 1-1: Portfolio index map. The 28 regions presented in the portfolio for Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au Hydrographic Survey (HS51): Orange, Queen Charlotte Sound and Tory Channel; Blue, Inner Queen Charlotte Sound Area A–E; Purple, Tory Channel Area A–D; Red, Middle Queen Charlotte Sound Area A–F; Green, Outer Queen Charlotte Sound Area A–E; and, Grey, Witts Rock, McManaway Rock, and Awash Rock.

Figure 1-2: **Locality map.** The major localities are presented here for Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au Hydrographic Survey (HS51). Appendix A contains further localities for Inner Queen Charlotte Sound, Middle Queen Charlotte Sound, Outer Queen Charlotte Sound and Tory Channel.

2 Environmental setting

2.1 Physiography

The Marlborough Sounds consists of a large network of NE-trending, narrow, sea-drowned valleys (rias) and elevated ridges, characterised by an array of small inlets, coves and islands at the northeastern top of the South Island. The Sounds cover an area of c. 4000 km^2, with a coastline length of ~1400 km, which represents about 1/10th of New Zealand's total coastline (Singh 2001; Nicol 2011). The main inlets fan away from Rangitoto ki te Tonga/D'Urville Island - Te Aumiti/French Pass in the northwest to Te Whanganui/Port Underwood in the southeast. From west to east, the most prominent inlets are the Pelorus Sound/Te Hoiere, Kenepuru Sound and Queen Charlotte Sound/Tōtaranui, with the ~17 km long Tory Channel/Kura Te Au branching off the latter into western Cook Strait. Pelorus Sound is the longest inlet at c. 55 km, with Queen Charlotte Sound about 45 km in length, while Kenepuru Sound is a tributary off upper Pelorus Sound that trends eastwards for ~20 km.

The Marlborough Sounds extend northwards into Cook Strait, a 20-60 km wide passage separating the North Island and South Island. Cook Strait was shaped by climatic, oceanographic and tectonic processes (Harris, 1990; Lewis et al. 1994). During the last-glacial maximum, about 20,000 years ago, the Strait formed a land bridge that connected both islands (Te Punga, 1953; Stevens, 1974, reprinted in 1990; Proctor and Carter, 1989).

2.2 Tectonic setting

The Marlborough Sounds lie on the continental crust of the overriding Australian Plate, 30–50 km above the Pacific Plate, which is obliquely subducting east to west (Figure 2-1). The Marlborough Sounds region lies immediately to the west of this region of active deformation associated with continental collision of the two tectonic plates (Barnes and Audru 1999; Wallace et al. 2009). The Marlborough Sounds region is bounded to the SE by the Wairau Fault and to the NW by the Waimea-Flaxmore fault. These faults are significant structures in the active Marlborough Fault System, a network of NE-trending faults that connect the major Alpine Fault to the Hikurangi subduction margin (Litchfield et al. 2014).

2.3 Geological setting

The rock substrata (basement) of the Sounds is composed of a series of "terranes", spanning in age from Permian to Cretaceous in age (290-65 Ma), including Mesozoic greywackes of the Haast or Marlborough Schist Group (Mortimer 1993; Begg and Johnston 2000). These metasedimentary rocks vary in texture, with the lowest, usually deepest and oldest, being the most metamorphosed. Overlying the basement terrane rocks are very localised outcrops of conglomerate, siltstone, coal and limestone of late Eocene age (Picton Outlier; Begg and Johnston 2000). Weathering is pervasive but irregular and may result in planes of weakness prone to deep and surficial slippage. As a consequence, many of the steep hills in the Sounds are characterised by numerous Quaternary (<2.5 Ma) alluvial fan and colluvial gravels and landslide deposits, especially along the indented edges of Pelorus and Kenepuru sounds (Begg and Johnston 2000).

To the north of the Marlborough Sounds beneath the northwestern reaches of greater Cook Strait is the South Wanganui Basin, which is a 4 km-deep sedimentary basin that has formed rapidly over the last 5 Ma (Anderton 1981). Subsidence of the basin is attributed in part to a pull-down effect of the subducting plate, caused by the locking of upper and lower plates in the region (Stern et al. 1993) and enhanced by sediment loading due to infilling of the basin with eroded sediments (Lamarche et al. 2005). Subsidence of the South Wanganui Basin played a role in the development of the Marlborough Sounds), with the NE-trending basement ridges and valleys that form the Sounds continuing to the NNE beneath the thick sediment cover of South Wanganui Basin.

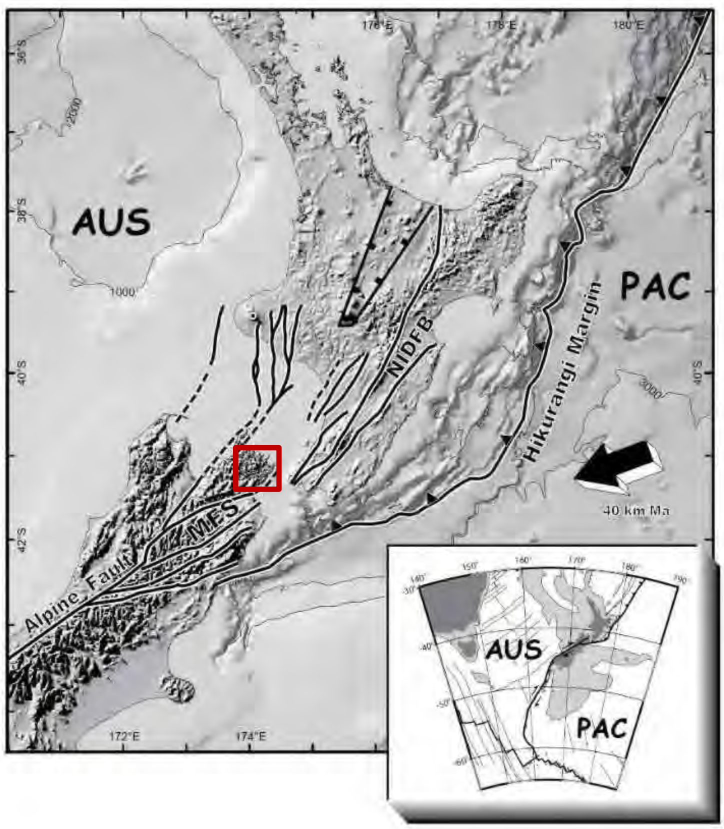


Figure 2-1: Central New Zealand and main active fault systems associated with the Pacific (PAC)-Australia (AUS) plate boundary. MFS: Marlborough Fault System, NIDFB: North Island Dextral Fault Belt (from Lamarche et al. 2005). Red box indicates Marlborough Sounds.

The soils in the Sounds that have formed on the greywacke and schist basement rocks are primarily silt and silty-clay loams. Coastal soils between the shoreline and 200 m elevation are generally clay-rich, highly weathered, and prone to erosion. Marine sediments that infill the drowned valleys are dominated by mud, grading to silts and sandy silts in the outer Sounds, with coarser substrates (silty and muddy gravelly sands, sandy calcareous gravels) along Tory Channel / Kura Te Au (Lewis and Mitchell 1980). These recent marine sediments may be more than 100 m thick in places, overlying ~400 m of older Quaternary alluvial gravels (e.g., Carter 1976; Singh 2001).

2.4 Geological origin

The Marlborough Sounds formed by river incision of the land, later followed by marine incursion (Lauder 1970; Cotton 1974; Lauder 1987; Singh 2001). Incision was facilitated and accelerated by uplifting and tilting of the land, associated with the subduction of the Pacific Plate at the Hikurangi Margin. The primary river valley incisions date as far back as, and possibly predate, 5 Ma (Miocene) (Nicol 2011). The subsequent drowning of these river valleys between 20 and c. 6 ka was made possible due to subsidence to the north in the South Wanganui Basin, which resulted in the north-eastwards tilting of the Sounds, contemporaneously with post-glacial sea level rise (Singh 2001; Nicol

2011). The apparent tilting of the region was first recognised by the apparent upstream draining of tributaries to the main river valleys, that are now occupied by the sea (Lauder 1970). This interpretation was confirmed more latterly by geological interpretations of the distribution of Quaternary gravels (Mortimer and Wopereis 1997), biological observations of genetic patterns in native freshwater fish populations (Craw and Waters 2007) and estimates of Holocene uplift rates derived from benthic foraminifera assemblage changes in shallow water sediment cores (Hayward et al. 2010). Craw et al. (2007) constrain the minimum age of the drainage reversal, as initially postulated by Lauder (1970) and other workers, to be c. 70 ka, with a maximum inferred age of c. 130 ka.

2.5 Physical oceanography

The wider Cook Strait region is subject to powerful, semi-diurnal (M2) tides that occur due to a phase difference (i.e. tidal heights) on either side of the strait (Walters et al. 2010; Stevens 2014). Current eddies downstream from rocky promontories or around rocky sills and shoals can further accelerate the tidal flow. Speeds averaged through the water ('all-depth average') of up to 0.8 ms^{-1} have been modelled around D'Urville Island and are most vigorous through French Pass and Stephens Passage and north of Stephens Island. These strong flows result in many deep holes scoured off headlands, such as Stephens Hole, Chetwode Hole, Jacksons Hole and Koamaru Hole (Vennell 1994; Mitchell 1996), (Figure 2-3).

Within the Sounds themselves, freshwater input has been recognised as an important process affecting the hydrography of the inlets, especially in Pelorus Sound, which is fed mainly by the Kaituna and Pelorus rivers (Heath 1974; Gibbs et al. 1991; Sutton and Hadfield 1997; Proctor and Hadfield 1998; Zeldis et al. 2008). Because the inlets are elongate, and in places narrow, the tidal currents are moderately strong, with reported neap tidal currents in Beatrix Bay of 0.2 ms^{-1} and spring tidal currents of 0.35 ms^{-1} (Sutton and Hadfield 1997). Tidal flows in the narrow (1-2 km) and shallow (30-40 m) constriction of Tory Channel can reach velocities of over 2 ms^{-1} at times (i.e. spring tide, Plew and Stevens 2013). Tidal flushing times in the inlets are in the order of ~20 days in Pelorus Sound (Heath 1974; Proctor and Hadfield 1998), ~13-22 days in Queen Charlotte Sound, and as little as ~10-13 days in Tory Channel, and in the outer part of the Sounds (Broekhuizen and Hadfield 2016).

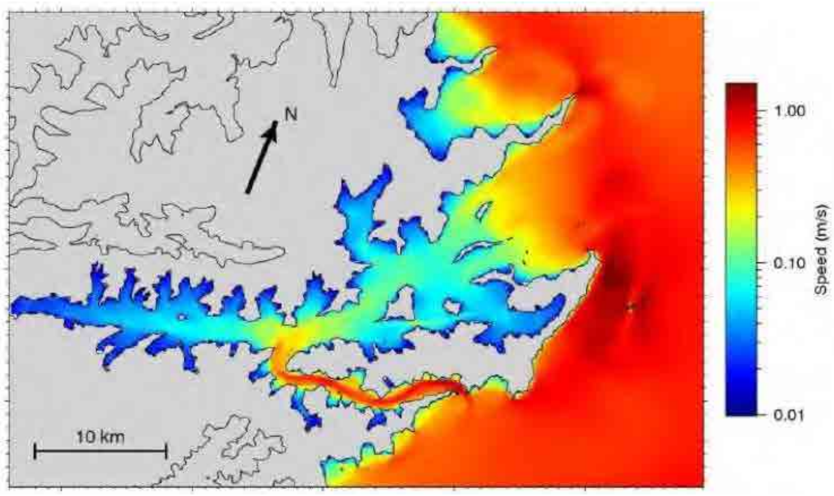


Figure 2-2: Queen Charlotte Sound Hydrodynamic Model of mean current speed. Relative speed of the current in log scale is reflected in the colour bar, with red 100 times faster than dark blue. A 200 m resolution grid was used for hydrodynamic simulations (Hadfield et al. 2014).

3 Results from HS51 survey

3.1 Background to seafloor mapping methods

Before acoustic methods to remotely detect the seafloor, ocean surveys were slow and imprecise, measuring depths by lowering a weighted calibrated rope, or lead line, and navigating by dead reckoning. Many of New Zealand's early coastal charts used lead-line depths recorded from Captain Cook's expeditions. Technology and navigation for mapping advanced significantly during the 1920's with the use of echo sounders or single pings of sound to measure depth with greater speed and accuracy, a technology initially developed from submarine warfare. Spot depths or depth profiles required interpolation between measurements to attain full bathymetric coverage of the seafloor.

The capacity to efficiently map large areas of the seafloor occurred in this millennium through the evolution of computers and multibeam echo sounders. Many tens of simultaneous pings provide near-full ensonification of the seafloor (Figure 3-1), significantly reducing the distance and errors interpolating between measured depths. This massively increases the survey efficiency because full three-dimensional coverage can be attained in real time with far superior results.

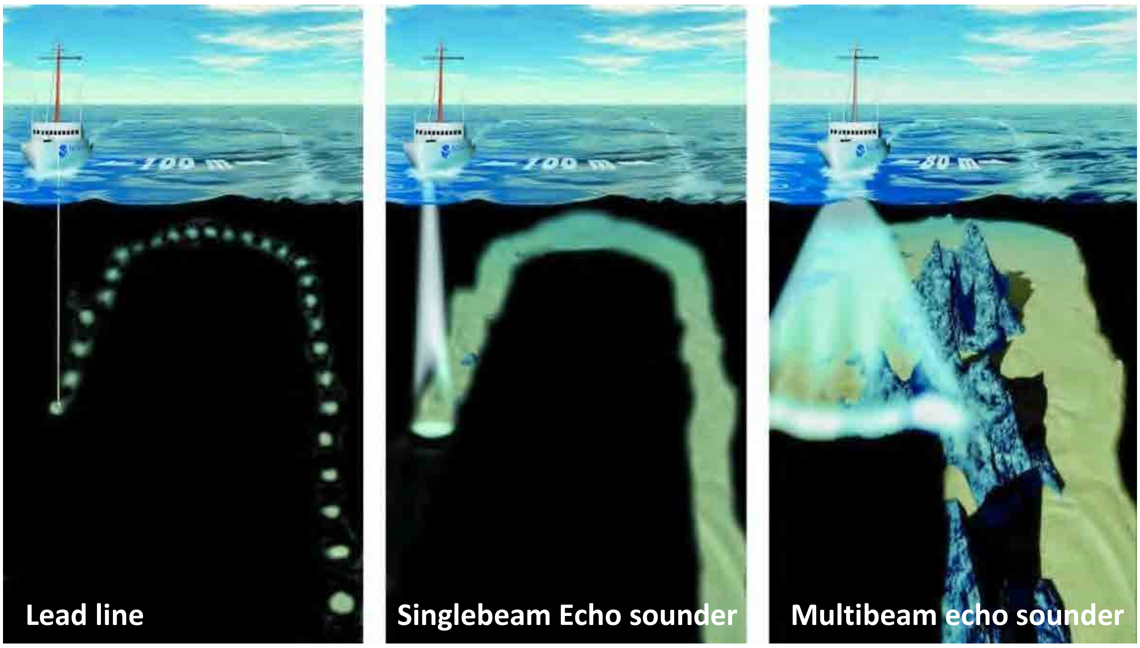


Figure 3-1: Evolution of seafloor mapping technology. Source: NOAA.

The seafloor mapping campaign for the survey (HS51) comprised 280 days on the water, of which 224 days of sounding was conducted over two vessel platforms. An additional 67 observational (coastal, seabed, and navigation aids) and tide gauge installation days were also completed. This survey has gathered more than 30 terabytes of digital information, with an estimated 5,549,300,000 depth-data points collected by the multibeam systems over from a 433 km^2 area. Following standard hydrographic screening protocols only 51,290 depths are plotted on the final Safety of Navigation rendered sheets. However, this guide and portfolio of science encompasses deliverables that capture the entirety of the datasets collected, including over 15 terabytes of water column soundings. Below we provide an overview to the portfolio of maps and processed digital data.

3.2 Bathymetry – Shape and depth of the seafloor

A total of 433 km^2 of bathymetric data were acquired and these data collectively illustrate the seafloor complexity of Queen Charlotte Sound/Tōtaranui (hereafter referred to as Queen Charlotte Sound) and Tory Channel/Kura Te Au (hereafter referred to as Tory Channel) (Figure 3-2). Bathymetry is illustrated as a sun-illuminated digital elevation model (DEM). The DEM was produced from a 2-m resolution dataset. Hillshades are a useful visual aid when illustrating bathymetry data as they help with depth perception (Figure 3-3).

Broad scale geomorphic features include flat plains, sills, seafloor depressions/scour and rocky ridges (Figure 3-4). Notable features include: the sill in outer Queen Charlotte Sound that separates the relatively quiescent inner Queen Charlotte Sounds from the tidally dominated deeper Cook Strait; the seafloor depression/scour that occurs throughout Tory Channel flanked by shallow bays; the extensive rocky ridges extending into Cook Strait, and the extensive flat areas of seafloor plains. The marginal bays and inlets of Queen Charlotte Sound, while shoaling at their heads, are similar depths to those of central Queen Charlotte Sound. In contrast, the marginal bays of Tory Channel are shallower than central Tory Channel.

A complete set of bathymetric images is provided in the standalone A2 map portfolio, with the underpinning processed data included in the digital delivery.

A brief overview of the bathymetry through the survey area aligned with the portfolio map sets (Figure 1-1) is provided below, starting from in the north of Cook Strait:

Witts Rock (Portfolio Outlying Areas Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 11 of 13)

- Witts Rock is comprised of two isolated rock features that shoal steeply from depths greater than 100 m to ~12 m and 38 m water depth, respectively, over distances of 100 to 200 m.

McManaway Rock (Portfolio Outlying Areas Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 11 of 13)

- McManaway Rock is a rock ridge that extends ~ 2 km between two bathymetric highs and shoals to water depths of ~12 m and ~24 m along its length.

Outer Queen Charlotte Sound (Areas A-E) (Portfolios Outer Queen Charlotte Sound/Tōtaranui, 2 and 3 of 13)

- The entrance to outer Queen Charlotte Sound (Cook Strait) is a complex mix of undersea ridges, sediment waves and depressions that extend into the strait. These include isolated steep-sided ridges and shoals that range in depths being emergent (Cook Rock) to depths of up to 380 m. *(Areas D&E)*
- Along the western coast of the entrance to Queen Charlotte Sound (Cape Jackson) a deepening scour exists from Kempe Point at ~50 m water depth to 380 m deep east of Walker Rock. *(Area D)*
- A rock ridge extends from Cook Rock towards Cape Koamaru. The ridge is emergent at Cook Rock and extends southwest at depths of 9.8 to 34 m before plummeting to depths greater than 75 m. On the west side of the ridge and across the ridge gap, a number of 50-m deep depressions occur below the surrounding seafloor at 50-150 m. *(Area E)*
- The Brothers Islands form part of a ridge and shoal system that trends north–south in Cook Strait. Depths on the shoal are generally less than 80 m but deeper channels exist to the

east and west of The Brothers Islands. A ridge extends from south of Cape Koamaru across the channel towards the north of The Brothers Islands. On the top of this ridge are large sandwaves with crests up to 20 m high. *(Area E)*

- Close inshore to the west of Cape Koamaru a very steep drop-off occurs between White Rocks and Stella Rock. A rock ridge, including White Rocks extends northwest at least 800 m and is surrounded by scour holes. *(Area C)*
- Passing from Cook Strait into Queen Charlotte Sound, a broad flat bank or sill (12 to 14 m deep) spans across the entrance. Within Queen Charlotte Sound, the background depths of the Sound increase to > 30 m half way along Long Island. *(Areas B&C)*
- Long / Kokomohua Islands and Motuara Island divide the entrance of the Sound into three discrete channels. Along the flanks of Long Island and Motuara Island there are numerous scour holes in the seabed, especially around headlands. At the northern end of Motuara Island a rocky ridge extends offshore. *(Area B)*
- The central seafloor of Ship Cove / Meretoto is flat and featureless, with depths at the entrance of ~15 m. The seabed has several small pockmarks along the coastal flanks of the cove. *(Area B)*

Middle Queen Charlotte Sound (Areas A-F) (Portfolios Middle Queen Charlotte Sound/Tōtaranui, 4, 5 and 6 of 13)

- East and Onauku bays are deep and generally flat and featureless along their centre around 40-48 m deep, while their coastal fringes have relatively steep slopes. At the head of Onauku Bay a gently sloping seafloor shoals onto an intertidal platform, and scour holes occur off the headlands. *(Area F)*
- Resolution Bay is steep sided but the central seafloor is generally flat with depths of 35–45 m. A deep scour hole exists off the northern headland, along with several smaller scour holes. *(Area C)*
- Endeavour Inlet is steep sided with depths ranging from 50 m at the entrance to 35 m near the heads of the bay. The inlet shoals steadily at its head to a very shallow and expansive tidal platform. *(Area A)*
- The steep sided channel between Blumine Island and Kurakura point is deep, generally 50-65 m. The southern end of Blumine Island extends into a reef structure and scour hole at its terminus. *(Area D)*

Inner Queen Charlotte Sound (Areas A-E) (Portfolios Inner Queen Charlotte Sound/Tōtaranui, 7 and 8 of 13)

- The main channel between Dieffenbach Point and Wedge Point is largely featureless and generally flat with depths between 35–45 m. *(Areas C&E)*
- Around the bays of the northern coast of inner Queen Charlotte Sound slopes are generally steep, whereas the southern bays are more gently shoaling. *(Areas B&D)*
- West of Wedge Point, depths gradually decrease across a generally featureless region. *(Area A)*

- A shoal on the eastern side of the approaches to Picton, opposite Wedge Point, extend approximately 250 m offshore. While in Shakespeare Bay, the area adjacent to Waimahara Wharf shows evidence of dredging activities. *(Area C)*

Tory Channel (Areas A-D) (Portfolios Tory Channel/Kura Te Au, 9 and 10 of 13)

- At the confluence of Tory Channel and Queen Charlotte Sound a mid-channel bank occurs with depressions along both coastlines adjacent to the bank. *(Areas A&B)*
- Between Snake Point/Bay of Many Coves to All Ports Island the northern coast has an array of pockmarks and scour holes at depths of 28–35 m. *(Area A)*
- Depths in Tory Channel gradually decrease from 67 m to 57 m at Arrowsmith Point, while the channel narrows from 1000 m at Diffenbach Point to 570 m at Arrowsmith Point. Inner Tory Channel is consistently steep sided with a deep mid channel axis. *(Area B)*
- Maraetia, Hitaua and Onapua bays along the southern margins of Tory Channel are all less than 30 m deep and have a shoal across their entrance. *(Area B)*
- Between Arrowsmith and Te Uira-Karapa points the mid channel is relatively flat with depths between 47–57 m. The three shallow bays of Kawhia, Erie, and Te Weuweu, have banks that are almost emergent at their entrance. *(Area C)*
- North of Te Uira-Karapa Point the depths in Tory Channel gradually shoal to~18 m off Jackson Bay. A gravel and shell ridge dissects the channel in an east–west direction between Kotoitoi Thoms bays. *(Area D)*
- Once over the ridge, the main channel is diverted north, where it narrows and flows over two depressions 60–63 m deep. A shallow rock ridge 28 m deep extends across the channel from Wheki Rock separates the two depressions. North of the rock ridge, Okukari Bay is a sandy area which shoals steadily. *(Area D)*
- Depths in the Tory Channel entrance are between 42–50 m inside the headlands and deepen to over 100 m into a basin 800 m offshore. The flanks of the entrance channel are very steep down to 10 m depth, then slope steadily to 30 m depth. The main channel seafloor is composed of rocky ridges and outcropping reefs. *(Area D)*

Awash Rock (Portfolio Outlying Areas Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 11 of 13)

- Awash Rock is a rock feature with numerous separate shoals rising to 3.5 m water depth.

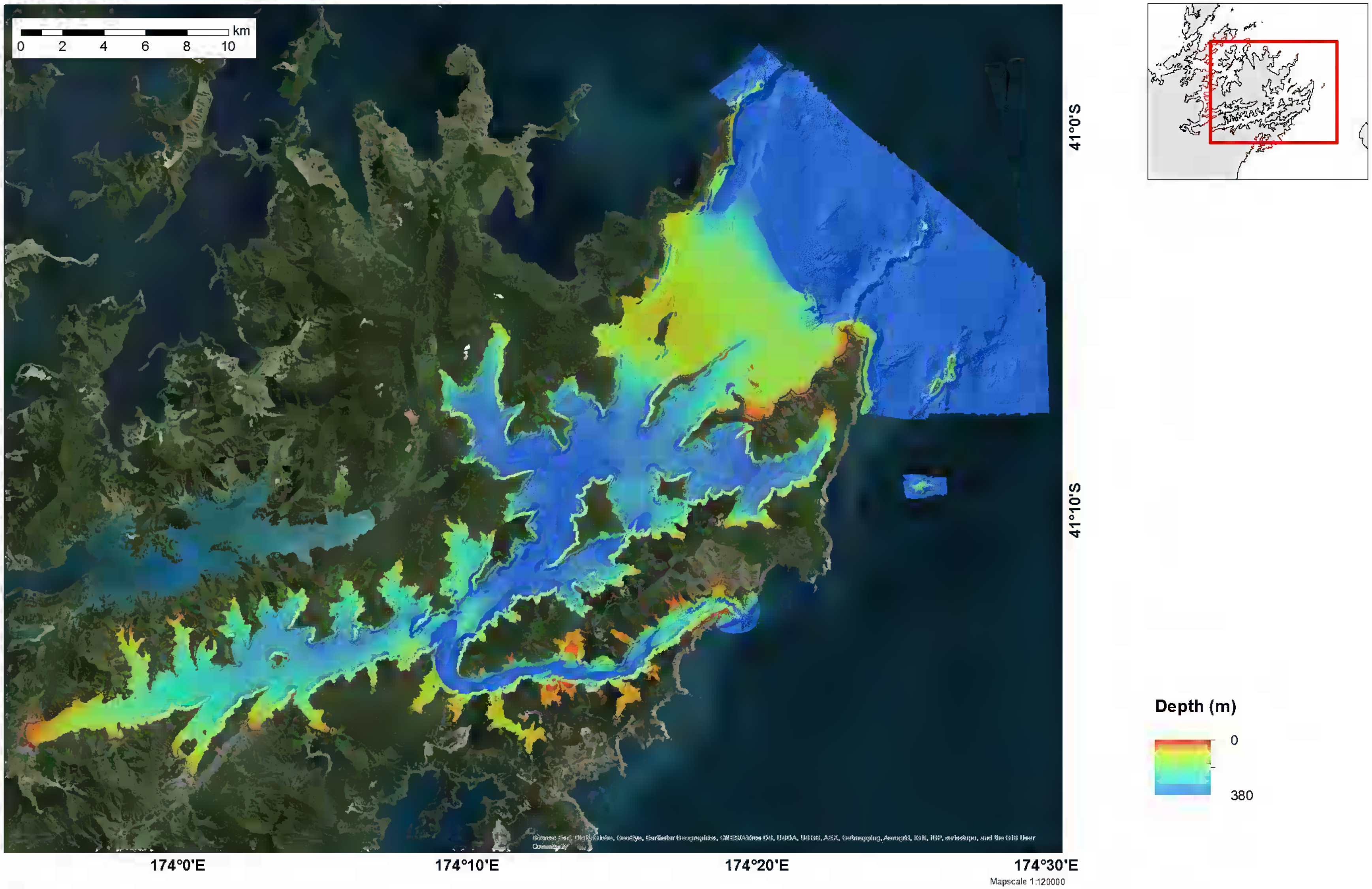


Figure 3-2: Bathymetry image (combined EM2040 and Geoswath bathymetry). Sun-illuminated 2 m digital elevation model (DEM).

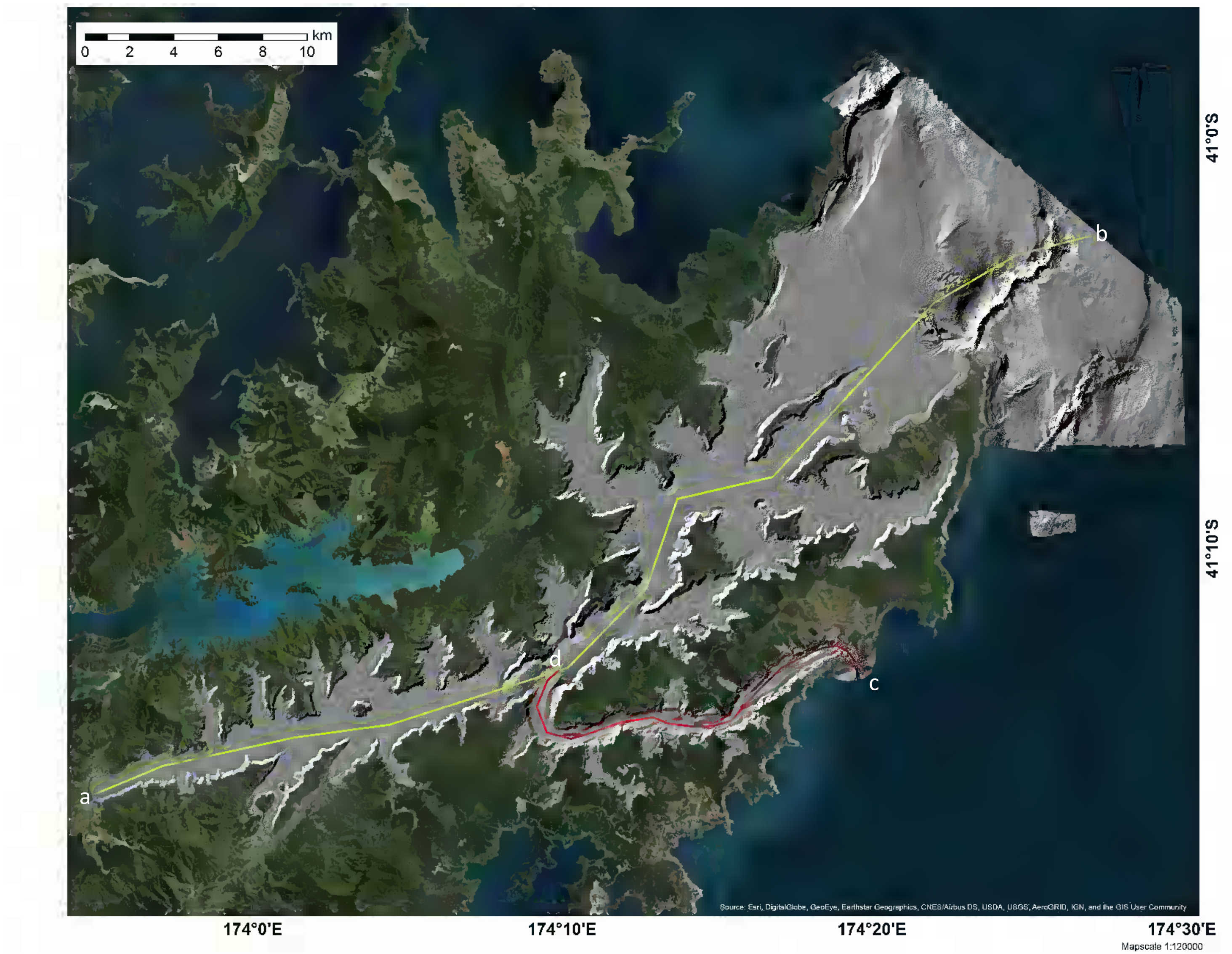
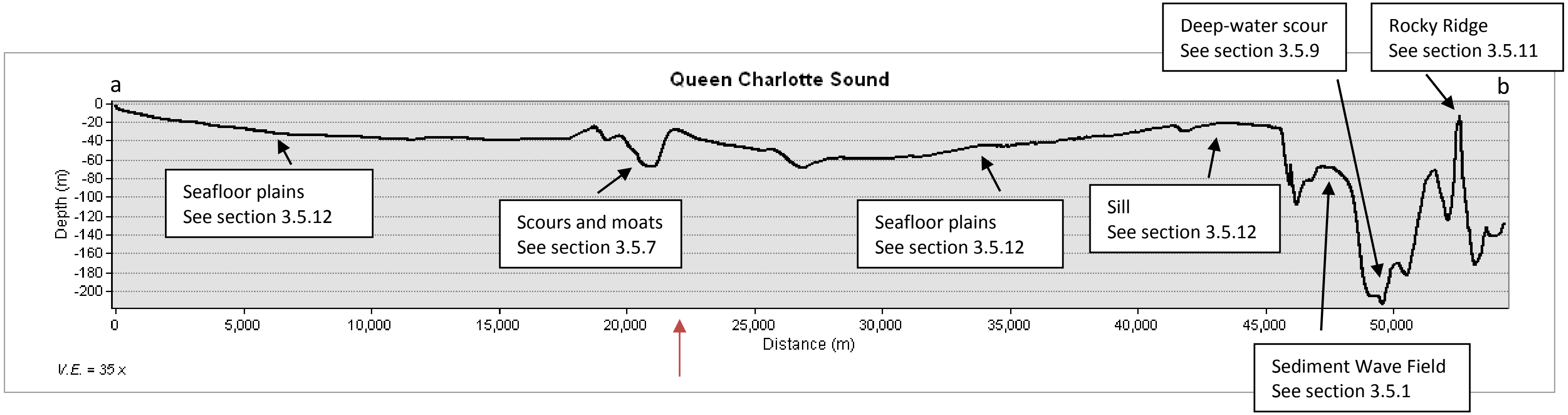


Figure 3-3: Hillshade image (combined EM2040 and Geoswath). Azimuth 315°, Altitude 45°, V.E. 1x. Location of profiles in Figure 3-4 shown on hillshade.



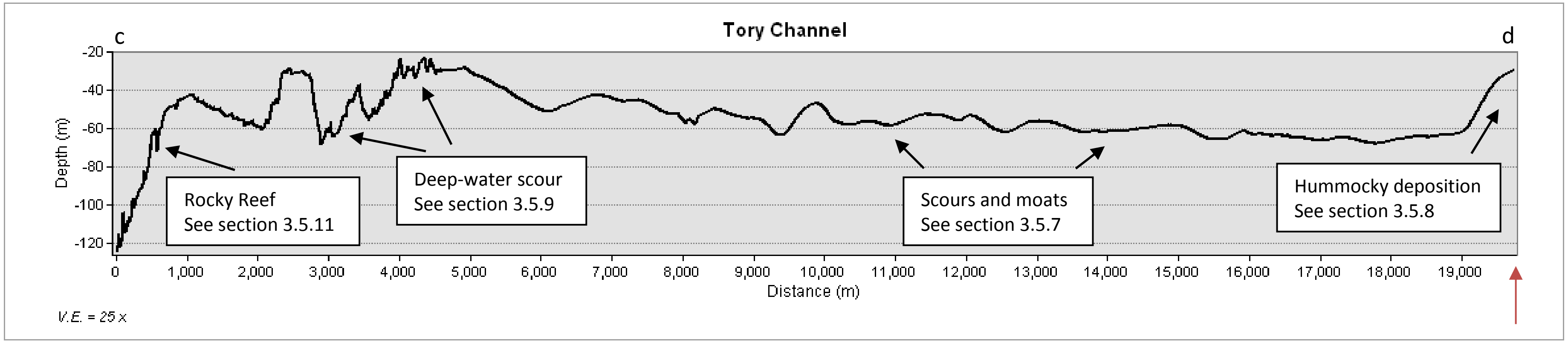


Figure 3-4: Bathymetric profiles along the central axes of Queen Charlotte Sound (top) and Tory Channel (bottom). Red arrows indicate where the Tory Channel profile intersects with the Queen Charlotte Sound profile. These profiles illustrate the broad-scale geomorphic features and indicate where these seafloor features are described in more detail. Location of profiles shown on Figure 3-3.

3.3 Benthic-terrain attributes

The DEM (2 m resolution) produced from the bathymetry was also used in the creation of standardised bathymetric position index (BPI) grids, as a process of terrain attribution. Methodology is outlined in Part 2 Section 1.11, and the attributes are illustrated within the accompanying 28 map sets within the portfolios. The eight terrain attributes used here are:

1. Depth (tidally corrected to sounding datum) of the seafloor (bathymetry, as described above in Section 3.2).

2. Depth range, which is the difference between the minimum and maximum depths. High values indicate steep areas where depth varies significantly, whereas low values indicate flat areas with minor variation in depth.

3. Standard deviation of depth is a statistical measure that quantifies depth variability from the mean depth of the immediately surrounding area. A low standard deviation indicates that the depth values tend to be very close to the mean, i.e. little depth variation. Alternatively, a high standard deviation indicates spread across a wider range of depth values, i.e. there is a high variation of depth.

4. Slope is the steepness of the seafloor gradient, attributed according to the angle (in degrees) from the horizontal. Values near zero are flat areas, while higher values (up to 85°) are areas that are increasingly steep.

5. Standard deviation of slope is a statistical measure that quantifies how much the slope differs from the mean slope of the surrounding area. A low standard deviation indicates that the slope values tend to be very close to the mean i.e. a low variation of slope, a high standard deviation indicates that slope values are spread across a wider range of values, i.e. there is a high variation of slope.

6. Curvature is the change of slope. That is a positive curvature indicates the surface is upwardly convex at that point e.g. a mound. Negative curvature indicates that the surface is upwardly concave at that point e.g. depression. A value of 0 indicates the surface is flat.

7. Aspect is the direction of down-slope dip, with north at 0° and south at 180°. Aspect can also be thought of as the slope direction.

8. Rugosity of the seafloor is the variation in three dimensions, and is a measure of terrain complexity. In the benthic environment, ecological diversity can generally be correlated with physical environmental complexity. As such, rugosity can help identify areas where high biodiversity may exist on the seafloor.

Composite terrain attributions for all of the survey area are illustrated below (Figure 3-5 to Figure 3-9), with a complete set of specific areas provided within the standalone A2 map portfolios. The underpinning processed data and graphics are included in the digital delivery.

A brief overview of the terrain attributions across the survey area is provided below (also see Section 3.5 - Seafloor features):

- Areas of greatest difference between minimum and maximum depth (depth range) are associated with the extensive rocky ridges extending into Cook Strait from Queen Charlotte Sound and Tory Channel, and the rapid deepening away from the coast and nearshore rocky reefs extending out from the shoreline. More moderate differences occur associated with the tidally dominated Cook Strait (outer Queen Charlotte Sound) and Tory Channel.
- Similarly, steep slopes are associated with the extensive rocky ridges extending into Cook Strait from Queen Charlotte Sound and Tory Channel, and the steep coast and shore-attached rocky reefs. Lower slopes often occur at the heads of the bays along the margins of Queen Charlotte Sound, while lower slopes are prevalent along most of the coastline of the bays along the margins of Tory Channel.
- The direction of slope (aspect) highlights the central axis of Tory Channel and many of the larger bays along the margins of Queen Charlotte Sound, e.g. Grove Arm, East Bay and Endeavour Inlet. Areas of increased seafloor roughness coincide with rocky ridge crests that extend into Cook Strait from Queen Charlotte Sound and Tory Channel, and the larger nearshore reefs, e.g. north of Long Island, south of Blumine Island and Dieffenbach Point. To a lesser degree, the sediment waves and larger seafloor depressions are associated with increased seafloor rugosity.

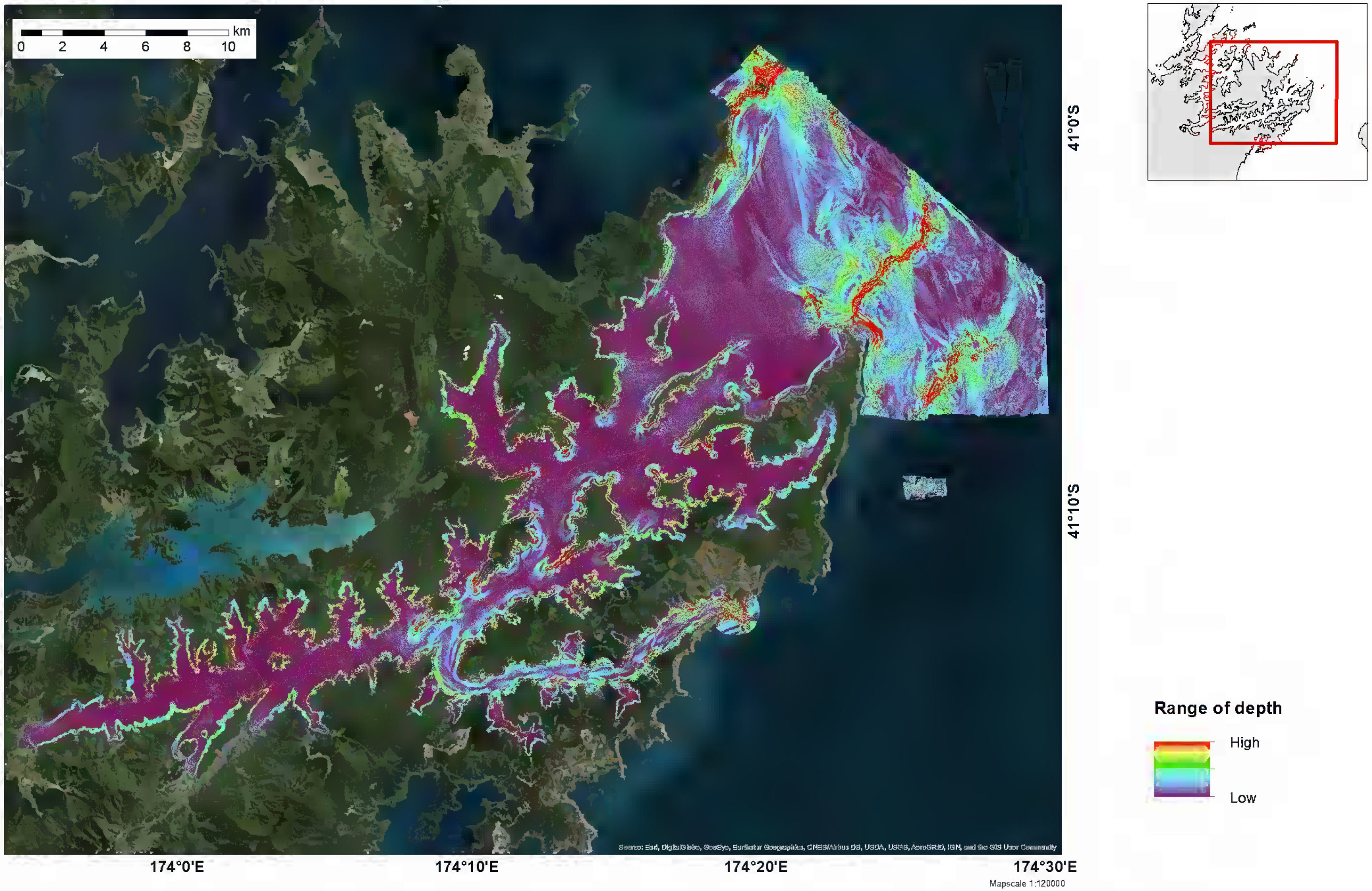


Figure 3-5: Range of depth terrain attribute (combined EM2040 and Geoswath bathymetry). (2 m resolution). Note the extensive rocky ridges extending into Cook Strait from Queen Charlotte Sound and Tory Channel, the steep slopes at the coast, and nearshore rocky reefs extending out from the shoreline. The full 28 map sets are included in the accompanying portfolios.

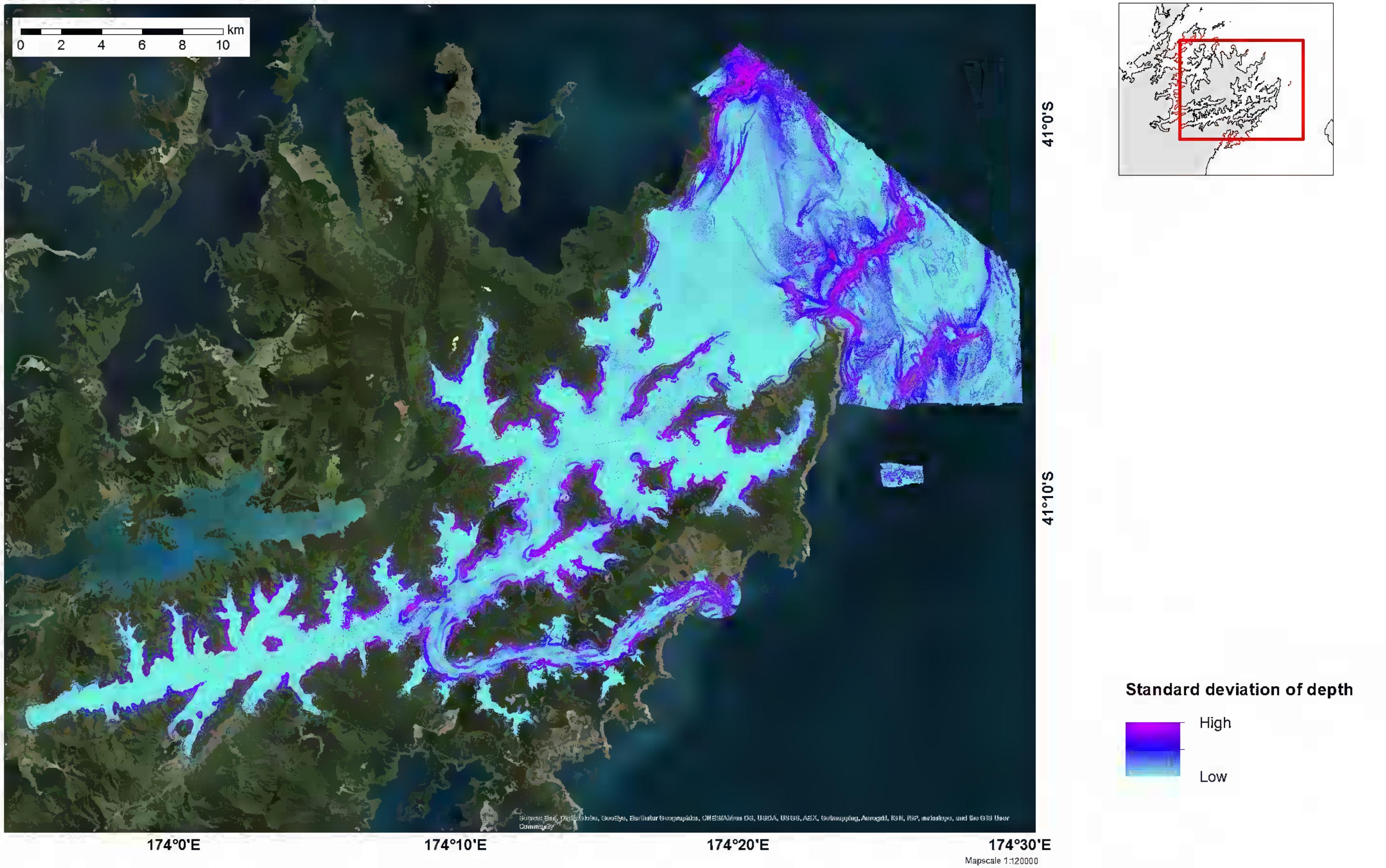


Figure 3-6: Standard deviation of depth terrain attribute (combined EM2040 and Geoswath bathymetry). (2 m resolution). Note the extensive rocky ridges extending into Cook Strait from Queen Charlotte Sound and Tory Channel, the rapid deepening away from the coast, and nearshore rocky reefs extending out from the shoreline. The full 28 map sets are included in the accompanying portfolios.

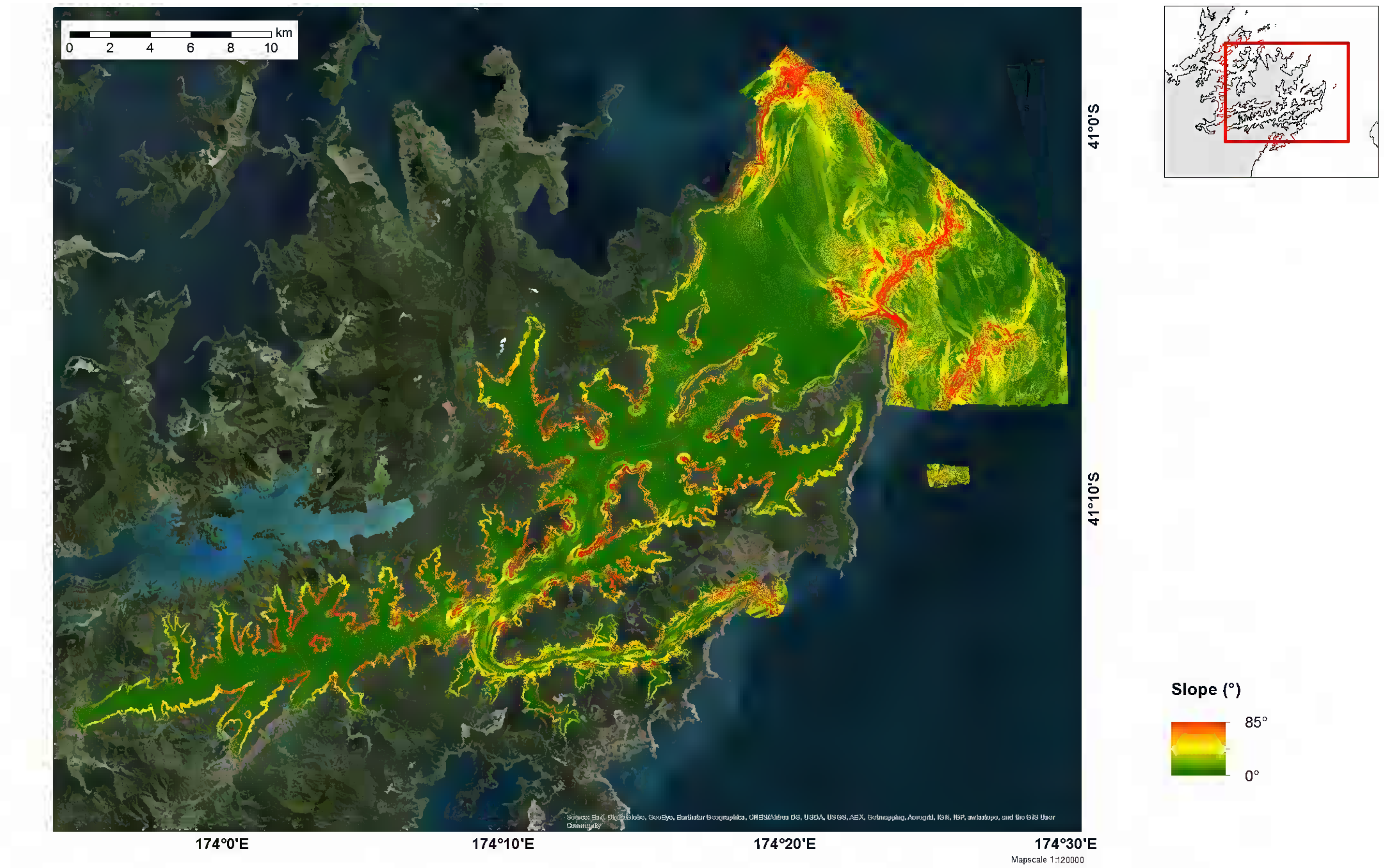


Figure 3-7: Slope terrain attribute (combined EM2040 and Geoswath bathymetry). (2 m resolution). Steep slopes coincide with the extensive rocky ridges extending into Cook Strait from Queen Charlotte Sound and Tory Channel, as well as the steep seafloor extending out from the coast. The full 28 map sets are included in the accompanying portfolios.

