Multibeam Echosounder Mapping to Identify Seafloor Habitats

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Key words: Cartography; Bathymetry; Remote sensing; Ecosystem Classification Map; Spatial planning; Coastal Zone Management.

SUMMARY

Undersea New Zealand, NIWA's national mapping product, provides a unique insight into the shape of the seafloor within one of the world's most extensive deepwater jurisdictions. It uses some 1.5 million square kilometres of multibeam coverage, supplemented by more than 5 million line kilometres of single-beam ship tracks, to illuminate the full richness of New Zealand seascapes: flat, deep (>4000m) abyssal plains; fracture zones in the Southwest Pacific and South Fiji Basins; and the structure of the >10,000 metre-deep Kermadec Trench. Vast submarine canyons incise the continental margin, and terrigenous material flows down sinuous channels into the deep ocean, both west and east of New Zealand. Many smaller structures are also mapped, showing the abundance of seamounts, volcanoes and flat-topped guyots.

NIWA also conducts baseline surveys that require multibeam bathymetry of the nearshore coastal region. Recently, two mapping initiatives (offshore D'Urville Island and Kaikoura) using NIWA's Kongsberg EM2040 high-resolution multibeam echo-sounder (MBES) have been undertaken to map the seafloor bathymetry and identify the diversity of physical habitats. The high density of soundings has been used to create bathymetric grids at 0.5 m resolution. Bathymetry data reveal the shape and depth of the seafloor, and the strength of the return signal (backscatter imagery) provides valuable information on the bottom substrate types and physical benthic habitats. In addition, data recorded through the water column (from echo-sounder to seafloor) can be used to help characterise water masses, identify bubbles and turbulence, and detect fish schools and other features not normally imaged in the bathymetry data. Interpreted together, these data form the basis of an ecosystem or habitat classification map that outline distinct environmental conditions for subsequent targeted photographic and sampling programmes. New nearshore survey data can be combined with existing multibeam data from deep ocean RV *Tangaroa* surveys to produce regional high quality MBES baseline coverage, gridded at 10 m resolution, over wider extents. NIWA has produced a range of digital and charting products that can be used to aid habitat demarcation and future sampling programmes.

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1. INTRODUCTION

The uniqueness of onshore New Zealand is also translated offshore, originating with the interaction and evolution of geologic, geodynamic, oceanographic, and climatic processes associated with the Australian-Pacific convergent plate boundary. Ninety-three percent of NZ’s continental mass is underwater, providing 570 million hectares of diverse marine environment, or approximately twenty-one times the size of our emergent land mass.

Bathymetry data are used to reveal the shape and depth of the seafloor, while the strength of the return signal (backscatter imagery) provides valuable information of the bottom substrate (seafloor composition and grainsize). Collectively these data are used to help identify different physical habitats. In addition, data recorded through the water column (from echo-sounder to seafloor) are used to help characterise water masses, identify bubbles and turbulence, detect schools of fish and other features not normally imaged in the bathymetry data. Digital bathymetric data can be processed in a benthic terrain model (BTM) to classify the seafloor into zones based on bathymetric variability or bathymetric-derived parameters. Interpreted together, these data form the basis of an ecosystem or habitat classification map that can be used to aid habitat demarcation and future sampling programmes and marine management.

This paper presents three selected case studies from recent bathymetric surveys undertaken by the National Institute of Water and Atmospheric Research (NIWA), New Zealand.

2. CASE STUDY ONE - UNDERSEA NEW ZEALAND

New Zealand is a small remote island nation with interests over one of the world’s most extensive marine areas, encompassing widely differing environments from subtropical to Antarctic climes. Undersea New Zealand, NIWA's national mapping product, provides a unique insight into the shape of the seafloor within one of the world's most extensive deepwater jurisdictions (Figure 1, Mitchell et al., 2015). Recent technological advances mean we can now map the seabed in detail approaching that of terrestrial mapping, producing accurate images of the seafloor. Water depth, or bathymetry, is calculated from the time it takes a sound wave to travel from a ship to the seafloor, and back to the ship. Multibeam echo-sounders (MBES)emit a fan of sound beams to the seafloor, scanning swaths of seafloor many kilometres wide and mapping seabed features in fine resolution. Compared with conventional echo-sounders, which produce a single beam of sound, often with gaps of several kilometres between transects, multibeam surveys provide 100% coverage. Undersea New Zealand uses some 1.5 million square kilometres of multibeam coverage, supplemented by more than 5 million line kilometres of single-beam ship tracks, to illuminate the full richness of New Zealand seascapes.