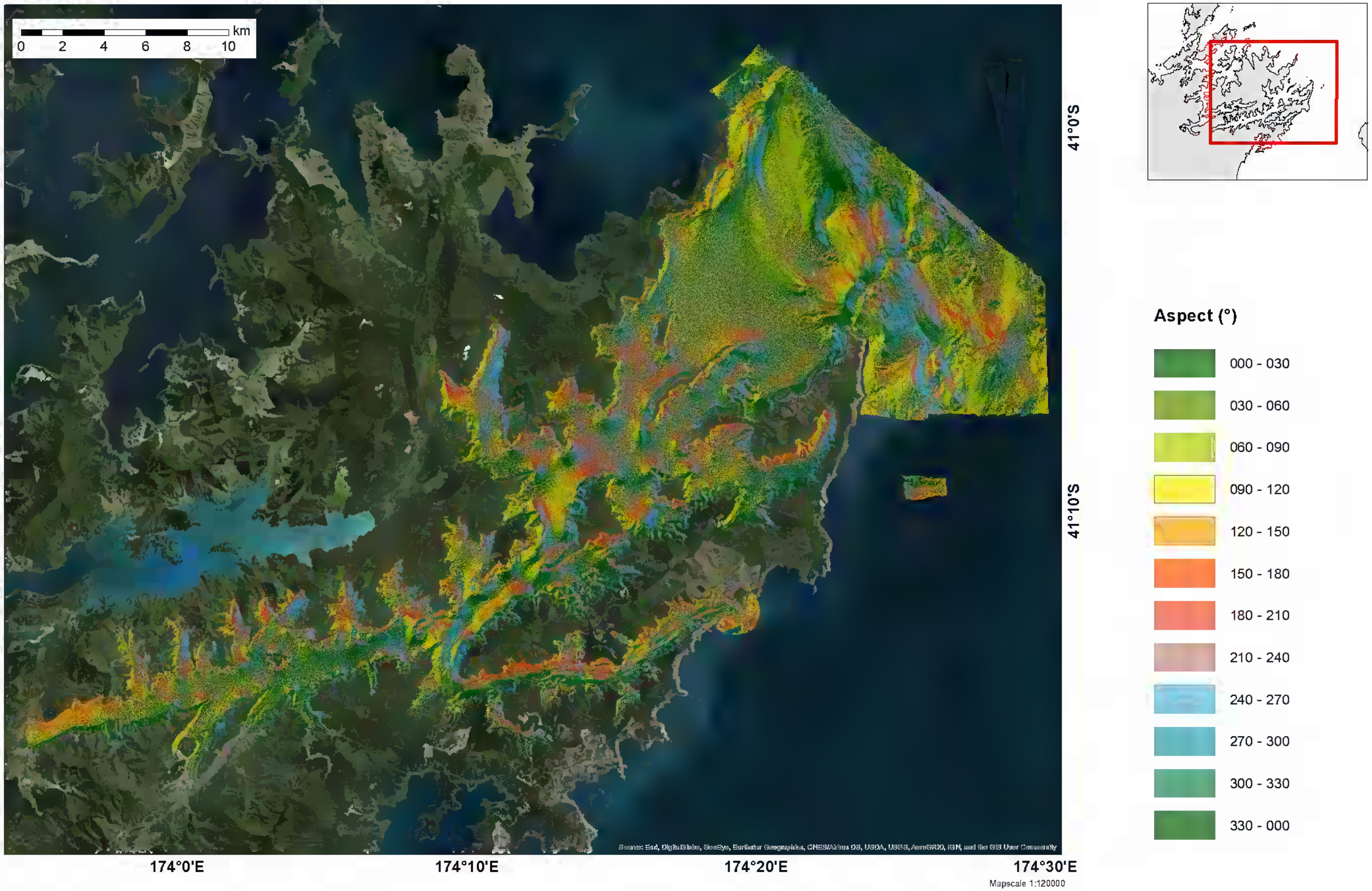


Figure 3-8: Aspect of terrain attribute (combined EM2040 and Geoswath bathymetry). (2 m resolution). Direction of slope (aspect) highlights the axis of Tory Channel and many of the larger bays along the margins of Queen Charlotte Sound e.g. Grove Arm, East Bay and Endeavour Inlet. The full 28 map sets are included in the accompanying portfolios.

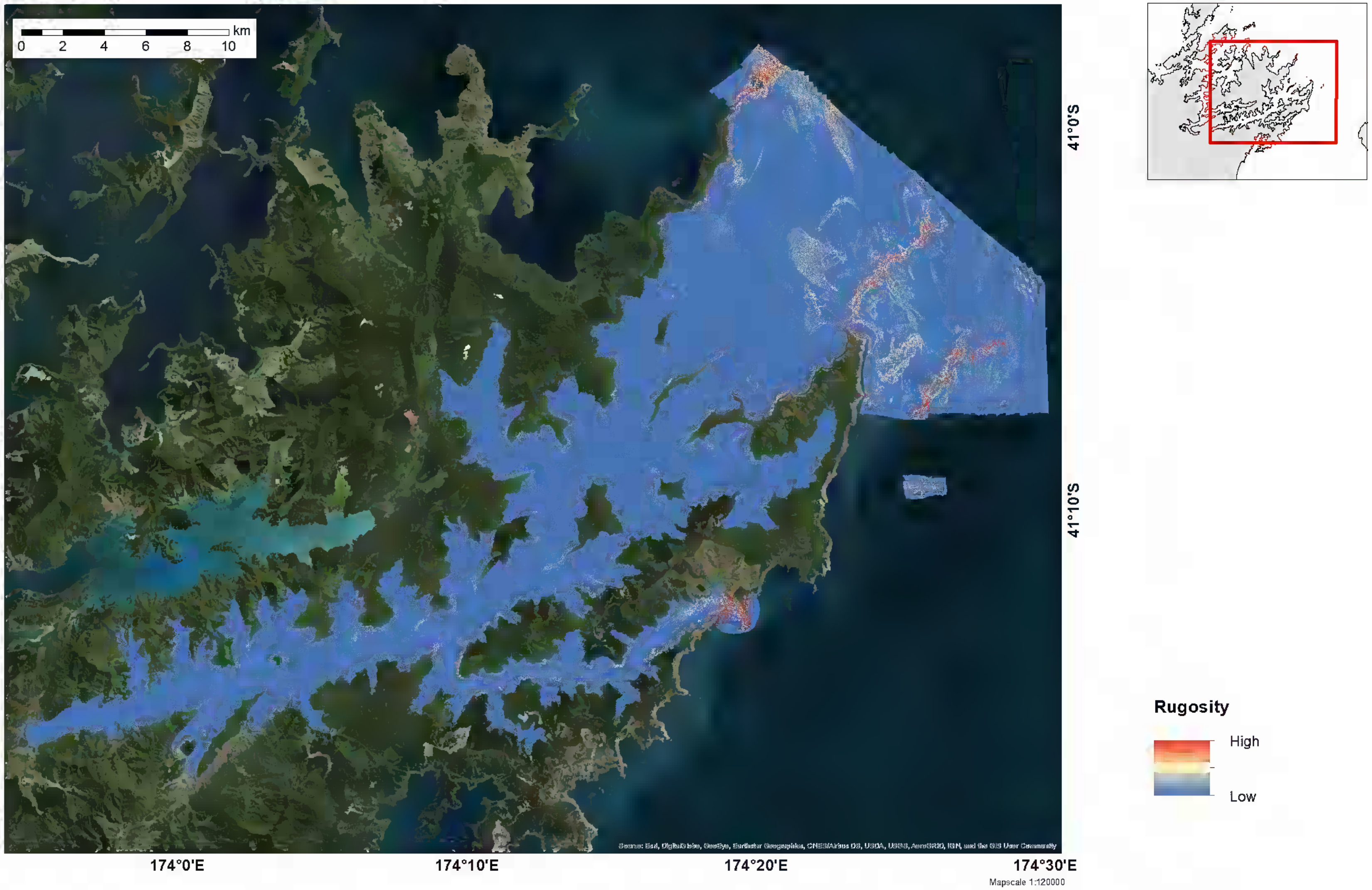


Figure 3-9: Rugosity of terrain attribute (combined EM2040 and Geoswath bathymetry). (2 m resolution) Areas of increased seafloor rugosity are associated with the crests of the rocky ridges extending into Cook Strait, and the larger nearshore reefs e.g. north of Long Island, south of Blumine Island and Dieffenbach Point. The full 28 map sets are included in the accompanying portfolios.

3.4 Seafloor backscatter

3.4.1 Background to acoustic backscatter as a mapping tool

When collecting multibeam bathymetry, a secondary signal of reflected sound intensity (backscatter) is also recorded. Backscatter intensity can help identify the type of seafloor substrate; whether it is hard or soft, or sediments are coarse- or fine-grained. This provides valuable information about the physical-benthic substrates.

The backscatter signal is the component of the transmitted sound signal that is reflected back from the seafloor, or any target (a feature that creates acoustic scatter) within the water column, and recorded by the sonar receiving arrays (Lurton and Lamarche 2015; Lamarche and Lurton, 2018). There is now a greater appreciation of the potential that can be derived from seafloor and water-column backscatter data and how appropriate data acquisition and processing may lead in qualitative and quantitative information on the substrate and water-column targets (so called 'scatterers') (see Lurton and Lamarche, 2015 for a full review of seafloor backscatter related issues).

Backscatter data relates to seafloor roughness (micro-topography, substrate, bedforms) and volume differences (heterogeneity) between scatterers. In turn, these are controlled by substrate-related characteristics such as sediment grain-size, composition, and bioturbation. The intensity of the backscatter signal provides a semi-quantitative indication of the nature of this substrate.

Backscatter imagery is displayed here in grey level mosaics with lighter shades (white being the extreme) for high backscattering intensity and darker shade (black being the extreme) for low intensity. The grey level of any pixel directly refers to the backscatter intensity value (in dB). apparent sharp boundaries or a step in the dB level (block variability in the grey scale) are visible in the mosaics over otherwise gradual seafloor change. Such limitations are not uncommon for large backscatter mosaics that span a range of water depths and bottom substrates, and acquired over long survey campaigns.

The range of acoustic backscatter observed across the survey area can be subdivided into so called discrete backscatter 'facies'. These facies types are defined, by Lamarche and Lurton (2018) as characteristics and spatial arrangement of seafloor patches that have common acoustic responses and that the response is measurable, as observed on the mosaics here. For example:

1) a homogeneous (similar), low-to-medium reflectivity facies (dark grey – Figure 3-10) relates to soft and homogenous material at the seafloor, which here may reflect mud. Mud (silt and clay) has low backscatter, and a wide range of backscatter and bathymetry variance; the sediment absorbs most of the acoustic energy as a result of high water content and the small particle size.

2) a homogeneous, medium-to-high reflective (light grey) facies relates to hard or heterogenous seafloor. Here, this may represent sandy seafloor, hard substrate or bioturbated sediments. Sand has medium to high backscatter variance and very low to medium bathymetry variance; some of the signal is refracted into the sediment and absorbed.

3) a highly heterogeneous (dissimilar) reflective facies (white – Figure 3-10) which here is likely to relate to rock. Lithified rock outcrops, coarse gravel and loose boulders have very high backscatter due to the high reflectivity and rugosity that scatters incident energy; a wide range of backscatter variance results from patchy outcrops and thin sediment veneers overlying bedrock.

In addition, Geoswath backscatter data provides qualitative information for shallow depths <5 m, which is visually comparable with the multibeam backscatter mosaic. We display both Geoswath and EM2040 multibeam backscatter mosaics on the same image to provide full coverage of the survey area. Continuity between multibeam and Geoswath mosaics is demonstrated by the acceptable matching of the grey levels, thus enabling a qualitative interpretation of the backscatter facies from the drying line to the deepest portions of the HS51 survey area.

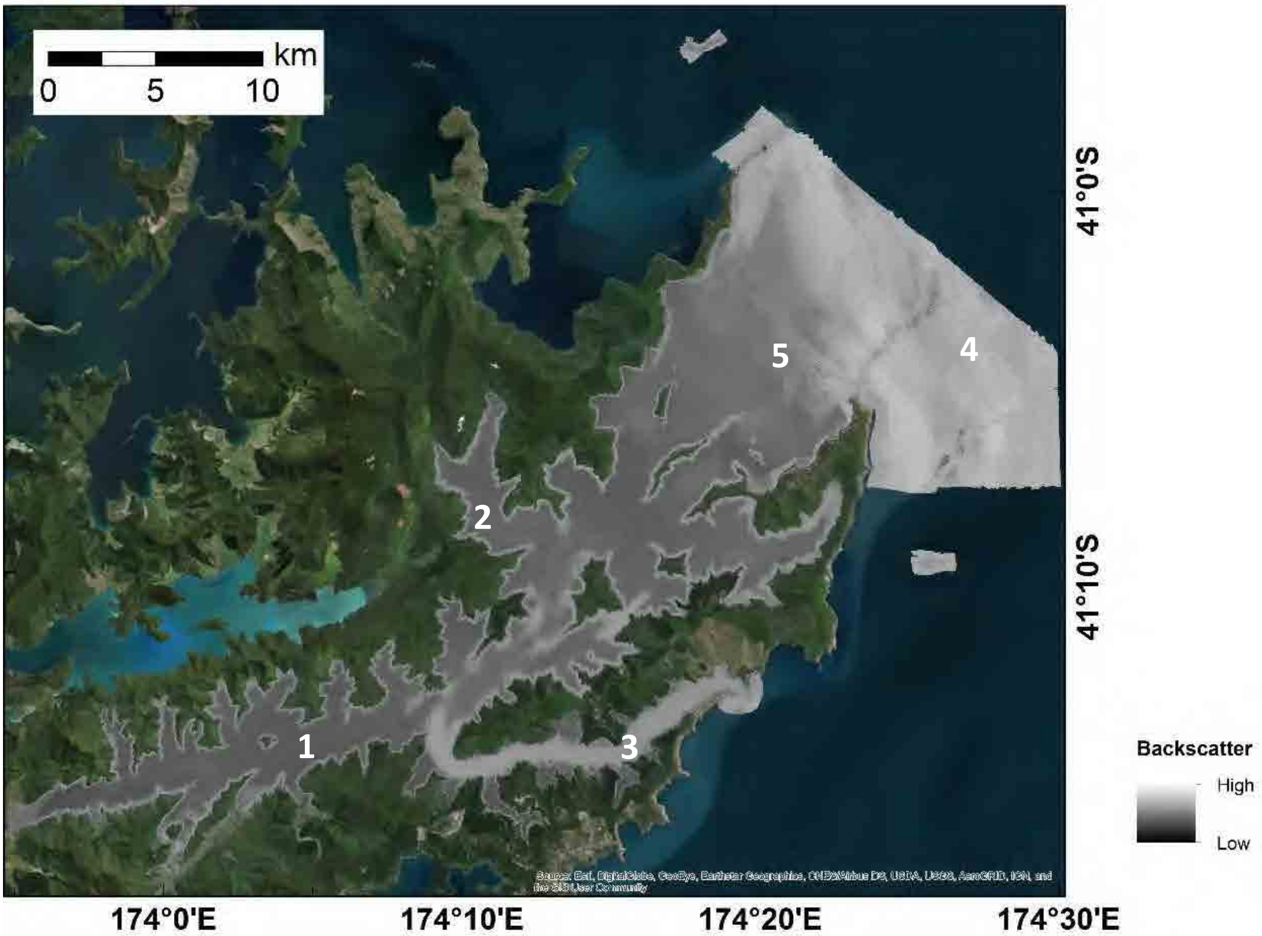


Figure 3-10: Seafloor backscatter imagery (combined EM2040 and Geoswath backscatter). The backscatter intensity is shown at 0.5 m grid resolution. Note the following regional features: (1) a low reflectivity (dark) homogenous-backscatter occurs over much of the central areas of inner and middle Queen Charlotte Sound; (2) a strip of medium to high reflectivity backscatter (grey) occurs on the steep slopes and rocky outcrops along the shoreline margins; (3) a consistent band of medium to high reflectivity backscatter (grey), which dominates the axis of Tory Channel, and reflects the coarse material within that area; (4) highly reflective (white) over the outer approaches of Queen Charlotte Sound (Cook Strait), indicative of rocky or very coarse; and, (5) small patches of an irregular backscatter separating middle Queen Charlotte Sounds from Cook Strait.

3.4.2 Seafloor classification of backscatter classes

Seafloor backscatter (for >5 m water depth) can be segmented into classes representative of the substrate or sediment types. In water depths <5 m backscatter is produced as qualitative imagery and cannot be included in the seafloor classification analysis (also see Section 3.7). Methodology is outlined in Part 2, Section 1.8.

Samples from the survey area predominately fall within two textural groups: muds to sandy-mud and gravelly-mud to gravel. A small number of samples are represented by the muddy-sand to sand textural classes (Figures 3-11). These four classes can be texturally discriminated from their backscatter-strength relationship.

Four classes were identified using a supervised segmentation/classification approach, the methodology for the classification is outlined in Part 2, Section 1.8. The resultant classification indicates ~49% of the area comprises low reflectivity mud, ~36% of the area comprises high reflectivity coarse sand or gravel, 8% of the area low-medium reflectivity fine sand, and ~6% of the area is medium-high reflectivity medium sand (Figure 3-12, Table 3-1). Seafloor images representative of these classes are illustrated in Table 3-2.

Table 3-1: Area and percentage of seafloor backscatter classes within Queen Charlotte Sound and Tory Channel.

Seafloor Classification	Area (km^2) of class within survey area	% of class within survey area
Low reflectivity (mud)	212.35	49.3%
Low-medium reflectivity (fine sand)	37.75	8.8%
Medium-high reflectivity (medium sand)	26.76	6.2%
High reflectivity (coarse sand/gravel)	153.55	35.7%

The seafloor backscatter classification for Queen Charlotte Sound (excluding the outer reaches/Cook Strait) indicates ~75% of the area comprises low reflectivity mud, ~11% of the area low-medium reflectivity fine sand, ~8% of the area comprises high reflectivity coarse sand or gravel, and ~6% of the area is medium-high reflectivity medium sand. Whereas, the outer reaches of Queen Charlotte Sound/Cook Strait are ~91% of the area comprises high reflectivity coarse sand or gravel, 4% of the area is medium-high reflectivity medium sand, ~3% of the area low-medium reflectivity fine sand, and ~2% of the area comprises low reflectivity mud.

Tory Channel seafloor backscatter classification across the four classes are ~42% of the area comprises high reflectivity coarse sand or gravel, ~28% of the area comprises low reflectivity mud, ~18% of the area is medium-high reflectivity medium sand, and 11% of the area low-medium reflectivity fine sand.

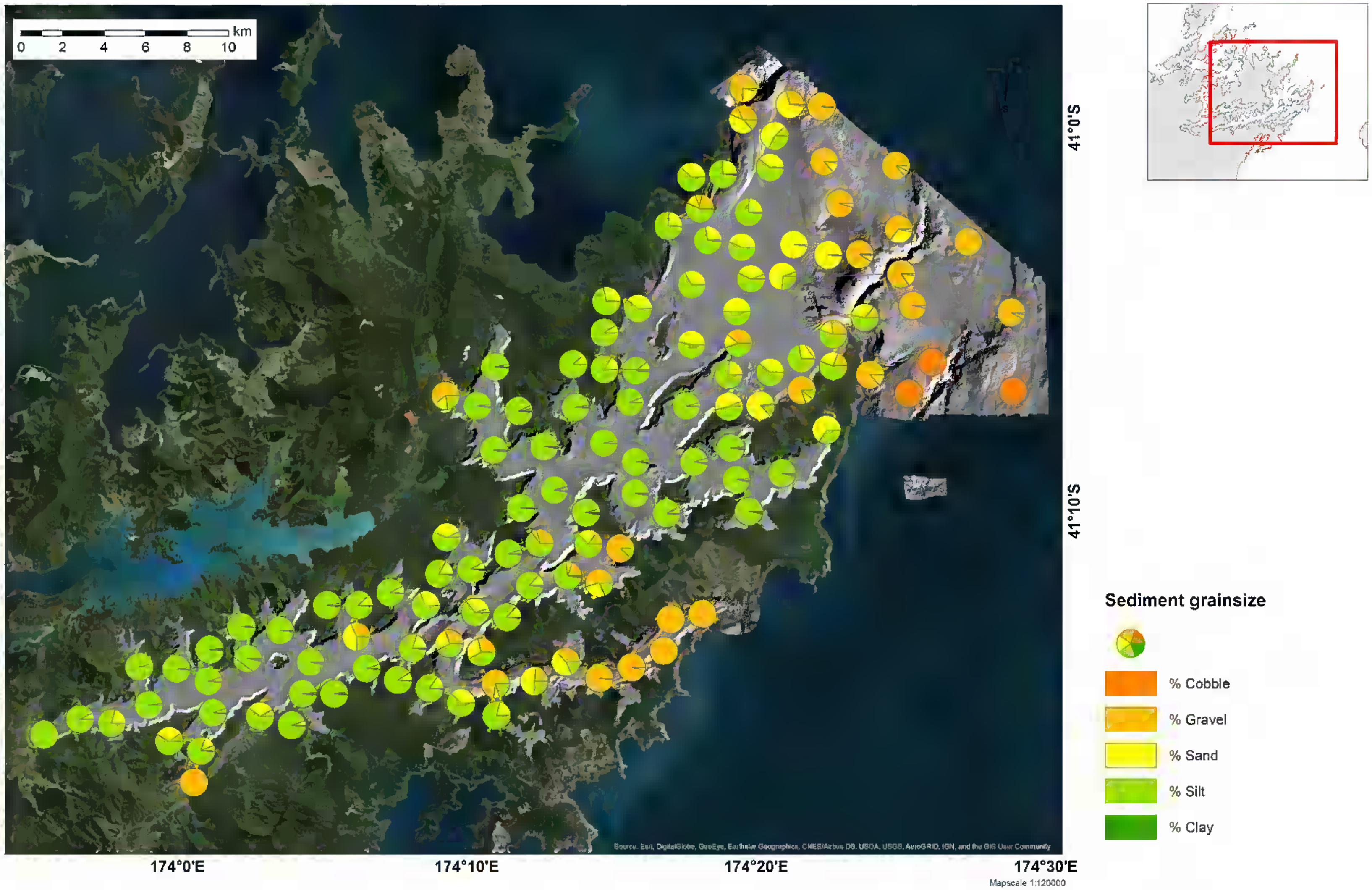


Figure 3-11: Seafloor grainsize. Figure shows the grainsize of the substrate samples within the survey area. The sounds are dominated by muds, whereas Tory Channel and Cook Strait are dominated by gravel. The grainsize was used to ground-truth the seafloor classification facies.

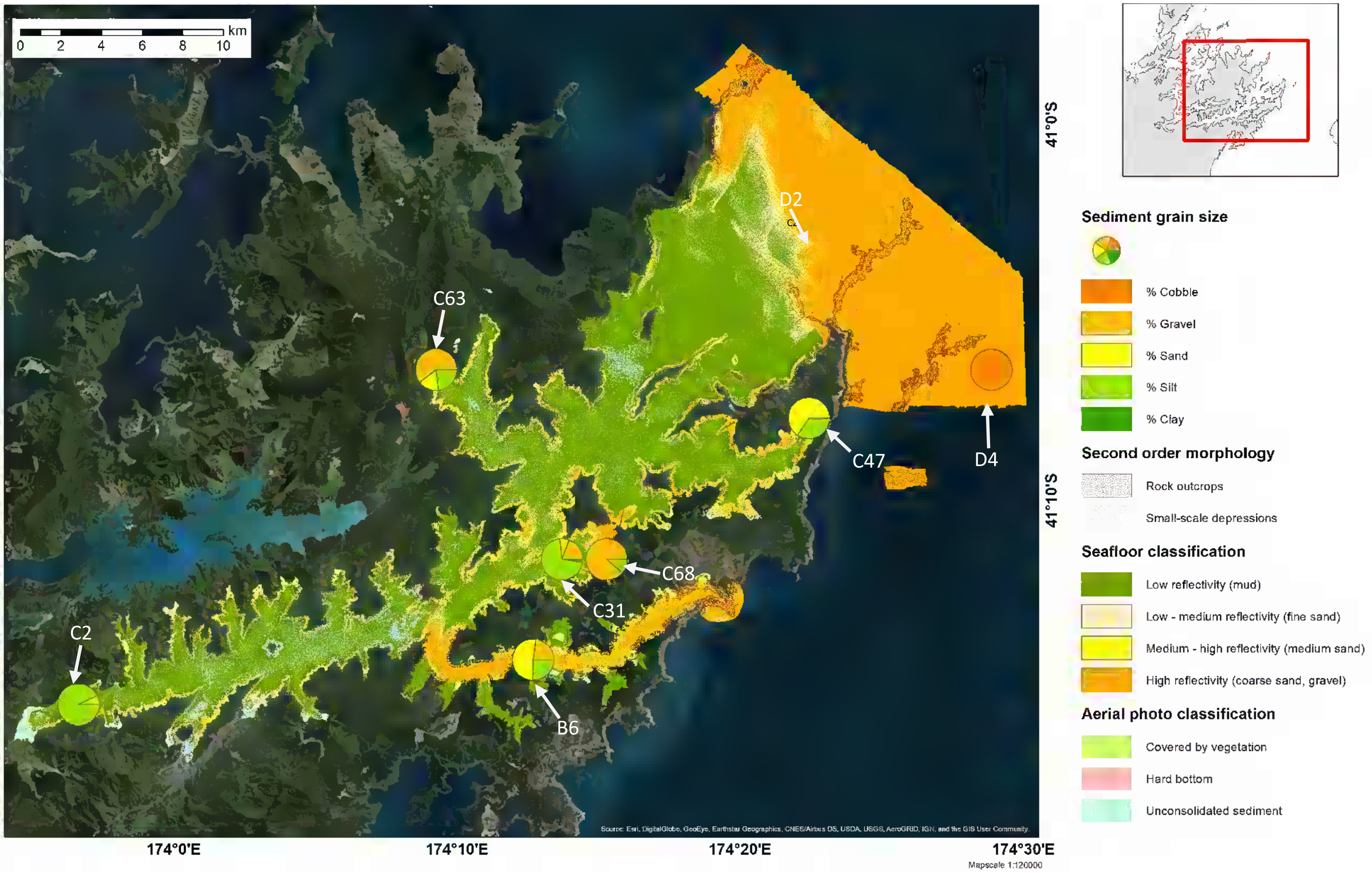
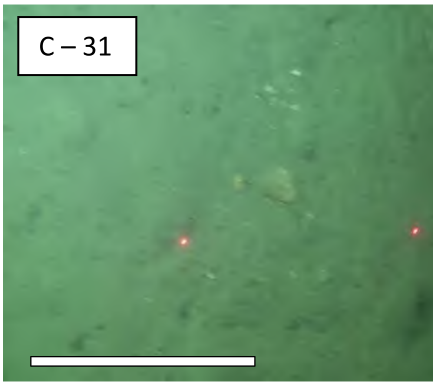
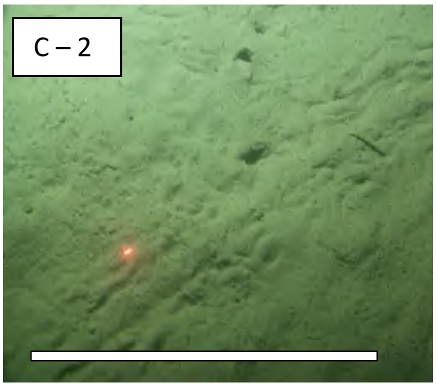
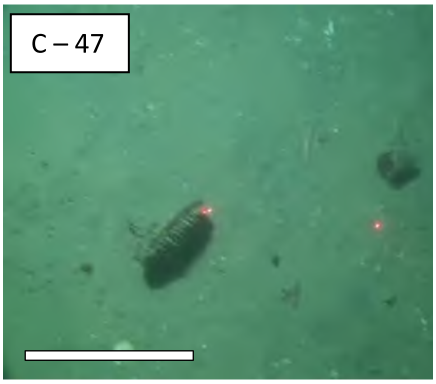
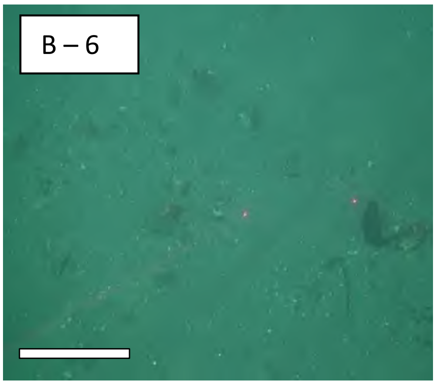
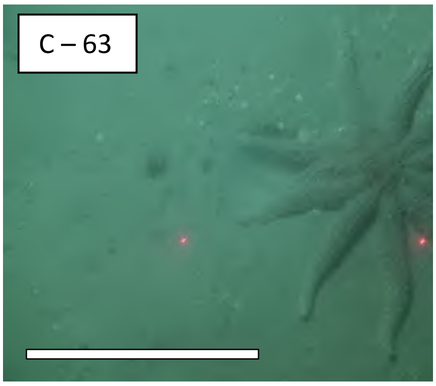
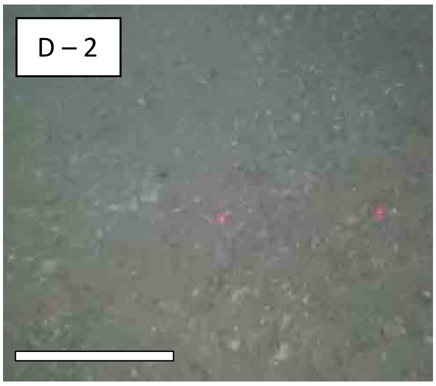
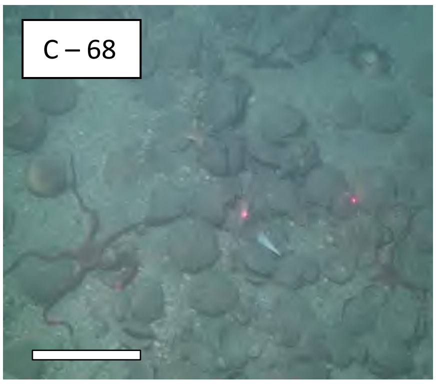
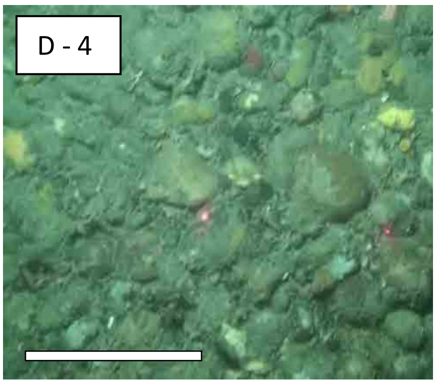


Figure 3-12: Seafloor classification map. Four classes were identified using a supervised segmentation/classification approach. The four classes are texturally discriminated from their backscatter strength relationship. The seafloor classification colours for each facies shown in the key are also used in Table 3–2. Seafloor images associated with sample numbers are illustrated in Figure 3-17. The aerial-photo classifications are described in Section 3.7.

Table 3-2: Seafloor samples representative of seabed classes. BS is Backscatter Strength or the intensity of backscatter echo. Location of seafloor images shown on Figure 3-11.

Seafloor Classification	Representative Seafloor Image	
Class 1 homogeneous, low reflectivity mud facies BS<-22dB		
Class 2 homogeneous, medium-to-high reflective fine sand facies -22<BS<-18 dB		
Class 3 homogeneous, medium-to-high reflective medium sand facies -18<BS<-16 dB		
Class 4 a highly heterogeneous (high) reflectivity coarse sand gravel facies BS>-16 dB		

3.4.3 Regional variation of backscatter classes

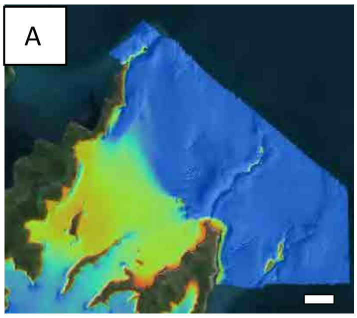
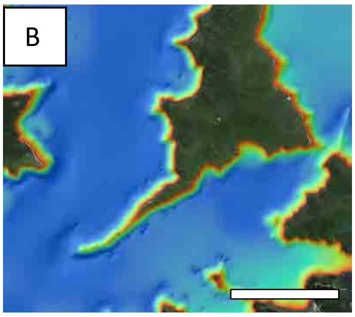
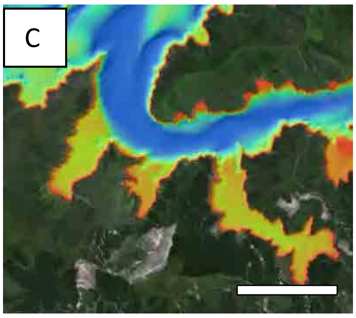
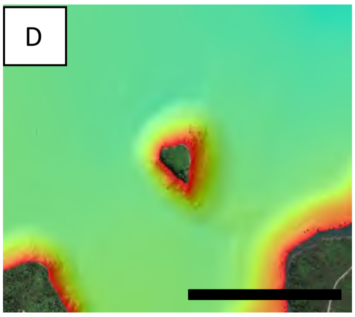
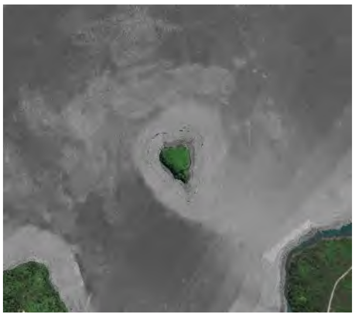
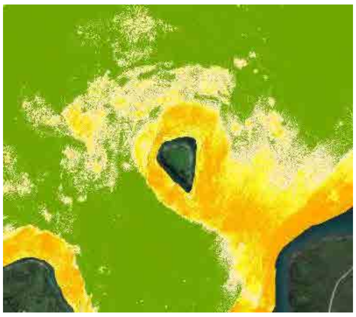
The approaches to Queen Charlotte Sound exhibit a progressive transition from high reflectivity backscatter in Cook Strait to low reflectivity within the Sound (Table 3-3). This is highlighted in the classification map with narrow bands of medium reflectivity (Class 2 and 3) separating a wide area of high reflectivity (Class 4) in the outer approaches of Queen Charlotte Sound and low, homogeneous backscatter (Class 1) dominating in Queen Charlotte Sound. This indicates a transition of substrate composition over ~3 km, rather than an abrupt transition from fine-grained muds within the Sound to coarse-gravel substrate in Cook Strait (Table 3-3 A).

The seafloor around Blumine Island is an example where the backscatter intensity contrasts strongly with that generally observed elsewhere in Queen Charlotte Sound. The narrow passages are characterised by irregular and patchy backscatter with high to very high backscatter intensities (Classes 3 and 4) are indicative of higher current and illustrate the extent of the coarse sediment deposits associated with this region (Table 3-3 B).

The centre of Tory Channel is dominated by high to very high reflectivity, clearly identified as Class 4. The marginal bays all exhibit low to medium reflectivity (Classes 1 and 2). The transition between the high reflectivity within Tory Channel to the low reflectivity of the bays is very sharp and coincides with the marked bathymetric change from Tory Channel to the shallower bays. A strip of medium to high reflectivity (Class 2 and3) marks the edges of Tory Channel, as elsewhere in the Sounds. This indicates that the Tory Channel seafloor is dominated by coarse substrate (gravel and coarse sand) and markedly differs with the marginal bay were fine sand and mud dominates (Table 3-3 C).

The area surrounding Mabel Island provides a good example of varied backscatter reflectivity in a limited geographic area (Table 3-3 D). The flanks of Mabel Island are highly reflective (Class 3 and 4) indicating their rocky nature. To the west and northwest of the island, a highly heterogeneous backscatter (Clases 2, 3 and 4) suggest features which are current driven, resulting from ship-propeller wash, or other port-related disturbance. The overall surrounding background has a homogeneous low reflectivity (Class 1), which is well depicted in the classification.

Table 3-3: Examples showing backscatter facies and comparison with bathymetry and seafloor classification. A: Outer Queen Charlotte Sound (see Portfolios Outer Queen Charlotte Sound/Tōtaranui, 2 of 13, and 3 of 13), B: Blumine Island (see Portfolios Middle Queen Charlotte Sound/Tōtaranui, 4 of 13, and 6 of 13), C: Tory Channel (see Portfolios Tory Channel/Kura Te Au, 9 of 13 and 10 of 13), D: Mable Island (see Portfolios Inner Queen Charlotte Sound/Tōtaranui, 7 of 13, and 8 of 13). (Bathymetry 2 m grid resolution, backscatter and seafloor backscatter classification 0.5 m grid resolution. Bathymetry, backscatter and seafloor classification illustrated at same scale (black scale = 500 m, white scale = 2000 m).

Bathymetry	Backscatter	Seafloor backscatter classification
		
		
		
		

3.5 Seafloor features highlighted in new bathymetric data

3.5.1 Sediment wave fields

A prominent geomorphologic feature in outer Queen Charlotte Sound is a sediment-wave field (Figure 3-13 and Figure 3-14). Sediment waves, megaripples and ripples can range in size from tens of metres to decimetres, and are the result of both oscillating water motions (e.g. tidal flows) and unidirectional currents. Here, sediment waves range in height from 2–3 m and have wavelengths (crest to crest) of ~120 m (Figure 3-14). Sediment-wave fields can develop extensively with strong flows up to ~ 0.7 ms^{-1}, which is attained by the mean current speed in the outer reaches of Queen Charlotte Sounds/Cook Strait which reach 0.5 - 1 ms^{-1} (Hadfield et al. 2014). Oscillating tidal flows can enhance the height of sediment waves and generally result in symmetrical bedforms, however a directional dominance of tidal flows or tidal asymmetry also encourages some asymmetry in the bedforms, with the steeper lee-slope facing upslope to the southeast. Here, a symmetrical nature of the bedforms is apparent Figure 3-14, resulting from wind and tidally driven flows in Cook Strait; with the curvilinear crest of the sediment waves trending approximately southwest -northeast, normal to the oscillating tidal current.

Smaller bedforms and megaripples are superimposed on the larger sediment waves (Figure 3-13 and Figure 3-14), with crest heights of up to 0.5 m and wavelengths (crest to crest) of ~ 10 m. Similarly, megaripples frequently have superimposed smaller ripples (e.g. Figure 3-14). This supposition of small, mobile bedforms is considered a consequence of the waxing and waning or oscillating flows. These megaripples exhibit the same approximate southwest -northeast orientation with ridge crests showing the same complex curvilinear pattern.

This style of sandy sediment-wave field is not unique in the wider Cook Strait region, with similar features previously recognised in the Narrows Basin and Wellington Harbour entrance and west of D'Urville Island (e.g. Carter 1992, Carter and Lewis 1995, Lamarche et al. 2011, Neil et al. 2015, 2015a). There, bedforms similarly developed in response to the strong tidal flows coupled with sediment supply.

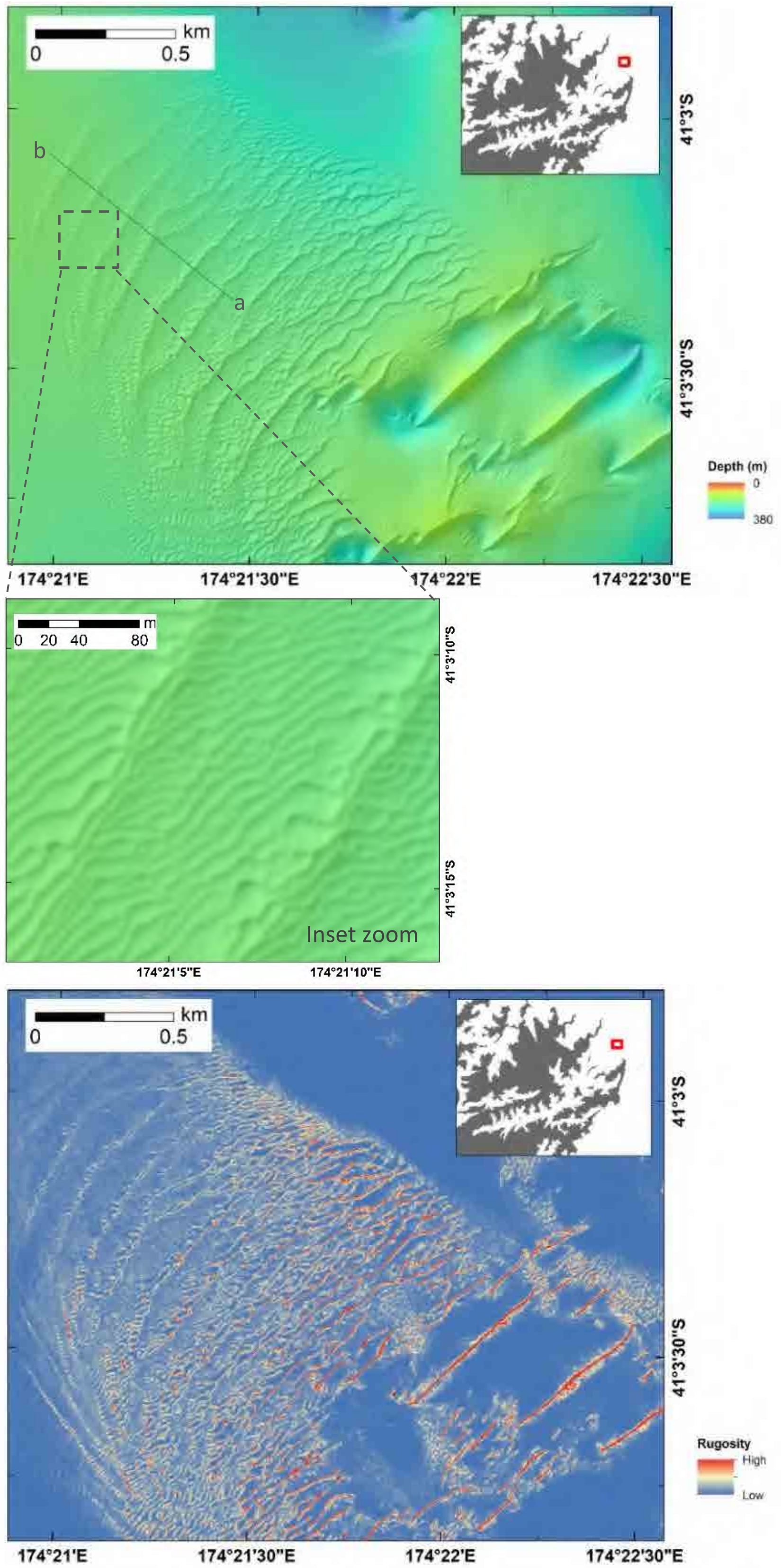


Figure 3-13: Bathymetric (upper and inset) and rugosity (lower) imagery illustrating sediment waves in Outer Queen Charlotte Sound. (2 m grid resolution). Inset shows two sediment wave crests (~120 m apart) with superimposed megaripples. Location of profile in Figure 3-14 shown on bathymetry. Also refer to Portfolios Outer Queen Charlotte Sound/Tōtaranui, 2 of 13, and 3 of 13 for larger scale images.

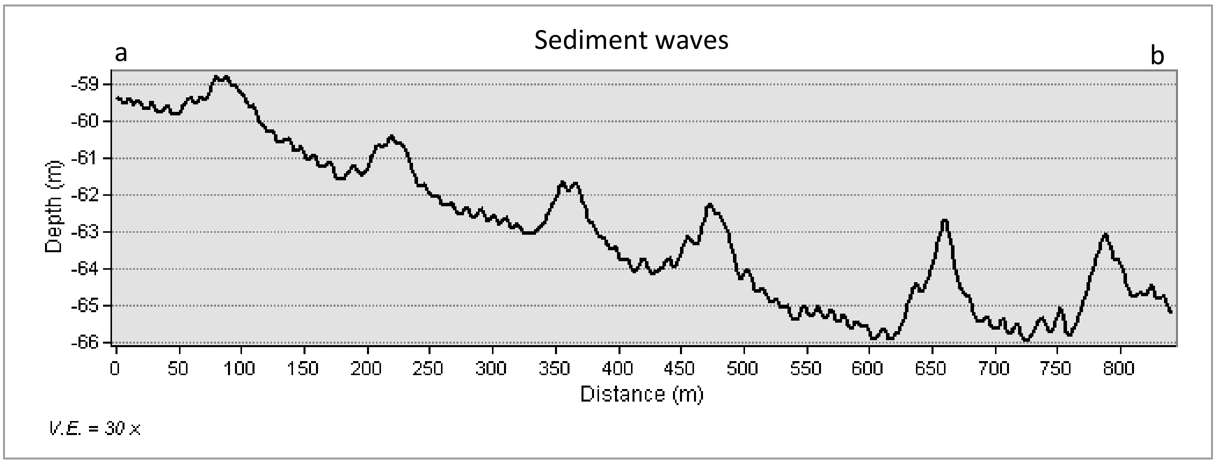
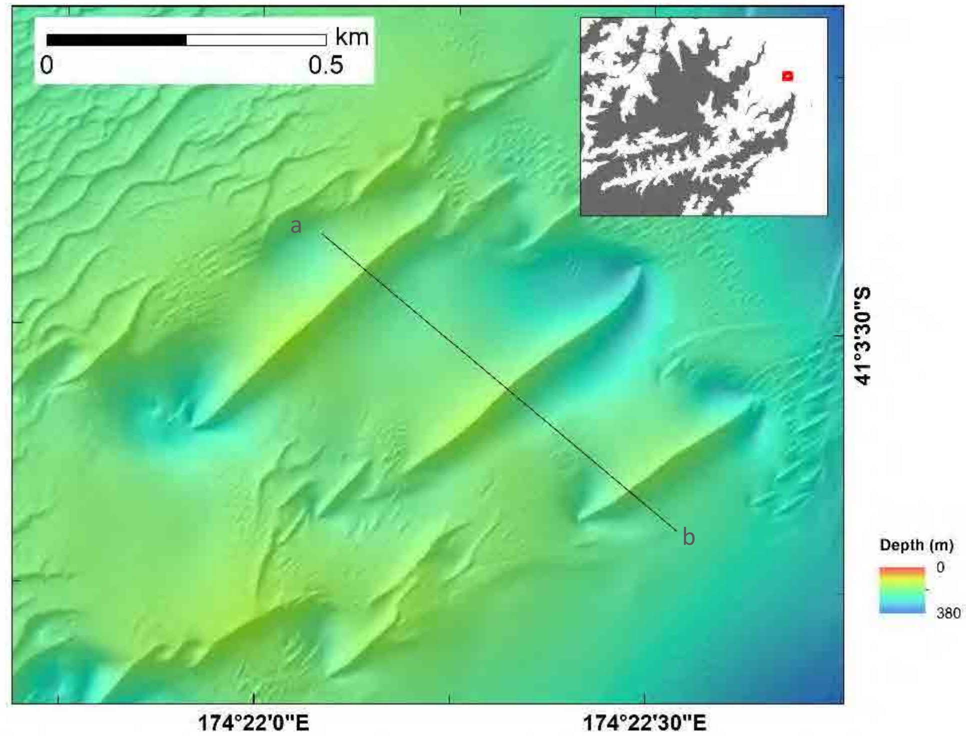


Figure 3-14: Bathymetric profile across sediment waves in Outer Queen Charlotte Sound. Location of profile is shown on Figure 3-13: bathymetry. Sediment waves in this profile are 2-3 m high with wavelengths of ~120 m, while megaripples are <0.5 m in height with wavelengths of ~ 10 m.

3.5.2 Prominent linear-sediment waves, outer Queen Charlotte Sound

Also prominent are three relatively linear sediment waves, orientated southwest-northeast in outer Queen Charlotte Sound (Figure 3-15). These features exhibit relatively straight crests, are symmetrical in cross-section, range in height from 15 - 20 m and have wavelengths (crest to crest) of 200–300 m (Figure 3-16). Their backscatter intensity is stronger than that exhibited by the curvilinear sediment waves, and bottom samples indicate that they are more coarsely grained (Figures 3-17 and 3-18). Their crests show more relief than the curvilinear sediemnt waves and depressions frequently occur at the ends of the crests. Higher backscatter intensities are observed in the depressions at the extremities and suggest the presence of coarse material (Figure 3-16). These features have been previously illustrated in the wider Cook Strait and west of D'Urville Island region (Lamarche et al. 2011, Neil et al. 2015).



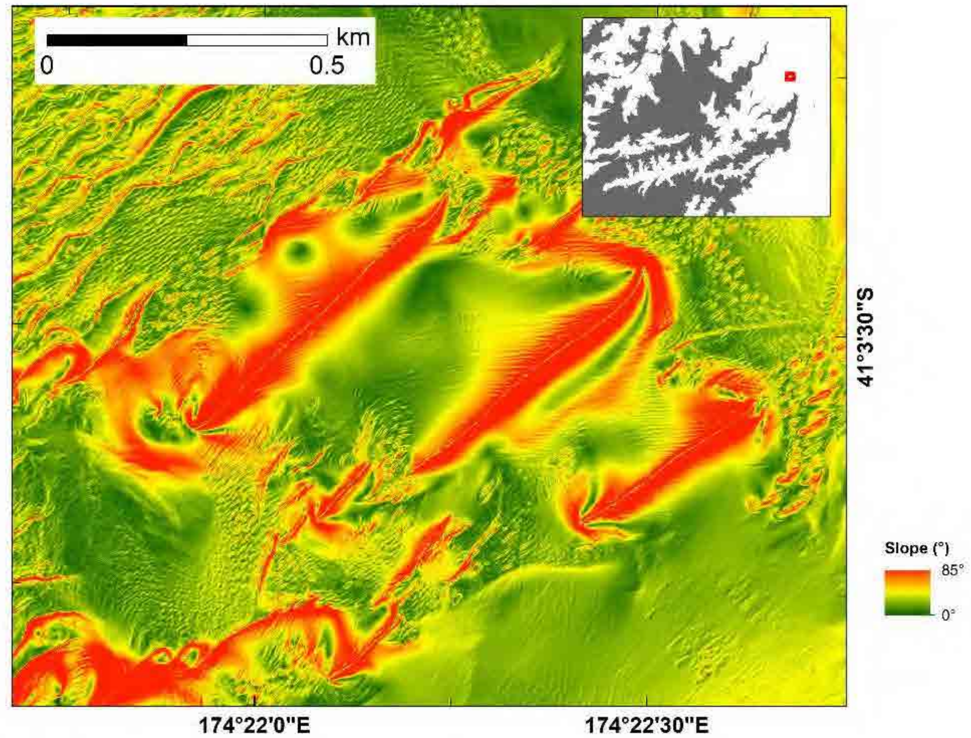


Figure 3-15: Bathymetric (upper) and slope (lower) imagery illustrating steep-sided linear sediment waves in outer Queen Charlotte Sound. (2 m grid resolution). Location of profile in Figure 3-16 shown on bathymetry.

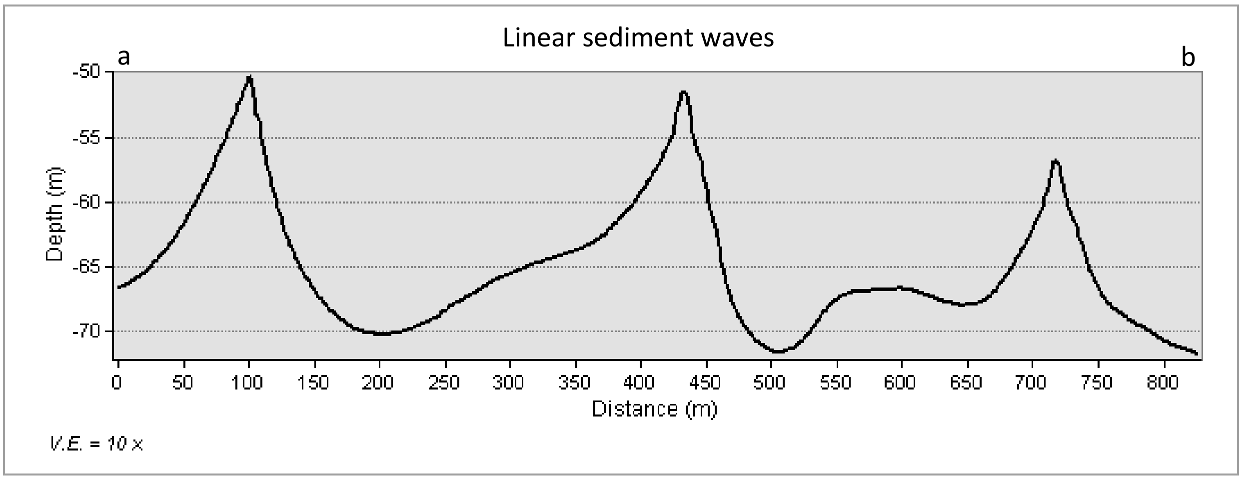


Figure 3-16: Bathymetric profile of linear sediment waves, outer Queen Charlotte Sound. Location of profile is shown on Figure 3-15: bathymetry. Sediment waves in this profile reach heights of 15-20 m high with wavelengths of 300-400 m.