Delineated on Undersea New Zealand are boundaries and areas including those defined by the United Nations Convention on the Law of the Sea (UNCLOS). The New Zealand Territorial Sea (12 NM) is an area out to 12 nautical miles from our coast, over which New Zealand has full national sovereignty. New Zealand’s Exclusive Economic Zone (NZ EEZ) is an area out to 200 nautical miles from the coast, over which New Zealand has rights regarding exploration, conservation and management of marine resources. The Outer Limits of the Extended Continental Shelf (NZ OLECS) is the area beyond the NZ EEZ to the limits of our continental margin, over which New Zealand has rights to the seabed.

New Zealand straddles an active tectonic plate margin, creating a highly complex and diverse seascape of submarine trenches, underwater volcanoes, active submarine canyons and quiescent broad plateaux. Undersea New Zealand illuminates the full richness of New Zealand seascapes: flat, deep (>4000m) abyssal plains; fracture zones in the Southwest Pacific and South Fiji Basins; the Louisville Seamount Chain, the longest chain of seamounts in the Pacific Ocean, stretching for at least 4000 kilometres from the Pacific-Antarctic Ridge; the structure of the >10,000 metre-deep Kermadec Trench, where the Pacific Plate is pushing under the Australian Plate; vast submarine canyons that incise the continental margin, down which terrigenous material flows via sinuous channels into the deep ocean, both west and east of New Zealand; an abundance of seamounts, volcanoes and flat-topped guyots; and the regional dominance of the seafloor by the flat, deep (over 4000 metres) abyssal Tasman, South Fiji and Southwest Pacific Basins.

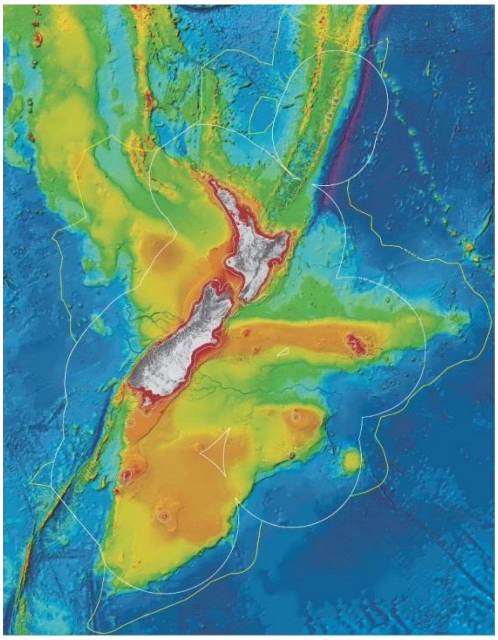

Figure 1 Undersea NewZealand – Delineated Boundaries (Mitchell et al., 2015)

3. CASE STUDY TWO - MULTIBEAM ECHO-SOUNDER MAPPING TO IDENTIFY SEAFLOOR HABITATS NORTHWEST OF D'URVILLE ISLAND.

The Marlborough District Council (MDC) recently identified a number of ecologically significant marine sites from published literature, and historical and contemporary local knowledge. Ecologically significant marine sites in Marlborough are described in Davidson et al. (2011), including the ecological values for significant sites that support rare, unique or special features. Some sites were identified for which information was sparse and further study was recommended. One such site identified is a large area (~6000 ha) immediately northwest of D’Urville Island (MDC Significant Ecological Site 2.3).

In May 2015 a joint mapping initiative between the MDC and NIWA using NIWA’s Kongsberg EM2040 high resolution MBES was undertaken to map the seafloor and identify the diversity of physical habitats (Neil et al., 2015a; 2015b). The mapping survey acquired close to one hundred square kilometres of multibeam bathymetry consisting of over 200 million soundings, which were used to create a bathymetric surface at 2 to 10 m-grid resolution (Figure 2). At Site 2.3, the shallowest portion is in the west (~45 m below Chart Datum), deepening to >140 m (below Chart Datum) in the east, while the deepest section (>220m) is associated with the large depression (Stephens Hole) to the northeast. The wider region naturally shoals against the Stephen and D’Urville Island’s coastlines to the south and east.