3.5.3 Sediment wave fields, backscatter and substrate

Sediment wave fields are also characterised by variations in the backscatter such that the backscatter facies generally follow the pattern of the bedforms. Over the mega-ripples the classification identifies alternating low and medium reflectivity backscatter classes indicating a succession of likely fine sand to medium sand, while the linear sediment waves are characterised by higher seafloor backscatter / coarser grainsize (Figures 3-17 and 3-18).

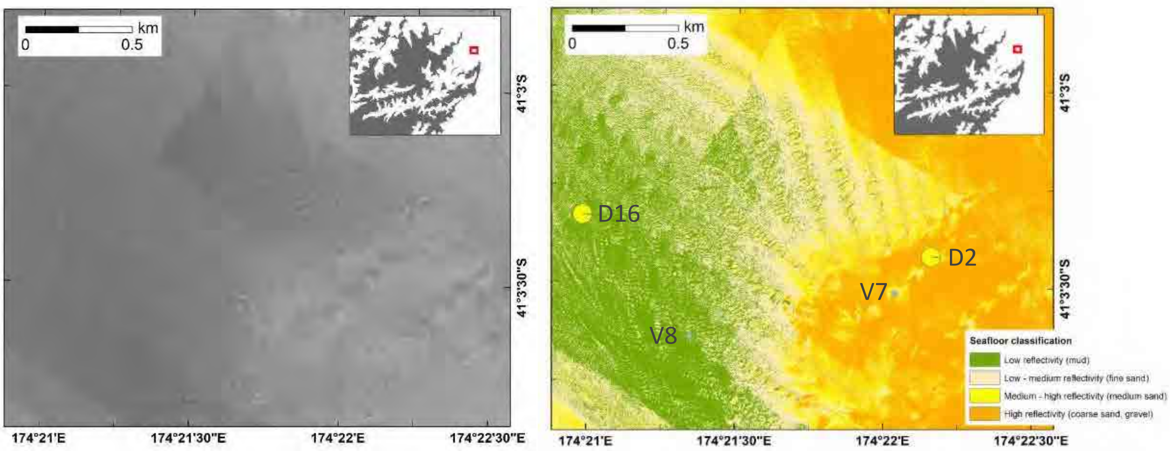


Figure 3-17: Seafloor Backscatter (left) and Seafloor Classification (right).(0.5 m grid resolution). Indicating the lower seafloor backscatter/finer grainsize of the mega rippled sediment waves and the higher seafloor backscatter/ coarser grainsize of the linear sediment waves. Pie charts reflect grainsize, samples D2 and D16 are sand, and grey dots indicate seafloor image locations, V7 and V8. Lower backscatter - dark grey, higher back scatter – light grey (left). Low reflectivity (mud) – green, Low-medium reflectivity (fine sand) – beige, Medium-High reflectivity (medium sand) – yellow, High reflectivity (coarse sand - gravel) – orange (right). Note the apparent boundary in the backscatter mosaic inherent to the complexity of backscatter data. Seafloor images associated with sample numbers are illustrated in Figure 3-18. Refer to Portfolios Outer Queen Charlotte Sound/Tōtaranui, 2 of 13, and 3 of 13 for larger scale image.

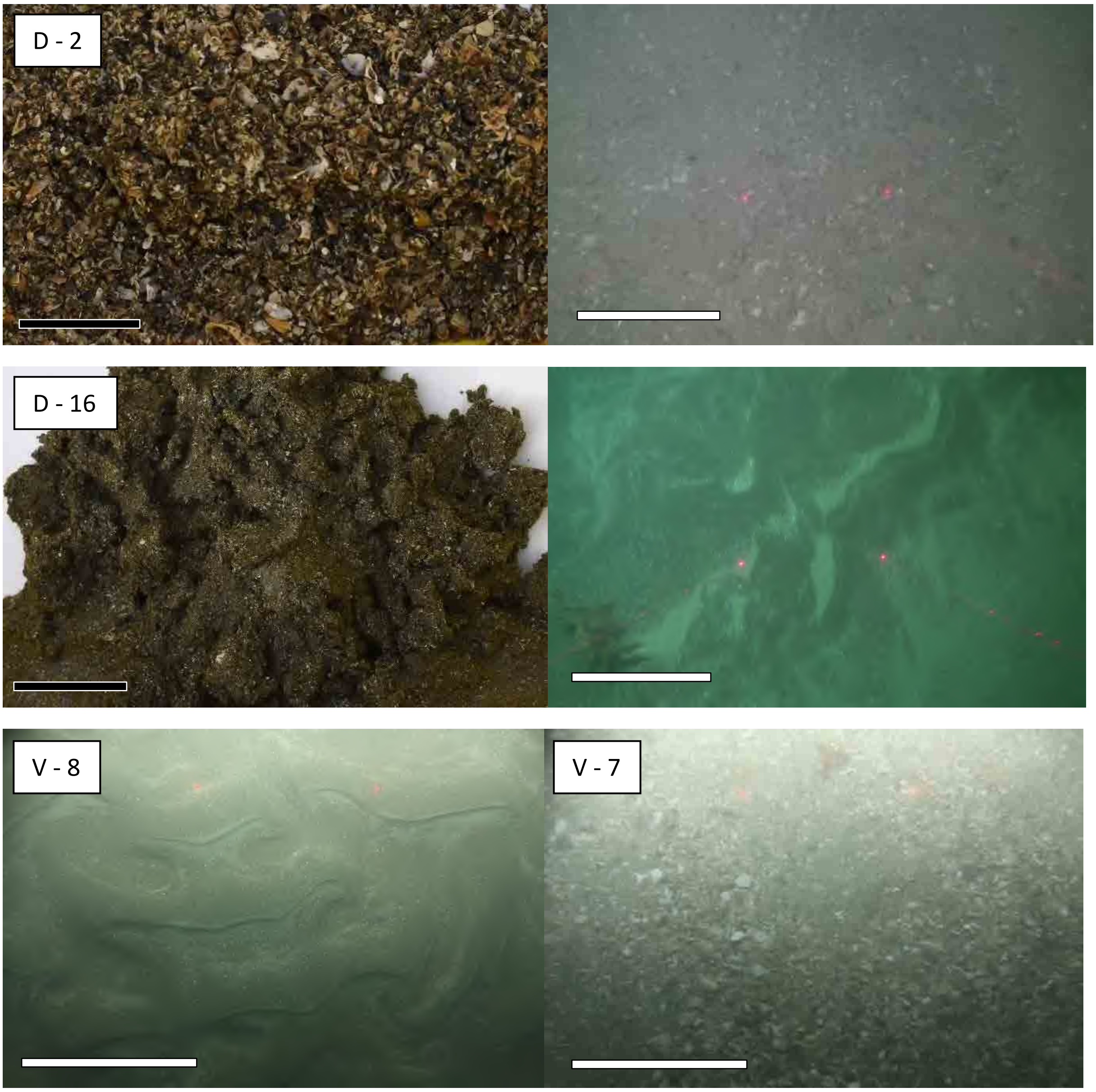


Figure 3-18: Seafloor and sediment Images. Sites D2 and V7 illustrate the moderately well-sorted coarse sand associated with the linear sediment waves. Sites D16 and V8 illustrate the moderately well sorted medium sand associated with the megarippled sediment waves. Physical sediment samples (black scale), scale = 5 cm; and seafloor images (white scale), scale = 20 cm. Location of seafloor and sample images shown on Figure 3-17.

3.5.4 Paired linear sediment-wave morphology, Cook Strait

A geomorphic variation of the linear sediment waves occurs on some shoaling ridges in an area of high tidal flows up to 1.5 ms^{-1} (Hadfield et al. 2014), in an open section of Cook Strait west of The Brothers. These features exhibit relatively straight crests, are symmetrical in cross section, and range in height from 15–20 m and have wavelengths (crest to crest) of ~ 300 m (Figures 3-19 and 3-20). However, as a set of features they appear to be intertwined and are offset in a stepwise manner from each other (Figures 3-19, 3-21, 3-22). Their origin is unclear, but the high tidal flows and their coarse-grained composition could result in differential movement of the crests and some unusual turbulence on their flanks. Symmetrical ripples (1-2 m high and ~20 m wavelength) occur either side of these bathymetrically higher, steep sided (>30°) features.

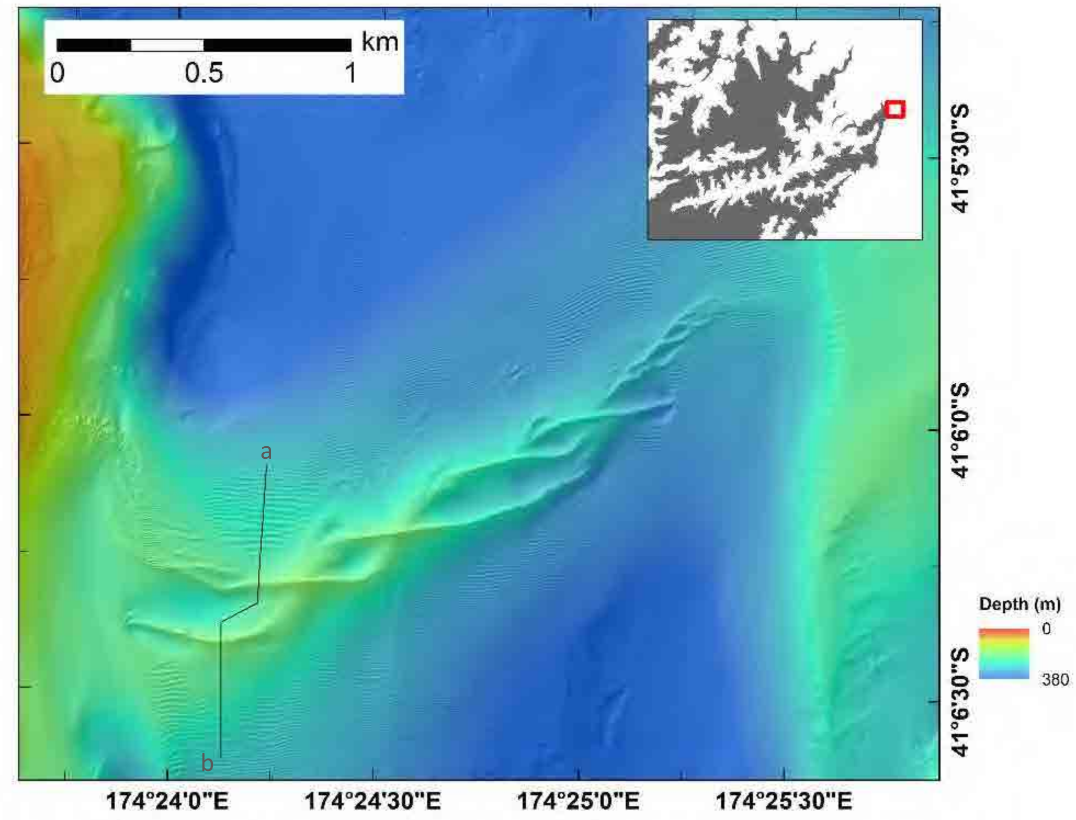


Figure 3-19: Bathymetric imagery illustrating linear sediment waves in Cook Strait. Location of profile in Figure 3-20 shown on bathymetry.

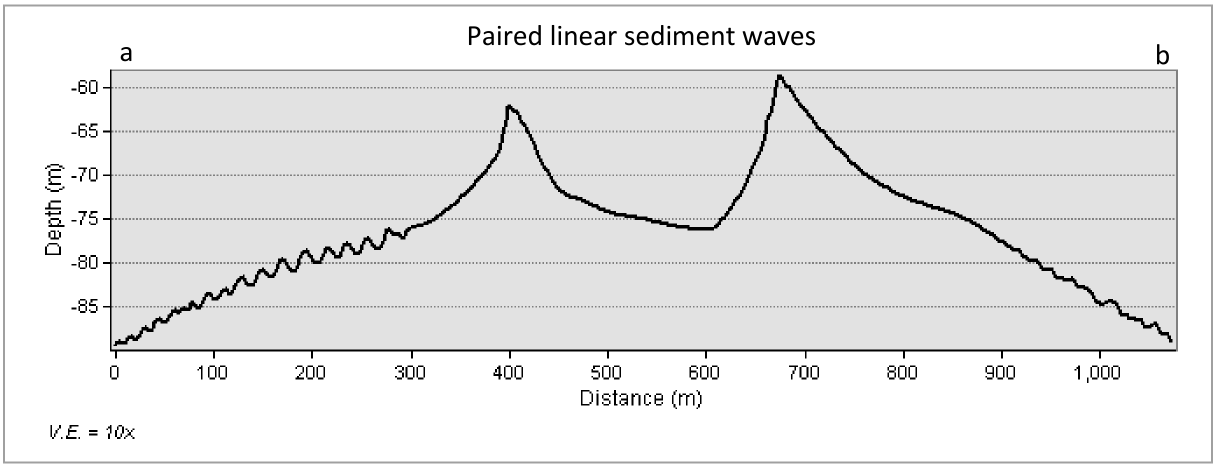


Figure 3-20: Bathymetric profile. Location of profile is shown on Figure 3-19. Two-prominent linear sediment waves crossed by this profile reach 15-20 m high with wavelengths of 300 m. Megaripples are visible on the lower flanks, possibly resulting from unusual turbulence and flow interactions with the paired crests.

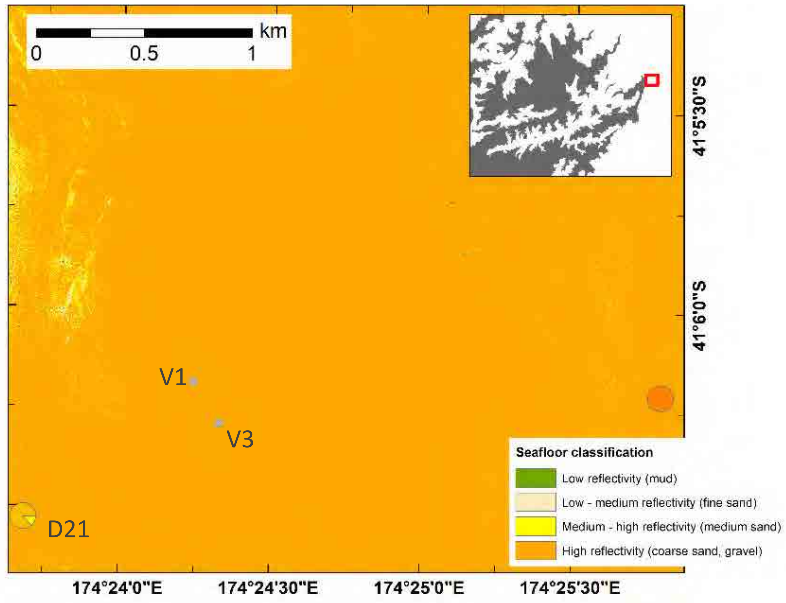


Figure 3-21: Seafloor Classification. Indicating the higher seafloor backscatter/ coarser grainsize of the paired waves field and associated megaripples. Pie charts reflect grainsize, sample D21 is gravel, and grey dots are additional video locations, V1 and V3). Medium-High reflectivity (medium sand) – yellow, High reflectivity (coarse sand - gravel) – orange. Seafloor images associated with sample numbers are illustrated in Figure 3-22. Also refer to Portfolio Outer Queen Charlotte Sound/Tōtaranui, 3 of 13 for larger scale image.

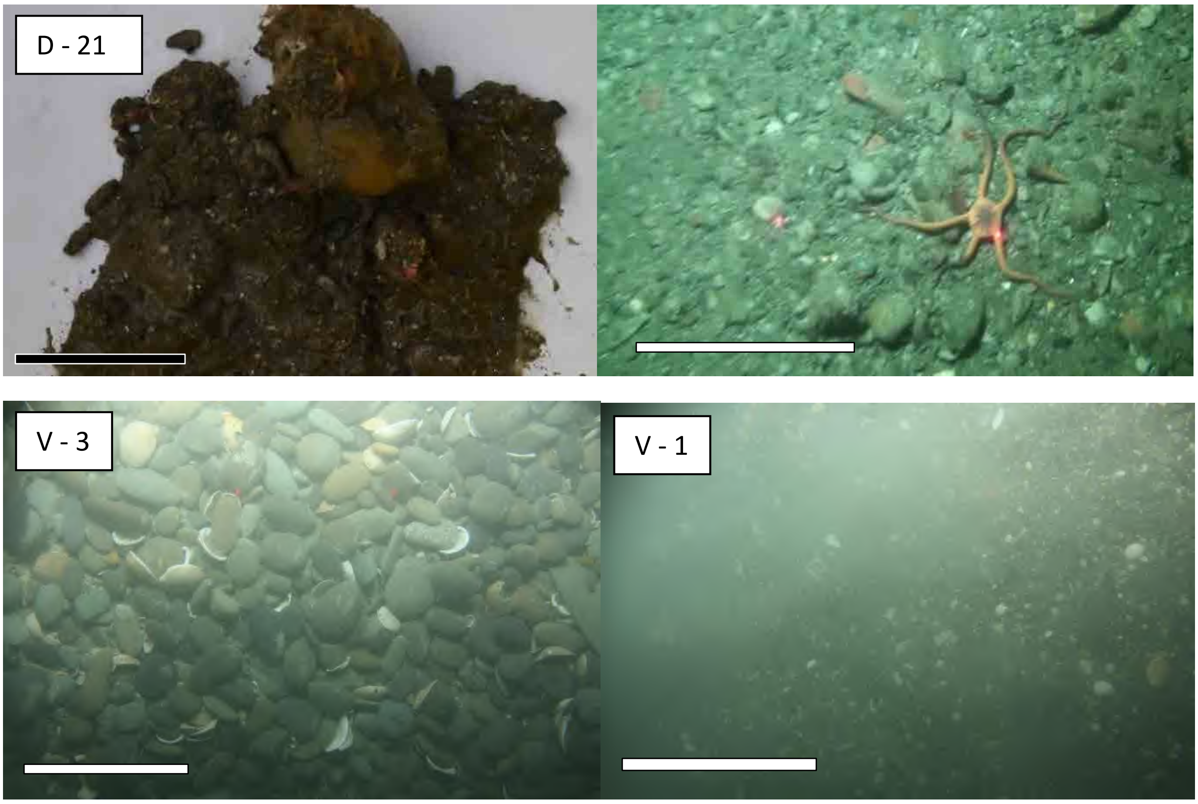


Figure 3-22: Seafloor and Sediment Images. Site V3 illustrates the coarse gravel associated with the paired wave field under the higher Cook Strait tidal regime, while Site V 1 illustrates the very fine gravel / coarse sand associated with the proximal megaripples, note the presence of mobilised fine sediment that was characteristic of the site. Site D21, proximal to this site, illustrates very fine gravel. Physical sample (black scale), scale = 5 cm; and seafloor image (white scale), scale = 20 cm. Location of seafloor and sample images shown on Figure 3-21.

3.5.5 Seafloor depressions

Geomorphometric classification is used to identify fine-scale depressions, as described in detail in Part 2, Section 1.6. While the initial intention was to identify depressions that may show an association to active groundwater seeps, the resultant analysis identified all fine scale (0.08 km^2) features (Figure 3-23), some of which can be related to anthropogenic activities. Large depressions, such as tidal scours, were excluded from this analysis as they are too numerous and overwhelm the identification of the finer-scale depressions.

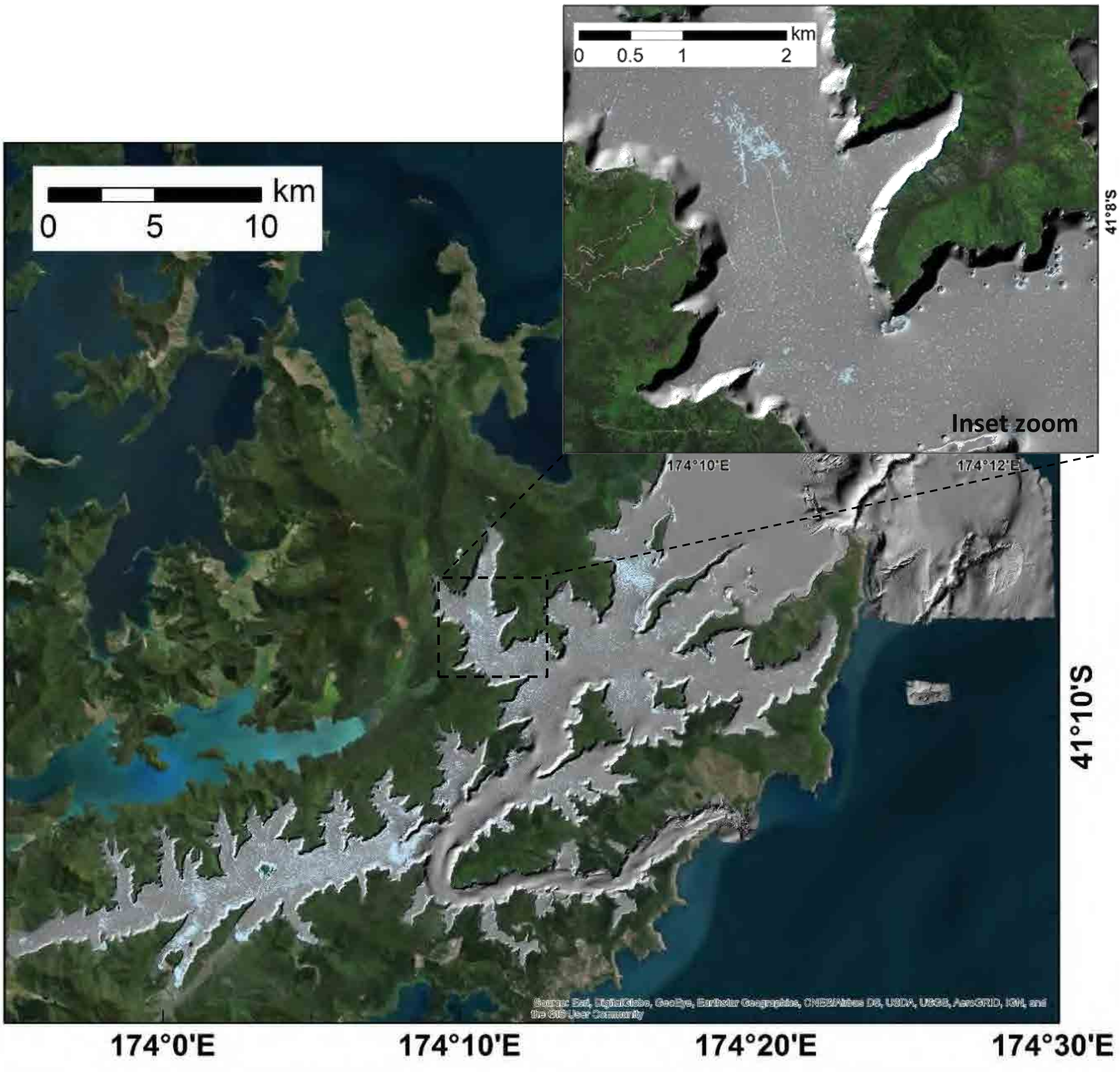


Figure 3-23: Small seafloor depression (second order morphology) overlain on hillshade. Depressions are indicated by the blue stippling. Inset illustrates the finer scale depressions associated with pockmarks (circular stipples, see Section 3.5.6) and shallow linear depressions associated with drag marks (see Section 3.5.11). Note the absence of stippling in the outer Queen Charlotte Sound, Cook Strait and Tory Channel. Depressions in these areas are defined as broad scale and discussed in Section 3.5.6 below.

3.5.6 Small pockmarks

Pockmarks are typically described as fluid expulsion features that occur at the seafloor, and are recognised by their concave, crater-like character (e.g. Pilcher and Argent 2007, Cartwright et al. 2007, Hovland et al. 2010). Types of expulsed fluid that can produce pockmarks include gas-rich fluids and/or groundwater. Pockmark-like features are widely distributed throughout the inner and middle Queen Charlotte Sounds. Andrews et al. (2010) define a pockmark as a roughly circular seafloor depression, however several morphological classes have been identified by Hovland et al. (2002). A 'typical' pockmark is defined to be a circular depression typically measuring 10-700 m in diameter and 1-45 m in depth (see examples from HS51 survey shown in Figure 3-24 and Figure 3-25).

The small pockmarks range in size from 0.5 to 1 m deep and 2 to 15 m wide through to 6 m deep and 40 m wide (Figure 3-24). These features can be attributed to seeps, probably freshwater, as evidenced in water column data (see Section 3.5). Most of these smaller pockmarks do not display a strong backscatter contrast.

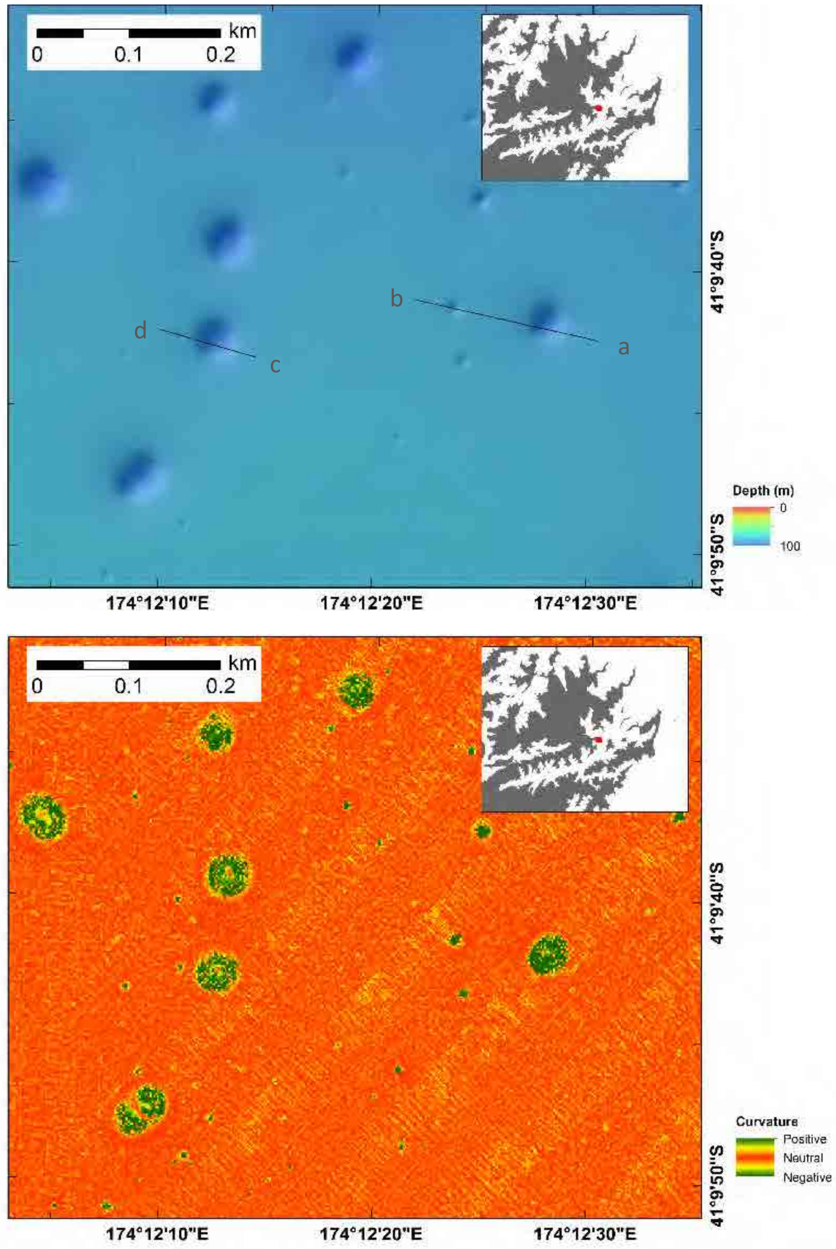


Figure 3-24: Bathymetric (upper) and curvature (lower) imagery illustrating pockmarks in middle Queen Charlotte Sound. In this case, the curvature is concave/negative. Location of profile in Figure 3-25 shown on bathymetry.

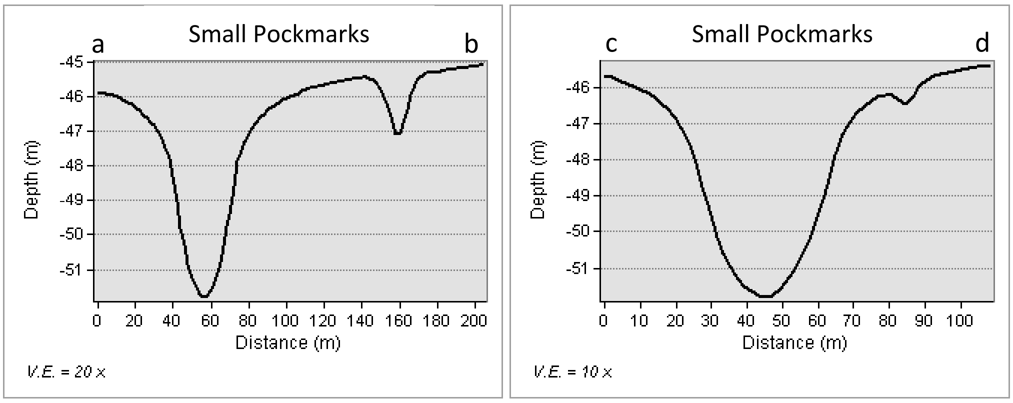


Figure 3-25: Bathymetric profiles of small pockmarks. Location of profiles is shown on Figure 3-24. Small pockmarks range in size from 0.5–1 m deep and 2–15 m wide through to 6–10 m deep and 40–60 m wide.

3.5.7 Large pockmarks

Large pockmarks (10 m deep and up to 100 m wide) are evident throughout the inner and middle Queen Charlotte Sound, and are prevalent along the coastal flanks and off headlands. These features frequently coalesce and, despite the relatively low mean-currents within Queen Charlotte Sound of ~0.05 ms^{-1} (Hadfield et al. 2014), these larger pockmarks likely originate from current and turbulence-induced erosion of the fine-grained mud (Figure 3-26). These may have been initiated by the presence of seep generated pockmark, providing a nucleus for turbulence and subsequent seabed erosion (c.f. Davy et al. 2018). Of the general pockmark morphological classes identified by Hovland et al. (2002), current scour erosion, merging of individual pockmarks, and inward gravity sliding of unstable pockmark flanks are considered to alter the initial circular geometry of the pockmark giving rise to larger-scale elongated, composite, complex morphologies (e.g. Hovland, 1982, 1983; Hovland & Judd, 1988; Stewart, 1999). Higher backscatter intensity is noticeable within these larger pockmark depressions indicating coarser material within the depression. In addition, their large size makes then readily identifable in the geomorphometric seafloor classification (Figures 3-27 and 3-28).

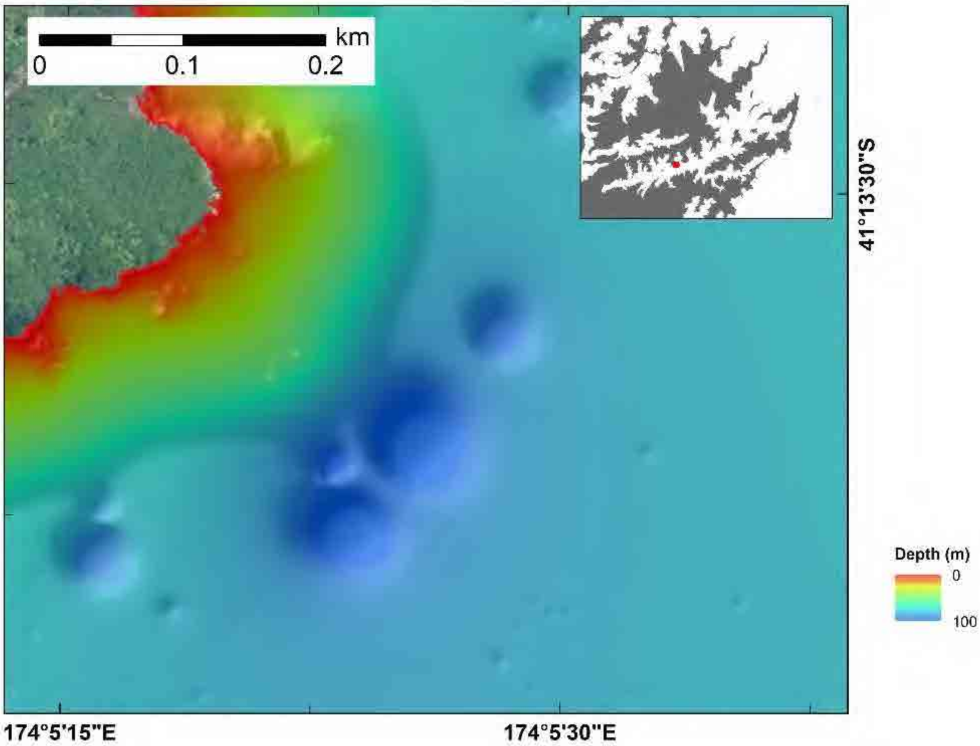


Figure 3-26: Bathymetric imagery illustrating coalescing pockmarks in middle Queen Charlotte Sound. (2 m grid resolution)**.**

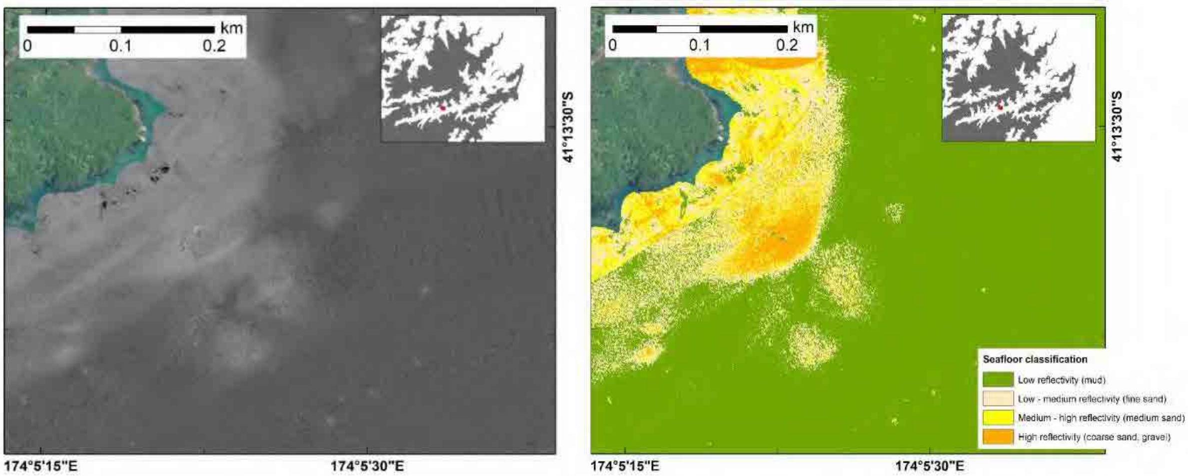


Figure 3-27: Backscatter imagery (left) and seafloor classification (right) illustrating coarser material within the depression. Lower backscatter - dark grey, higher back scatter – light grey (left). Low reflectivity (mud) – green, Low-medium reflectivity (fine sand) – beige, Medium-High reflectivity (medium sand) – yellow, High reflectivity (coarse sand - gravel) – orange (right). (0.5 m grid resolution).

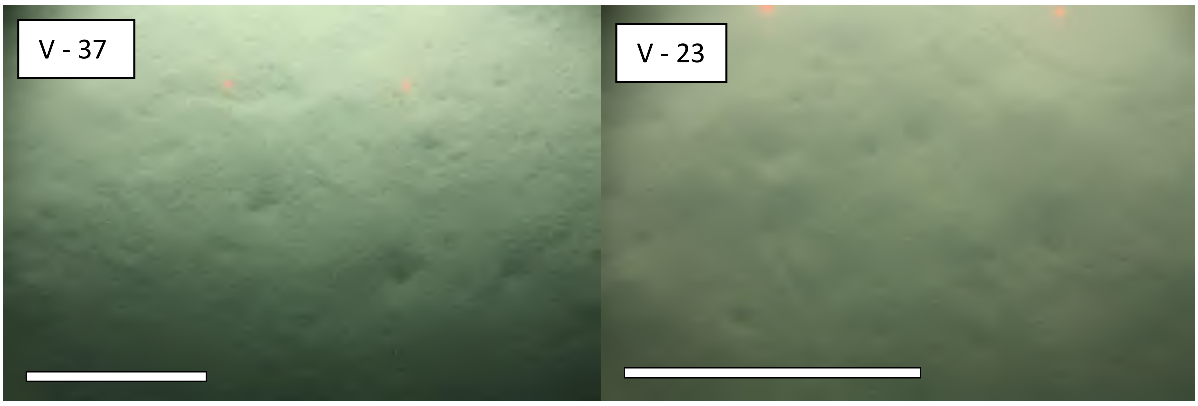


Figure 3-28: Seafloor Images. Site V37 and V23 illustrates the mud and fine sand sediments representative of those associated with pockmarks and the surrounding seafloor. Seafloor image (white scale), scale = 20 cm.

3.5.8 Scours and moats

Numerous scours occur along the coastline and particularly at headlands, especially in the outer Queen Charlotte Sound/Cook Strait (Figure 3-29). They occur along the boundary between relatively flat seafloor in deep water and the shelving coastline. Scours range in size from 10–50 m deep and 2–15 m wide, through to 6–10 m deep and 200–400 m wide (Figure 3-30), often extending several kilometres parallel to the coast. Their formation could be considered as a continuum of large pockmark depressions, as they also likely originate from current erosion (Figure 3-31).

Additionally, these scour features may also be the result of enhanced tidal flows, turbulence and constrictions around headlands. Acceleration of tidal flows around headlands in Cook Strait has been sufficient to scour holes in the seafloor (e.g. Vennell, 1994).

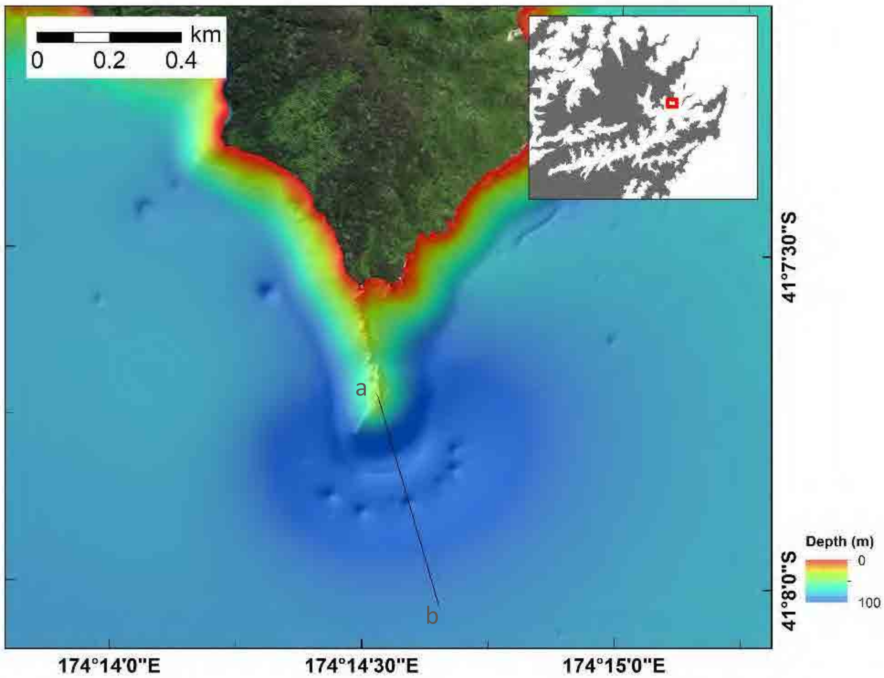
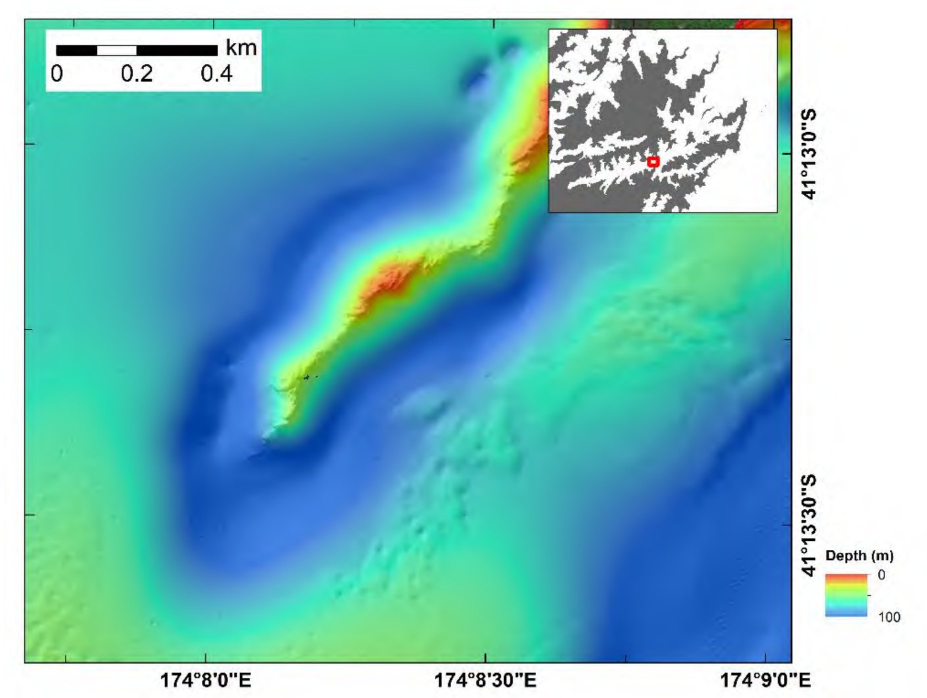


Figure 3-29: Bathymetric imagery illustrating scour depressions in middle and outer Queen Charlotte Sound. (2 m grid resolution). Top (this page) – headland of Resolution Bay, note the pockmark features within the moat-like scour; Middle (next page) – headland of Ruakaka Bay; Bottom (next page) - headland south of Anakakata Bay. Location of profiles in Figure 3-30 shown on bathymetry.



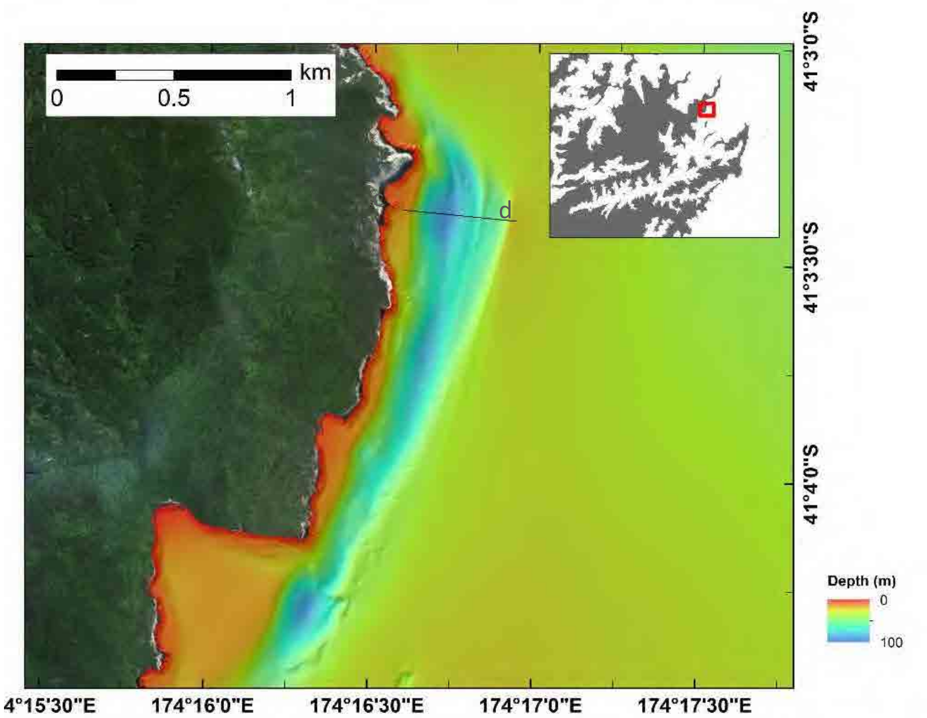
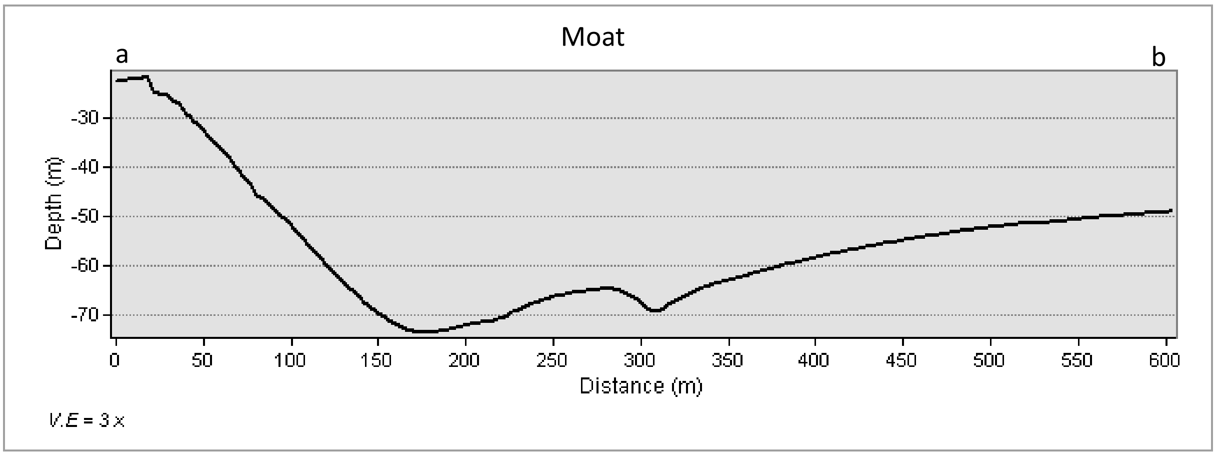


Figure 3-29 cont: Bathymetric imagery illustrating scour depressions in middle and outer Queen Charlotte Sound. (2 m grid resolution). Top (previous page) – headland of Resolution Bay, note the pockmark features within the moat-like scour; Middle – headland of Ruakaka Bay; Bottom - headland south of Anakakata Bay. Location of profiles in Figure 3-30 shown on bathymetry.



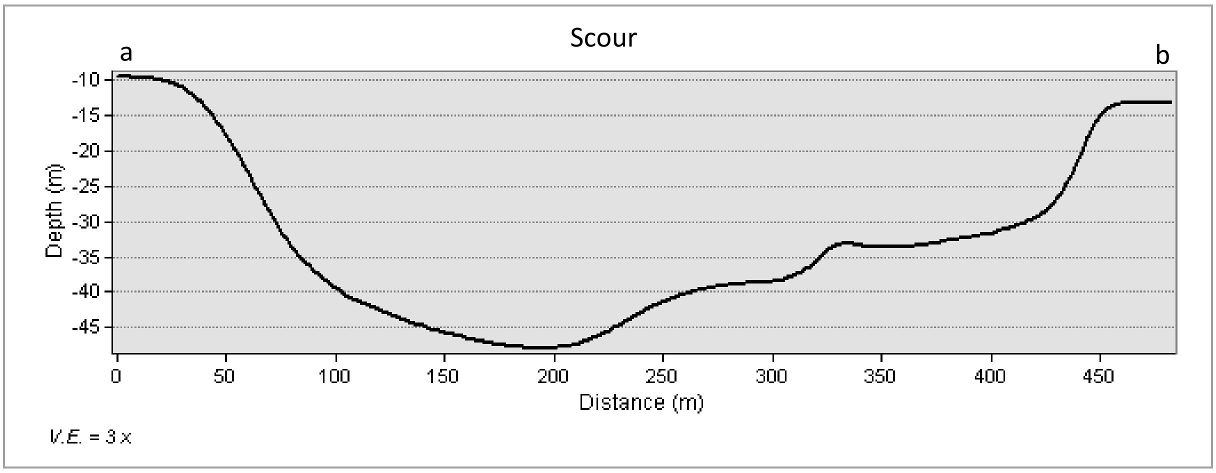


Figure 3-30: Bathymetric profiles of scour depressions and moats. Location of profiles is shown on Figure 3-29. Top – Resolution Bay, Bottom – Anakakata Bay. Scour range in size from 10–50 m deep and 2–15 m wide through to 6–10 m deep and 200–400 m wide. Note the small pockmark to the right of the main depression in the top profile.

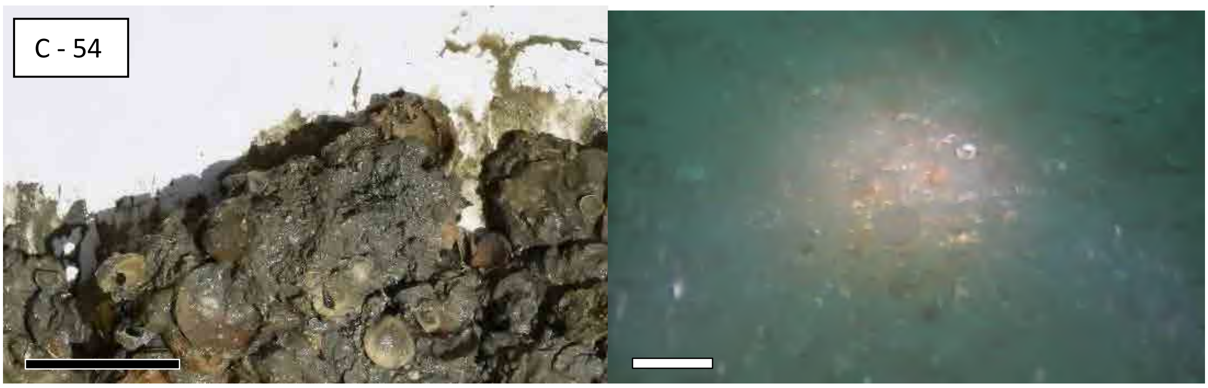


Figure 3-31: Bottom sample and seafloor images. Representative of seafloor associated with scours. Site C54 (scour off Kurakura Point) and C58 (scour north of Anakakata Bay) both illustrate the gravelly mud associated with scours. Physical sample (black scale), scale = 5 cm; seafloor image (white scale), scale = 20 cm.

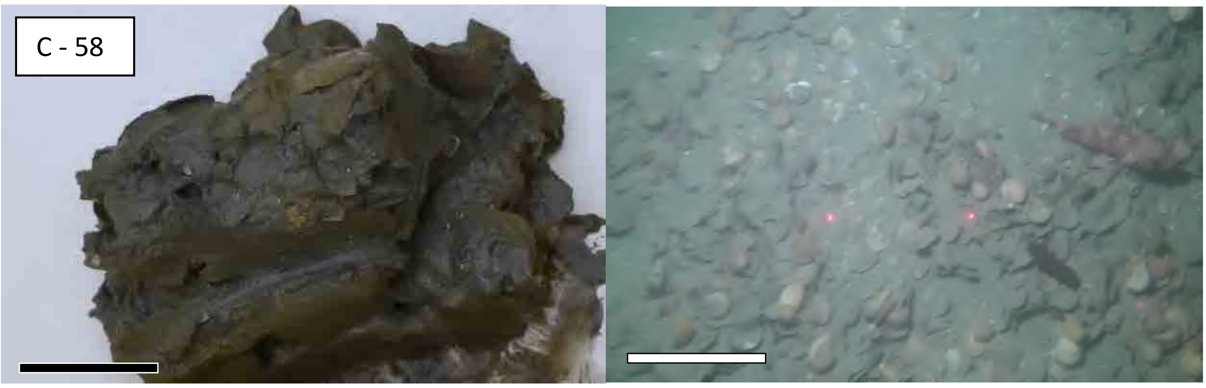


Figure 3-31 cont.: Bottom sample and seafloor images. Representative of seafloor associated with scours. Site C54 (scour off Kurakura Point) and C58 (scour north of Anakakata Bay) both illustrate the gravelly mud associated with scours. Physical sample (black scale), scale = 5 cm; seafloor image (white scale), scale = 20 cm.

3.5.9 Hummocky deposition

Hummocky deposition occurs within Queen Charlotte Sound on seafloor predominately composed of fine-grained mud, which is proximal to areas of tidal constriction e.g. either side of Blumine Island and where Tory Channel enters Queen Charlotte Sound. As tidal flows relax as they enter the less confined area of the sound, sediment deposition can occur. The nature of the hummocky seafloor is readily depicted in both bathymetry and the depth-range bathymetric attribute (Figures 3-32 and 3-33).

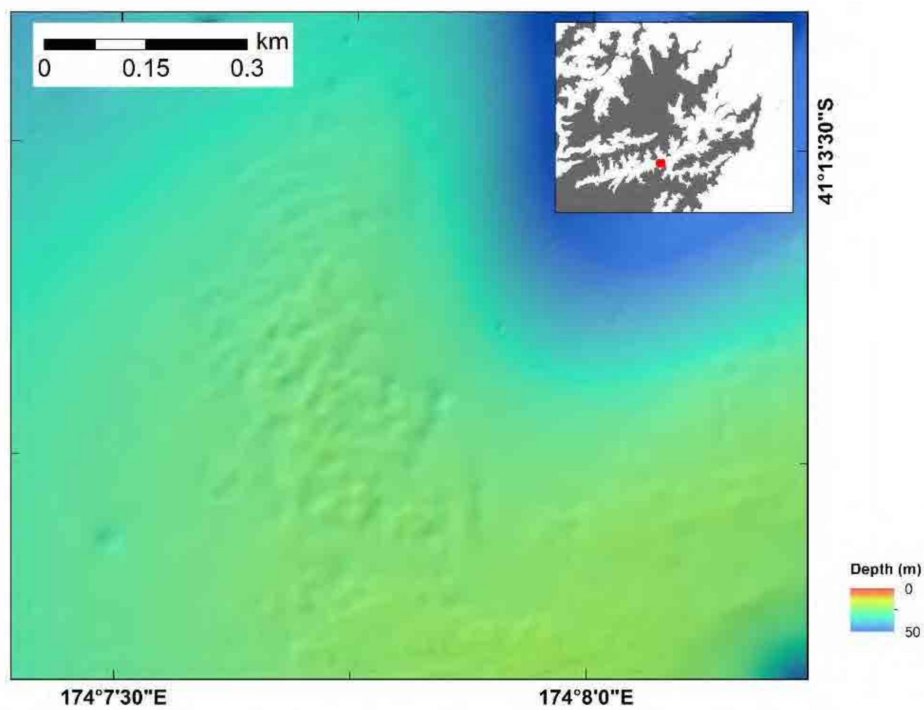


Figure 3-32: Bathymetric imagery illustrating hummocky deposition in middle Queen Charlotte Sound.(2 m grid resolution).

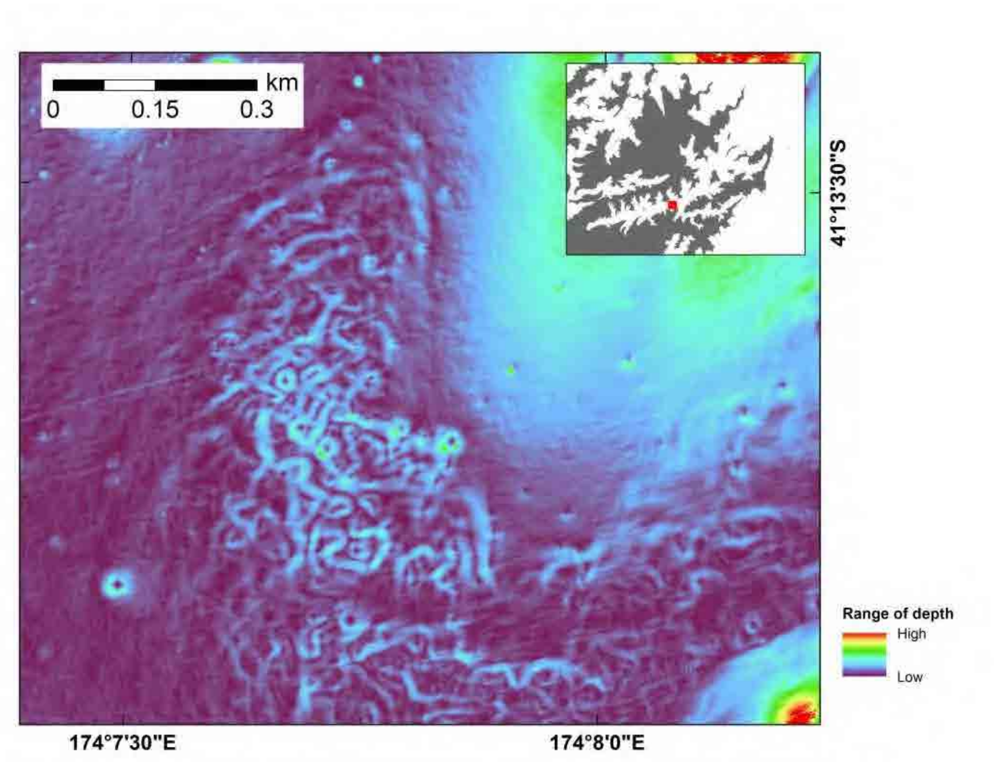


Figure 3-33: Range of depth imagery illustrating hummocky deposition in middle Queen Charlotte Sound. (2 m grid resolution).

3.5.10 Deep-water scours in Cook Strait and outer Tory Channel

Significant seafloor depressions occur in the deeper water of outer Queen Charlotte Sound and outer Tory Channel (Cook Strait). These large features are commonly tens of metres deep and kilometres long (Figure 3-34). Backscatter data indicate high to very high seafloor reflectivity, indicative of coarse sediments, as well as a rough seafloor (fine scale, mm to cm) bathymetric changes) (Figure 3-35). Sediment samples show very-fine gravel through to coarse-cobble sized gravels (Figure 3-36). These depressions are the result of the powerful semi-diurnal (M2) tides that occur due to a tidal-height difference on either side of Cook Strait (e.g. Heath 1978, Heath 1982). These strong flows accelerate over shoals and ridges, and through the constricted Tory Channel (mean speed of 1.2 ms^{-1}, Hadfield et al. 2014), sufficient to resuspend and transport very-coarse sand.

As currents relax in open water sediment deposition can occur, as evinced by sediment lobes with megaripples proximal to either seafloor depressions or significant scour holes (Figure 3-34). Sediment is often dispersed from discrete zones of seabed erosion, such that an increasing supply of fine grained material tails downstream from a scour.

Scouring and downstream deposition are imaged in both the backscatter and terrain classification maps in outer Tory Channel (Figure 3-35), with patches of low to medium-backscatter intensity observed on the edges of the channel, in small coves and bays, suggesting localised fine-grained deposits.

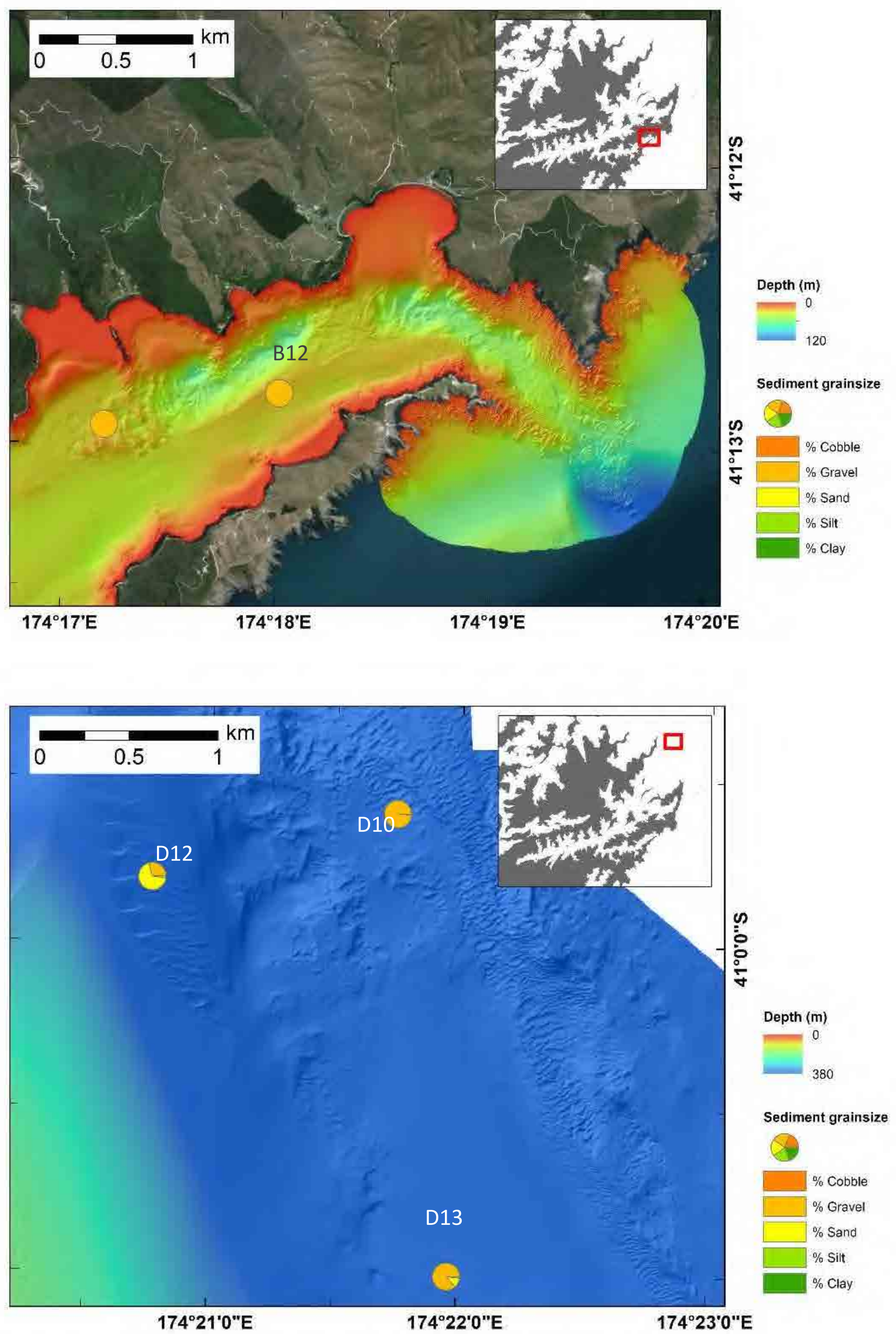


Figure 3-34: Bathymetric imagery illustrating significant seafloor depressions in Tory Channel (top) and Cook Strait (bottom). Sediment grainsize is represented with pie charts, samples B12, D10 and D13 are gravel, and D21 is sand. Note the rocky reef that extends into the depression at the entrance to Tory Channel. Seafloor images associated with sample numbers are illustrated in Figure 3-36. Also refer to Portfolio Tory Channel/Kura Te Au, 9 of 13 for larger scale image.

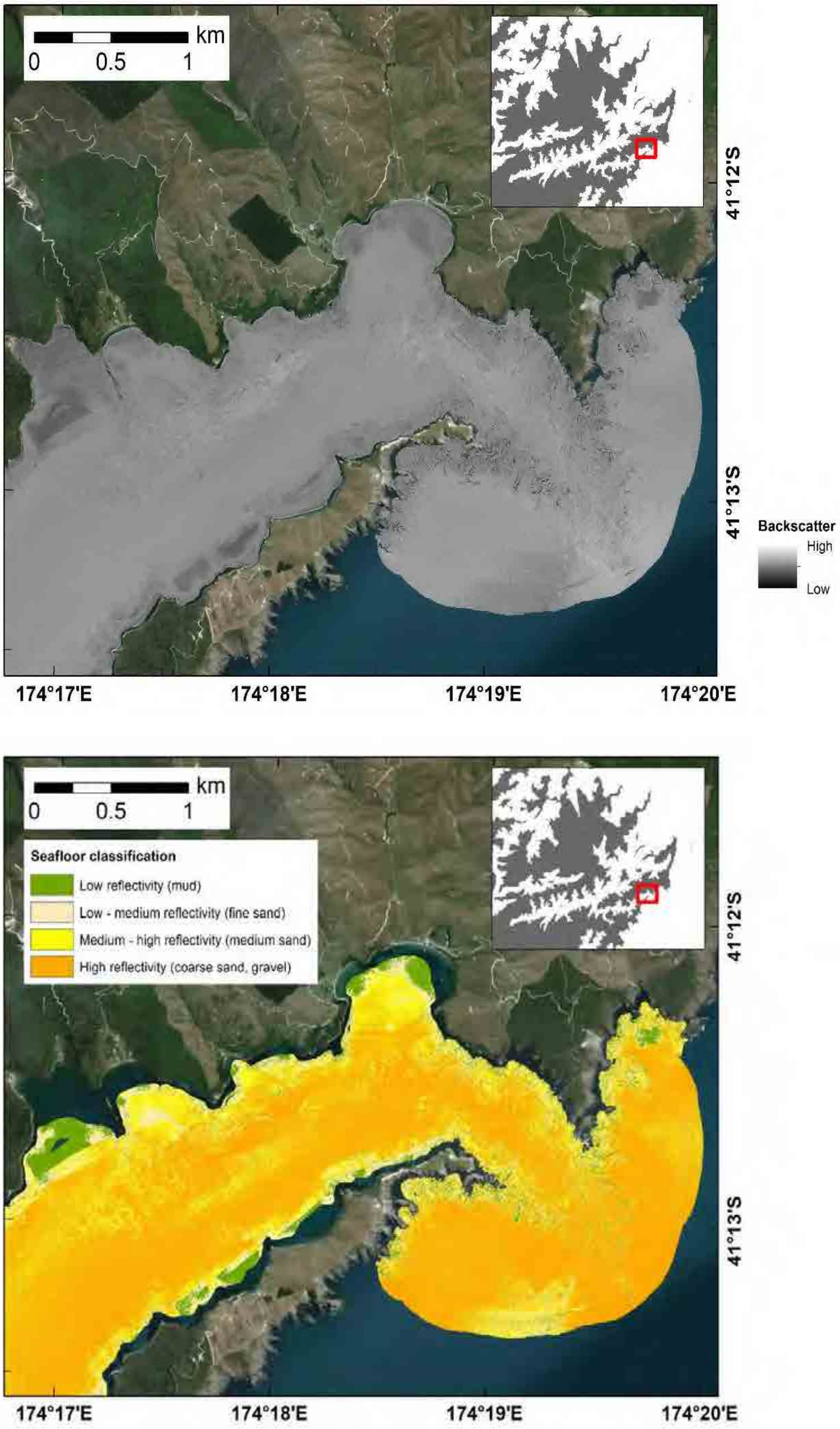


Figure 3-35: Backscatter imagery (top) and seafloor classification (bottom) illustrating coarser material in Tory channel and localised finer deposits. (0.5 m grid resolution). Note the boundaries in the backscatter mosaics within the shallow marginal bays due to displaying both Geoswath and multibeam backscatter on the same image.

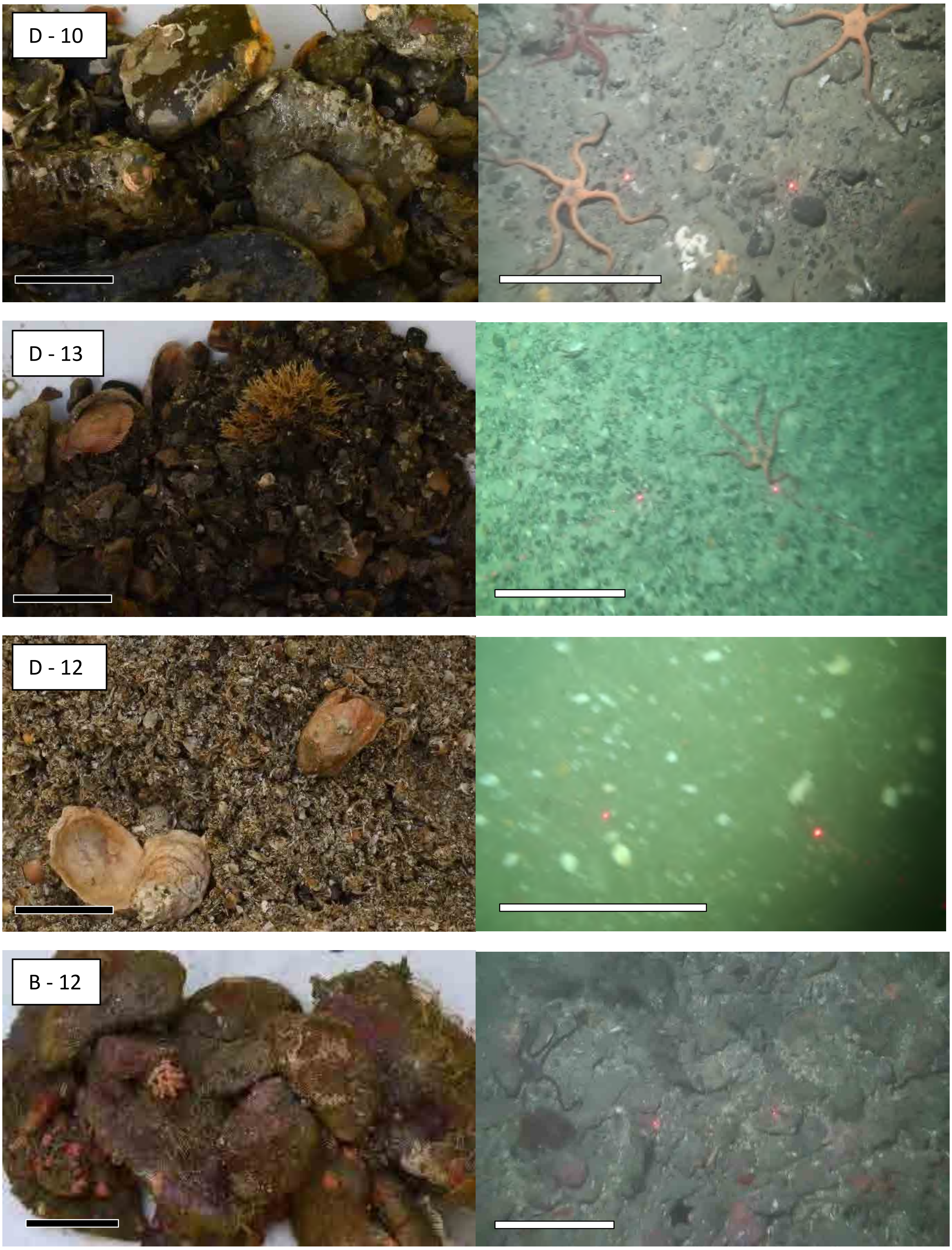


Figure 3-36: Seafloor images. Samples illustrate the very fine gravel through to coarse-cobble sized gravels associated with seafloor depressions under strong tidal flows. Left column, physical sample (black scale), scale = 5 cm; right column, seafloor image (white scale), scale = 20 cm. Location of sample and seafloor images shown in Figure 3-34.

3.5.11 Anthropogenic seafloor features

Several anthropogenic features are captured distinctly in the bathymetry, and many small depressions can be identified by the automated analysis of bathymetry (see Section 1.6.2). Of note are the following:

- The original survey of 1942-3 includes the location of the telephone cables between the islands. New bathymetric data from this survey shows continuous trenches up to 0.4–0.8 m deep where the cables had been laid (Figure 3-37).
- Drag marks are also evident as shallow depressions ~0.2 m deep, especially within Picton Harbour and Port area, across the inner Queen Charlotte Sound to Double Cove, Bay of Many Coves, and Endeavour Inlet (Figure 3-38).
- Mooring blocks and erosive moats around blocks are present in several bays and evident in both bathymetry and backscatter images. Notably, the moat features consistent with the presence of mooring blocks are far more numerous than the mooring blocks currently permitted, however many of these moorings may be abandoned (Figure 3-39).
- A partially dredged area is evident in Shakespeare Bay adjacent to Waimahara Wharf.
- Marine farm structures are discussed separately in Section 3.9 below.

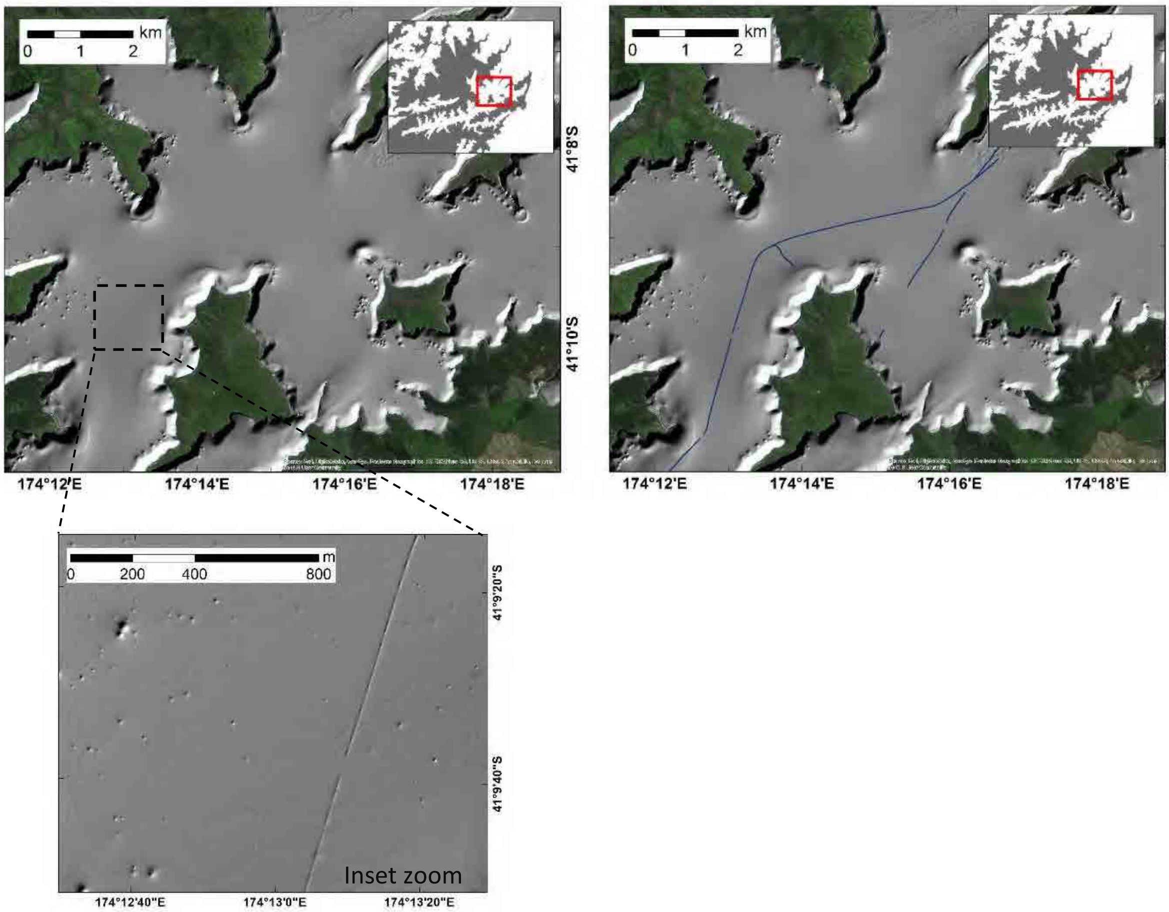


Figure 3-37: Hillshade illustrating trenches between islands associated with cables (previous or existing). Uninterpreted hillshade image (left) and the interpreted route of seafloor cables depicted in dark blue (right). Inset shows detail of the trench. Refer to Portfolios Middle Queen Charlotte Sound/Tōtaranui, 4 and 6 of 13.

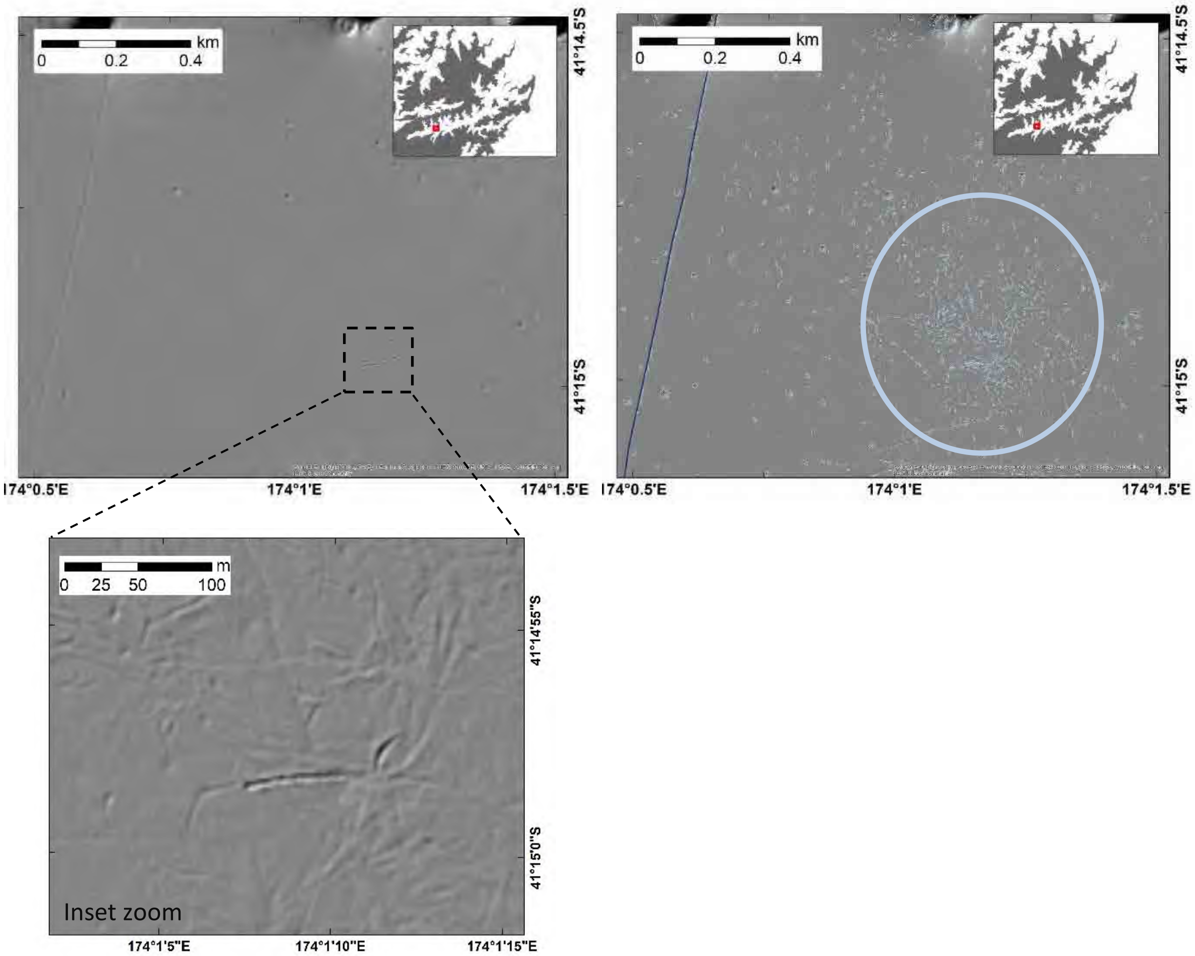


Figure 3-38: Hillshade illustrating drag/dredge marks in inner Queen Charlotte Sound. Uninterpreted hillshade image (left). Depressions are depicted in light blue, those attributed to drag marks are within the circle (and in inset below), while those outside the circle depict small pockmarks (right). Seafloor cables are depicted in dark blue (right). Refer to Portfolios Inner Queen Charlotte Sound/Tōtaranui, 7 and 8 of 13.

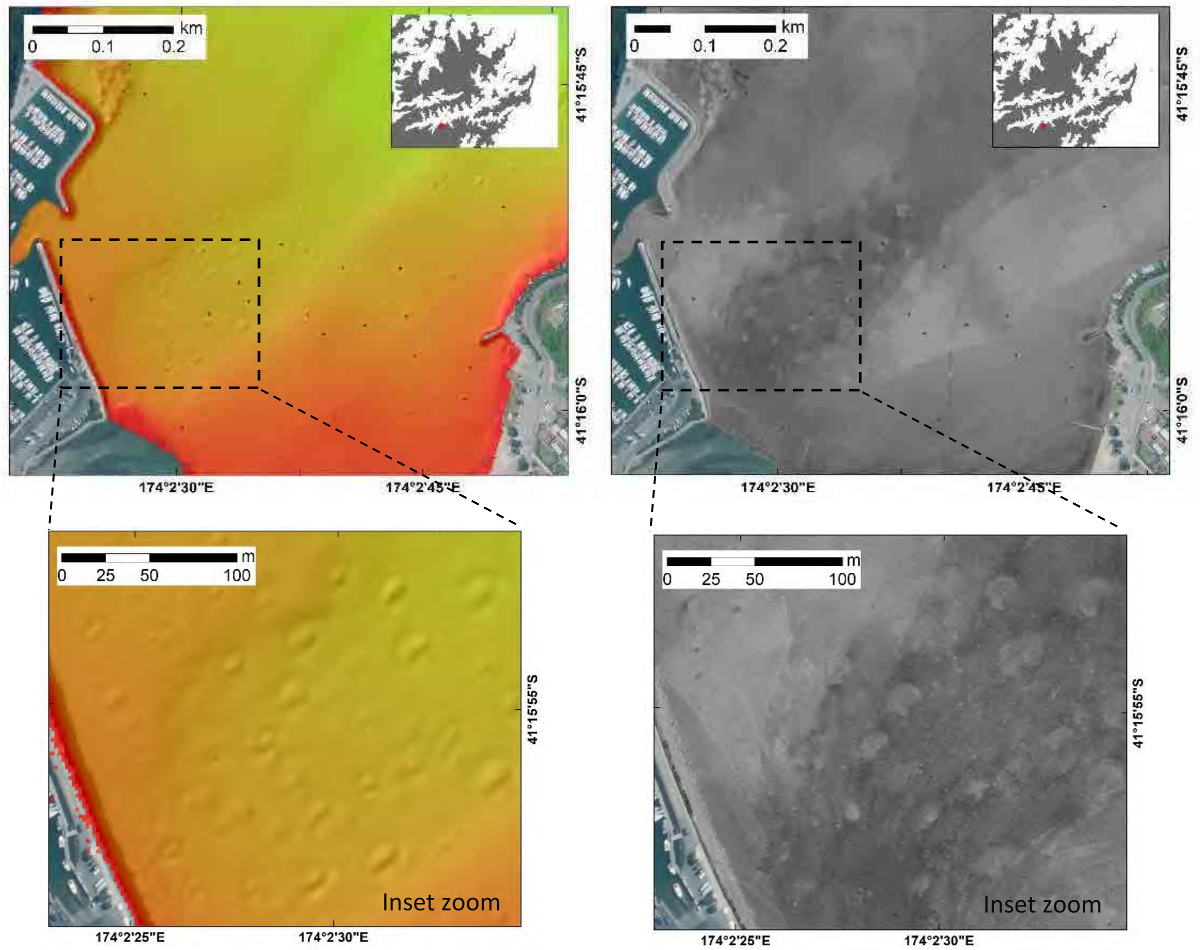


Figure 3-39: Mooring blocks in Waikawa Bay. Bathymetry (left) and backscatter (right). MDC granted moorings are shown as grey dots. Inset shows detail of the mooring blocks. Refer to Portfolio Inner Queen Charlotte Sound/Tōtaranui, 7 of 13.

3.5.12 Rocky reefs and ridges

Outer Queen Charlotte Sound and Tory Channel (Cook Strait) includes significant areas of rocky ridges and shoals (Figure 3-40). These steep-sided features rise above the surrounding seafloor, with the rocky ridge or shoals exhibiting complex micro-topography or roughness (Figure 3-41). These features are either extensive rock ridges (e.g. from Cook Rock towards Cape Koamaru) or a series of ridges such as those near The Brothers. In addition, there are isolated steeply shoaling reefs within Cook Strait, such as: Awash Rock, a rock feature with numerous separate shoals; Witts Rock, an isolated rock feature with a shoal to the north east; and McManaway Rock, a rock ridge with two shoals.

Within Queen Charlotte Sound, the island promontories often fringe into a rocky reef structure e.g. Blumine Island, Long Island, and rocky reefs occur around much of the steep coastline (Figure 3-41). Shallow-intertidal platforms and deltas often occur in the absence of rocky reefs e.g. Endeavour Inlet and East Bay.

The seafloor backscatter of rocky outcrops, such as Awash Rock, is characterised by medium (grey) to very high intensity (light grey-white) reflectivity. The flanks of Awash Rock display the highest backscatter intensity, whereas the submerged summits display uneven and patchy backscatter consisting of a mix of dark and light grey levels. The outcropping rock's rough texture is well depicted by both the backscatter and classification maps (Figure 3-42). The classification indicates that the steep flanks are largely dominated by rocks, and coarse material, whereas the summits of the rocky shoals display patchy backscatter suggesting some sediment or biological cover, which could be for example sponges, or fine to medium sand infilling grooves, fissures and shallow depressions (Figure 3-43).

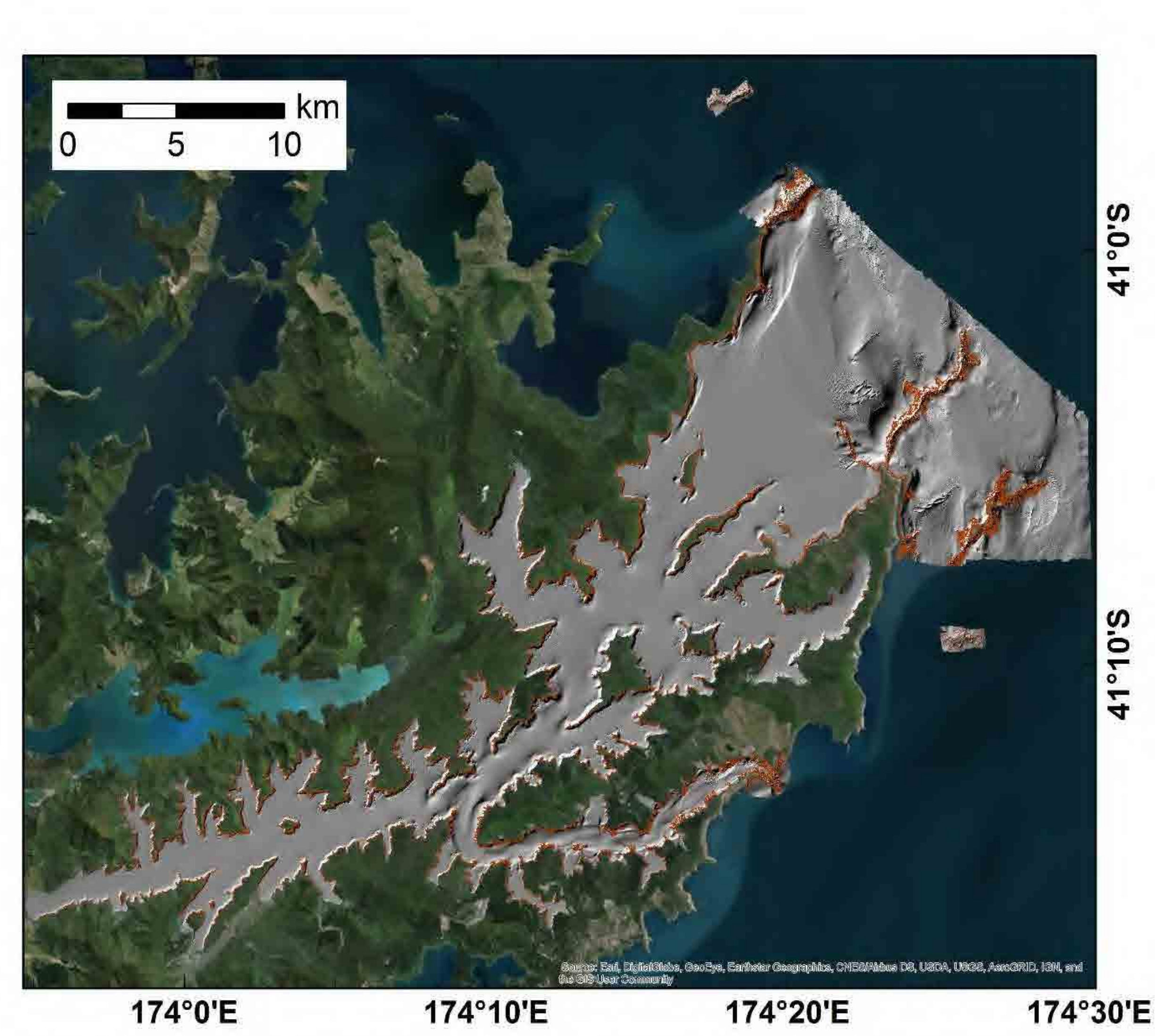


Figure 3-40: Rocky reef (second order morphology) overlain on hillshade. Rocky ridges, reefs, and outcrops are indicated by the red stippling.

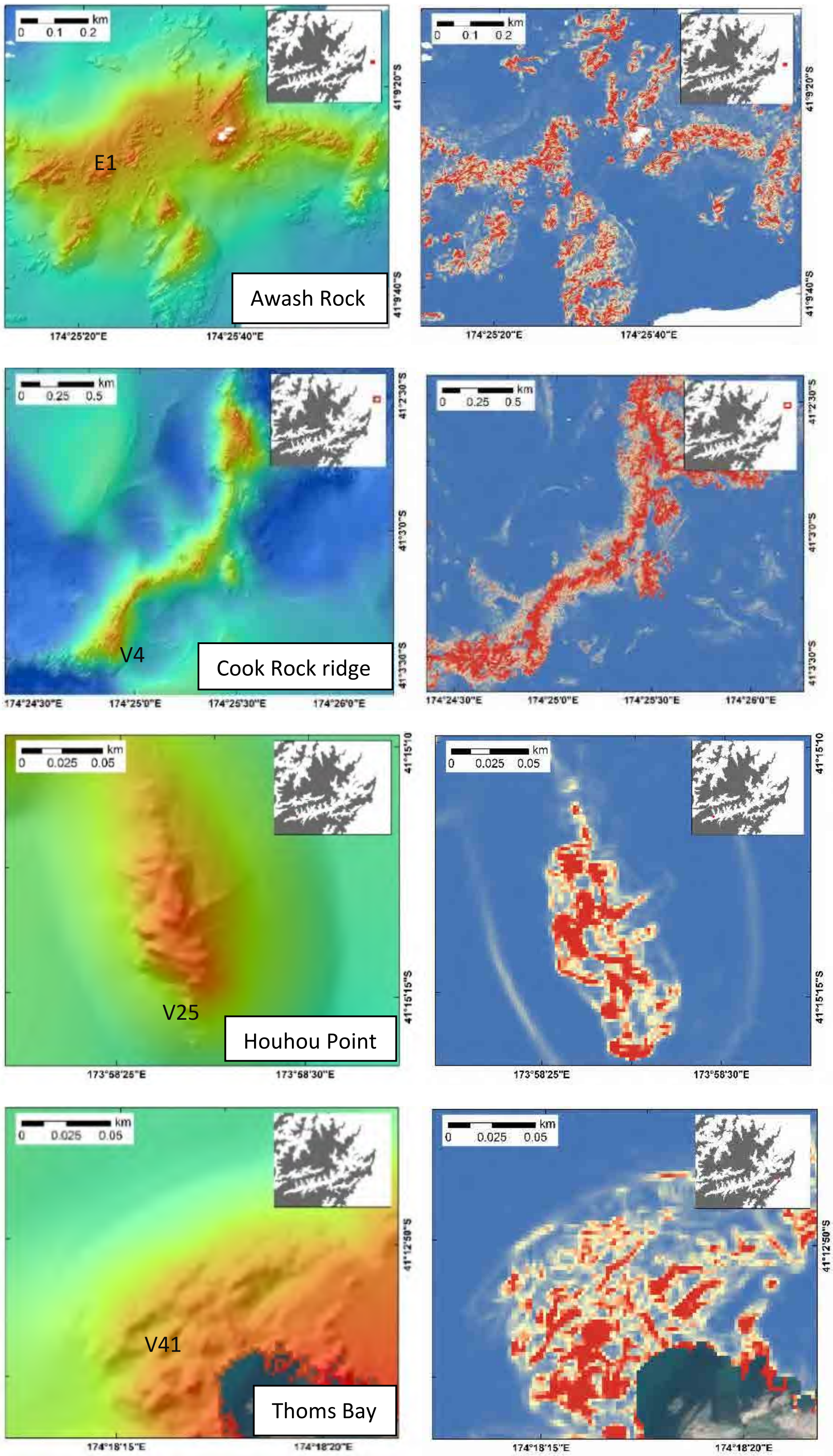


Figure 3-41: Bathymetric (left) and rugosity (right) imagery illustrating rocky ridges and reefs. Awash Rock, Cook Rock ridge, rocky reef northeast of Houhou Point, Thoms Bay rocky reef. Also see Tory Channel in Figure 3-34. Seafloor images associated with sample numbers are in Figure 3-43. High rugosity – red, low rugosity – blue. Refer to Portfolios Outer Queen Charlotte Sound/Tōtaranui, 2 and 3 of 13; Inner Queen Charlotte Sound/Tōtaranui, 7 and 8 of 13; Tory Channel/Kura Te Au, 9 and 10 of 13; and Outlying Areas, 11 of 13.

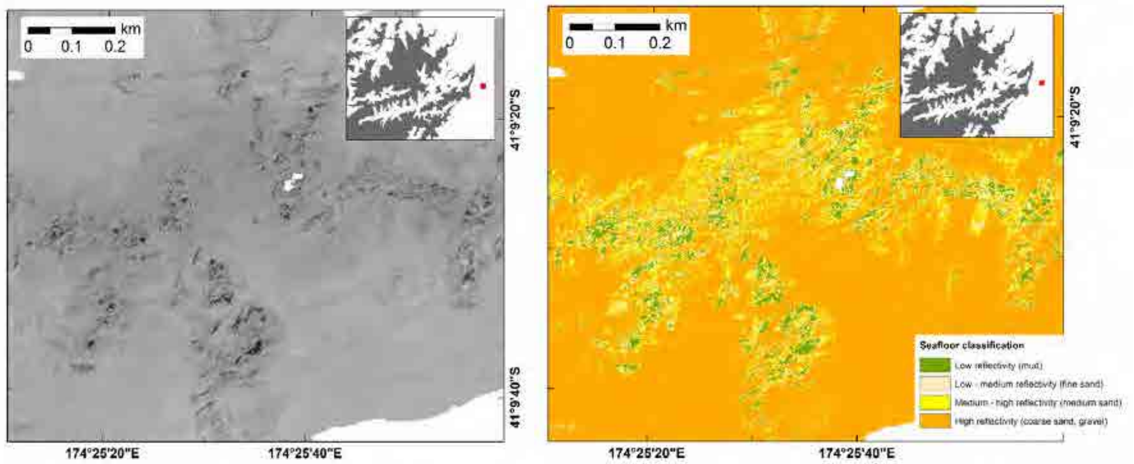


Figure 3-42: Awash Rock backscatter (left) and seafloor classification (right). Lower backscatter - dark grey; and higher back scatter – light grey (left). Seafloor classifications: Low reflectivity (mud) – green; Low-medium reflectivity (fine sand) – beige; Medium-High reflectivity (medium sand) – yellow; and, High reflectivity (coarse sand - gravel) – orange (right). (0.5 m grid resolution). Refer to Portfolio Outlying Areas Queen Charlotte Sound/Tōtaranui, 11 of 13.

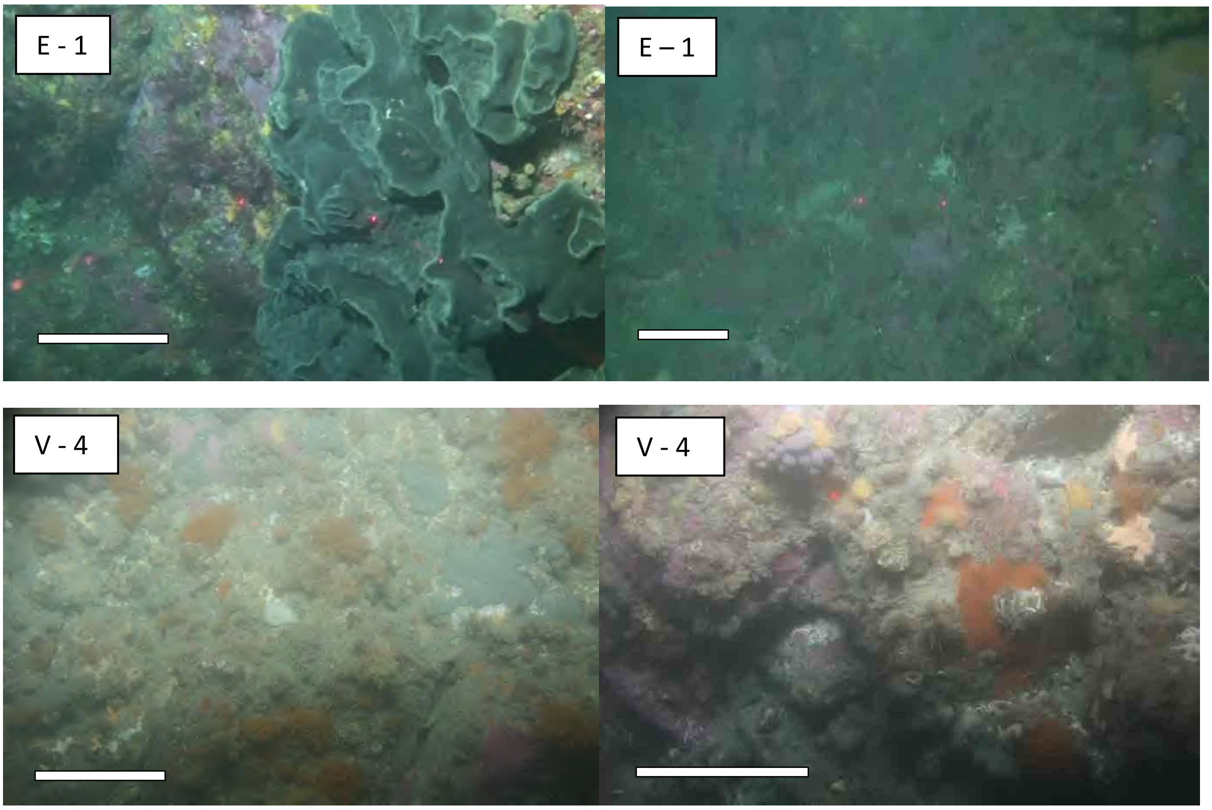


Figure 3 43: Seafloor Images of rocky reefs and ridges. Awash Rock, Cook Rock ridge, rocky reef northeast of Houhou Point, Thoms Bay rocky reef. Note the biology and finer sediments (fine sands and muds) that occur as veneer within the complex structure of the rocky reefs. Seafloor image (white scale), scale = 20 cm. Location of seafloor images shown on Figure 3-41.

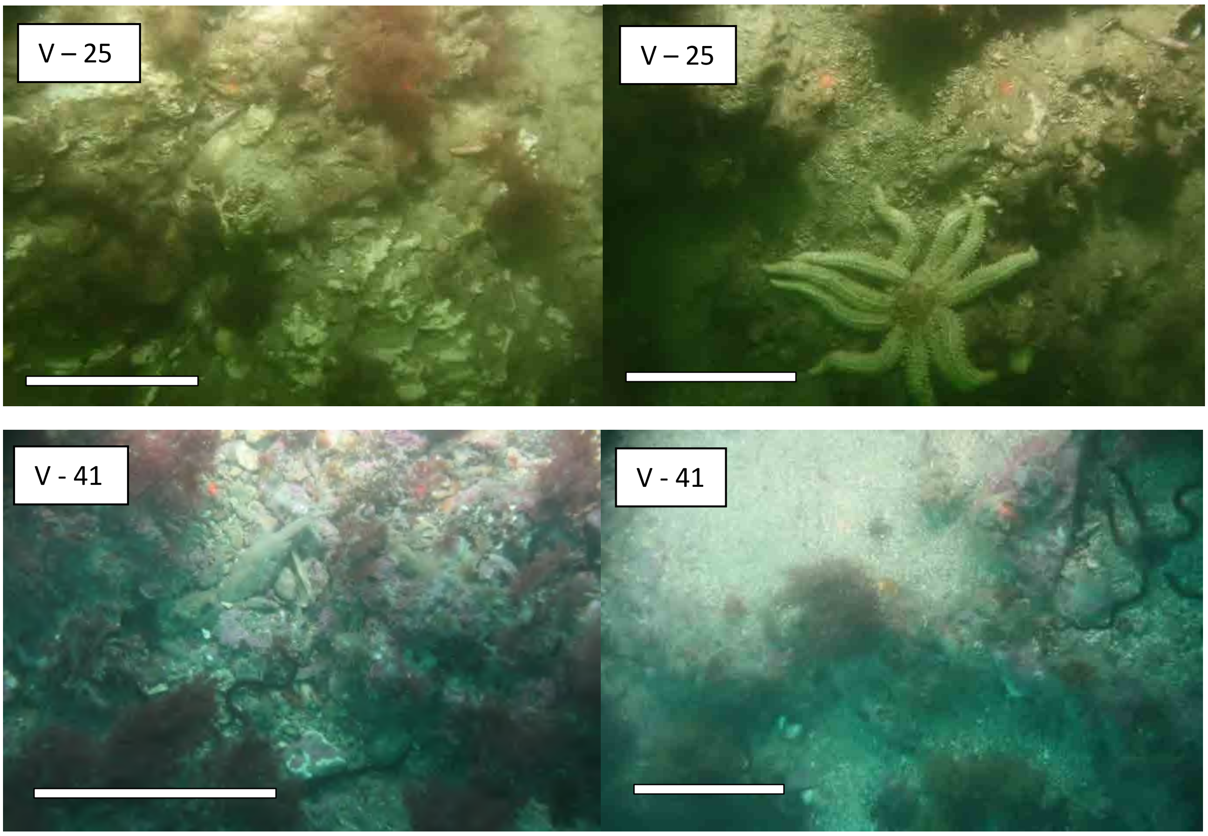


Figure 3-43 cont.: Seafloor Images of rocky reefs and ridges. Awash Rock, Cook Rock ridge, rocky reef northeast of Houhou Point, Thoms Bay rocky reef. Note the biology and finer sediments (fine sands and muds) that occur as veneer within the complex structure of the rocky reefs. Seafloor image (white scale), scale = 20 cm. Location of sea floor images shown on Figure 3-41.