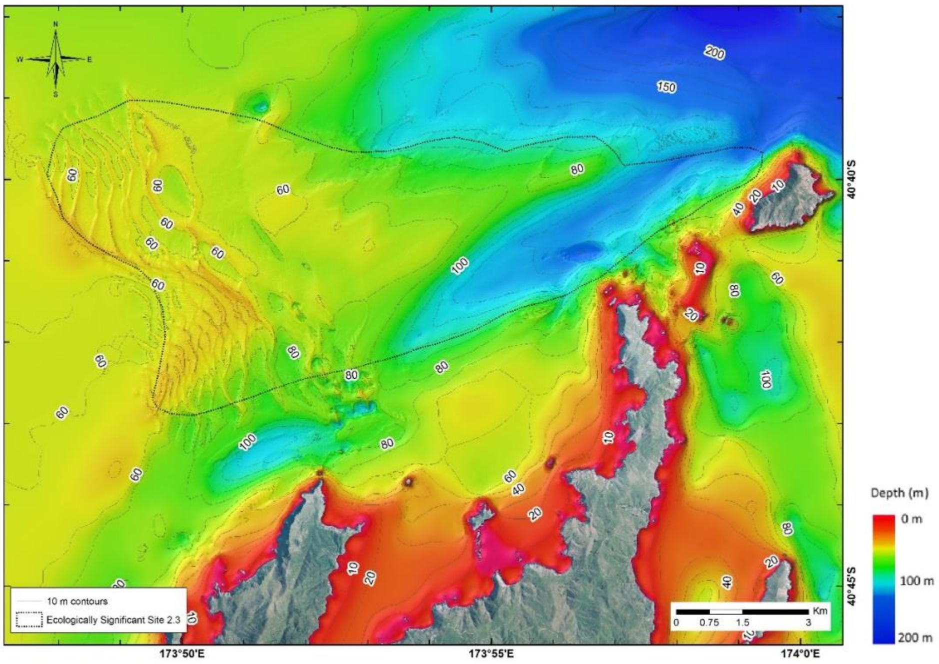

Figure 2 Sun illuminated digital elevation model (DEM) of Marlborough District Council Significant Ecological Site 2.3. Surrounding DEM sourced from NIWA's high resolution bathymetric database. The key shows the colour ramp used to depict bathymetry (water depth, in metres), with red shallowest and blue deepest. Bathymetric contours at 10 m interval.

Seafloor backscatter data relate to seafloor microtopography (or roughness) and sediment volume heterogeneity, which in turn relates to sediment grain size and composition (e.g. Jackson and Biggs, 1992). Hence, the backscatter signal can be used as a qualitative indication of the nature of the substrate (e.g. Hughes Clarke et al. 1996). The seafloor backscatter imagery were gridded into a 0.5-m grid (Figure 3). The backscatter data from Site 2.3 indicates that the region is predominately highly reflective seafloor, indicative of coarse sediments. The sediment-wave field in the western portion of Site 2.3 displays lower reflectivity, which may be related to finer grained sediment, or more likely in this instance is a consequence of the complex nature of the seafloor (roughness), scattering the return signal (e.g. Lamarche et al. 2011).

These data interpreted together reveal five marked geomorphic features: bathymetric depressions, strike ridges, sediment waves, disturbed seafloor and rocky reef; of which three are expanded on below.