3.5.13 Seafloor plains

Flat seafloor plains dominate in middle and inner Queen Charlotte Sound. Here, the seafloor is generally featureless or bioturbated fine-grained mud, with low backscatter reflectivity, rugosity, slope and depth range (Figure 3-44).

The sill at the outer Queen Charlotte Sound, which separates the relatively quiescent inner Queen Charlotte Sounds from the tidally dominated deeper Cook Strait, is a significant flat plain within the survey area. Some biological characteristics do occur in this largely featureless area (Figure 3-44).

Tory Channel can be considered a large seafloor scour, but many sections of the channel axis have low slopes, depth range, and rugosity, despite exhibiting high backscatter reflectivity. As opposed to the majority of the flat sea floor, the substrate here is generally coarse sand and gravels (Figure 3-44).

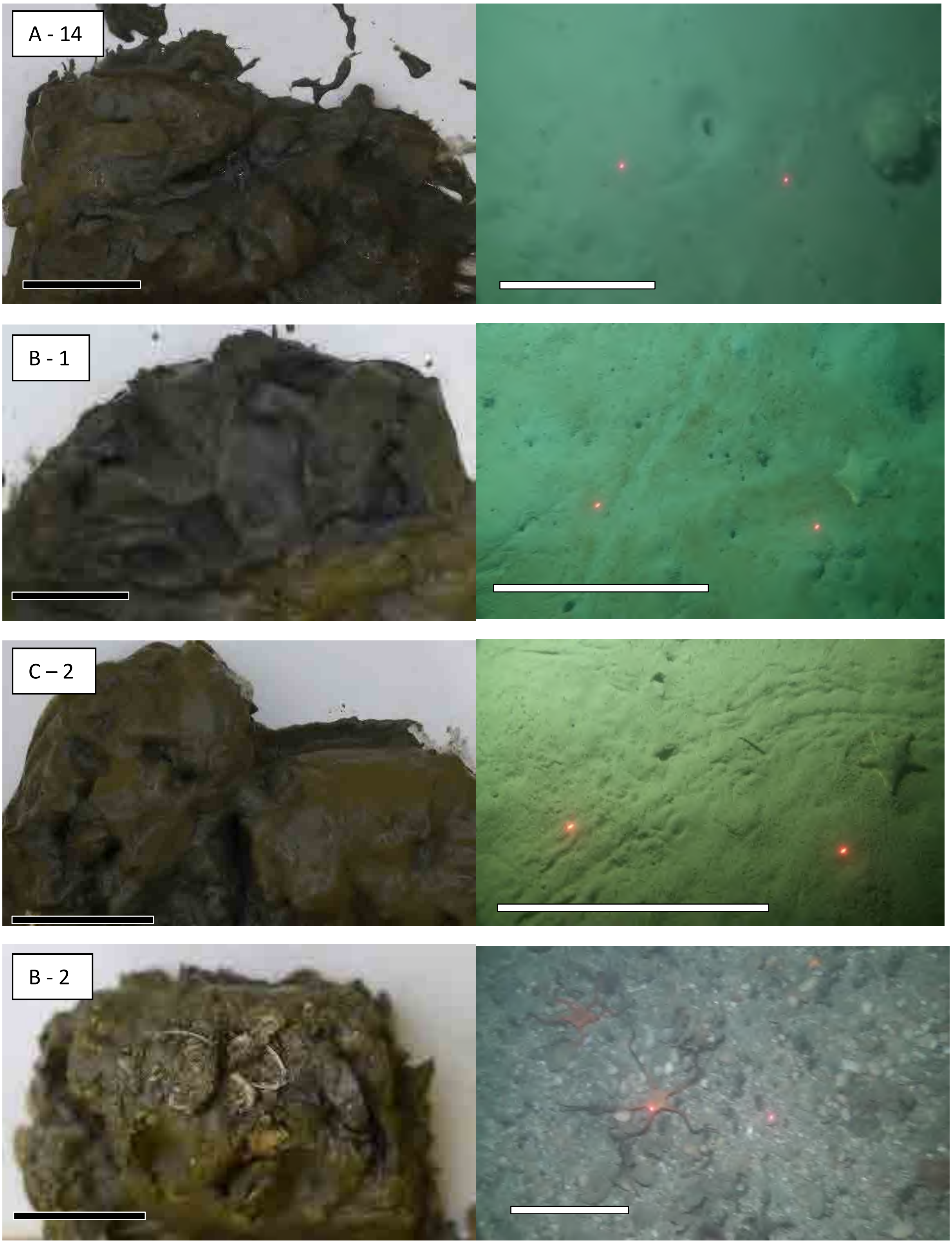


Figure 3-44: Sample and seafloor Images of seafloor plains. Images illustrate the nature of the flat, generally featureless, bioturbated seafloor throughout the survey area. A 14 – outer Queen Charlotte Sound west of Long Island, B1 – Maraetai Bay, C 2 – inner Grove Arm, B2 – inner Tory Channel. Left column, physical sample (black scale), scale = 5 cm; right column, seafloor image (white scale), scale = 20 cm.

3.6 Water column

Various objects through the water column can scatter the emitted sound pulse from the MBES, and this acoustic backscatter echo from the water column was recorded. These data can be used to image features such as kelp beds, gas or oil bubbles, biomass aggregations such as fish schools, shipwrecks, seafloor pipelines. In addition, water-column data can characterise density differences from water masses and identify areas of turbulence.

A particular focus was applied to the occurrence of: kelp beds; seeps and the possibilities of freshwater springs; anthropogenic features such as mooring lines, marine farms, and wharf structures; and other features not normally imaged in the bathymetry data (Figure 3-45) (e.g., Colbo et al., 2014).

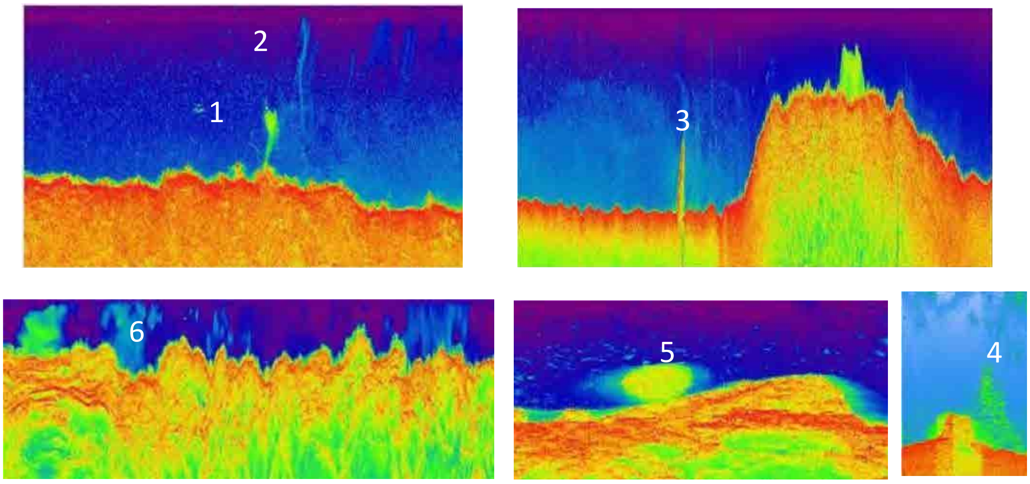
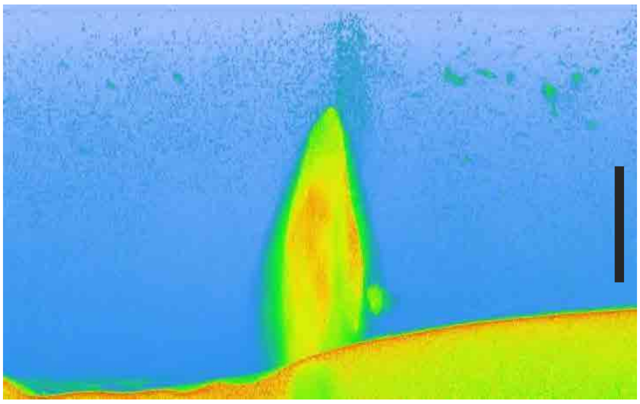
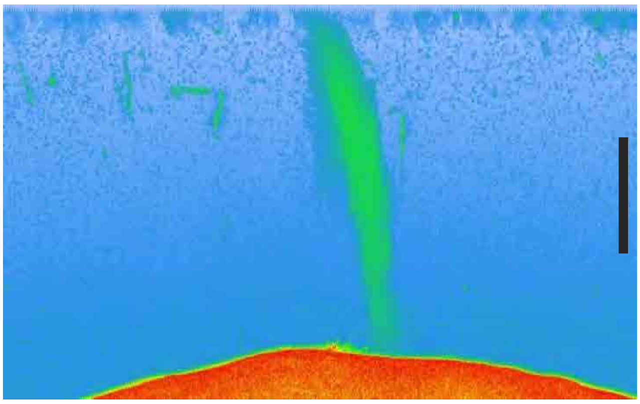
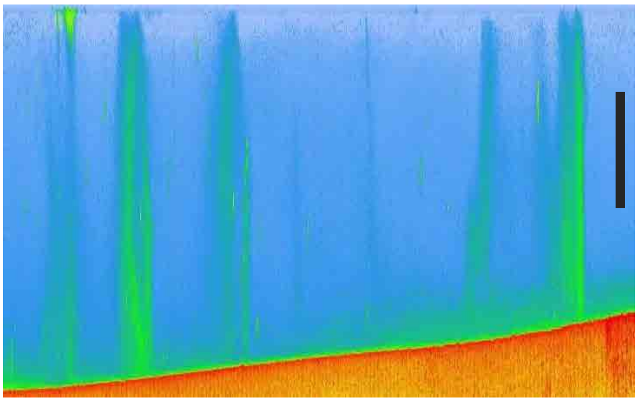
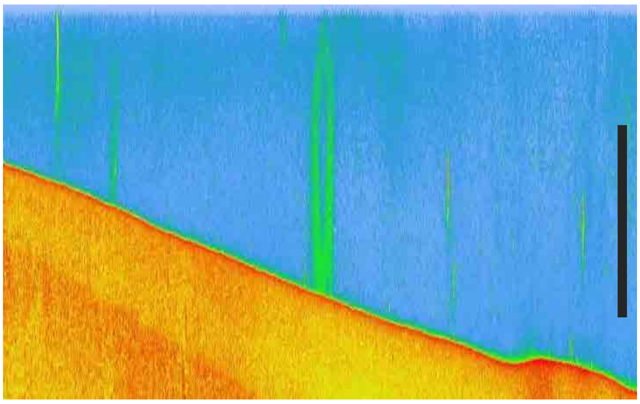


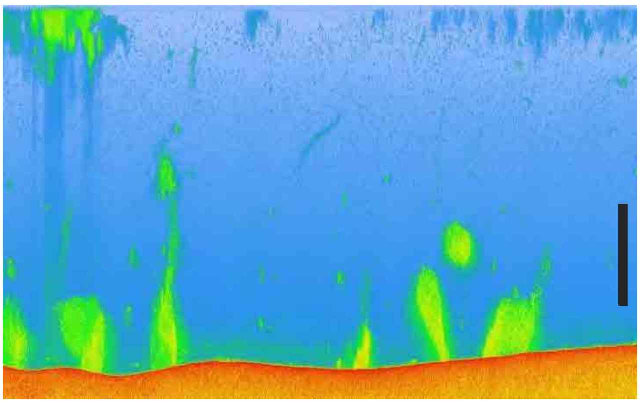
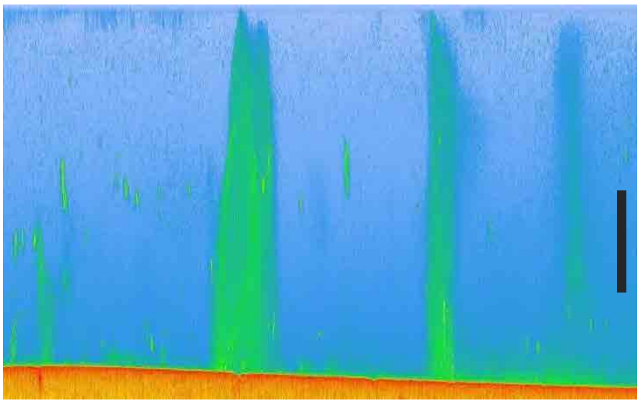
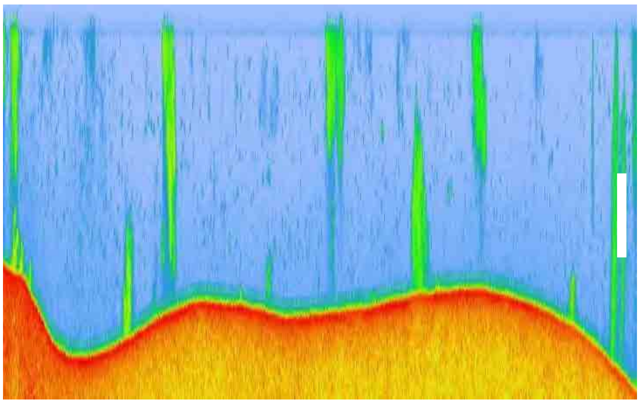
Figure 3-45: Water column imagery from other NIWA surveys showing a wide variety of water-column features observed around the New Zealand coastline: (clockwise from upper left) kelp (1), pot and float (2), hard pinnacles (3), biomass accumulation next to a rocky reef (4), and biomass accumulation above seafloor (5) and water turbulence (6) (c.f., Colbo et al., 2014) (from Neil et al., 2015, 2015b).

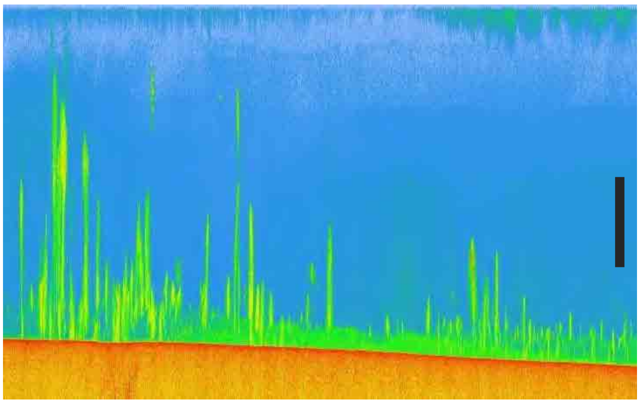
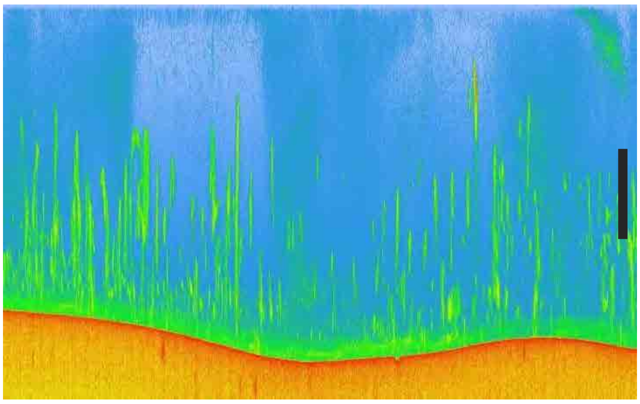
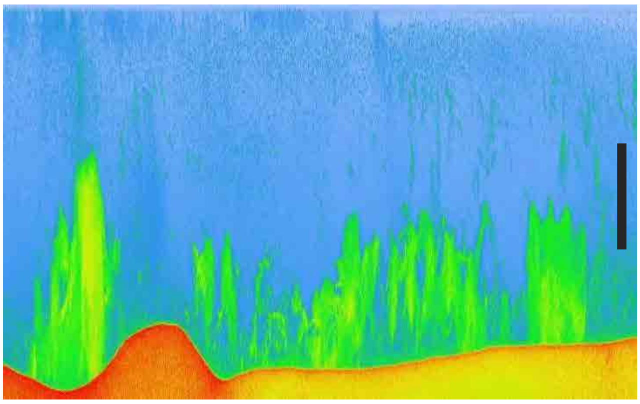
3.6.1 Seep plumes

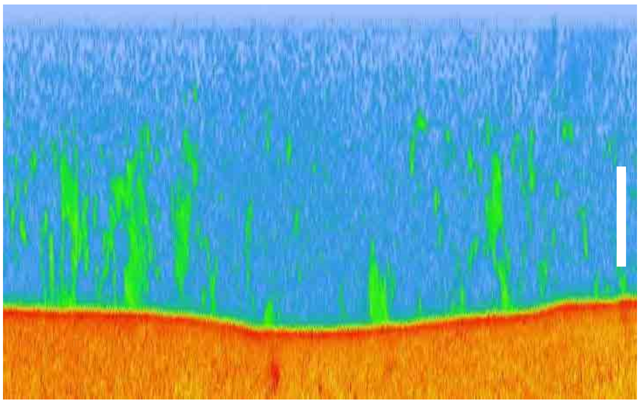
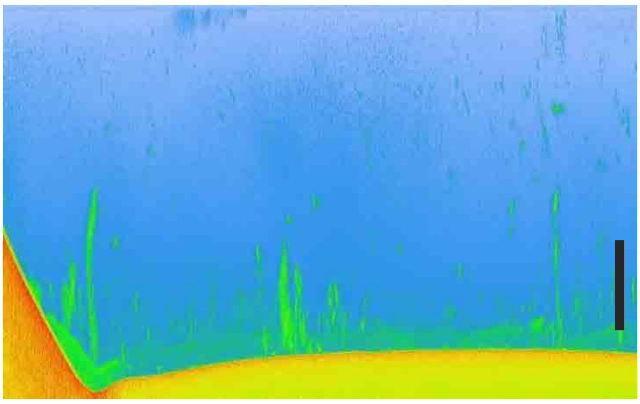
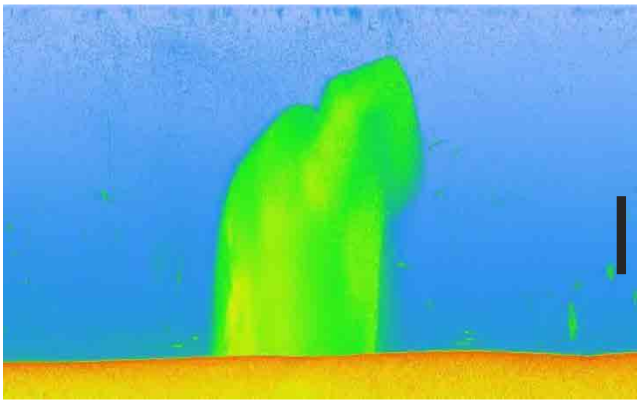
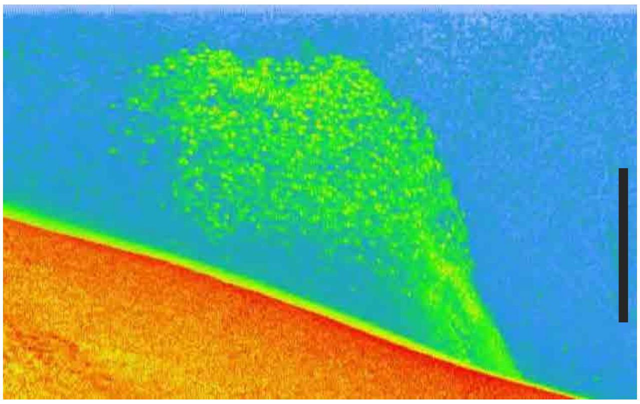
Seep plumes were identified within the water column at numerous locations throughout the survey area. Seep plumes were classified according to their nature - either a strong coherent signal or diffuse signal, along with their vertical extent through the water column. Some plumes are imaged as being attached to the seafloor and others are detached. They are also classified according to their association with other seeps, either solitary, member of a field of seeps, or a seepage field. Table 3-4 illustrates type examples for each seep feature classification, describes their defining characteristics and associations. During the survey it was observed that these features were more active following periods of heavy rain, after which activity then subsequently diminished.

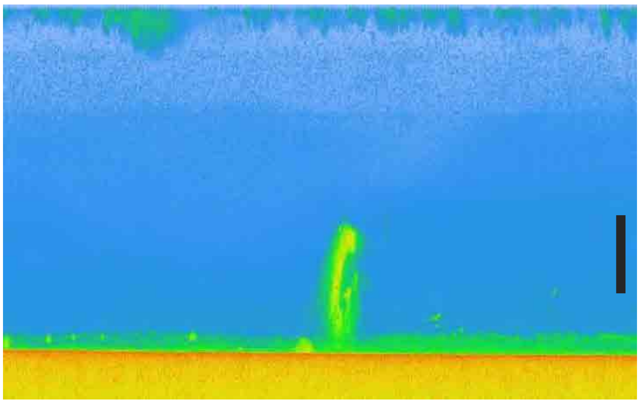
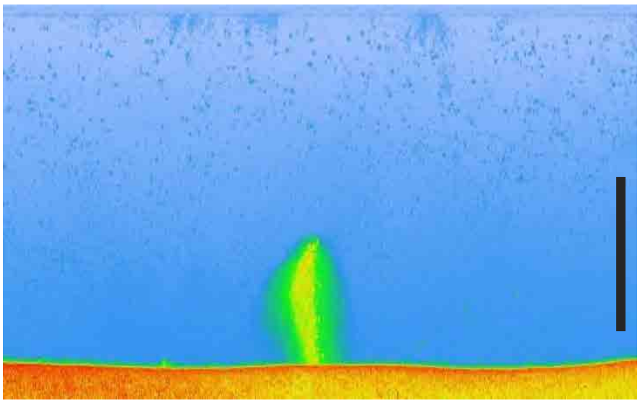
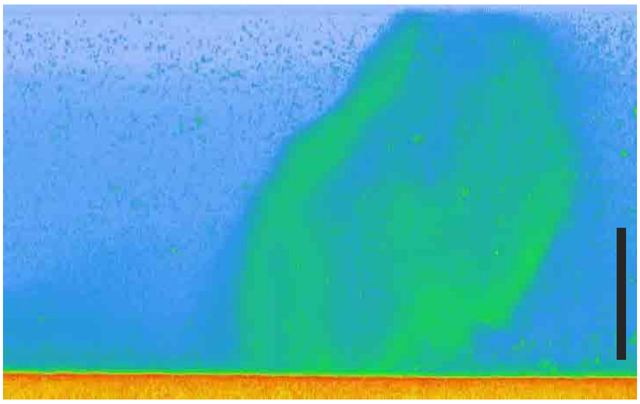
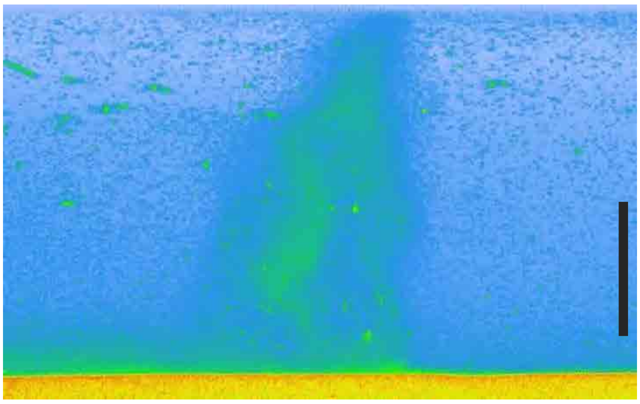
Table 3-4: Seep Classification. Water column image: White scale = 2 m, Black scale = 10 m.

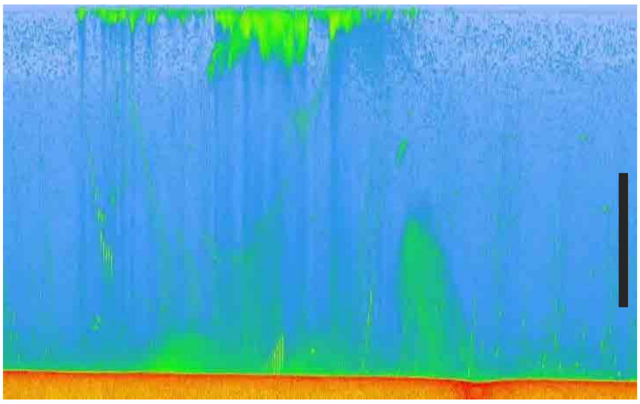
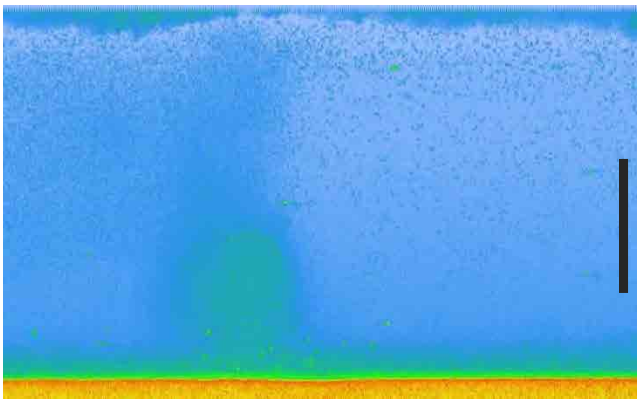
Classification	Description	Location	Stacked Water Column Image
Solitary Seep (Association a)	The type example of a solitary seep is a single feature, at a significant distance from any other seep feature.	Bay of Many Coves – Clay Point	
		Queen Charlotte Sound – Blumine Island	
Field of Seeps (Association b)	The type example of this association of “field of seeps” arbitrarily contains 6 to 8 seeps, all well-spaced and distinct.	Picton Harbour – Mabel Island to Picton Point	
		Grove Arm – Okiwa Bay to Ngakuta Bay	

Classification	Description	Location	Stacked Water Column Image
		Ruakaka Bay – Kahika Bay	
Field of Seeps (Association b – extreme example)	Extreme examples of "field of seeps" are those that most resemble a seep field or multiple individual seeps, but remain a field of seeps (<8 seeps and >4 seeps, respectively).	Queen Charlotte Sound – Allports Island to Ngatawhetawheta Point	
		Tory Channel – Erie Bay	

Classification	Description	Location	Stacked Water Column Image
Seep Field (Association c)	The type example "seep field" is defined as multiple seeps in an area that are individually indistinct. This lack of individual seeps is what differentiates a seep field from a field of seeps.	Onauku Bay	
		Queen Charlotte Sound - Parikohikohi Point to Allports Island	
		Queen Charlotte Sound - Waikakaramea Bay	

Classification	Description	Location	Stacked Water Column Image
Seep Field (Association c – extreme example)	Extreme examples of this “seep fields” association are seep fields that also have, or appear to have, a few primary seeps fit into this category.	Okiwa Bay	
		Umuwheke Bay	
Dominant Seep (Class 1)	Strong signature, persistent through >2/3rds of the water column.	Queen Charlotte Sound – Bull Head	
		Queen Charlotte Sound – Pickersgill Island	

Classification	Description	Location	Stacked Water Column Image
Minor Seep (Class 2)	Strong signature, persistent in <2/3rds of the water column.	Onauku Bay	
		East Bay	
Dominant Diffuse Seep (Class 3)	Diffuse signature, persistent in >2/3rds of the water column.	Grove Arm – Whenuanui Point	
		Grove Arm – Torapapa Point	

Classification	Description	Location	Stacked Water Column Image
Minor Diffuse Seep (Class 4)	Diffuse plume signature, present in <2/3rds of the water column.	Grove Arm – Iwirua	
		Picton Harbour – Wedge Point	

The distribution of seep plumes is predominantly through the inner and middle Queen Charlotte Sounds, and shallow bays of Tory Channel. The distribution correlates well with the distribution of pockmark and coastal scour seafloor features. However, not all pockmark features are co-characterised by the presence of an active seep. In turn, this indicates that not all pockmarks have active seeps and/or the seeps are ephemeral, as evinced by field observations during the survey. Solitary pockmarks and fields of seep associations, in particular, are most commonly proximal to the coastline, again inferring a potential link with groundwater recharge (Figures 3-45 to 3-48).

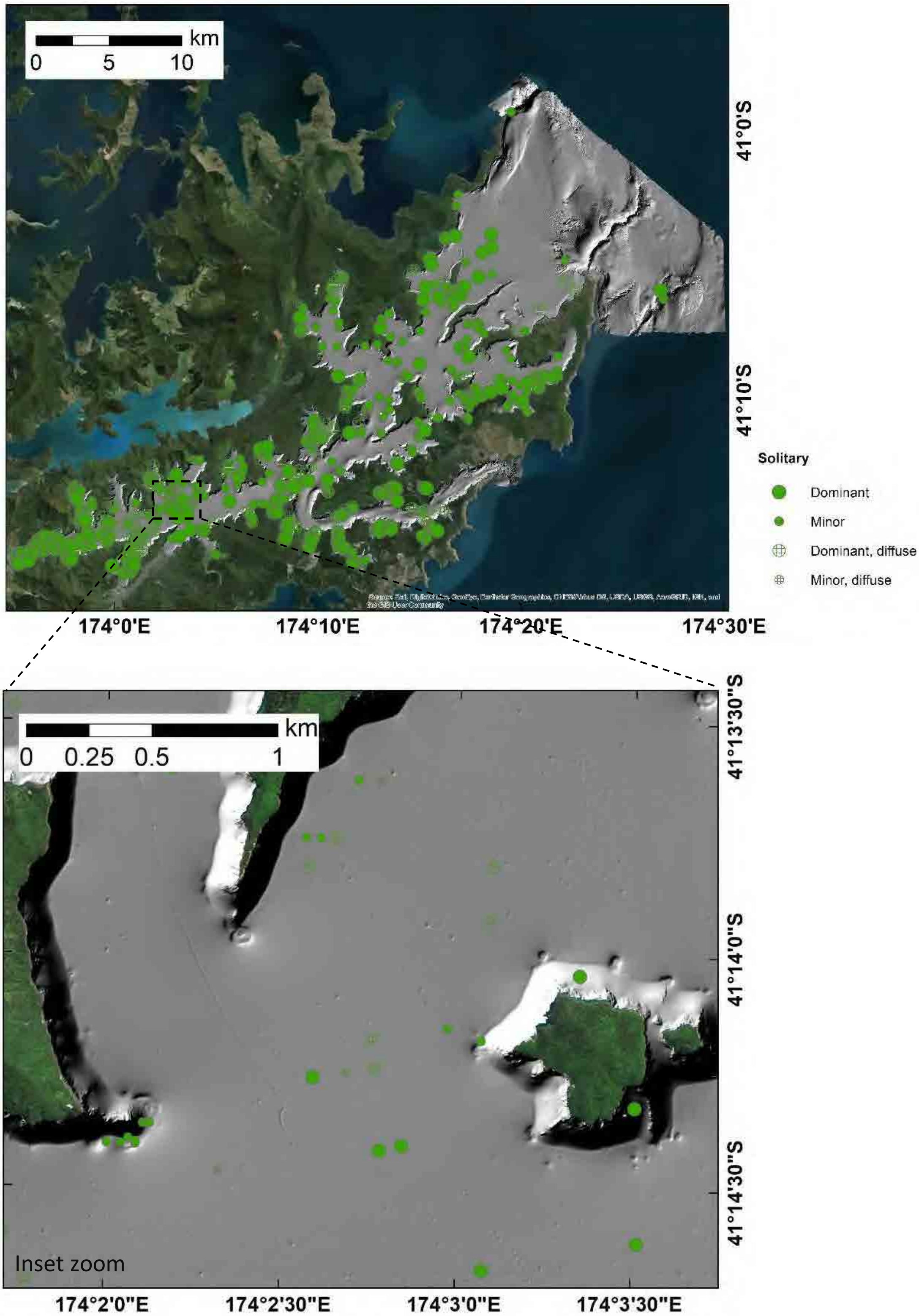


Figure 3-46: Distribution of solitary seeps. Locations (green) are overlain on hillshade (grey). Inset illustrates the classification of solitary seeps according to their nature - either a strong coherent signal or diffuse signal, along with their vertical extent through the water column. Refer to Portfolio Overall Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 1 of 13 for larger scale image.

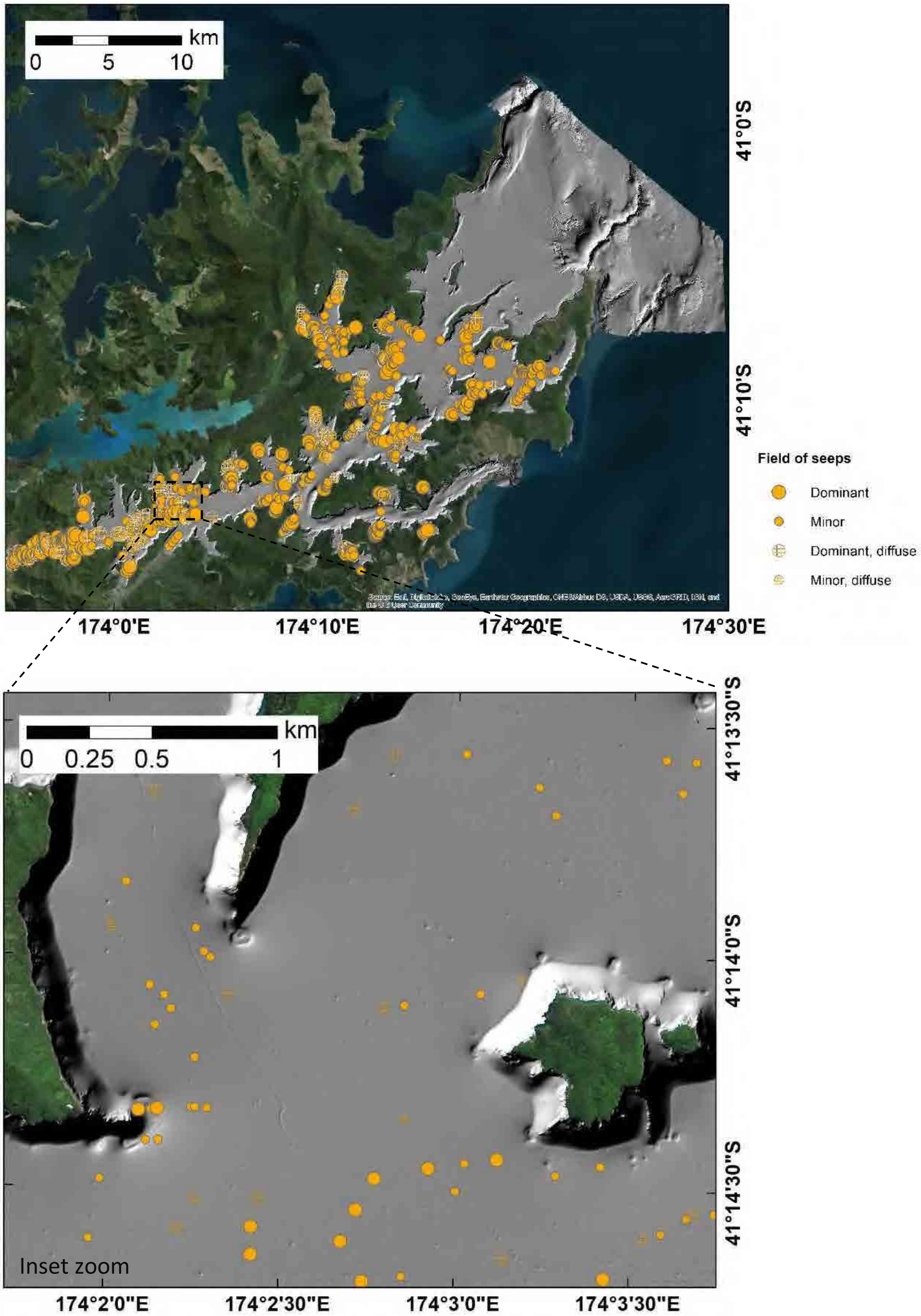


Figure 3-47: Distribution of fields of seeps. Locations (orange) are overlain on hillshade (grey). Inset illustrates the classification of fields of seeps according to their nature - either a strong coherent signal or diffuse signal, along with their vertical extent through the water column. Refer to Portfolio Overall Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 1 of 13 for larger scale image.

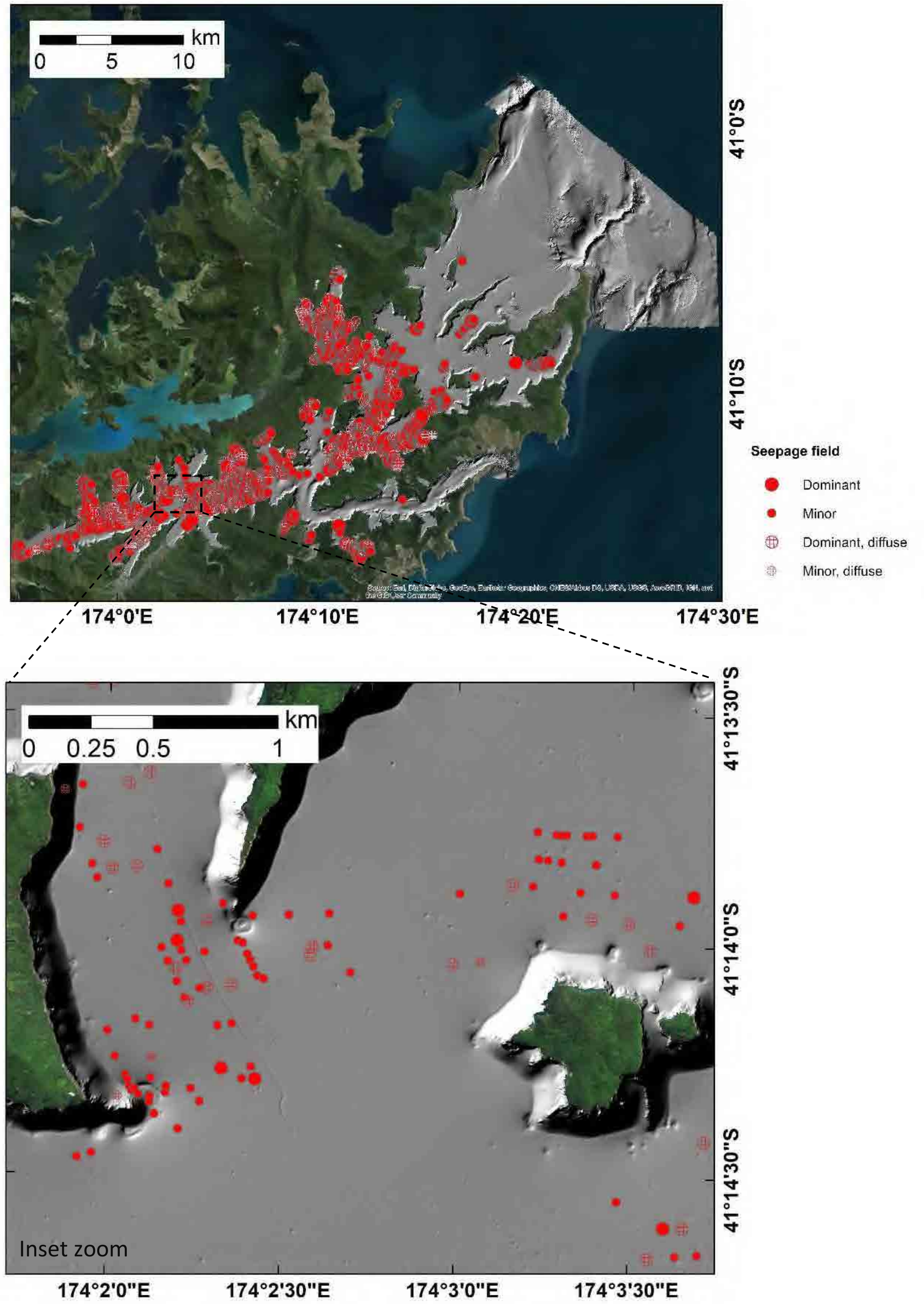
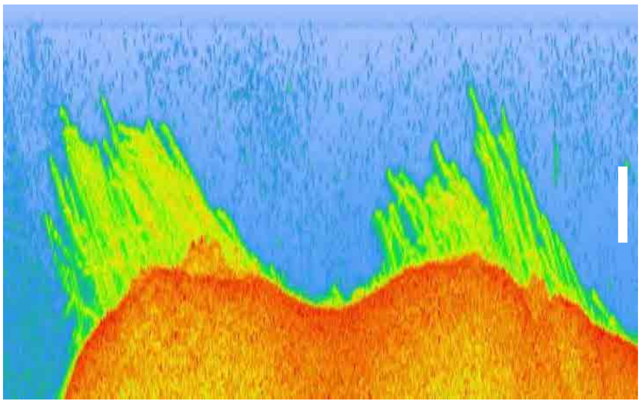
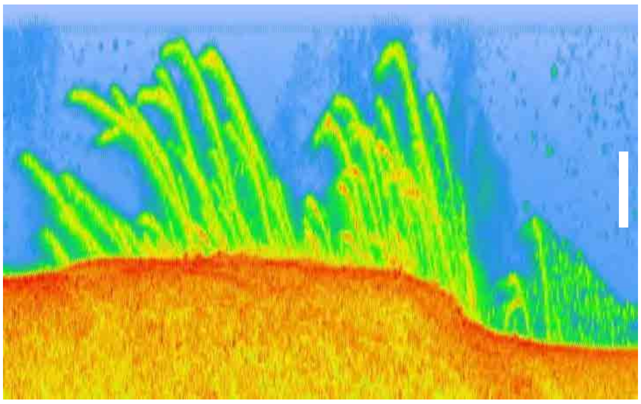
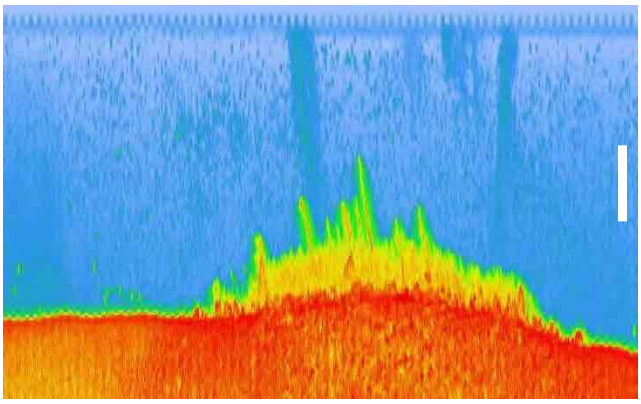


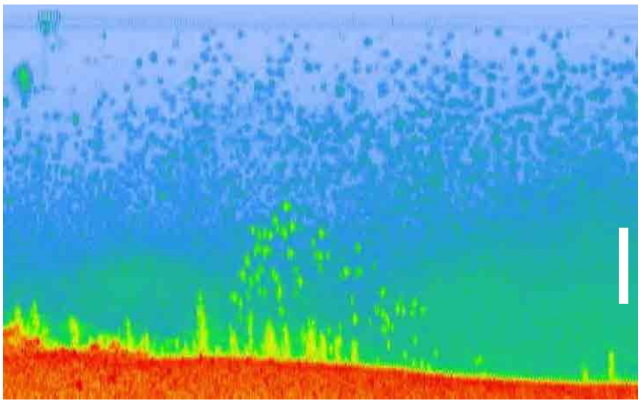
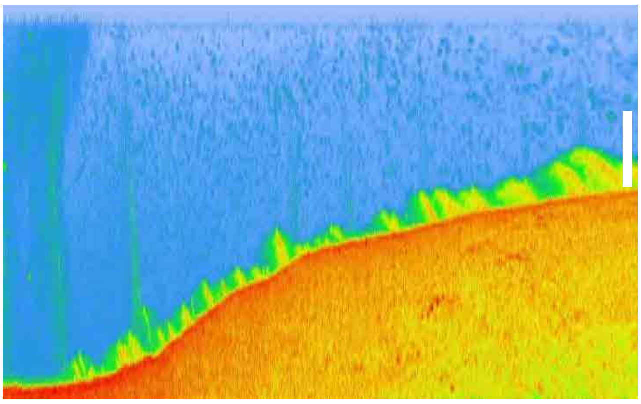
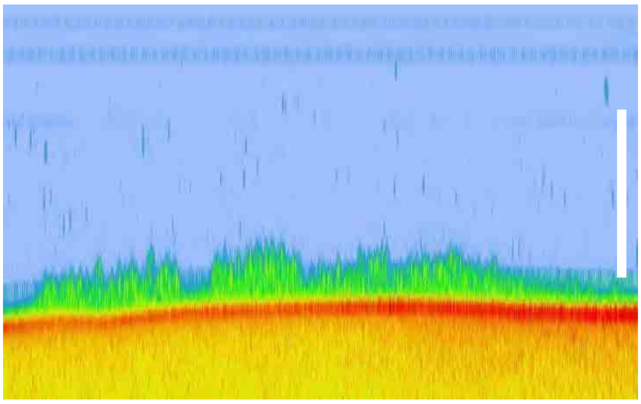
Figure 3-48: Distribution of seep field. Locations (red) are overlain on hillshade (grey). Inset illustrates the classification of seeps in a field according to their nature - either a strong coherent signal or diffuse signal, along with their vertical extent through the water column. Refer to Portfolio Overall Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 1 of 13 for larger scale image.

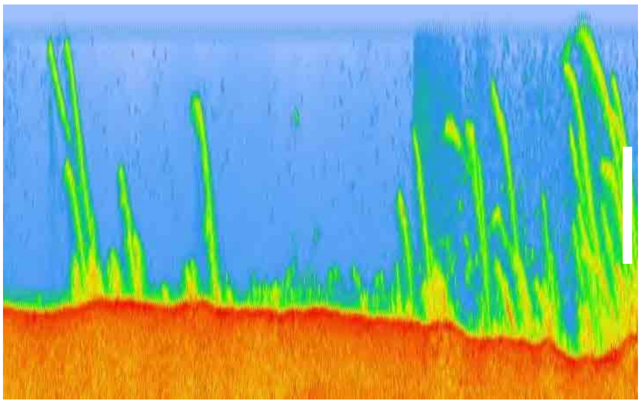
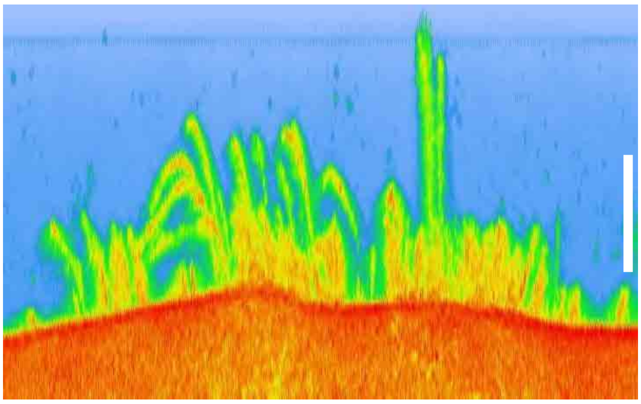
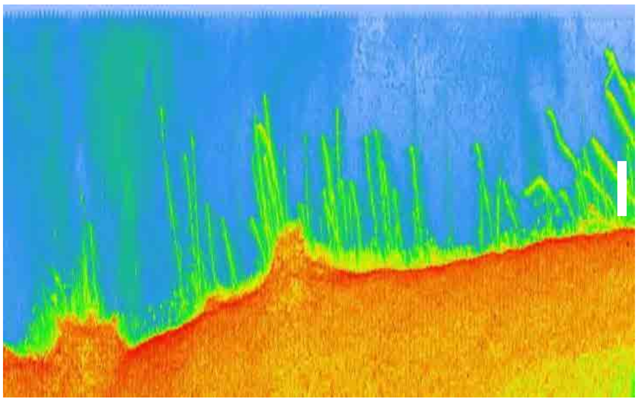
3.6.2 Kelp

Kelp features identified in the water column were classified according to their height above the seafloor. This resulted in three classifications: (1) tall kelp features greater than 1 m in height; (2) low kelp features <1 m in height, which could also be young or nascent kelp; and (3) a mix that comprises both of the classes above (Table 3-5). Kelp observed in the water column data generally occurred over, or proximal to, rocky shoals and ridges with high occurrences in Tory Channel, as well around Pickersgill Island, Arapawa Island and Cape Jackson (Figures 3-49 to 3-51). The spatial extent of kelp observed during coastal observations is also indicated in Figures 3-50 and 3-51. These distributions should also be considered with the information attained from the Aerial Photo Classification (see Section 3.7).

Table 3-5: Kelp Classification. Water column image: White scale = 2 m.

Classification	Description	Location	Stacked Water Column Image
Tall	Defined as >1 m in height.	Tory Channel – Arrowsmith Point	
		Tory Channel – Scraggy Point	
		Queen Charlotte Sound – Oamaru Bay	

Classification	Description	Location	Stacked Water Column Image
Low	Defined as <1 m in height, possibly young or nascent.	East Bay – Paerata Point (Note: biological accumulations above kelp).	
		Tory Channel – Okukari Bay	
		Tory Channel – Te Weuweu Bay	

Classification	Description	Location	Stacked Water Column Image
Mix	Defined as comprising both the above classes.	Tory Channel – Motukina Point	
		Tory Channel – Thoms Bay	
		Tory Channel – Whekenui Bay	

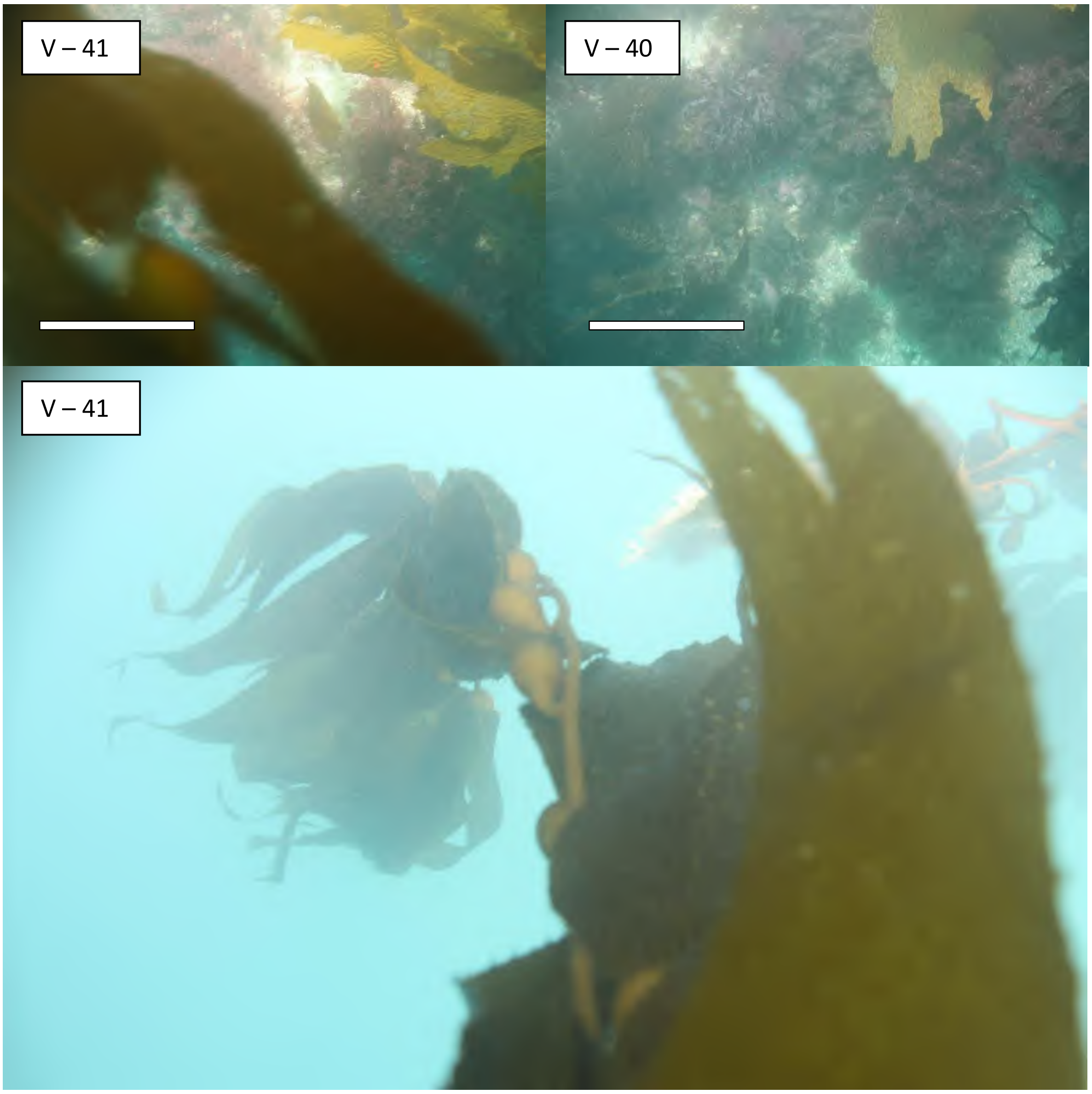


Figure 3-49: Underwater images of Kelp from Thoms Bay, Tory Channel. Seafloor image (white scale), scale = 20 cm.

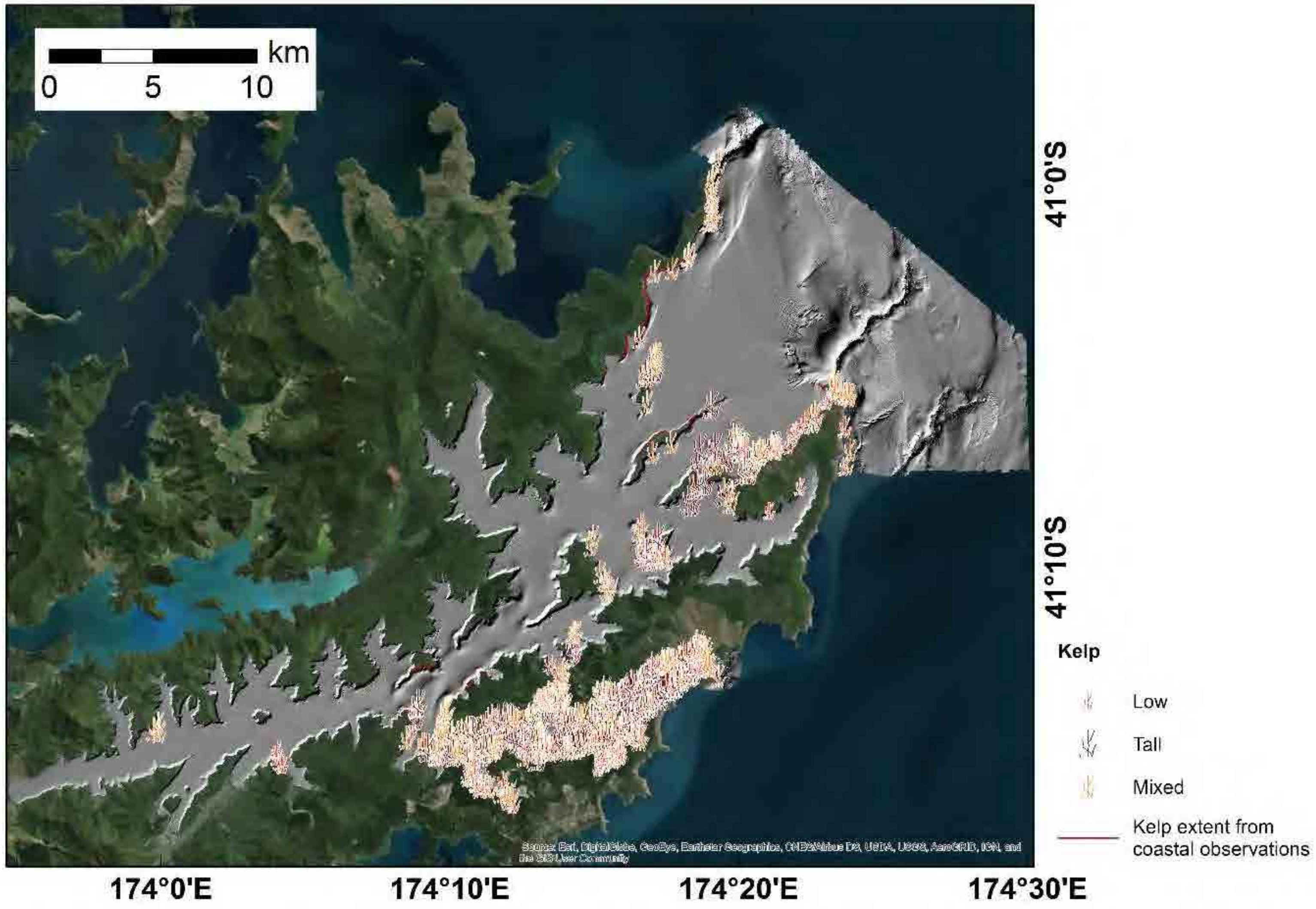


Figure 3-50: Kelp distribution over survey area. Classifications (Low (red), Tall(brown), Mixed(orange)) are overlain on hillshade (grey). Note the high occurrences in Tory Channel, as well around Pickersgill Island, Arapawa Island and Cape Jackson. Refer to Portfolio Overall Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 1 of 13 for larger scale image.

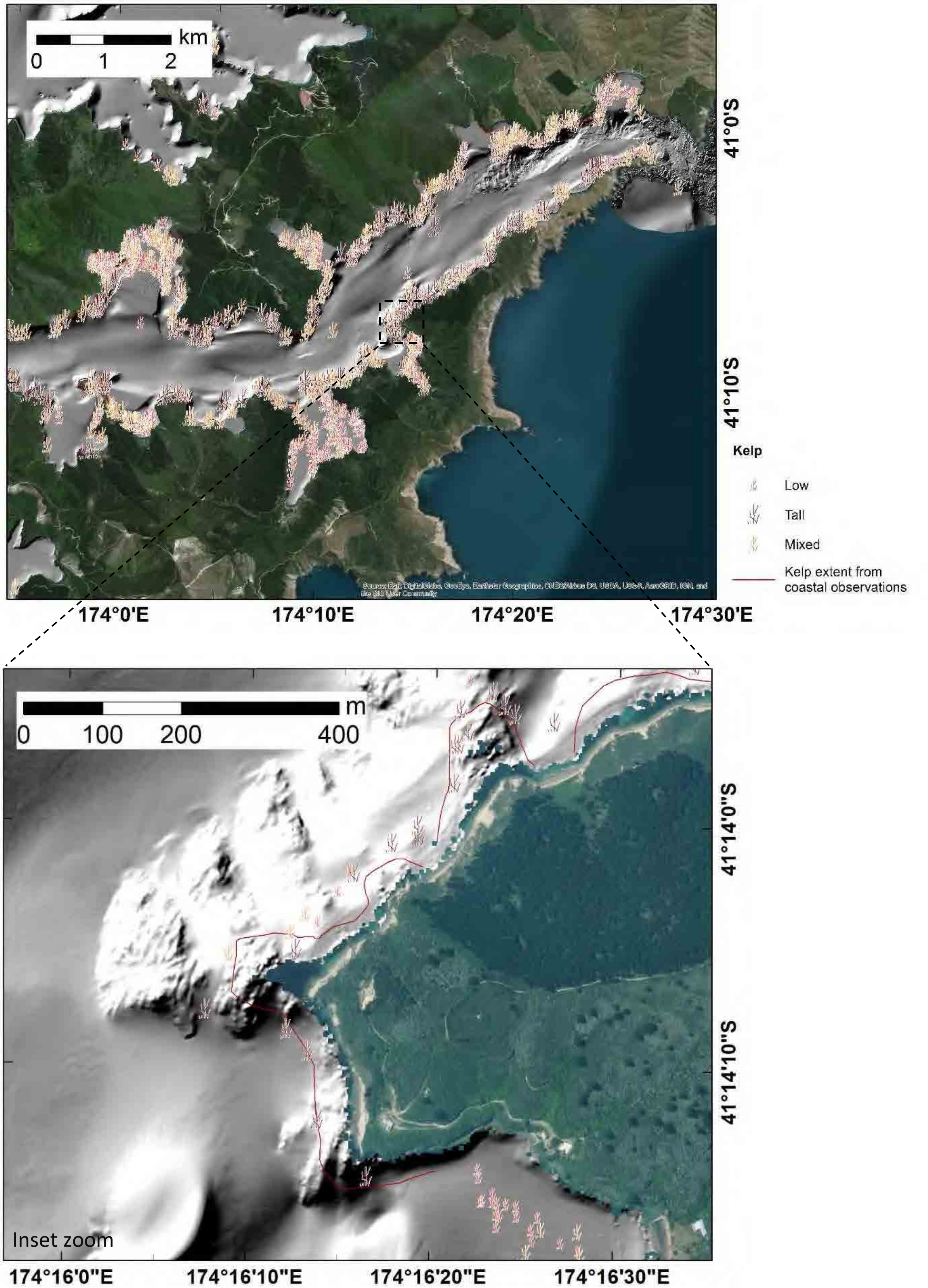


Figure 3-51: Kelp distribution within Tory Channel: Classifications (Low (red), Tall (brown), Mixed (orange)) are overlain on hillshade (grey). Inset shows detail of kelp north of Te Rua Bay in Tory Channel. Refer to Portfolio Tory Channel/Kura Te Au, 10 of 13 for larger scale image.

3.6.3 Other Biological Features

Other features represented in the water column data are those associated with spatially ephemeral biological aggregations or large mammals (Figure 3-52). Notes on their occurrence are contained within the water column screening database should future work programmes require this information. Due to the transient nature of their occurrence they are not spatially represented here.

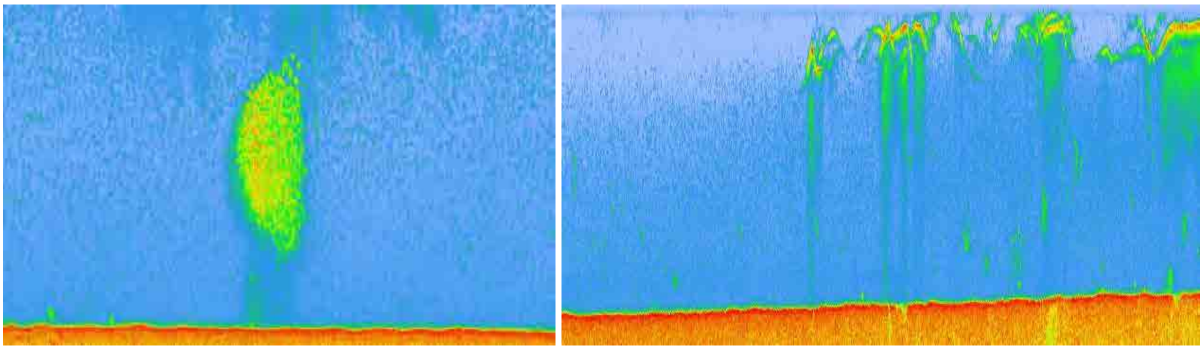


Figure 3-52: Water-column images illustrating biological accumulations, probably fish (left) and dolphin activity (right).

Marine-Mammal Observations

Marine-mammal observations were recorded during the survey and the sightings database was delivered in June 2017 (Davey et al. 2017). Overall, there were 229 sightings made comprising mainly bottlenose dolphins, dusky dolphins, common dolphins, Hector's dolphins and NZ fur seals (Figure 3-53). For completeness, sightings are summarised within the Portfolio compilation for the Overall Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 1 of 13.

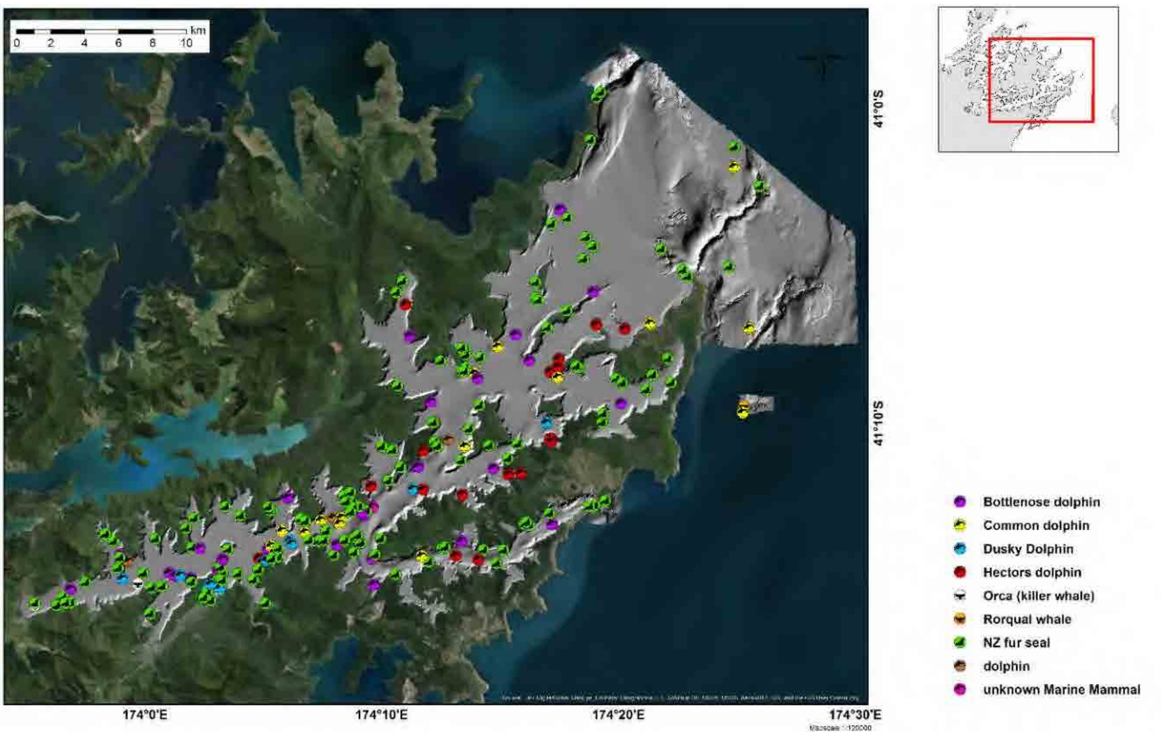


Figure 3-53: Marine-mammal sightings. For the period 24th October 2016 to 18th June 2017. Refer to Portfolio Overall Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 1 of 13 for larger scale image.

3.6.4 Anthropogenic features

A range of anthropogenic features can be visualised in the water column (Figure 3-54). Here, we collated the locations of: mooring blocks, which at the time of survey were associated with a mooring line (Figure 3-55); wharf structures - usually the associated piles (Figure 3-55); and submerged wrecks. Wrecks have been previously reported in the Report of Survey for HS51. Marine farm structures were also visualised in the water column and are discussed in Section 3.9.

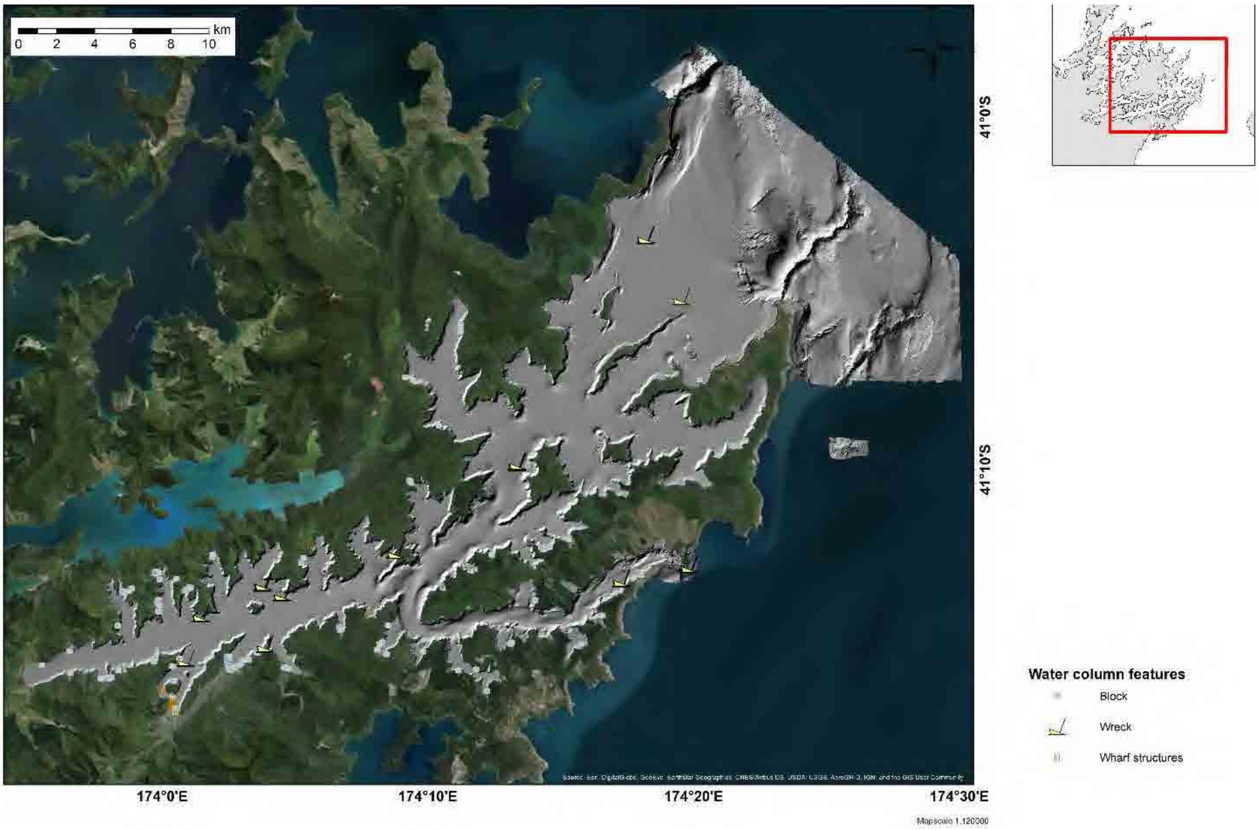


Figure 3-54: Anthropogenic features identified within watercolumn data: Location of features are overlain on hillshade (grey). Refer to Portfolio Overall Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 1 of 13 for larger scale image.

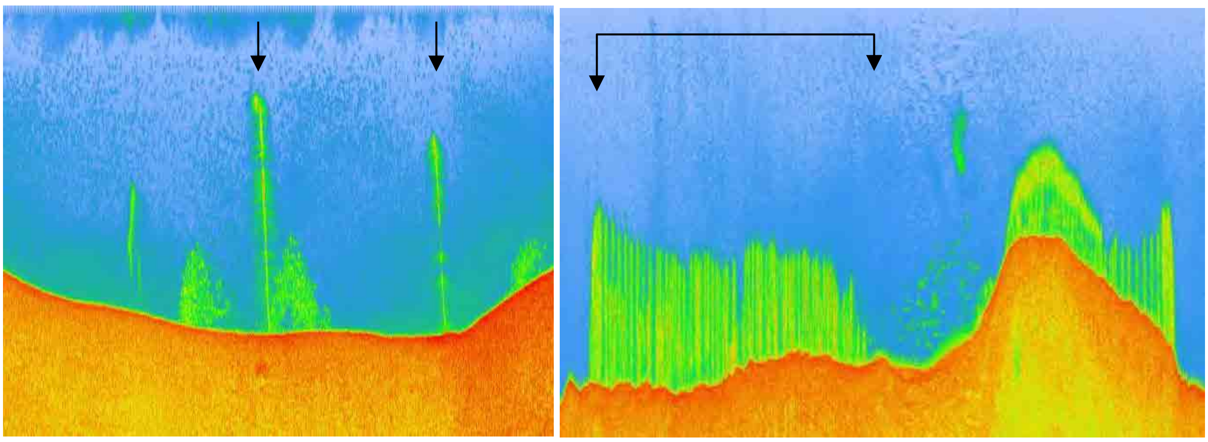
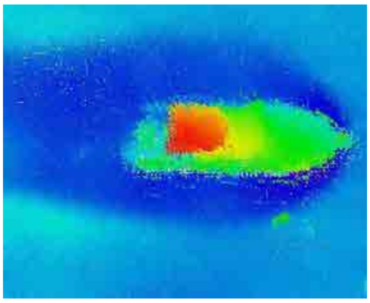
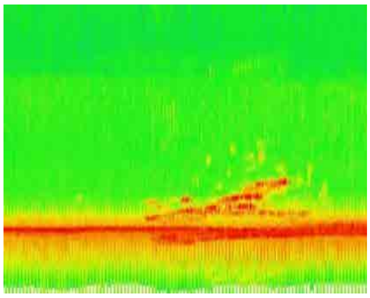
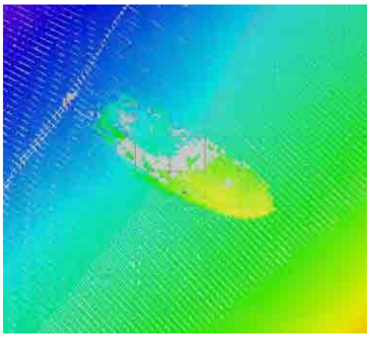
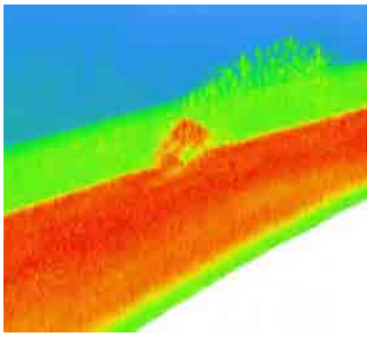
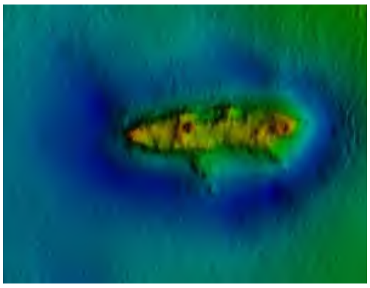
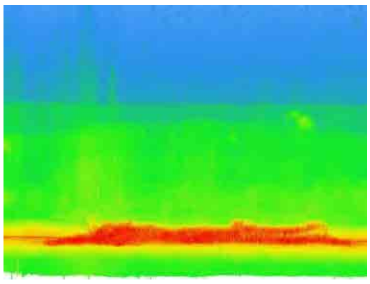
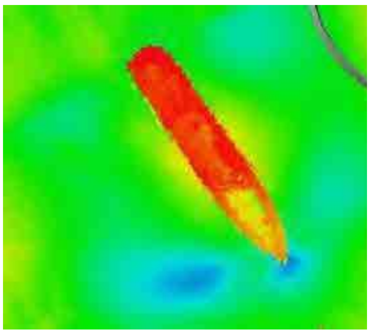
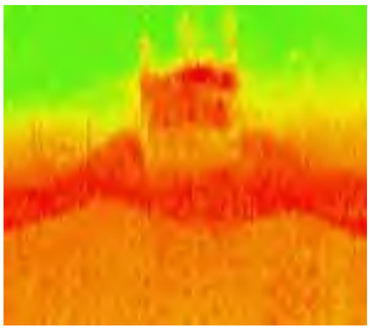


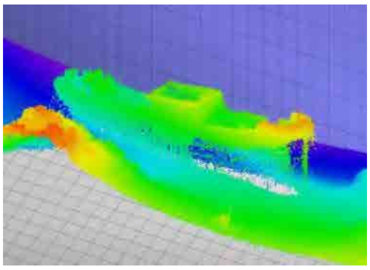
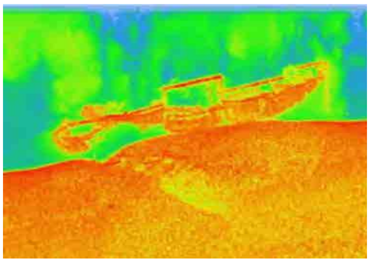
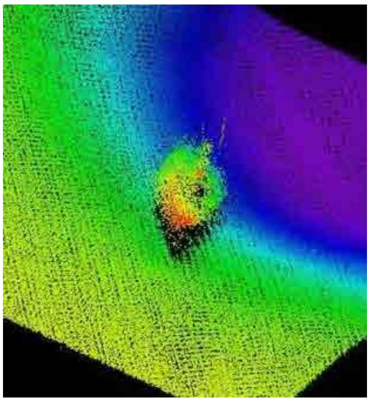
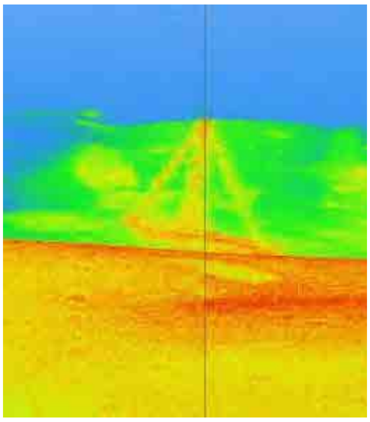
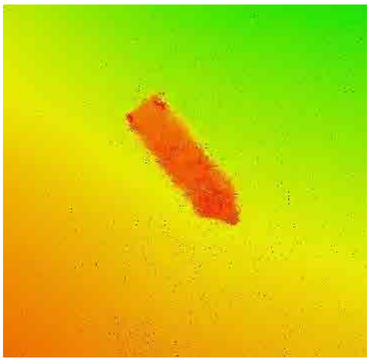
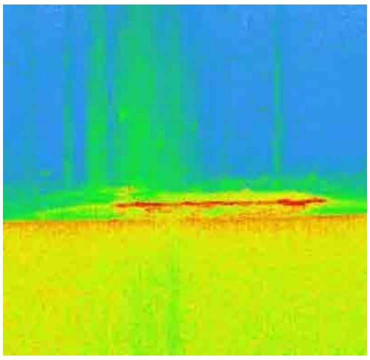
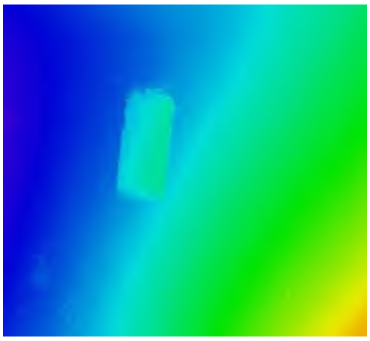
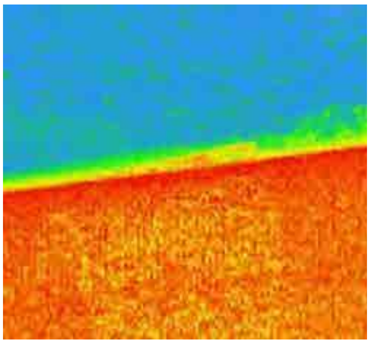
Figure 3-55: Water-column images illustrating the mooring lines commonly associated with mooring blocks (left) and wharf piles in Picton Harbour (right). The black arrows in the left image indicate the mooring lines, and in the right image wharf piles.

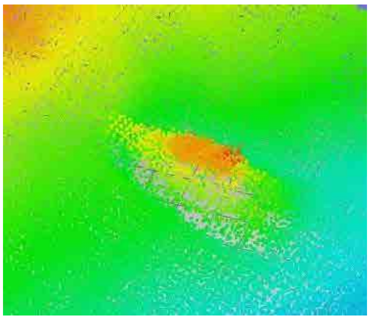
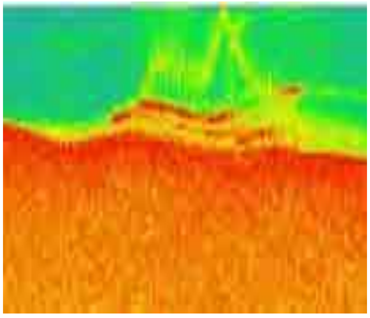
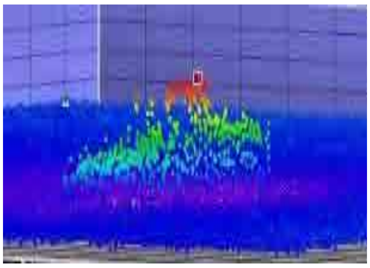
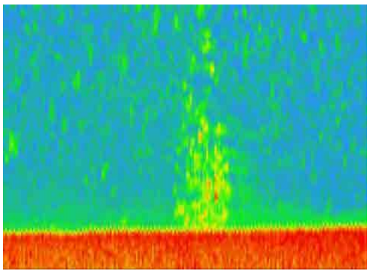
Submerged wrecks

A total of 10 wrecks were detected during the survey, and are fully described within the Report of Survey, but included here for completeness. Table 3-6 below illustrates the wrecks as visualised in bathymetry and water column data, with images of some wrecks shown in Figure 3-56. 3D visualisations of some wrecks are included within the Portfolio Overall Queen Charlotte Sound/Tōtaranui and Tory Channel/Kura Te Au, 1 of 13.

Table 3-6: Submerged wrecks identified in the survey data. Summarised from Report of Survey.

Feature Id	Latitude Longitude	Description	Bathymetric Visualisation	Water Column Visualisation
121.1	41° 03.5000' S 174° 17.8833' E	10 m long launch sitting upright on seabed in scour hole LD19.9 m. 22.0 m surrounding depths. Uncharted.		
144.1	41° 15.2418' S 174° 03.7883' E	14 m long by 4 m wide. LD 8.7 m. Surrounding depth 11 m sloping. Uncharted.		
152.1	41°09'58.93"S 174°13'10.84"E	39 m long by 11 m wide. Uncharted wreck of large vessel lying in channel west of Blumine Island. Assumed to be the HIPPALOS lost on 27 Nov 1909. LD 58.2 m. Surrounding Depth 60 m on a flat seabed.		
159.1 and also Target 168.1	41° 13.2470' S 174° 17.1572' E	27 m long, MBES **Charted** west of Thoms Bay. Sitting on Mound in centre of large scour hole (50 m wide, 2 m deep). LD 33.5 m. Surrounding Depth 35 m.		

Feature Id	Latitude Longitude	Description	Bathymetric Visualisation	Water Column Visualisation
188.1	41°14.3915' S 174°01.3720' E	34 m long, Uncharted wreck of vessel 30m off shoreline. Wreck is KOI a known local diving site. LD 4.5 m at Bow. Surrounding Depth 11 m.		
192.1	41°13.7802' S 174°04.4108' E	11 m long by 5 m wide, pleasure craft yacht with mast. Uncharted west of Golden Point and north of Allports Island. 37.5 m from WC to top rigging. LD by bathy 48 .4 m. Surrounding Depth 52 m on the edge of a hole, increasing to 56 m.		
192.2	41°13.4917' S 174°03.6693' E	22 m long by 5.5 m wide. Uncharted feature potential wreck of working barge south of Kaipakirikiri Point and north of Allports Island. LD 44.3 m at stern. Surrounding Depth 47.0 m on a flat seabed.		
231.1	41°12.5302' S 174°08.6555' E	12 m long by 5.6 m wide. Uncharted feature potential wreck of floating platform north of West Head in Ruakaka Bay and east of marine farm. LD 12.8 m. Surrounding Depth 16.2 m on sloping sea bed rinsing up to 14.7 m.		

Feature Id	Latitude Longitude	Description	Bathymetric Visualisation	Water Column Visualisation
245.1	41°12.8232' S 174°19.6980' E	9 m long by 2.6 m wide x 1.6 m above the seabed. Wreck of small pleasure craft or fishing boat. Uncharted 0.3nm SE of East Head at the entrance to Tory Channel. LD 58.5 m. Surrounding Depth 59 m on gently sloping sea bed.		
Wedge	41° 15.6815' S 174° 00.8390' E	10 m Long by 3.2 m Wide. 1.8 m high above seabed. **Charted** wreck of potential Fishing boat. Slightly sunk in seabed. LD 29.0 m. Surrounding 30.8 m on flat seabed.		

Wrecks as artificial reefs

- The wreck of the Koi is known to divers, but has not previously been officially charted. The Koi was a twin-propeller steamer used as a ferry and coal hulk before she finally sank at her moorings in Picton in March 1940. In May 1940 she was raised and towed to her present location where she acts as an artificial reef with abundant encrusting marine life.
- The Hippalos was a barque that struck Walkers Rock in 1909. All hands made ashore but the abandoned vessel was holed and taken in tow. The intake of water soon overwhelmed the ship's pumps and the Hippalos foundered and eventually sank off Blumine Island (Ingram, 1984). Bottom photos show that the wreck is now covered with encrusting communities including branching and bushy bryozoans, sponges, anemones, ascidians, as well as cancer crabs. Numerous common fish were also seen sheltering under the wreck overhangs, including: roughy, sea perch (Jock Stewarts), mackerel, and triplefin.
- The elevated wreck charted west of Thoms Bay in Tory channel sits on coarse sand / gravel base and is heavily encrusted with several sponge species, bushy bryozoans, tubeworms, and algae. It features kina, crayfish, seaperch (Jock Stewarts) and a school of common roughy within the wreck structure. Numerous blue cod, tarakihi and red cod gather around the wreck.
- Another wreck known to divers within the survey area is the Rangitoto which struck a reef on Cape Jackson and sunk shortly after. Due to the rocky nature of the shoreline her remaining structure is largely indistinguishable from the reef structure along Cape Jackson, and as such is not mapped or formerly listed here.

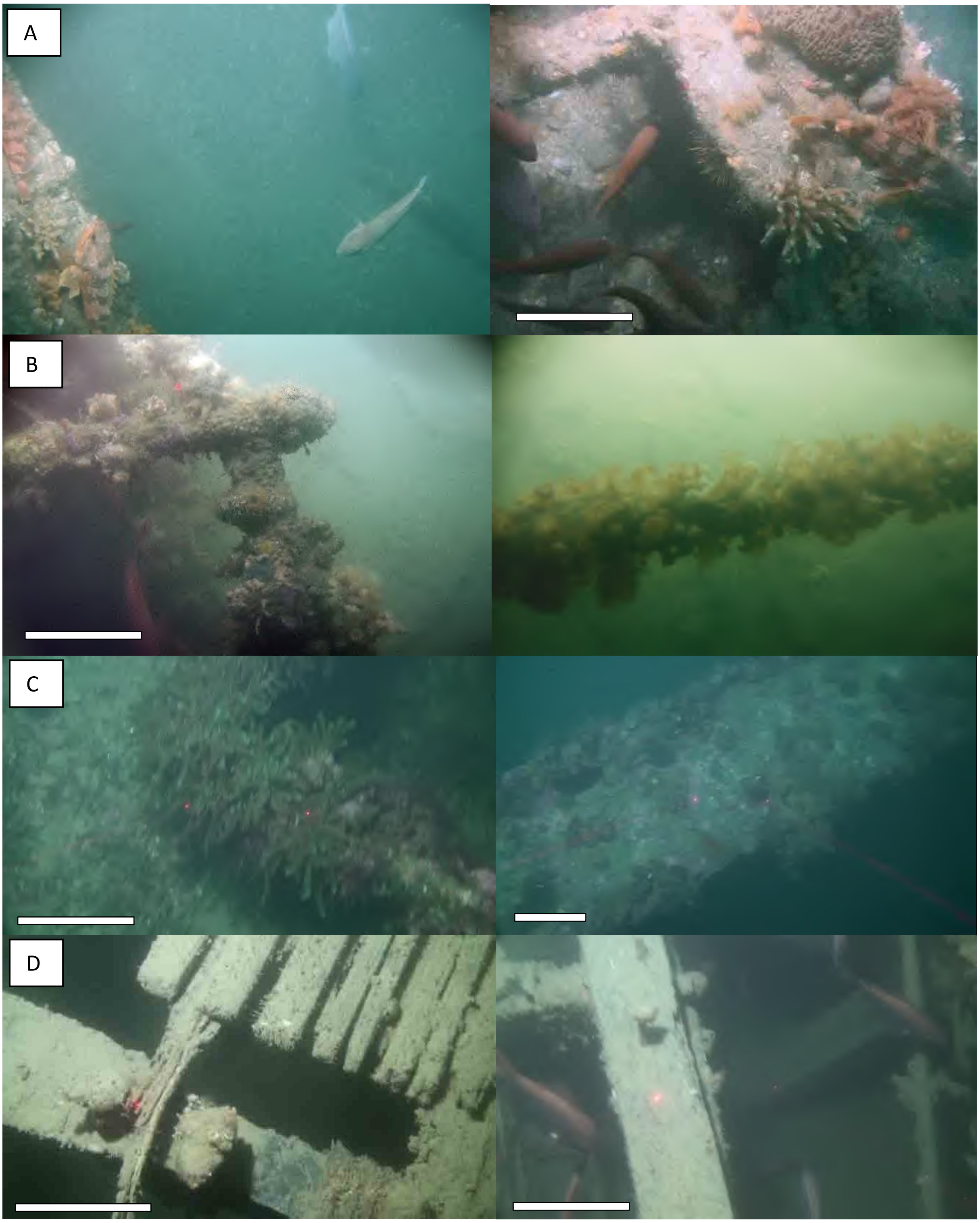


Figure 3-56: Underwater images illustrating wrecks with Queen Charlotte Sounds and Tory Channel A – wreck, charted west of Thoms Bay, B - wreck of *Hippolas,* west of Blumine Island, C - wreck of *Koi,* offshore Double Cove, D – barge, south of Kaipakirikiri Point and north of Allports Island. Underwater image (white scale), scale = 20 cm.

3.7 Aerial Photo Classification

Using aerial imagery, seafloor coverage was successfully classified down to an average depth of 10 m. This dataset provides coverage across areas of seafloor (water depths <5 m) not included in the backscatter seafloor classification (Figure 3-57). Detailed methodology is provided in Part 2, Sections 1.5.5, 1.8.2, and Appendix C).

This resultant classification produced three seafloor classes within the survey area:

1. Vegetated seafloor which is either seagrass on soft bottom or algae on hardbottom types;
2. Hardbottom which might partially be covered by algae; and
3. Unconsolidated sediment, usually a soft bottom, not or sparsely covered by vegetation.

Of particular interest is the areas of vegetated seafloor which correspond with observations of kelp and algae from both water-column analysis and coastal observations (Section 3.5.2), as well as with Algal and Eel Grass Ecologically Significant Marine Sites (see Section 3.7.1). Representative seafloor images or bathymetry corresponding with these aerial photo classifications are illustrated in Table 3-7.

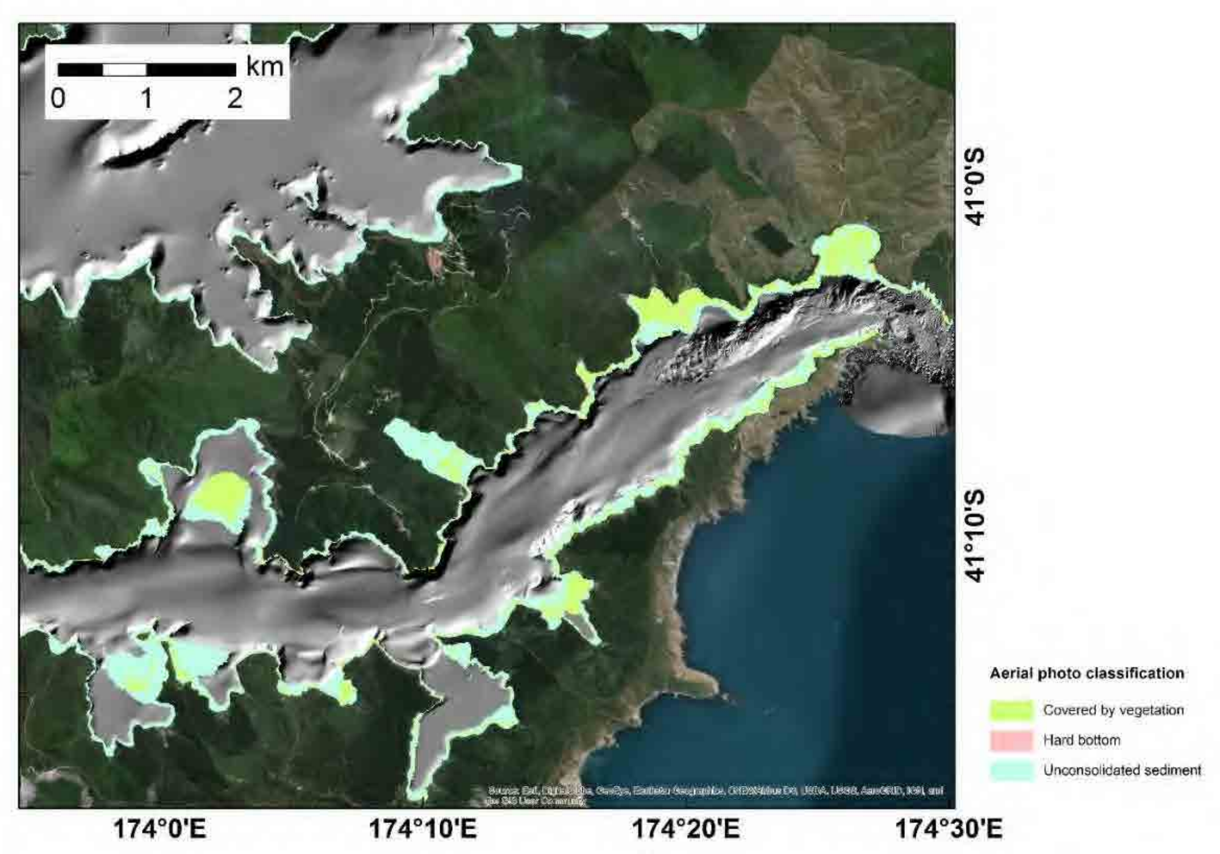
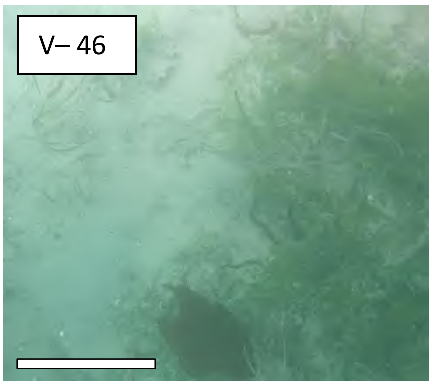
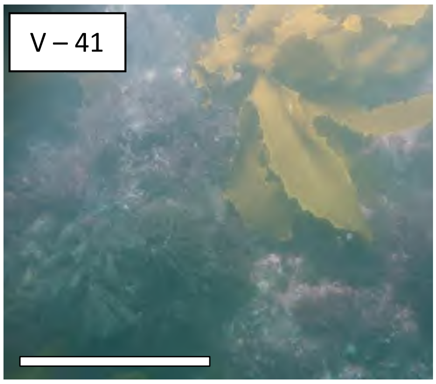
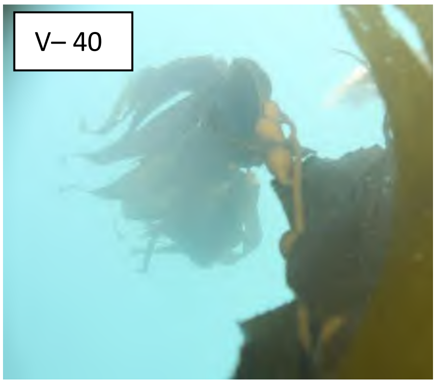
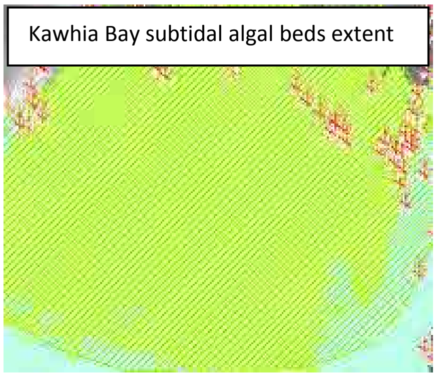
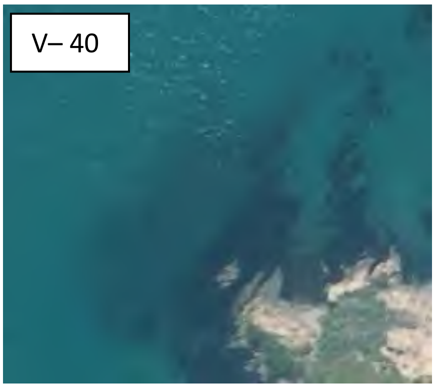
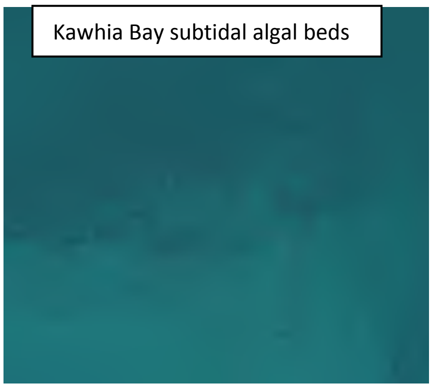
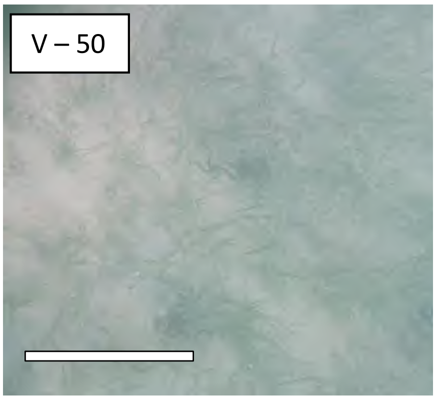
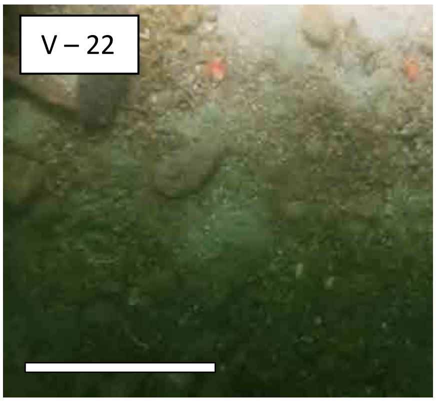
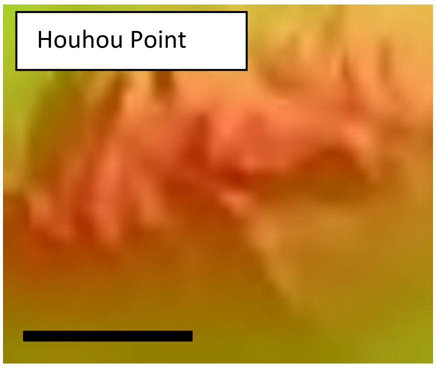
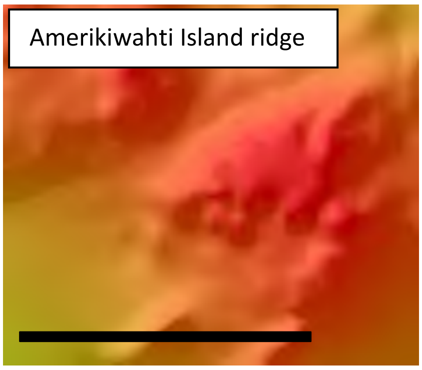


Figure 3-57: Example of Aerial Photo Classification from Tory Channel. Classification types are overlain on hillshade (grey). Refer to Portfolio Tory Channel/Kura Te Au, 10 of 13 for larger scale image.

Table 3-7: Seafloor and bathymetry images representative of photo classifications. Seafloor image (white scale), scale = 20 cm. Bathymetry (black scale), scale = 50 m. Indicative aerial photography shown here is sourced from MDC. Kawhia Bay subtidal algal beds derived from aerial imagery are represented by the green extent (covered by vegetation), as defined in MDC Significant Marine Sites by green hatching, red/brown symbols represent kelp. In particular, refer to Portfolio Tory Channel/Kura Te Au, 10 of 13 for larger scale image.

Aerial photo Classification	Representative Images	
Covered by vegetation		
Covered by vegetation cont.		
Aerial Imagery - Covered by vegetation		

Aerial photo Classification	Representative Images	
Unconsolidated sediment		
Hard bottom		

3.8 Benthic Terrain Classifications

3.8.1 Background

The 2 m digital elevation model (DEM) produced from this bathymetric survey was processed using ArcGIS Benthic Terrain Modeler (BTM) tools (Wright et al. 2012), which classifies the seafloor into zones based on variations in the bathymetry (depth). The information from the depth, slope, rugosity and other data sets is used to create a classification scheme for the benthic terrain. Methodology is outlined in Part 2 Section 1.11. These zones form the basis of an ecosystem classification scheme that underpin a benthic-habitat map. In turn, each class is predicted to have distinct environmental conditions, and can form the basis of future targeted photographic and sampling programmes.

3.8.2 Terrain classifications from the survey

The benthic terrain classifications used here is user-defined based on BPI's, slope, standard deviation breaks, and depth. The benthic zones employed here in the output layer includes crests, depressions, flats, and slopes. The benthic structures in the output layer used here consist of: flat plains; broad slopes; steep slopes; broad platforms or depressions; lateral mid-slope platforms or depressions; scarps (or cliffs); depressions; crevices or narrow gullies over elevated terrain; narrow slopes; rock outcrop highs, beach platforms or narrow ridges; and local depressions. The following are also finer-scale benthic structures that occur in, or on, larger scale benthic structures: local ridges, boulders, pinnacles in depressions (i.e. smaller scale ridges on a larger scale depression); local ridges, boulders, pinnacles on broad flats (i.e. smaller scale ridges on a larger scale broad flats); local ridges, boulders, pinnacles on slopes (i.e. smaller scale ridges on a larger scale slopes), (Figure 3-58).

Table 3-8: Area and percentage of benthic terrain classes, Queen Charlotte Sound and Tory Channel.