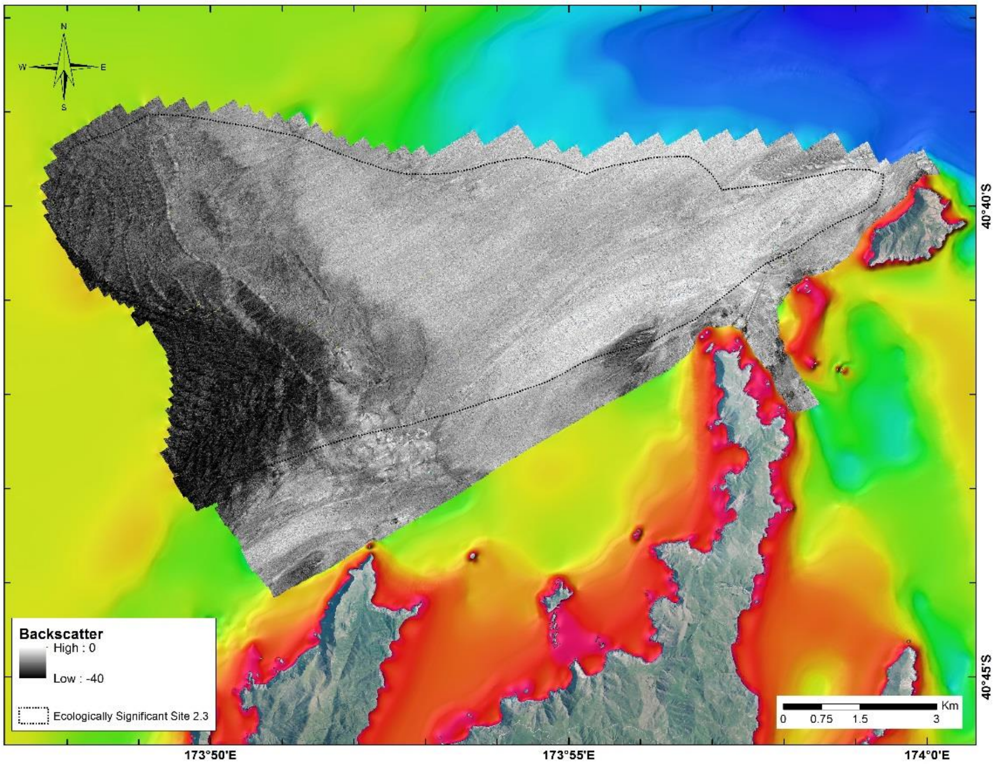

Figure 3 Backscatter imagery from Site 2.3. Areas of high reflectivity (coarse sediment) are represented by light grey and low reflectivity (muddy/fine sediment) are displayed as dark grey or black. Surrounding DEM sourced from NIWA's high resolution bathymetric database.

3.1 Geomorphic features

3.1.1 Bathymetric Depressions

Seafloor bathymetic depressions form a natural boundary for Site 2.3 to the north (Stephens Hole) and west, offshore from the headlands of Stephens and D'Urville Islands. For example, the large depression to the northeast is ~9 km long and over 2 km wide and reaches depths of ~140 m (Figure 2). Another scour occurs west of Stephens and D'Urville Islands. This feature is up to 1 m long, ~500 m wide and erodes ~40 m into the seafloor (Figure 2). The backscatter data indicate that these depressions are predominately highly reflective seafloor and therefore indicative of coarse sediments (Figure 3). They are considered the result of erosion and scour of the seafloor as a consequence of accelerated tidal flows around the headlands (e.g. Vennell 1994).

3.1.2 Strike Ridges

The seafloor morphology of the continental shelf in the wider Cook Strait region can be variably characterised by rock outcrops of marine siltstone and mudstone, as well as grain sizes ranging from coarse gravel to muds. Strata, or layers, of resistant material dipping perpendicular to the main powerful tidal currents is often more resistant to erosion, which results in the formation of emergent strike ridges that protrude above the surrounding seafloor, and depressions at their lateral extremities as a consequence of erosion of less resistant material, such as sands and gravels with higher backscatter. Strike ridges occur north of one of the major seafloor depressions identified in Site 2.3 and protrude ~30 m above the surrounding seafloor and are ~ 600 m in length (Figure 4). Their along-ridge profiles are often concave as a consequence of erosion at their extremities. These features have previously been illustrated in bathymetry and backscatter data from the wider Cook Strait region and the Narrows by Lamarche et al. (2011), but their origin was not speculated.

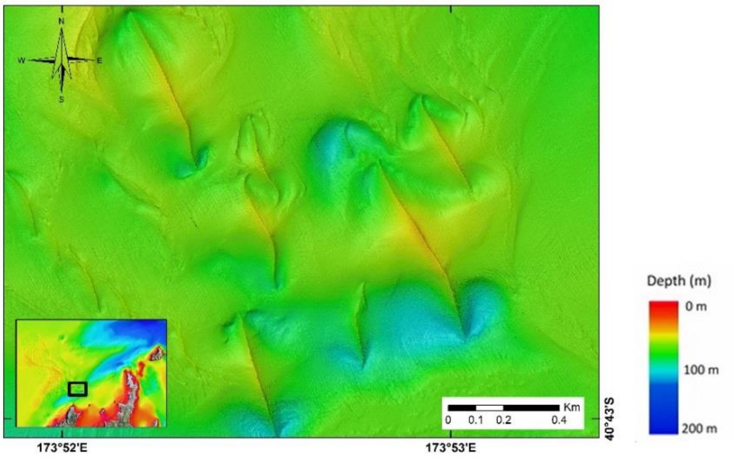

Figure 4 Bathymetry of strike ridges, Site 2.3.