Benthic Terrain Class	Area (km^2) of class within survey area	% of class within survey area
Flat Plains	278.42	62.9%
Broad Slopes	74.27	16.8%
Steep Slopes	8.12	1.8%
Broad Platform or Depressions	29.58	6.7%
Lateral Midslope Platform or Depression	5.47	1.2%
Scarp, Cliff	0.56	0.1%
Broad Depressions	7.04	1.6%
Crevices, Narrow Gullies over elevated terrain	1.35	0.3%
Narrow Slopes	19.29	4.4%
Rock Outcrop Highs, Beach Platforms, Narrow Ridges	15.6	3.5%
Local Ridges, Boulders, Pinnacles in Depressions	0.15	0.03%
Local Ridges, Boulders, Pinnacles on Flat Plains	0.27	0.1%
Local Ridges, Boulders, Pinnacles on Slopes	2.29	0.5%
Local Depressions	0.51	0.1%

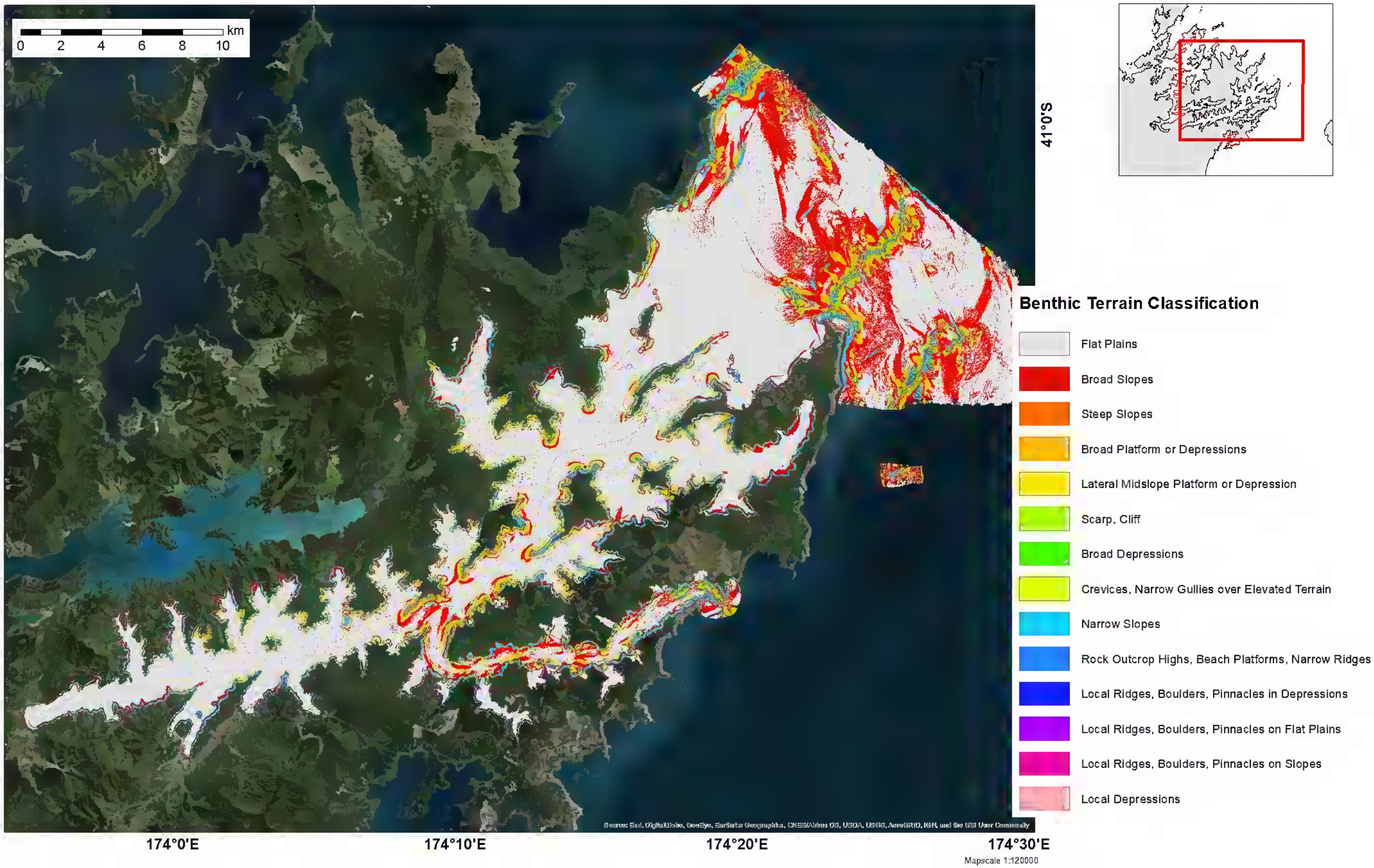


Figure 3-58: Benthic terrain classifications generated from bathymetric data. Also see detailed images within the 28 map sets included in the portfolios and Table 3-9.

The dominant resultant terrain classifications for Queen Charlotte Sound and Tory Channel combined are the geomorphic habitats of 63% flat plains, 17% broad slopes, 7% broad platforms or depressions, and 4% narrow slopes and rock outcrop highs (Figure 3-58, Table 3-8).

The terrain classifications for Queen Charlotte Sound (excluding the outer reaches/Cook Strait) are geomorphic habitats of 71% flat plains, 9% broad slopes, 8% narrow slopes and rock outcrop highs, and 6% broad platforms or depressions. Whereas, the resultant classification for outer reaches of Queen Charlotte Sound/Cook Strait is geomorphic habitats of 50% flat plains, 31% broad slopes, 8% broad platforms or depressions, and 6% narrow slopes and rock outcrop highs.

Tory Channel terrain classifications are geomorphic habitats of 43% flat plains, 22% broad slopes, 14% narrow slopes and rock outcrop highs and 10% broad platforms or depressions.

The larger area benthic terrain classes: flat plains, broad slopes, broad platforms or depressions, narrow slope/narrow ridge, and rock outcrops are discussed in more detail below.

3.8.3 Flat plains

The flat plain habitat defined here dominates Queen Charlotte Sound and the embayments of Tory Channel, which is comprised of low reflectivity muds, often bioturbated with communities of asteroids, tube anemones, scallops, kina, bivalves, worms, shrimp and fish (e.g. Table 3-9, A). However, this habitat also extends across coarser grained sands and gravels, with medium to high reflectively, which occur locally within Queen Charlotte Sound (e.g. Picton Harbour, Table 3-9, B). The sill that separates Queen Charlotte Sound and Cook Strait is also included within the flat plain habitat (Table 3-9, C) and while dominated by low reflectivity muds, it also includes a patchy biogenic habitat with encrusting communities such as sponges, bryozoans and algae. The axis of the Tory Channel is also defined as a flat plain habitat (Table 3-9, D). This environment has substrates of coarse sands and gravels with high reflectivity, experiences moderate tidal flow and often dense and diverse encrusting fauna e.g. coralline algae, encrusting and erect sponges, ascidians, bryozoans, ophiuroids, kina, sea tuplids and fish - blue cod, tarahiki, red cod, common roughy.

3.8.4 Broad slopes

The broad slope habitat, with slopes generally less than 20°, occurs predominately along the coastal flanks (Table 3-9, F), including across the entrance of the shallower bounding bays of Tory Channel (Table 3-9, E). This habitat is typically comprised of fine to medium sands with low to medium and slightly gravelly sands with medium to high reflectivity.

A joint flat plain/broad slope habitat also occurs within many of the tidally dominated areas such as Cook Strait and Tory Channel, encompassing seafloor features such as sediment waves (Table 3-9, G) and hummocky (mud) seafloor (Table 3-9, I). For example, the troughs of the sediment waves inside of The Brothers comprise the flat cobble seafloor, while the wave-like structures are comprised of mobile coarse sand/fine gravel sediment forming the sloping sediment waves (Table 3-9, H).

3.8.5 Broad platforms or depressions

Broad platforms also occur in the heads of embayments between the broad nearshore slopes and central flat plain habitat e.g. Tawa Bay (Table 3-9, K), while board depressions frequently occur directly offshore of headlands corresponding frequently to seafloor scours e.g. Kurakura Point (Table 3-9, J). Consequently, sediment in this habitat type ranges of the fine-grained low reflectivity muds through to the coarse grained fine to medium sands of the medium reflectivity backscatter classification.

3.8.6 Narrow slope/narrow ridge

A distinctive narrow slope/narrow ridge combined habitat occurs almost exclusively in association with the linear, immobile sediment waves of Cook Strait. Substrate is composed of highly reflective gravels with shell hash and few fauna (Table 3-9, L).

The narrow slope habitat occurs along much of the nearshore of Tory Channel. Often this habitat occurs inshore of associated rock outcrop and/or broad slope habitat e.g. Thoms Bay, where the substrate comprises muds and fine sands with eel grass and associated fauna like ophiuroids (Table 3-9, M).

3.8.7 Rock outcrops, and associated benthic terrains

Two examples of the benthic habitats along a rocky reef transect are illustrated in Table 3-9, N to S and T to Z. The first transect (N to S) is located up a headland of Thoms Bay (Tory Channel) from 30 m to 10 m water depth. This transect progresses across:

N. Broad depression habitat comprising gravels and cobbles many of which are encrusted with coralline algae, fauna includes encrusting fauna - sponges, ascidians and tube worms, numerous cushion stars, some ophiuroids, isolated red and brown algae, and several juvenile blue cod.

O. Scarp habitat with large irregular and rounded cobbles, shell hash and sand between the hard substrate. Heavily encrusted with coralline and other encrusting fauna, cushion stars are common, along with ophiuroids, kina in patches, sponges and ascidians including a sea tulip, and several fish - spottys, juvenile blue cod, jock stewarts.

P. Local ridges on slopes comprising sloped bedrock with shell hash and sand patches, bedrock is heavily encrusted with coralline and other algae, sponges and ascidians and other encrusting fauna, with ophiuroids common.

Q. Rock outcrop of bedrock on elevated slope, encrusting with coraline algae, red brown and red algae and diverse encrusting fauna including sponges and ascidians, sand gravel and shell fragments in patches.

R. Narrow slope with a densely encrusted and steep bedrock with sand, gravel and shell hash in crevices. Diverse species of kelp and algae – *Macrocystis* sp. kelp and several species of red brown and coralline algae. Other fauna include sponges, bryozoans and ascidian, and fish - Tarakihi and spottys.

S. Rock outcrop with extensive kelp and algae (green brown and red), encrusted cobbles and bedrock (encrusted by coralline algae) with sand in hard substrate crevices, bottom fauna is largely obscured by kelp and algae fronds but includes sponges, and some Tarakihi.

The second transect (T to Z) is located up a headland of Houhou Point (Grove Arm) from 30 m to 17 m water depth. This transect progresses across:

T. Broad slope with muddy substrate, small burrows, tracks, worm shapes, tube anemone, shrimp, opalfish.

U. Broad depression comprising muddy substrate with numerous burrows and tracks, minor shell fragments, tube anemone, and fish – flounder.

V. Midslope depression with a substrate of mud, many burrows and tracks, shell hash including patches of large bivalve shells and horse mussel.

W. Steep slopes comprising mud, patchy shell hash, burrows, horse mussels, octopus, Sections of ascidian encrusted rope on the seafloor.

X. Scarp habitat of sand and mud sediment likely over bedrock, intact shells including scallop, cockle and horse mussel and shell fragments, live horse mussels and scallop, fish – gurnard, opalfish.

Y. Local ridges on slope with bedrock/biogenic substrate in terraces, mud with shell hash in between, coralline algae, encrusting fauna, green and red algae, encrusting sponges, bryozoans, a large black cod (rock cod), and several starfish species.

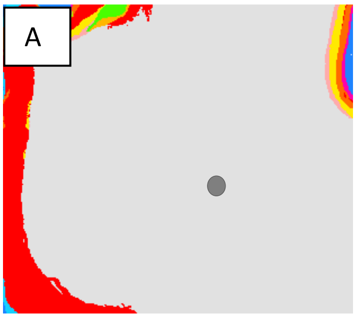
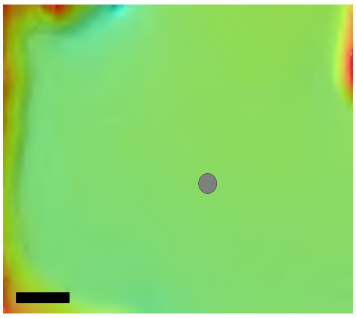
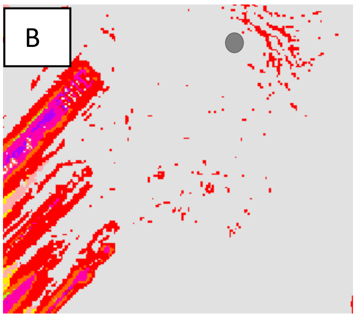
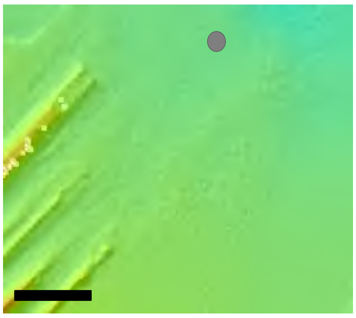
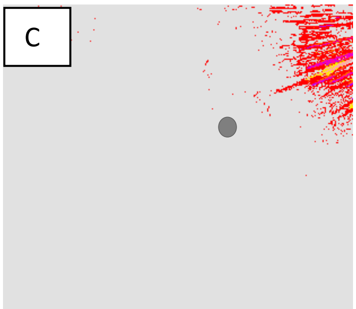
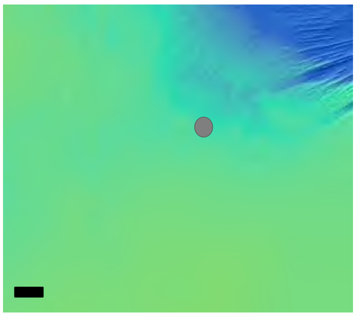
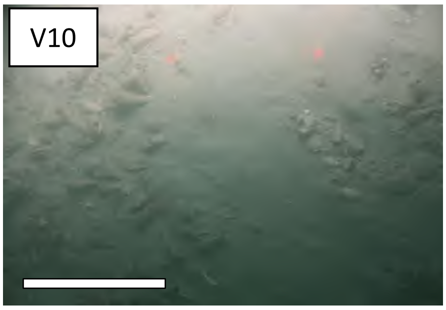
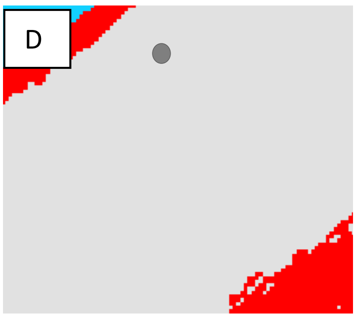
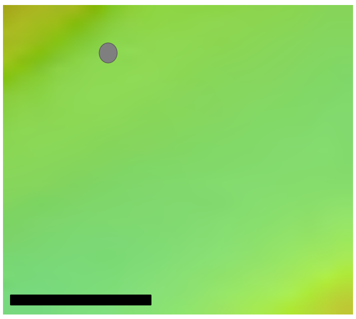
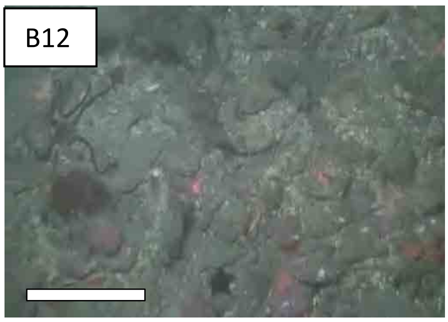
Z. Rockout crop of bedrock/biogenic substrate with encrusting sponges and other encrusting fauna, sand and shell hash in crevices, fish – spotties, triplefins.

3.8.8 Rock ridges

A rocky ridge transect from 60 –10 m water depth across the deep ridge traversing from Cape Koamaru to Cook Rock progress across a steep slope/scarp habitat to a complex rock outcrop and narrow slope habitat. The seafloor substrate comprises bedrock heavily encrusted with coralline algae, sponges and bryozoans, several species of bushy algae, other encrusting fauna, several sea tulips and other ascidians, large grey plate sponges and bulbous grey sponge, white and orange sponges, ophiuroids, butterfly perch, jock stewarts, adult blue cod and triplefins (Table 3-9, AA - AC).

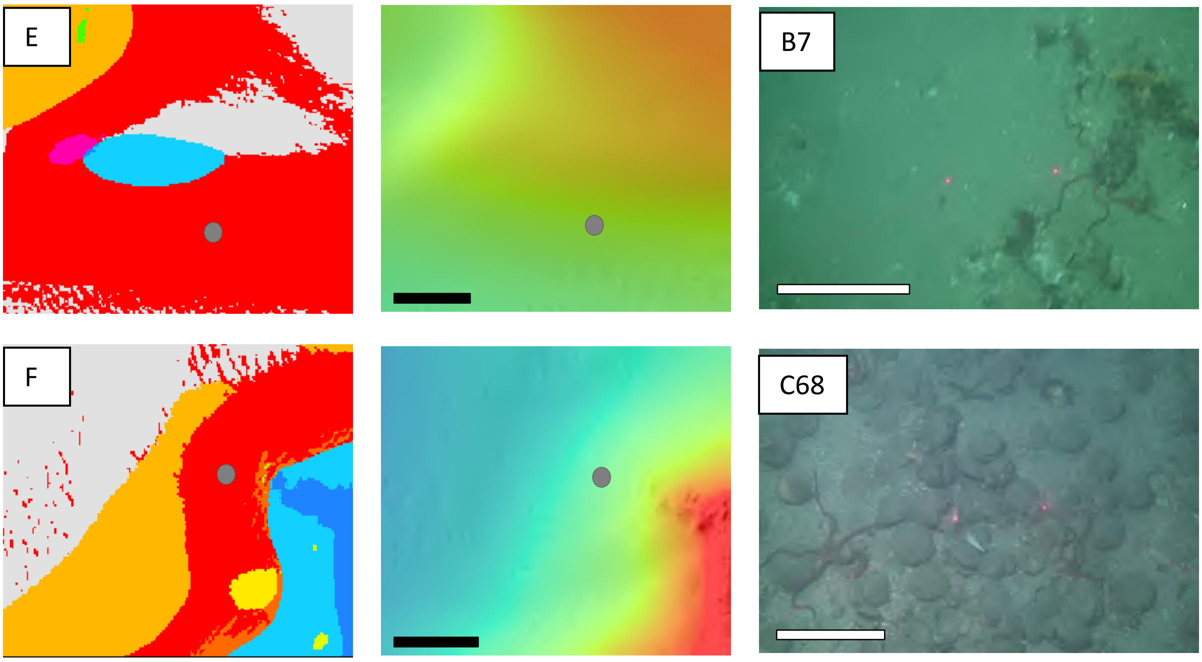
In the benthic environment, ecological diversity can be associated with complex environments, hence this classification scheme, combined with geomorphic features, backscatter classification, and sediment and biological data, can inform future targeted programmes (see Section 3.9).

Table 3-9: **Benthic terrains with bathymetry and seafloor images representative of terrains.** Locations of images associated with each terrain indicated by grey dots. Benthic terrain and bathymetry illustrated at same scale (black scale), scale = 50 m. Seafloor image (white scale), scale = 20 cm.

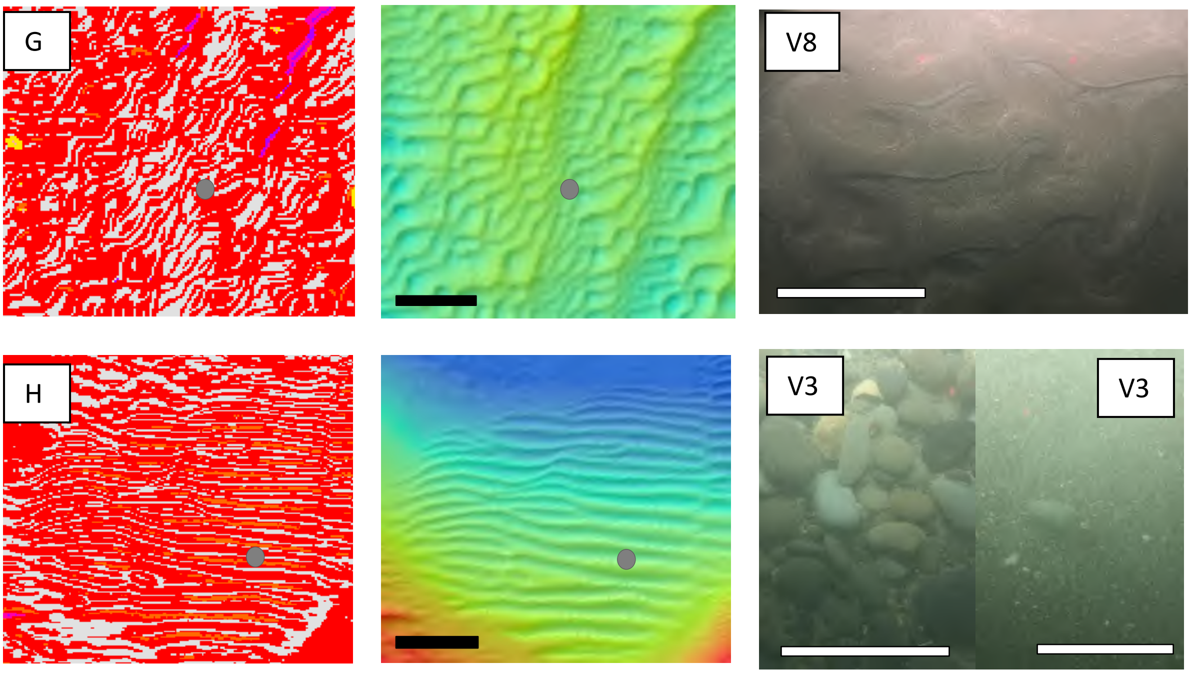
Benthic Terrain Classification	Bathymetric DEM	Seafloor Image
Flat Plains		
		
		
		
		

Benthic Terrain Classification	Bathymetric DEM	Seafloor Image

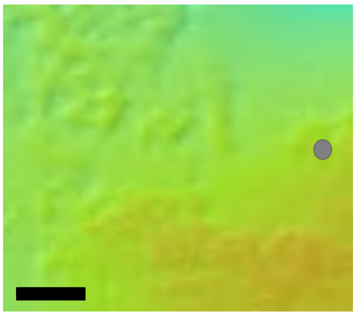
Broad Slopes

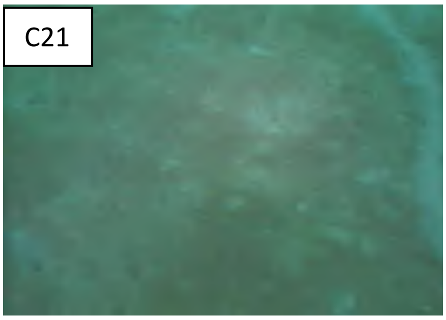


Flat Plains/Broad slope

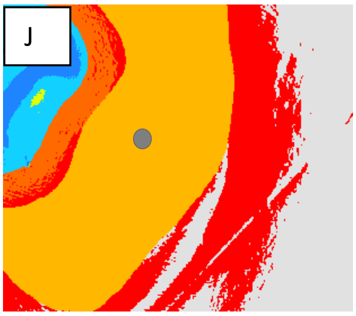


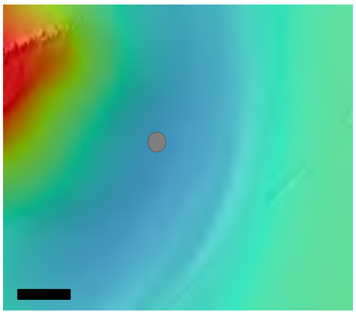
Benthic Terrain Classification | **Bathymetric DEM** | **Seafloor Image**

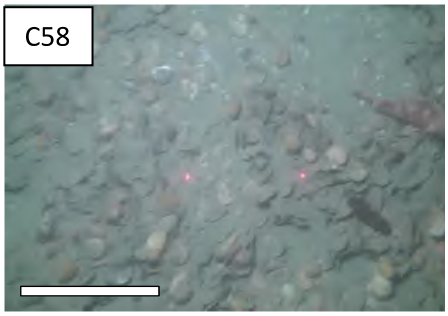


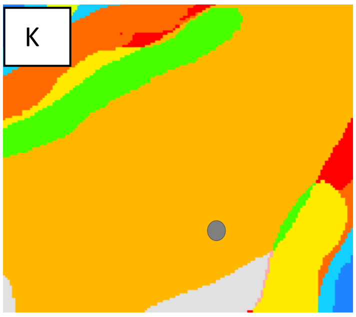


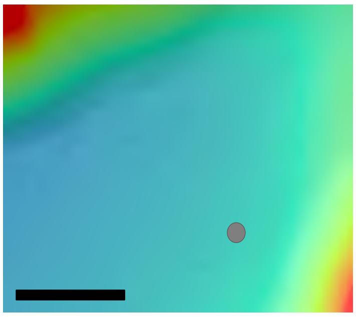
Broad platform or depression



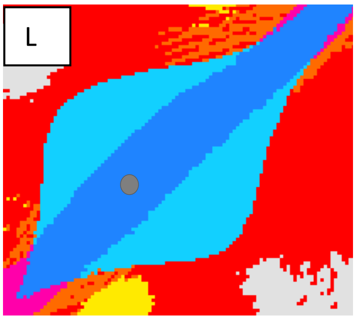


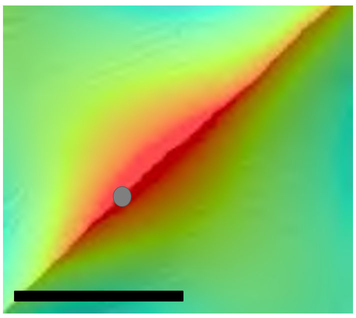


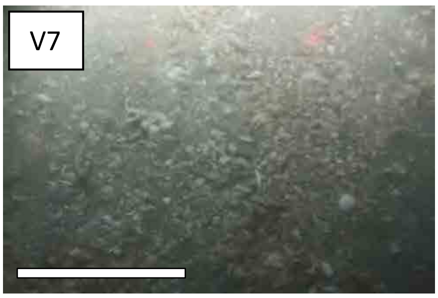


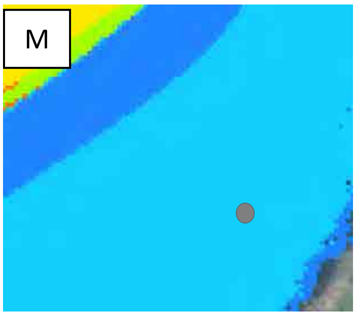
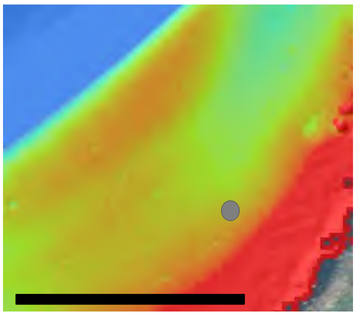
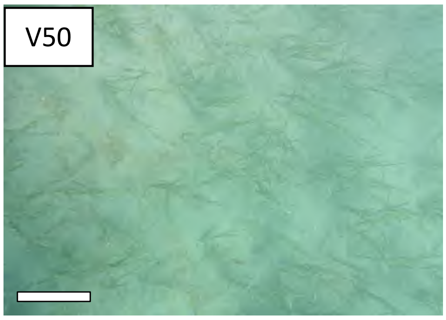
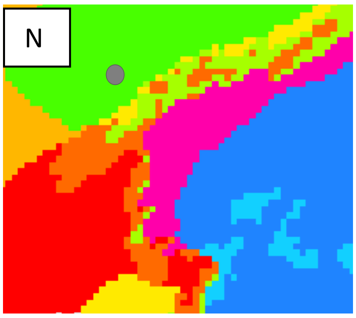
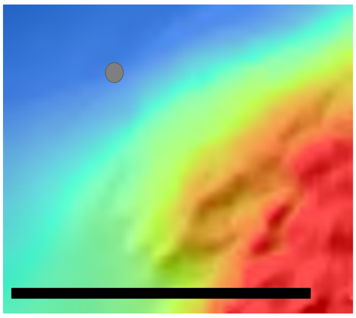
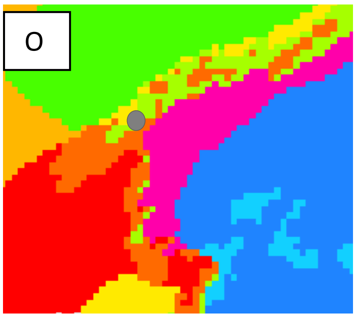
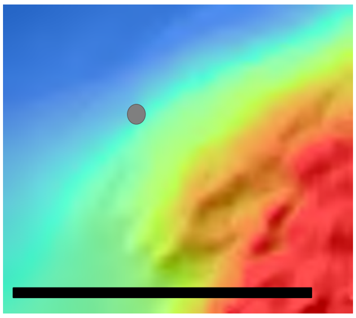
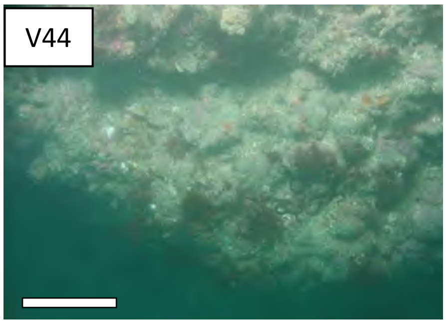
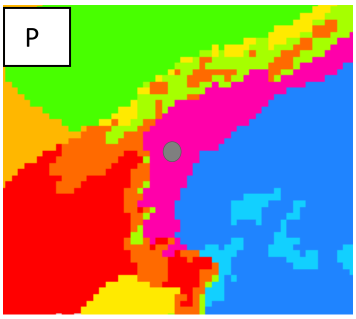
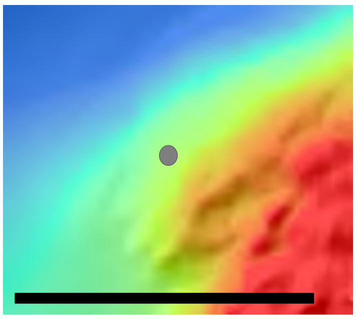


Narrow Slope/ Narrow Ridge

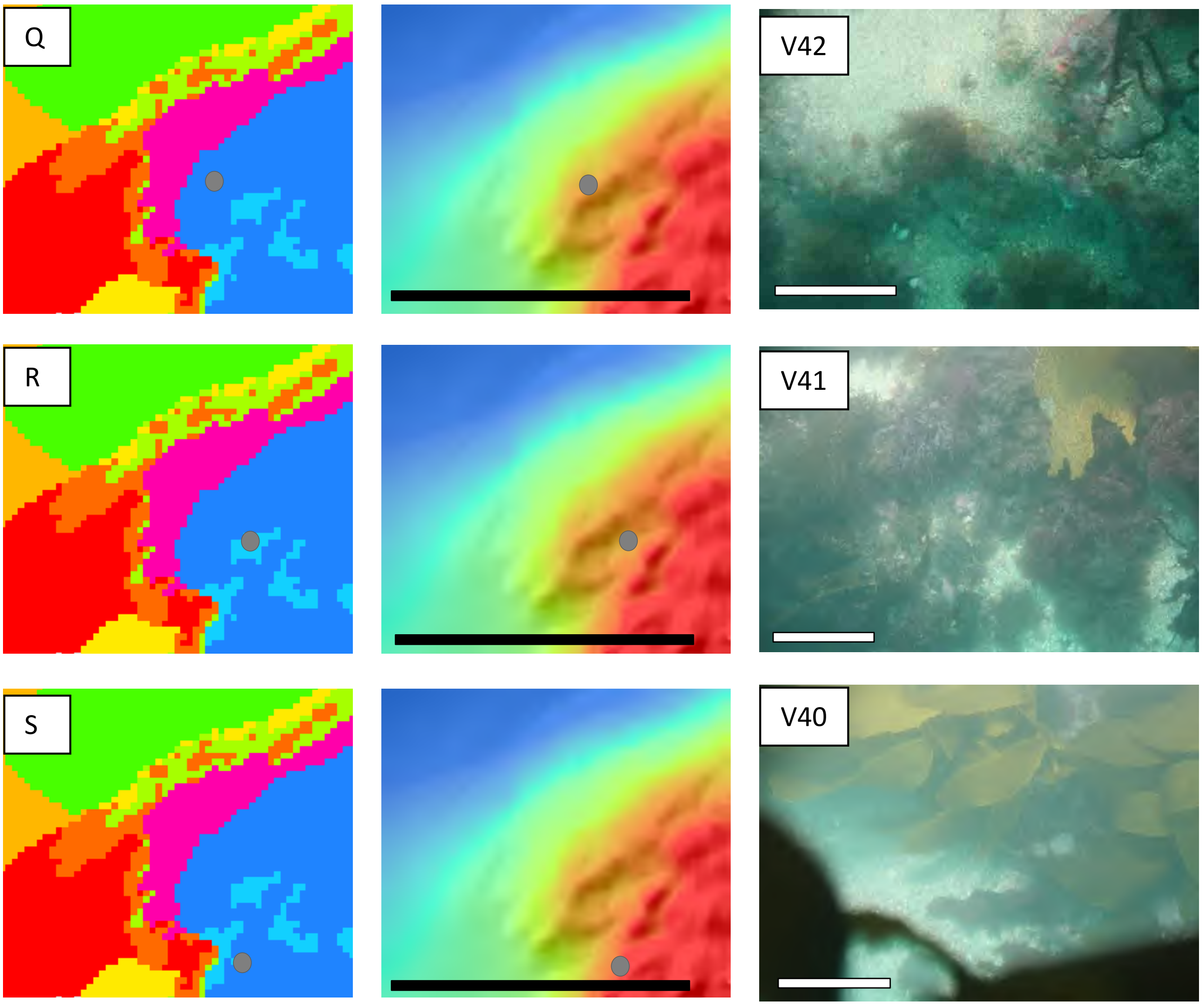




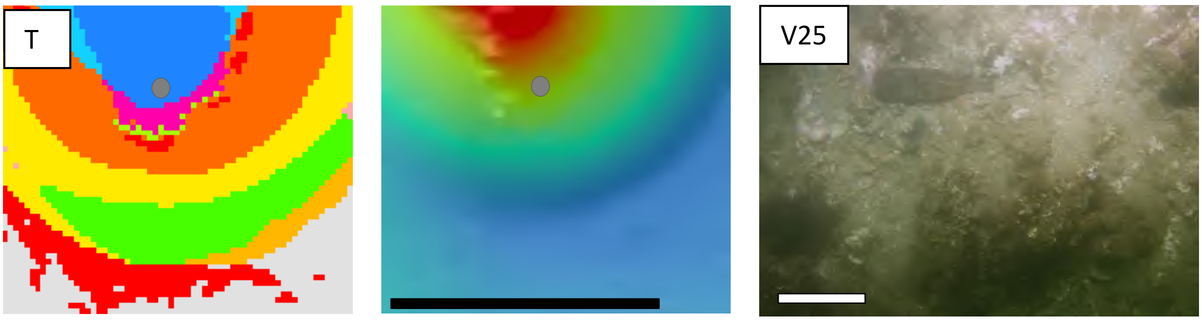


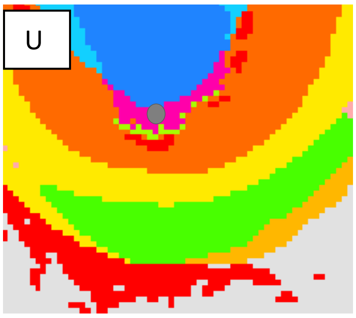
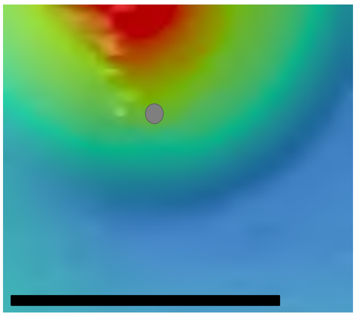
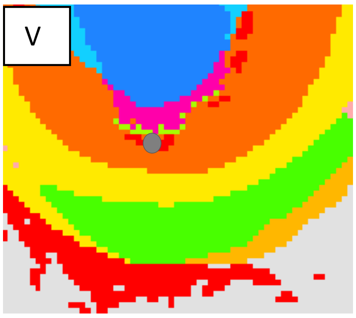
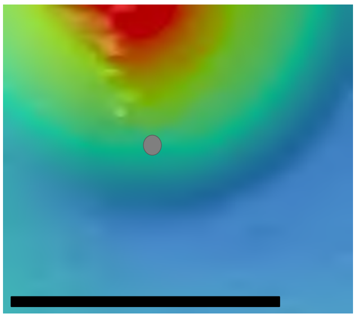
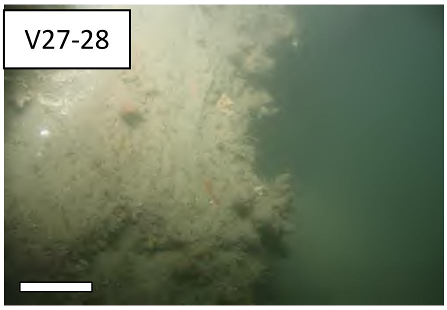
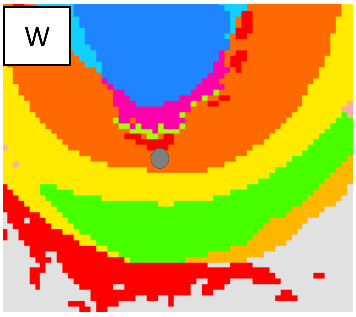
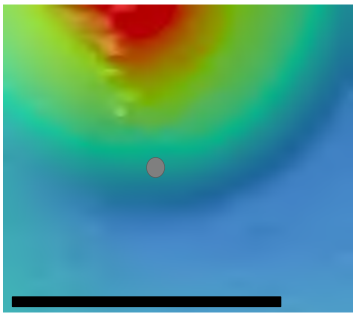
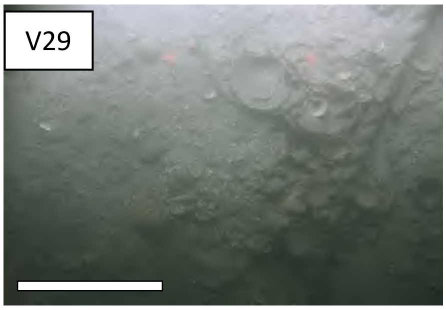
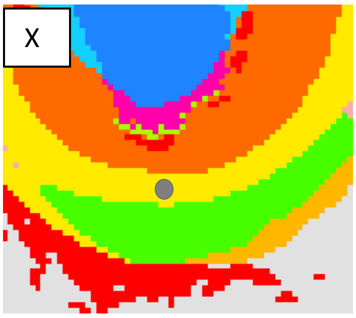
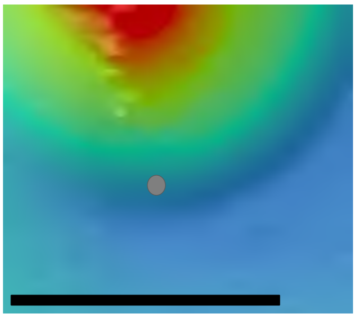
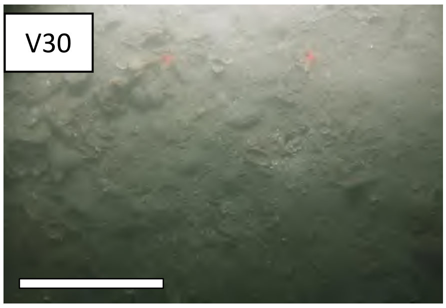
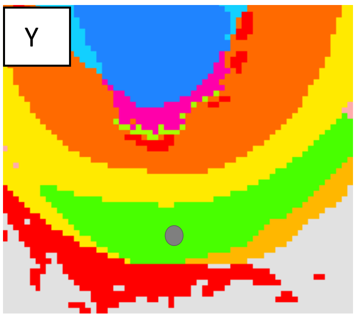
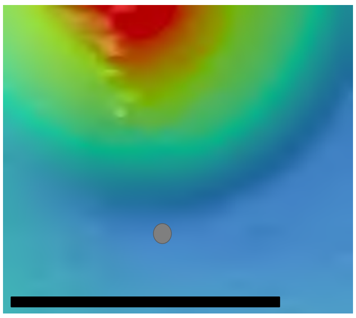
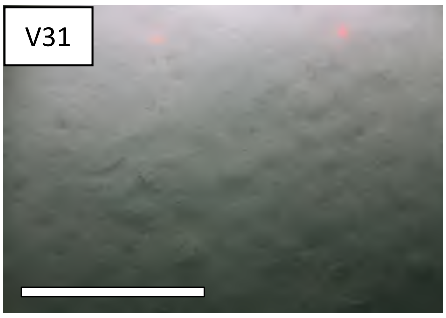
Benthic Terrain Classification	Bathymetric DEM	Seafloor Image
Narrow Slope		
		
Rocky Reef Transect - Rock Outcrop /Narrow Slope /Local Ridges /Scarp /Broad Depressions		
		
		
		

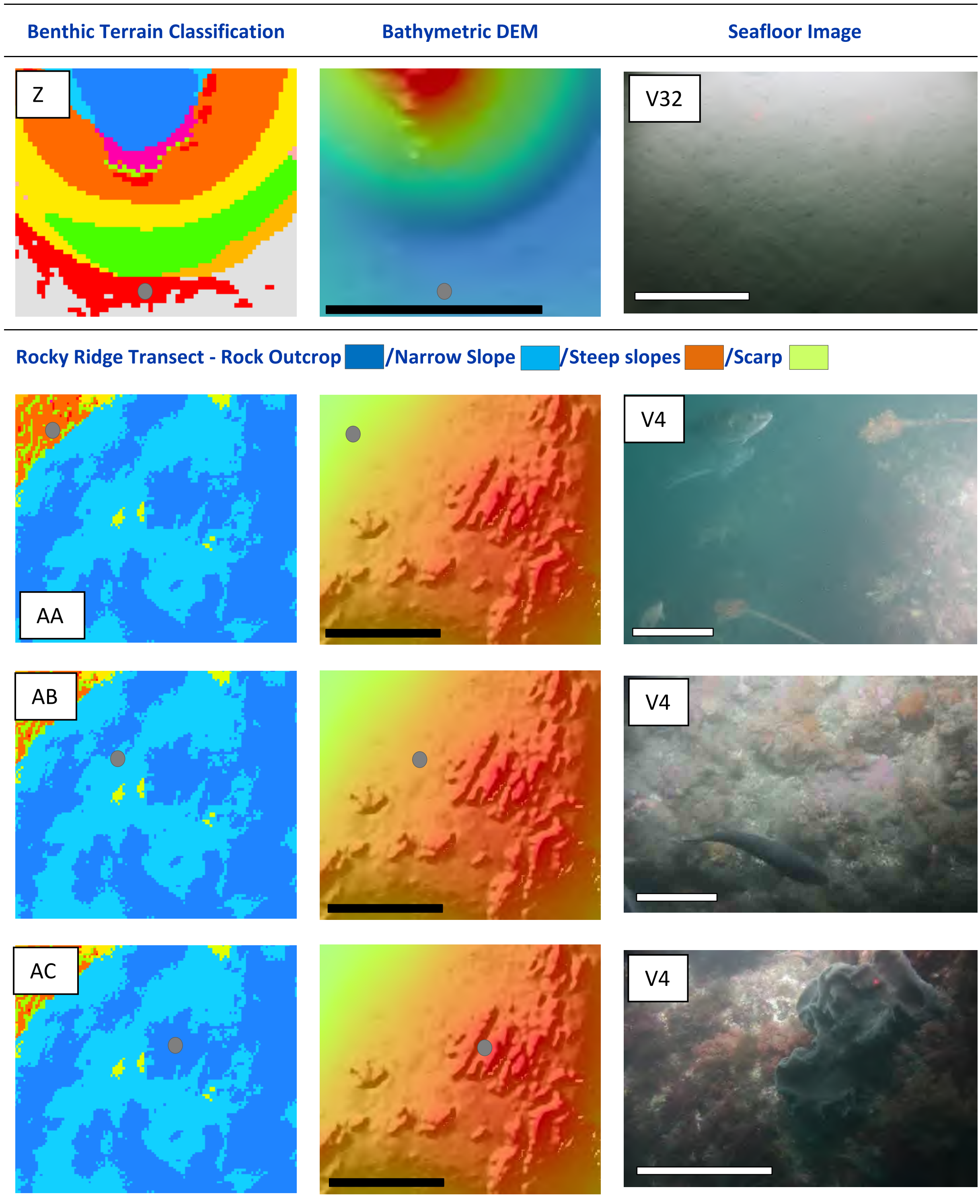
Benthic Terrain Classification | **Bathymetric DEM** | **Seafloor Image**



Rocky Reef Transect - Rock Outcrop / Local Ridges / Scarp / Steep Slopes / Midslope depression / Broad Depression /Broad Slope



Benthic Terrain Classification	Bathymetric DEM	Seafloor Image
		
		
		
		
		



3.8.9 Ecologically Significant Marine Sites

Ecologically significant marine sites in the Marlborough region were initially described in Davidson et al. (2011), with several surveys and monitoring conducted since (see https://www.marlborough.govt.nz/environment/coastal/coastal-reports-and-special-investigations).

In addition, Long Island - Kokomohua Marine Reserve, managed by the Department of Conservation, is defined around Long Island as '463 m offshore from the charted rock and from the high-water mark around the islands' *(*Figure 3-59), where the water depths attain 20 to 60 m.

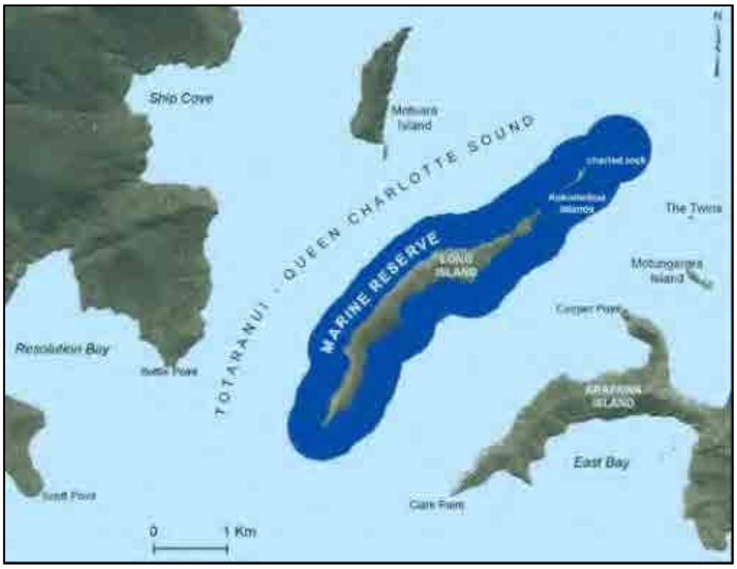


Figure 3-59: Indicative Long Island Marine Reserve Boundary. Image Source DOC

There are sixty ecologically significant sites identified within the Queen Charlotte Sounds and Tory Channel area (Figure 3-60), but there are large areas of the marine environment that have never been surveyed. This survey is the first comprehensive bathymetric survey of the region, and combining the information herein, with knowledge of the ecosystem, new sites of significance may be identified and the boundaries or spatial extent of site determined.

The benthic terrain classification derived here has been related to the sites identified by Davidson et al. (2011 and subsequent monitoring reports):

- One site is at Wedge Point (5.8) is an elephant fish spawning area which occurs across narrow, steep and broad slope bathymetrically defined geomorphic features;
- Thirteen sites of Eel Grass in Tory Channel (5.10 a- m), that predominately occur on narrow slopes and beach platforms;
- Sixteen Bryozoan, sponge and hydroid biogenic habitats (5.4 e - n, 5.8 g - l) in Tory Channel that occur across a range of bathymetrically defined habitats in the near shore, but primarily rock outcrops, narrow slopes, and midslope platforms or depressions;
- Two Ngaruru subtidal algal beds (5.11 a-b) that occur predominately over shallow flat plains;
- Four red algae sites (4.4, 4.6, 4.7, 4.13) within inner Queen Charlotte Sound occurring across rock outcrops, narrow and broad slopes;
- Twenty four invertebrate sites: one at Motuara Island comprising horse mussel beds (7.4) which occurs across flat floor, board slopes and local ridges/rock outcrops; five within inner Queen Charlotte Sound (4.2, 4.9, 4.11, 4.14, 4.16) predominately across narrow slopes; four in East Bay (4.21, 4.22, 4.24, 4.25) across broad slopes and flat plains except for 4.25 which

extends along a complex coast with bathymetric habitats ranging from rock out crops, steep slopes and broad depressions; thirteen sites along the nearshore rock out crops, narrow and steep slopes, board slopes and mid-platform depressions of Tory Channel.

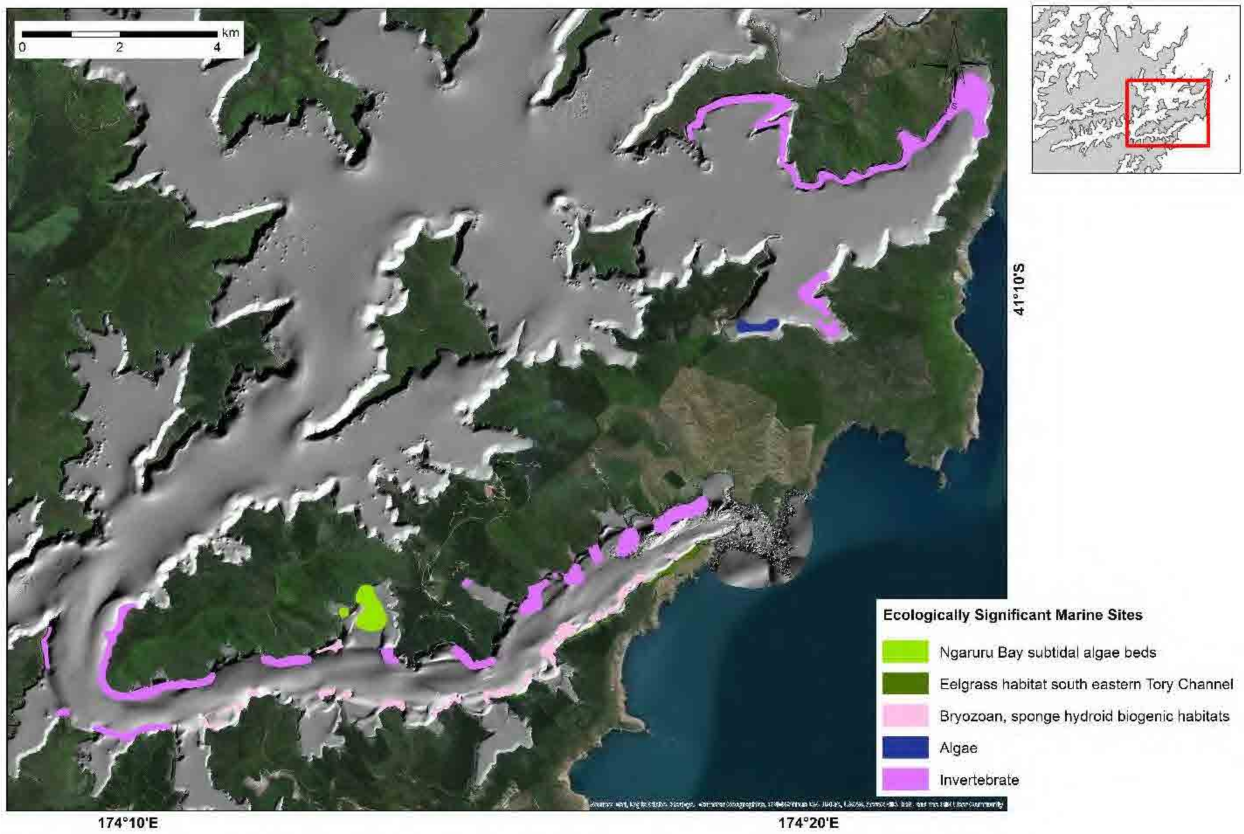


Figure 3-60: Ecologically Significant Marine Sites Tory Channel and East Bay. (MDC, see Davidson et al. 2011 and subsequent reports). These sites are also included on map sets in the accompanying portfolios.

3.9 Marine Farms

The co-collection of bathymetric and water-column data allows the three-dimensional investigation of features that extend from the seabed into the water column. The utility of this dataset to characterise aquaculture facilities within Queen Charlotte Sound and Tory Channel was recognised early in the survey design. In particular, there is interest to understand the relationship between existing marine farms and physical habitats identified in the processed bathymetric data, such as rocky reefs.

Many marine farms in this region were grandparented into the Resource Management Act (RMA), and pre-date any benthic biology assessments or morphological characterisation of the seabed. This survey programme offered the opportunity to undertake a regionally integrated and relatively cost-effective assessment that didn't directly burden individual marine farm licensees. The survey coverage here allows characterisation at a bay and sound-wide scale.

This information can inform the consenting process for marine farms by providing background environmental data, such as: the type of preferred seabed habitats for moorings or identifying where benthic biological assessments should be undertaken. New insights afforded by this survey data will help develop an integrated understanding for sustainable management.

As part of the data processing and map presentation herein, the marine farm boundaries have been overlain on the bathymetry, rugosity, slope, benthic terrain and seafloor classifications. In addition, any associated water-column structures have been extracted and computer-rendered three-dimensional movie scenes created for each marine farm. These movie scenes allow an observer to spatially visualise the area and farms structures, as well as the underlying seafloor. These movie scenes are provided within the digital delivery and can be viewed using the freely available software program "iView4D".

Some key features of seafloor and water column features visualised around the marine farms are:

- localised sediment ridges around ~20 cm high seen beneath marine farms which exhibit a relationship to the number and spacing of the aquaculture lines (Figures 3-61 to 3-63);
- rocky outcrops that protrude seaward beneath marine farms (Figures 3-62 and 3-63);
- diverse range of benthic terrain classes beneath the marine farms ranging from rocky outcrops, local ridges, and slopes beneath farms that lie over a sloping seafloor (Figure 3-64);
- utility of rugosity for visualising the localised ridges, anchor blocks, and the roughness of the ridges beneath the marine farm (Figure 3-65);
- localised bed elevations directly beneath caged marine farms (Figure 3-66);
- visualisation of midwater marine-farm structures, namely mussel lines, anchor lines or fish cages (Figure 3-67).

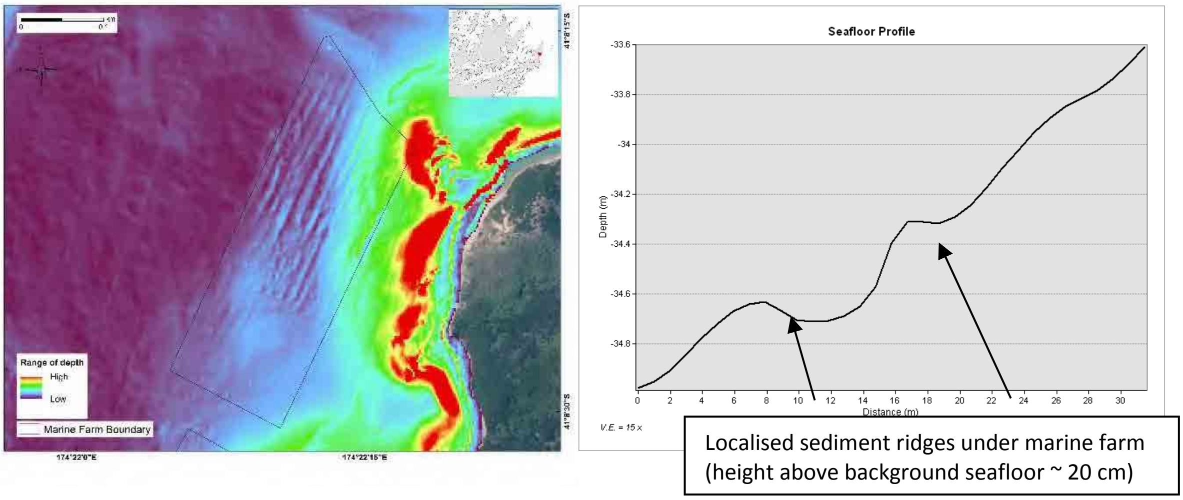


Figure 3-61: The attribute range of depth and a seafloor profile highlighting localised ridges beneath a marine farm. The alignment of these ridges mirrors the geometry of aquaculture lines within the farms. Refer to Portfolio Marine Farms, 12 of 13 for larger scale image.

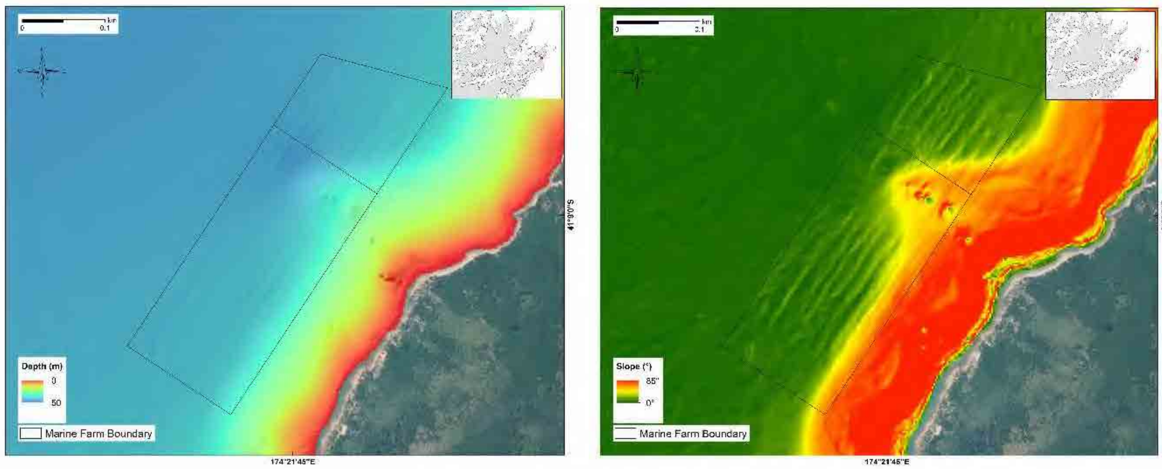


Figure 3-62: Bathymetry and slope illustrating rocky outcrops that extend seaward under the farm. They also show the alignment of ridges mirrors the geometry of aquaculture lines within the farms. Refer to Portfolio Marine Farms, 12 of 13 for larger scale image.

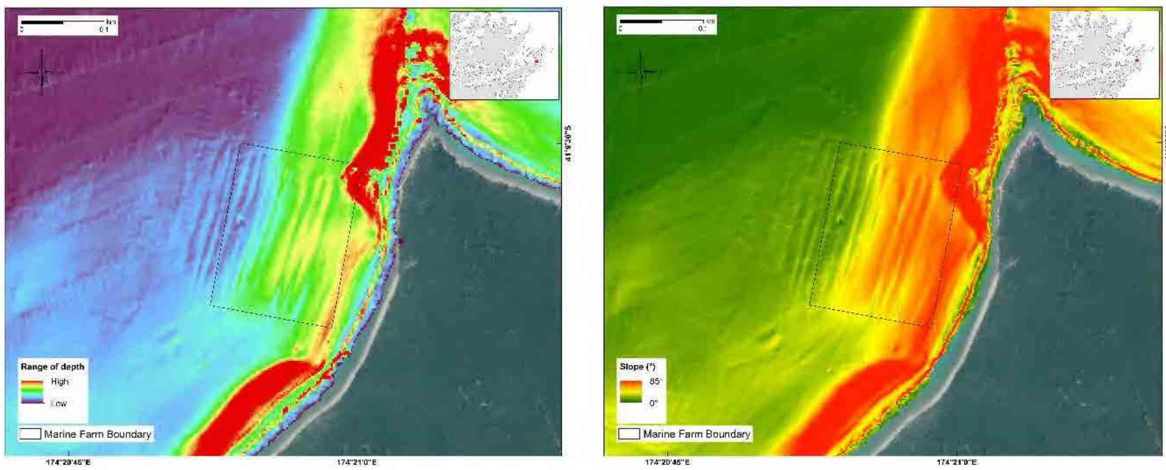


Figure 3-63: Range of depth and standard deviation of slope are also useful in highlighting the localised sediment ridges beneath marine farms. These features are common beneath farms that lie over a sloping seafloor. The alignment of these ridges mirrors the geometry of aquaculture lines within the farms. In this example the prominent rocky ridge to the north of the marine farm is also highlighted. Refer to Portfolio Marine Farms, 12 of 13 for larger scale image.

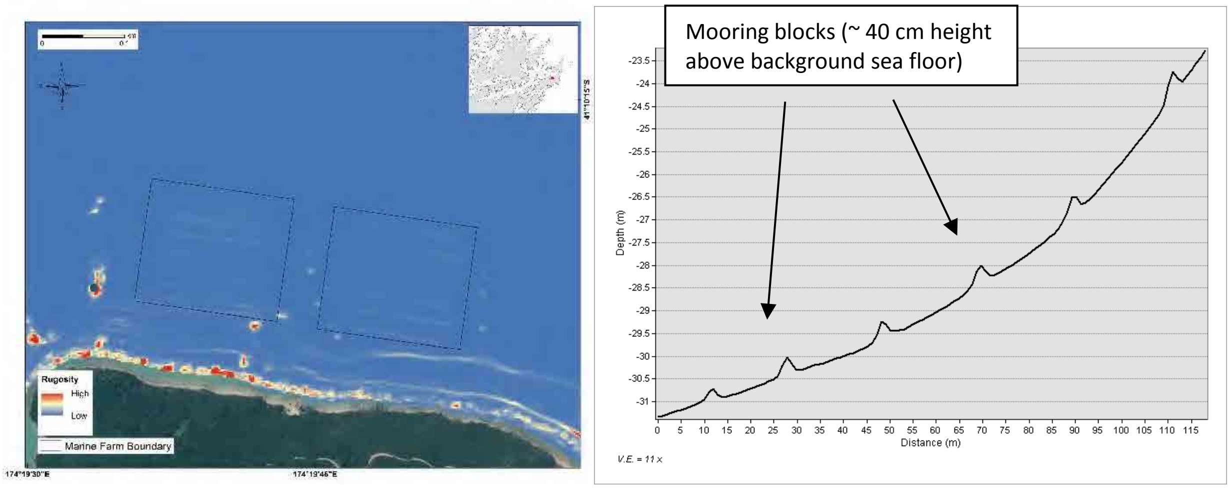


Figure 3-64: Rugosity highlights the localised ridges, anchor blocks and other roughness on the ridges, beneath the marine farm. Refer to Portfolio Marine Farms, 12 of 13 for larger scale image.

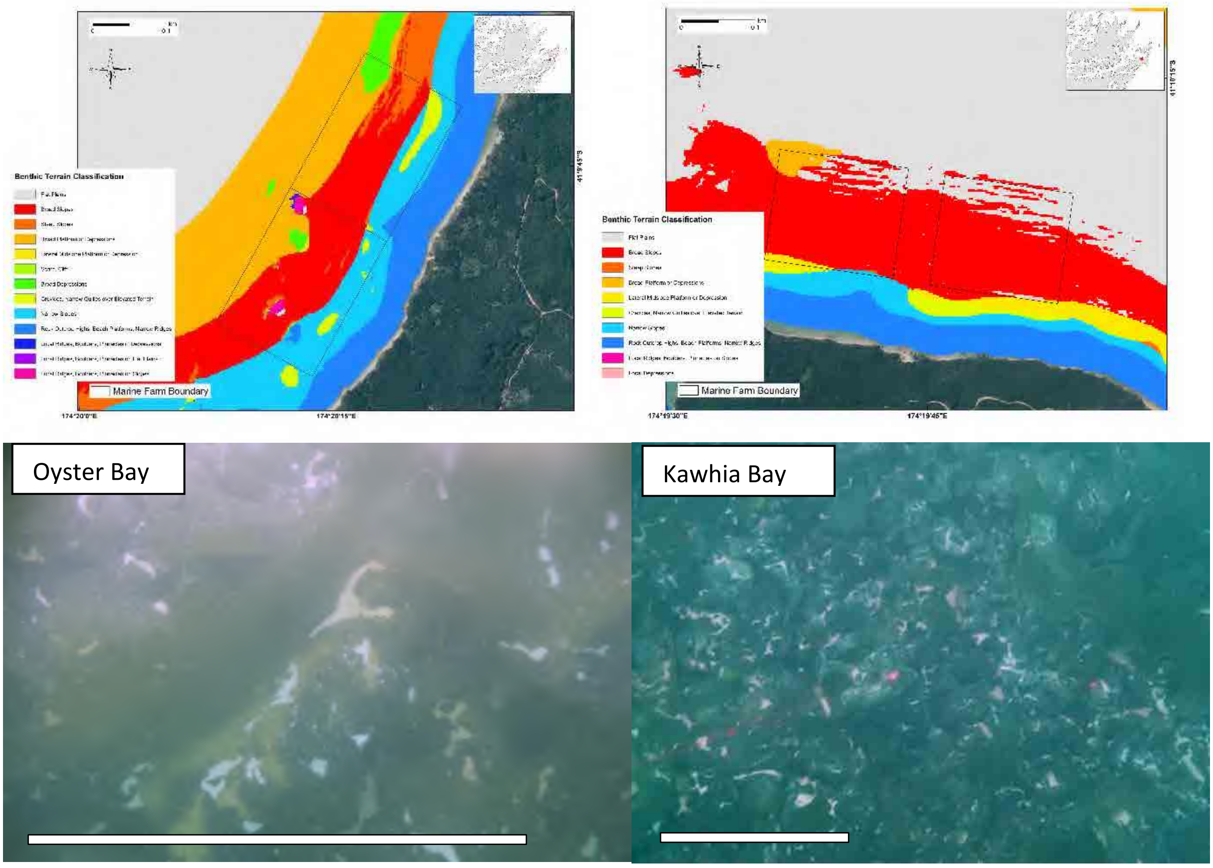


Figure 3-65: A diverse range of benthic terrain classes occur beneath marine farms that lie over a deepening slope. Terrain classes range from narrow slopes, broad slopes, broad depressions, local ridges and rock outcrops (top left) and broad slopes and flat plains (top right). Seafloor images beneath or proximal to marine farms in Oyster Bay (left) and Kawhia Bay (right), where the seafloor is largely obscured by sea lettuce. White scalebar in seafloor images is 20 cm long. Refer to Portfolio Marine Farms, 12 of 13 for larger scale image.

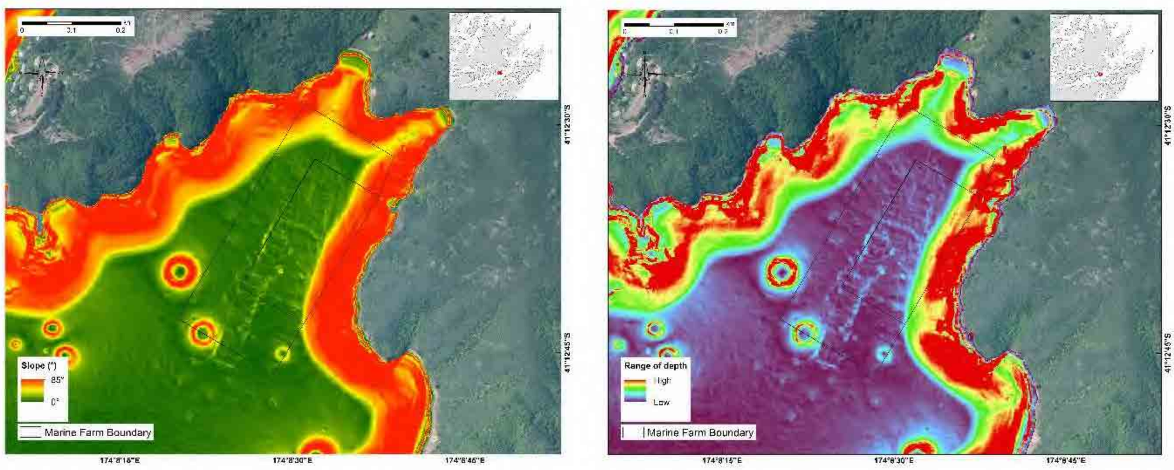


Figure 3-66: Bathymetry and standard deviation of slope highlight the localised bed elevations beneath a marine farm. Circular features are seafloor pockmark depressions that occur naturally in this region. Refer to Portfolio Marine Farms, 13 of 13 for larger scale image.

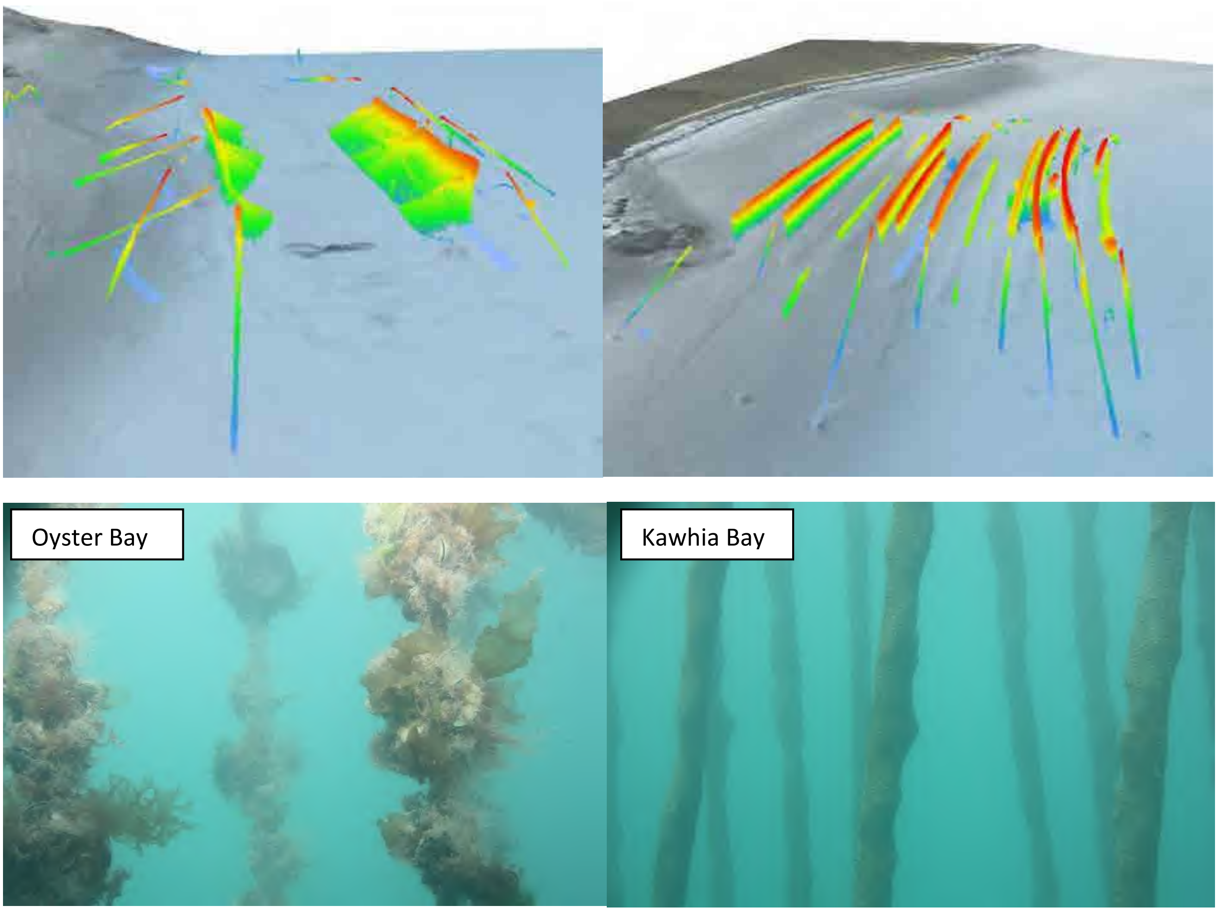


Figure 3-67: Three-dimensional visualisations of marine farms using MBES water-column data. Top left: mussel-farm lines, which are curved from tidal and wind-driven currents. Top right: midwater marine farm structures (cages), the structures in the middle of the farm are not resolved due to limitations of safe navigation close to the farm. Bottom: underwater images of the mussel lines that are imaged acoustically in the water column data. Refer to Portfolio Marine Farms, 12 of 13 for larger scale image.

3.9.1 Benthic Terrain and Seafloor Classification beneath marine farms

Benthic-terrain and seafloor classifications can provide a local and regional understanding of the type of seabed habitats associated with marine farms. The area and percentages by class are summarised in Tables 3-10 and 3-11. The dominant four classes beneath the marine farms are shaded in grey, and the dominant two backscatter classes are also shaded in grey. The primary terrain classes across all the marine farms are Broad Platform or Depressions, Local Depressions and the combined classes that include Rock Outcrops/Local Ridges. The dominant backscatter class beneath the marine farms is Low-medium reflectivity (fine sand).

Table 3-10: Area and percentage of benthic terrain classes within Queen Charlotte Sound and Tory Channel. Shaded cells indicate the dominant four classes under marine farms.

Benthic Terrain Class	Area (km²) of class within survey area	% of class within survey area	Area (km²) of class beneath marine farms	% of class beneath marine farms
Queen Charlotte Sound/ Tory Channel				
Flat Plains	278.42	62.9%	0.615	0.2%
Broad Slopes	74.27	16.8%	0.555	0.7%
Steep Slopes	8.12	1.8%	0.035	0.4%
Broad Platform or Depressions	29.58	6.7%	0.274	0.9%
Lateral Midslope Platform or Depression	5.47	1.2	0.058	1.1%
Scarp, Cliff	0.56	0.1%	0.001	0.2%
Broad Depressions	7.04	1.6%	0.043	0.6%
Crevices, Narrow Gullies over elevated terrain	1.35	0.3%	0.005	0.4%
Narrow Slopes	19.29	4.4%	0.078	0.4%
Rock Outcrop Highs, Beach Platforms, Narrow Ridges	15.6	3.5%	0.032	0.2%
Local Ridges, Boulders, Pinnacles in Depressions	0.15	0.03%	0.0001	0.1%
Local Ridges, Boulders, Pinnacles on Flat Plains	0.27	0.1%	0.003	1.2%
Local Ridges, Boulders, Pinnacles on Slopes	2.29	0.5%	0.018	0.8%
Local Depressions	0.51	0.1%	0.008	1.5%
East Bay				
Flat Plains	7.16	63.2%	0.140	2.0%
Broad Slopes	1.99	17.6%	0.244	12.3%
Steep Slopes	0.13	1.2%	0.007	5.1%
Broad Platform or Depressions	0.53	4.7%	0.086	16.3%
Lateral Midslope Platform or Depression	0.09	0.8%	0.006	7.1%
Scarp, Cliff	0.001	0.01%	0.0001	10.7%
Broad Depressions	0.06	0.6%	0.005	6.9%
Crevices, Narrow Gullies over elevated terrain	0.06	0.5%	0.004	7.0%
Narrow Slopes	0.64	5.7%	0.041	6.4%
Rock Outcrop Highs, Beach Platforms, Narrow Ridges	0.63	5.6%	0.001	0.2%
Local Ridges, Boulders, Pinnacles in Depressions	0.0002	0.002%	0.0001	43.3%
Local Ridges, Boulders, Pinnacles on Flat Plains	0.002	0.02%	0.0001	3.0%
Local Ridges, Boulders, Pinnacles on Slopes	0.02	0.2%	0.001	4.1%
Local Depressions	0.003	0.03%	0.00004	1.2%

Benthic Terrain Class	Area (km²) of class within survey area	% of class within survey area	Area (km²) of class beneath marine farms	% of class beneath marine farms
Ruakaka Bay				
Flat Plains	2.02	54.7%	0.056	2.8%
Broad Slopes	0.43	11.6%	0.007	1.6%
Steep Slopes	0.12	3.3%	0.005	4.1%
Broad Platform or Depressions	0.24	6.4%	0.028	12.0%
Lateral Midslope Platform or Depression	0.16	4.3%	0.011	6.8%
Scarp, Cliff	0.00	0.1%	0.0002	7.7%
Broad Depressions	0.10	2.6%	0.005	4.9%
Crevices, Narrow Gullies over elevated terrain	0.01	0.3%	0.000	0.0%
Narrow Slopes	0.31	8.3%	0.0004	0.1%
Rock Outcrop Highs, Beach Platforms, Narrow Ridges	0.30	8.1%	0.00005	0.0%
Local Ridges, Boulders, Pinnacles in Depressions	0.001	0.0%	0.000	0.0%
Local Ridges, Boulders, Pinnacles on Flat Plains	0.001	0.0%	0.000	0.0%
Local Ridges, Boulders, Pinnacles on Slopes	0.01	0.1%	0.000	0.0%
Local Depressions	0.01	0.2%	0.001	13.2%
Tory Channel				
Flat Plains	14.17	43.2%	0.364	2.6%
Broad Slopes	7.43	22.6%	0.297	4.0%
Steep Slopes	0.69	2.1%	0.018	2.6%
Broad Platform or Depressions	3.22	9.8%	0.131	4.1%
Lateral Midslope Platform or Depression	0.95	2.9%	0.030	3.2%
Scarp, Cliff	0.09	0.3%	0.001	0.8%
Broad Depressions	0.70	2.1%	0.029	4.2%
Crevices, Narrow Gullies over elevated terrain	0.22	0.7%	0.001	0.3%
Narrow Slopes	2.37	7.2%	0.036	1.5%
Rock Outcrop Highs, Beach Platforms, Narrow Ridges	2.24	6.8%	0.030	1.4%
Local Ridges, Boulders, Pinnacles in Depressions	0.03	0.1%	0.000	0.0%
Local Ridges, Boulders, Pinnacles on Flat Plains	0.06	0.2%	0.003	5.2%
Local Ridges, Boulders, Pinnacles on Slopes	0.55	1.7%	0.017	3.2%
Local Depressions	0.13	0.4%	0.006	4.4%

Table 3-11: Area and percentage of seafloor backscatter classes within Queen Charlotte Sound and Tory Channel.

Seafloor Classification	Area (km²) of class within survey area	% of class within survey area	Area (km²) of class beneath marine farms	% of class beneath marine farms
Queen Charlotte Sound/ Tory Channel				
Low reflectivity (mud)	212.35	49.3%	0.706	0.3%
Low-medium reflectivity (fine sand)	37.75	8.8%	0.469	1.2%
Medium-high reflectivity (medium sand)	26.76	6.2%	0.295	1.1%
High reflectivity (coarse sand/gravel)	153.55	35.7%	0.244	0.2%
East Bay				
Low reflectivity (mud)	5.39	50.8%	0.080	1.5%
Low-medium reflectivity (fine sand)	1.86	17.5%	0.154	8.3%
Medium-high reflectivity (medium sand)	1.66	15.7%	0.141	8.5%
High reflectivity (coarse sand/gravel)	1.70	16.0%	0.162	9.5%
Ruakaka Bay				
Low reflectivity (mud)	2.43	69.1%	0.062	2.6%
Low-medium reflectivity (fine sand)	0.56	15.9%	0.032	5.8%
Medium-high reflectivity (medium sand)	0.33	9.3%	0.012	3.6%
High reflectivity (coarse sand/gravel)	0.20	5.8%	0.007	3.4%
Tory Channel				
Low reflectivity (mud)	8.23	28.2%	0.503	6.1%
Low-medium reflectivity (fine sand)	3.40	11.7%	0.250	7.4%
Medium-high reflectivity (medium sand)	5.24	18.0%	0.131	2.5%
High reflectivity (coarse sand/gravel)	12.31	42.2%	0.069	0.6%

3.10 Future directions

This survey programme produced a wide range of new spatial-data products for the Marlborough Sounds. These products can create new and practical opportunities for further analysis to benefit Iwi and stakeholders with an interest in the Sounds region, spanning practical applications locally to new research of global relevance. The projects that could be developed also include innovative outreach and educative products that can improve the visualisation of datasets, to advanced applications for specific local communities and end-users.

Below, is a non-exhaustive list of examples of potential projects that could be readily developed from the survey results.

3.10.1 Environmental Management and Policy

Juvenile fish bottlenecks

The data generated from the bathymetric survey of the Sounds are an outstanding baseline for further applied and research work. They will be of great value for the MBIE Endeavour Fund Research Programme “Juvenile Fish Bottlenecks”, through providing 100% cover seafloor bathymetric and backscatter substrate maps that can be directly incorporated into the predictive nursery-habitat modelling work being done in the Bottlenecks programme. This will assist in interpolating the Bottlenecks point sample data collected (beam trawl / towed video array) into full habitat map coverage, to identify where key nurseries and their associated (biogenic) habitats are found. Combined with Local Ecological Knowledge (LEK) and Traditional Ecological Knowledge (TEK), as well as other data sources, it will also help identify where key habitats once existed but have been historically lost to environmental degradation and other impacts; and in turn, where active and passive habitat restoration effects might best be focussed to restore these lost key ecological and fisheries habitat functions.

In addition, through assessing what kinds of ecological habitats (especially biogenic) the multibeam data can differentiate and map (e.g. horse mussel beds, rhodolith fields, sponge gardens, kelp forests), it will be possible to build a ‘reference library’ of multibeam ‘signatures’. These will be of high value in targeted processing of both existing and new multibeam at key locations where the validation data exists (e.g. Separation Point, small areas of the Hauraki Gulf, Wairoa Hard in Hawkes Bay, coastal Kaikoura). It is timely to start building a regional and national spatial inventory of what habitats exist, where they are found, and what human stressors and impacts are interacting with them.

Characterisation of epifauna

Relatively little is known about the distribution of different habitats of significance for indigenous biodiversity within coastal waters. This is a knowledge gap which affects Council’s ability to identify and maintain biodiversity, as habitats provide ecosystem services, as well as underpin recreation and commercial activities.

Characterisation of epifauna in representative habitats can be advanced by new biological surveys that build on the physical habitats mapped during this survey. This will provide information on spatial occurrence and abundance of key habitat-forming taxa, and significant or notable taxa. These surveys could be conducted along a continuum from a rapid semi-quantitative seafloor characterisation survey (*spatially-explicit, good coverage with detailed seafloor habitat and biological assemblage characterisations*) to a fully-orthogonal habitat and community survey (*towed-video, epibenthic sled and sediment and infauna cores collected at all sites*). Distribution and proportional occurrence of fine-scale habitats, geomorphology and key taxa can by graphically represented directly over the physical habitats and geomorphology derived from the multibeam survey, and/or by photo mosaicking high-resolution imagery of habitats and species-distribution models etc. Key areas such as under marine farms could also be characterised using such an approach. Thus, providing information on the significance of the benthic values relative to the marine ecological values in the wider marine biogeographic region. Hence, potential hotspots of habitats high in marine biodiversity can be identified and adverse effects avoided, remedied or mitigated.

Ecosystem services

NIWA in conjunction with Sustainable Seas is presently researching methods to cost effectively measure ecosystem services. One way of doing this relates to describing “potential” service delivery based on ecological principles (Townsend et al 2011). These principles are generally based on presently available physical data (e.g., depth, sediment type, current speed). Over the next two years this project is going to validate two ecosystem services in the Marlborough Sounds. The ability of multibeam data to provide detailed sediment and bathymetric layers, as well as surface roughness, means that the data provided in this project could prove to be very useful, providing a paradigm shift from old hydrographic charts.

Hydrodynamic and tsunami modelling - Active faults study

"Better bathymetry = Better hydrodynamic modelling”. The new bathymetric dataset provides the material to enhance the recent current flow and biophysical models commissioned by MDC (and others) in the Sounds (e.g. Hadfield et al. 2014, Broekhuizen and Hadfield 2016). This would have knock-on effects for improved environmental impact assessments of aquaculture facilities and activities (e.g. biodeposition dispersal halos around farms, throughput rates) and their future engineering and siting requirements. Similarly, improved oceanographic models would in turn be useful for species/habitat distribution models.

Better bathymetry, undoubtedly also provides the means to develop far more realistic tsunami inundation models, since it is recognised that it is the coastal bathymetry that has the most significant impact on tsunami acceleration and land inundation. Most - if not all - tsunami models are erroneous because of poorly defined coastal bathymetry.

Likewise, improved bathymetry will undoubtedly lead to better imaging and identifying of active and relict faults at and immediately beneath the seafloor. Understanding and quantifying of regional uplift/subsidence, would benefit from accurate bathymetry data. Effects of such natural hazard events in the Sounds could therefore be evaluated from detailed bathymetry and substrate information.

These topics, whilst developed and resolved by scientists have direct relevance to decision and policy makers in terms of impact mitigation and preparedness, and could form the basis of large funding proposal such as the MBIE Endeavour Fund.

Ecologically Significant Marine Sites

There are sixty Ecologically Significant Marine Sites identified within the survey area. However, the *Significant Marine Sites Inventory Report 2011* (Davidson et al. 2011) and subsequent monitoring reports, were based on scarce bathymetric data as a very large part of area had not been surveyed with full coverage survey techniques prior to this project. The comprehensive bathymetric survey of the region combined with the morphometric, reflectivity and ground-truthing information now provide the means to reassess details on boundaries and spatial extent of those sites using both bathymetry, water column features and aerial photo classification. For example: a range of kelp datasets are now available: water column occurrence, coastal observations of kelp extent, information on shallow vegetation attained from the Aerial Photo Classification. These datasets in combination with existing kelp research programmes can provide both bay- and sound-wide assessments.

Managing marine ecosystems and resources

Managing marine ecosystems or resources requires that the natural environment be identified and mapped over a range of scales. Seafloor geomorphology and habitat mapping form the basis of any such analysis and feeds directly into planning processes for future marine protected areas. While we have proposed a preliminary classification system for this survey, which is consistent with NIWA's national coastal classification, multiple classification systems have been developed for specific purposes, and a very wide range of spatial scales can be used, depending on the objectives and use of the classification.

Developing and comparing various seafloor and benthic habitat classification schemes would enable a range of stakeholders to benefit from them. Specifically, multivariate, supervised, or unsupervised classification could be developed that would lead to various applications and added value for New Zealand and globally. Use of multiple indicators (or proxies) need to be tested, whereby statistical analysis of the relationships of various indicators (slope, rugosity, salinity, temperature, water depths, backscatter) dramatically increases the potential to generate classification maps with specific focus. They would also enable the development of confidence maps.

Reassessment and monitoring of structures, for example moorings

High-resolution seafloor topography allows a more robust assessment of, and around, abandoned mooring blocks and the impact of removal versus leaving them in place. Here, the Council, or other legal authorities, now have the data to interrogate and assess existing features and the environment surrounding future structures - especially anthropogenic additions, where survey data differs to that shown in council consent records, e.g. mooring blocks, number, and location. For example: the recent report commission by MDC '*Effects of moorings on different types of marine habitat*' (Morrisey et al. 2018) can be utilised with the information here to inform consent conditions in terms of the physical nature of the seabed environment.

Quantifying seep behaviour

Fresh water seeps are of great interest and have been identified throughout Queen Charlotte Sound. Their activity could be better monitored and understood and questions that could be addressed using the survey data as a reference point are: Is activity directly associated with rainfall and freshwater discharge, as presumed from field observations? What is the geological link between offshore fresh water discharge and onshore freshwater sources? Could the study of offshore freshwater springs contribute to the better management of freshwater resources in terms of alternative water sources and catchment water quality?

Analysis of high intensity plumes observed on water column echograms remains essentially qualitative, i.e. it provides a general description and localisation of the source of the plumes (most generally here as fresh water springs). Quantitative estimate of freshwater flux through the water column could provide essential information for e.g. managing freshwater resources, impact of climate on freshwater discharge. A number of approaches could be developed to provide estimates of freshwater flux, all starting from further analysis of the acoustic features imaged in this dataset, in order to relate the intensity of the flare to freshwater flux.

Renewable energy resources

The information generated in the report provide a suitable framework for investigating a variety of renewable energy resources applications around use of tidal power generation and site suitability. This topic is of increasing interest for resource managers, industry, the development of national policies and scientists. The database now available in the Queen Charlotte Sound forms an excellent basis for developing a federative research project through the MBIE Endeavour Fund on renewable marine energy.

Future aquaculture site assessments and habitat vulnerability.

In assessing the effects of economic activity, the information from the mapping survey will assist the consenting process in understanding the type and vulnerability of different seabed habitats for mooring and marine farm applications. The survey coverage enables a complete picture at the bay- and sound-wide scale, thereby fostering an integrated understanding of the region for sustainable management. Many marine farm licences were grandfathered into the Resource Management Act (RMA), and have not had a benthic (seabed biology) assessment done, this dataset offers the opportunity to undertake an integrated and relatively cost-effective assessment of marine farms allowing council to propose to have lines or farms shifted to reduce any adverse impacts where sensitive habitats are identified.

Submarine cables and pipelines

Seafloor topography and substrate have direct financial and technological implications on the deployments of telecommunications and power transmission cables, as well as freshwater or wastewater pipelines at sea. Positioning of any structures on or above the seafloor also requires good knowledge of habitats and the ecosystems, all information that are readily available from this study. Maintenance and monitoring of existing structures could also benefit from accurate and precise bathymetry and target identification on the seabed. The present work will improve the safety and efficiency of such future submarine cable and pipeline operations.

3.10.2 Academic and Science focus

Here, we present a limited number of possible research projects that could be developed using this dataset as underpinning information. The massive data volume and sample density make the information collected from the survey an unprecedented platform from which to develop future research, and offers a definite leading advantage for the development of large research proposals. All of the sub-areas of the Sounds survey programme would make fertile ground for detailed, discipline-specific study. These could be developed in collaboration with any stakeholder. The main source of potential funding for large mission-led science projects is the MBIE Endeavour Fund, within the Research Programme and Smart Ideas fund streams.

Hydrodynamics and geomorphic development of the seascape

Many examples were found of geomorphic features within the Sounds. Sediment waves and megaripples provided some of the most arresting terrain maps, many of which had clear evolutionary links to the strong tides and currents known throughout the region. Unprecedented opportunities now exist for follow-up hydrodynamic studies (in addition to the recent studies commissioned by council and others (e.g. Hadfield et al. 2014, Broekhuizen and Hadfield 2016) to measure and unravel the processes that have built these features. This might involve the deployment of current meters, drifters, wave gauges and bed sensors to collect critical data that will help quantify the nuances of the water motions. In addition, such studies will also inform ecological research as these same areas are generally considered to have higher habitat complexity and benthic diversity.

Predictive habitat and substrate mapping

This area of developing academic science aims at using the acoustic signal recorded by multibeam echosounders at a large range of incidence angle on the seafloor to better characterise the backscatter echo. This method, still in development by the scientific community, is providing some extremely promising results. However, large and robust datasets are missing to fully develop such projects. This academic project is supported by the multibeam echosounder manufacturing industry as it has the potential to provide measurable, systematic and repeatable (i.e. quantitative) information on substrate and benthic habitat.

The use and application of MBES water-column data is still undergoing significant research and development. For the reasons noted above, and the multitude of water-column targets detected in the Sounds survey, the dataset could make a valuable resource to contribute to this emerging field of acoustics and science. Additional ground-truthing for habitat and benthic community characterisation can also be achieved using underwater video and photographs.

Pockmark spatial analysis

Pockmarks, or seafloor craters/depressions, occur worldwide in a variety of geologic settings and remains enigmatic (Brothers et al. 2011). Pockmarks are often associated with fluid (water, gas) discharge and can be seen as indicators of such resource. However, they also represent a hazard for seafloor infrastructures. The mechanisms responsible for pockmark initiation and further development and preservation is still very poorly known. Some of the questions to address include: Is active fluid venting required? What is the role of water currents? What is the subseafloor geology beneath pockmarks? What are the relationships between pockmarks and seafloor depth? Do pockmarks have specific ecosystems associated with them?

Studies specific to HS51 include (1) is the relationship between area of pockmark to the distance from shore or inner Queen Charlotte Sound, i.e. do pockmarks get bigger closer to the outer reaches, or away from the coast? Investigating the relationships between complexity of pockmarks (normal vs elongate vs chain) to distance from coastline and between pockmarks and seep features seen in mid-water returns; (3) develop follow up sub-bottom surveys to investigate the relationships between pockmarks/seep and subsurface layers and/or gas.

3.10.3 General Public

Public Outreach

Outreach and educative products can be readily derived from the survey data. Example include, but are not limited to:

- <u>Interactive maps</u> with scalable visualisation, whereby the scale of map feature-sets change by zooming in/out, similar to www.topomap.co.nz or GoogleEarth.
- <u>Underlying georeferenced maps</u> for chart plotters for use by mariners, e.g. Olex, MaxSea etc.
- <u>Fly through animations</u>: downloadable three-dimensional products, such as fly-throughs, are excellent visualisation aids to inform and motivate the public about the submarine world. These can be customised to any specific purposes and can integrate onshore topography with offshore bathymetry. Free visualisation software are available that can be used to visualised the end products e.g., Fledermaus iView4d is a free viewer that allows anyone to view and navigate their way through the three-dimensional data. A topical example might be

an animation (e.g., mp4 file) that traverses the route of the Picton Ferry, “flying” above digital seabed through Tory Channel and Queen Charlotte Sound.

- Web-based videos and photography taken as future surveys progress may be provided to the public in highly interactive products, linked to interactive maps included this survey dataset.
- Paper products: The present portfolio already captures a range of scientific products, but more site-specific information packs or posters can readily be generated for recreational or conservational purposes, e.g. diving spots, wrecks, seeps, areas of high faunal diversity e.g. NIWA Miscellaneous Chart Series ‘Beneath the Waves’.
- Atlas for Queen Charlotte Sound: This could be a large-format “coffee table” book that highlights the many seafloor features discovered during the survey. The content would be high-level with emphasis on the graphic and simple explanations to the varied and special seascapes.
- 3D printed visuals: the data set provides the right information for generating three-dimensional reconstructions using 3D printing technology. These can be playful, educational, or industry focused.

Engagement with tour operators.

Development of site-specific or theme-specific information packages (app, electronic or otherwise) that are directly relevant to tour operators and tourists are certainly within reach from this new dataset. These would inform clients of environmental highlights within the Sounds, unique qualities of the seabed and its habitats, or other features of topical interest, such as pockmarks. New knowledge will enrich the experiences of visitors to the Sounds and lend support for its ongoing management.

Smart phone Apps

This niche area of outreach could carry a substantial added-value for educational, tourism, industry or management alike. The material now at hand could enhance and enrich the Marlborough District Council Smart Map App and Cruise Guide to the Marlborough Sounds, and new Apps - either web based or smart phone focused - could be developed. Apps could have a significant role in citizen science and crowd sourcing (see below).

Educational resources

It is beyond doubt that the material now available provides countless possibilities for interacting with schools, colleges and tertiary education institutions, whether in the local jurisdiction of the Sounds or nationally. Many of the suggestions listed in this section could be adapted for any level of the school and university curriculum. Projects could nicely relate and contribute to science curriculum as well as history, geography, etc. Electronic and paper resources could be utilised for motivating students to work on their own region and 'backyard'. Involvement of scientists would be an advantage to demonstrate the potential of the data, to teachers and students alike. At tertiary level, research and applied subjects could be developed in collaboration with research organisations to enhance and add value to the data set.

Recreational application for dive sites on the wreck locations newly identified in the MBES data.

The Sounds is already a well-established area for divers and wreck diving. The identification and validation of new wreck sites could provide new recreational opportunities for divers, and commercial opportunities for support industries.

Citizen science and crowd sourcing

The requirement for keeping this incredible dataset up to date, to grow it with new data, or to expand it to neighbouring regions will obviously be a challenge. Crowd-sourcing and citizen science initiatives are developing worldwide and may provide part of the answer to this challenge, whereby the collection of data by members of the general public would contribute to this issue.

Flagship for similar projects in other parts of New Zealand

The Sounds survey provides a leading example and reference point for other surveys where a diverse range of hydrographic digital deliverables and science products are required.

Contributions to national and international databases

Data such as contours, digital elevation models, georeferenced images could contribute considerably to public or private platforms, such as Koordinates (http://koordinates.com), the Nippon Foundation-GEBCO Seabed2030 project, or Google Earth. Putting spatial data onto such platforms has the advantage of being able to provide a variety of data formats and projections for users. In addition, it makes the data discoverable by providing metadata which can be harvested into data catalogues such as NZ Government data catalogue (see http://data.govt.nz).

The Seabed 2030 is a project that aims at mapping the entire ocean of the world by 2030 and is funded by the Nippon Foundation, a non-for profit, Non-Governmental Social Innovation Organisation. This project has high visibility worldwide and relies on countries contribution for coastal data. NIWA, LINZ and GNS are leading the South and West Pacific region. Coastal data are an integrative part of the Seabed 2030 project and this dataset would add significant value and increase awareness of the Marlborough Sounds worldwide.

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Appendix A Locality Maps

Figure A-1: Locality Map. The major localities are presented here for Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au Hydrographic Survey (HS51).

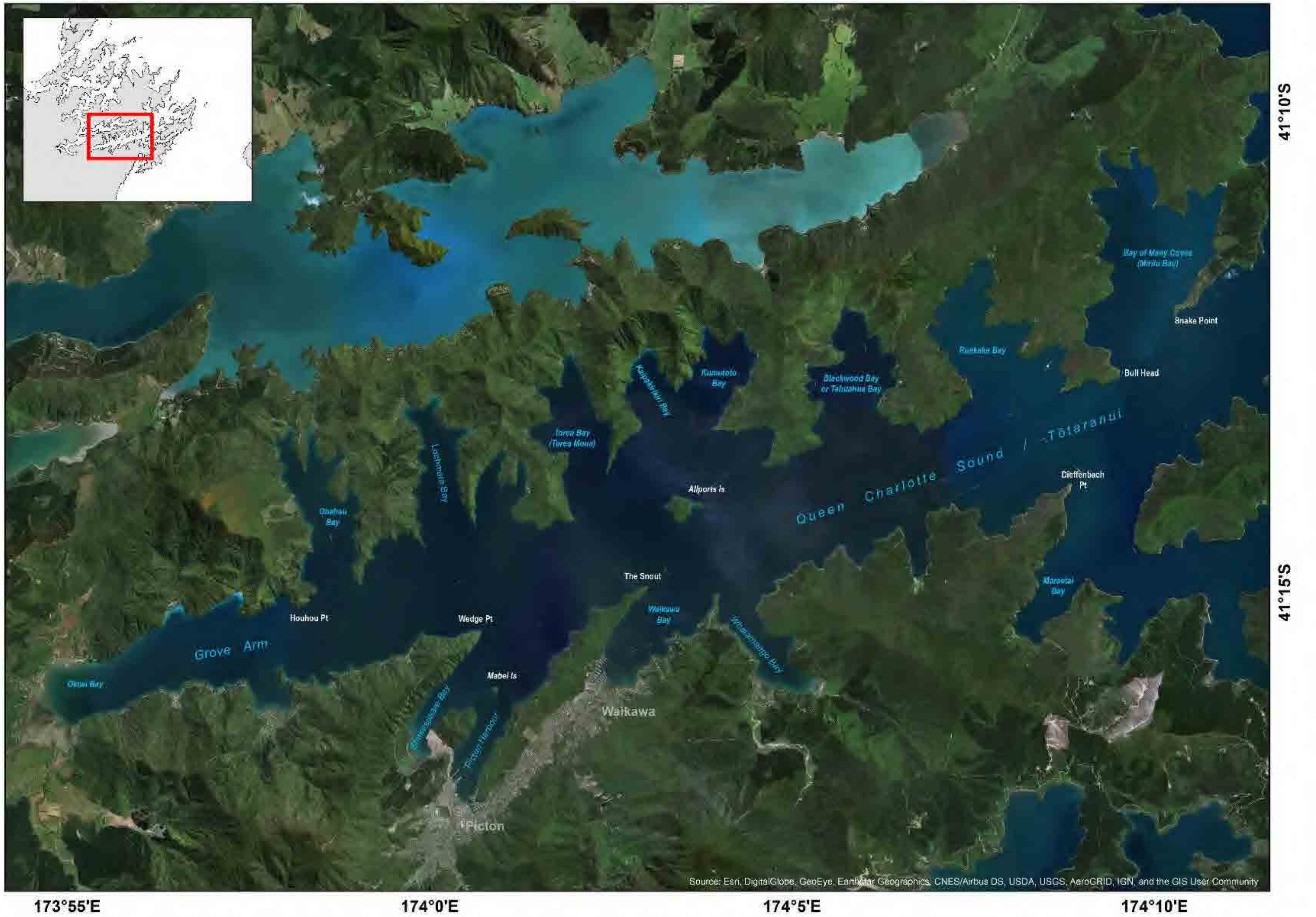

Figure A-2: Locality Map - Inner Queen Charlotte Sound. The major localities are presented here for Inner Queen Charlotte Sound / Tōtaranui Hydrographic Survey (HS51).

Figure A-3: Locality Map - Middle Queen Charlotte Sound. The major localities are presented here for Middle Queen Charlotte Sound / Tōtaranui Hydrographic Survey (HS51).

Figure A-4: Locality Map - Outer Queen Charlotte Sound. The major localities are presented here for Outer Queen Charlotte Sound / Tōtaranui Hydrographic Survey (HS51).

Figure A-5: Locality Map – Tory Channel. The major localities are presented here for Tory Channel / Kura Te Au Hydrographic Survey (HS51).

Appendix B Acknowledgements and Personnel

In a survey of this scale and duration there are many individuals and organisations deserving of formal acknowledgement. None more so than the people and businesses of Picton and the Queen Charlotte Sound region. NIWA thanks you all for embracing us within your community over a year-long field campaign. Your hospitality and support endured long after our work was completed. We acknowledge Te Atiawa o Te Waka-a-Māui, Department of Conservation (DoC) and community members of the Marine Mammal Liaison Group; as well as Land Information New Zealand (LINZ) and Marlborough District Council (MDC). We are also indebted to our three international reviewers, Dr Margaret Dolan (NGU), Dr Vanessa Lucieer (IMAS) and Prof Xavier Lurton (IFREMER) for their constructive criticism and detailed review of our final documents. The following personnel assisted with the field survey of HS51 (Table D-1).

Table B-1: HS51 Survey Personnel.

Staff	Company	Qualification	Position
Mr B.R. Wallen	DML	BSc, IHO Cat A, MNZIS	Relief SIC Nov 2016 – May 2017
Mr D. Stubbing	DML	BSurv, CPHS1, MNZIS, CLM	Initial SIC Oct-Nov 2016
Mr G.J. Cox	DML	IHO Cat A, CPHS1, MNZIS	Backup SIC, Surveyor
Mr K. D. Smith	DML	RPSurv, MNZIS	Contract Manager, Data Processor
Mr C.A. Holmes	DML	IHO Cat A	Surveyor
Mr C. Donselaar	DML	IHO Cat B	Surveyor
Mr B. Waller	DML	BSurv	Surveyor
Mr A. Knyvett	DML	BSurv	Surveyor
Mr D.J. Graham	DML	BSurv	Surveyor
Mr I. Hauman	DML	BSurv	Data Processor
Mr A. Podrumac	DML	MSc (Earth Sciences)	Data Processor
Dr H. Neil	NIWA	PhD (Earth Sciences)	Senior Marine Geologist, Project Director, National Project Manager
Mr S. Wilcox	NIWA	NZCE Electronics and Computer Science	Project Manager and Data Acquisition Operator
Mr J. Hadfield	NIWA	Commercial Launch Master	NIWA Vessels Designated Person Ashore
Mr R. Mitchell	NIWA	Certificate in Occupational Health and Safety level 4 – EMA	HSE Manager
Mr K. Mackay	NIWA	BSc Hons. Geology	Data Acquisition Operator and Data Manager
Mr A. Pallentin	NIWA	Diplom Geologe/Palaeontologe	Data Acquisition Operator
Mr T. Kane	NIWA	MSc. Marine Geology and Geophysics	Data Acquisition Operator and Wader

Staff	Company	Qualification	Position
Mr P. Gerring	NIWA	MSc. Marine Science	Data Acquisition Operator
Mr M. McGlone	NIWA	NZ Offshore Master	RV *Ikatere* Boat Skipper
Mr B. Bennett	NIWA	NZ Offshore Master	RV *Ikatere* Boat Skipper
Mr G. Bennett	NIWA	NZ Coastal Fishing Skipper	RV *Ikatere* Boat Skipper
Mr A. James	NIWA	NZ Coastal Fishing Skipper	RV *Ikatere* Boat Skipper
Mr P. Notman	NIWA	MSc. Hons Marine Biology	RV *Rukuwai* Boat Skipper and Wader
Ms. N. Davey	NIWA	MSc. Hons Marine Biology	Marine Mammal Liaison
Mr N. Eton	NIWA	NZCE Communications and Radar	Electronics Support
Mr J. Forman	NIWA	NZCS. Biology and Microbiology	RV *Rukuwai* Boat Skipper
Mr O. Anderson	NIWA	BSc Hons Zoology	RV *Rukuwai* Boat Skipper
Mr J. Mitchell	NIWA	BSc Geology/Zoology	Field Technician
Dr T Steinmetz	NIWA	PhD (Geoinformatics)	GIS Analyst
Dr A Orpin	NIWA	PhD (Geology)	Internal reviewer
Dr G. Lamarche	NIWA	PhD (Geophysics)	Internal reviewer