3.1.3 Sediment Waves

A prominent geomorphologic feature of Site 2.3 is an extensive sediment-wave field in the west and southwest (Figure 2 and Figure 3). Sediment waves, megaripples and ripples range in size from tens of metres to decimetre scale and are the result of both oscillating water flows (e.g. tidal flows) and unidirectional flows (e.g. currents). Here, sediment waves range in height from 5 m up to 10 m (amplitude) and have wavelengths (crest to crest) of ~200 m up to ~ 400 m (Figure 5). A directional dominance of tidal flows or tidal asymmetry results in asymmetrical bedforms with the steeper lee slope facing downstream. The asymmetrical nature of the bedforms is apparent in Figure 6. Of note is the progressive shift from west-sloping lee faces in the northern sediment-wave field, to northeast facing lee slopes in the southern sediment-wave field. This is a consequence of variability or divergence in the direction and location of the predominant tidal flow during the ebb and flood cycles (e.g. Tuckey et al. 2006). The flood tide is directed southwards, the ebb tide flow is rotated slightly more to the east within eastern Tasman Bay, and a residual outflow from Tasman Bay also passes along the western flank of D'Urville Island.

This style of 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 (e.g. Carter 1992, Carter and Lewis 1995, Lamarche et al. 2011). There, bedforms similarly developed in response to the strong tidal flows coupled with sediment supply.

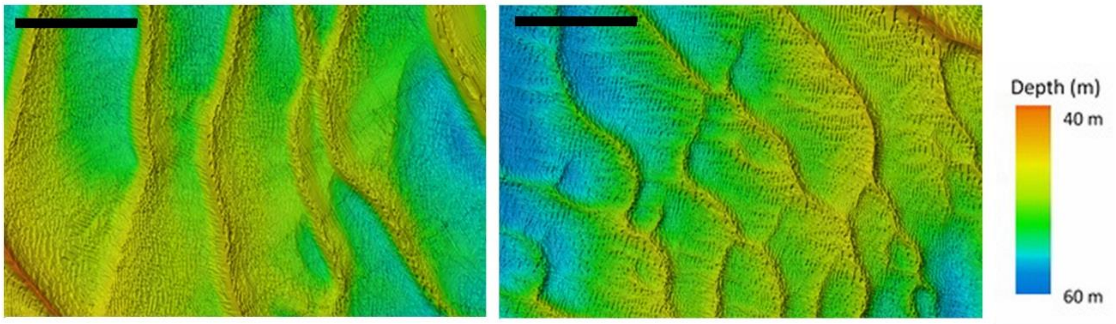

Figure 5 Bathymetric images for the northern sediment-wave field (left) and southern sediment-wave field (right) illustrating the superposition of sediment waves, megaripples and ripples. Scale bars indicate 500 m.

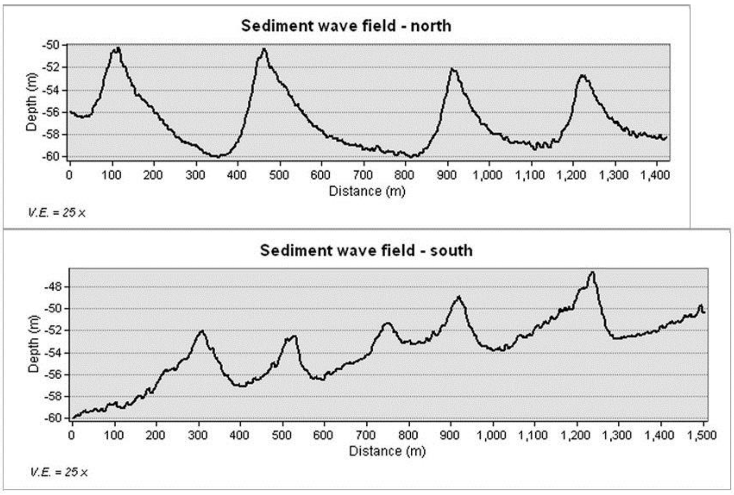

Figure 6 Bathymetric profiles across sediment-wave fields (northern - top and southern - bottom).

3.2 Benthic Terrain Model

The digital elevation model (DEM) produced from the Northwest D'Urville bathymetric survey can be used within a benthic terrain model (BTM) which classifies the seafloor into zones based on variations in the bathymetry and its derivatives. These zones form the basis of ecosystem classification scheme and underpin a benthic habitat map. In turn, each class is predicted to have distinct environmental conditions.

Terrain classifications used here include, amongst other, depth range, angle of slope, aspect and rugosity (roughness of seafloor). Areas of greatest difference between minimum and maximum depth are associated with the downslope (lee side) of sediment waves, strike ridges and nearshore rocky reefs and coastal regions. More moderate differences occur on slopes flanking the broad seafloor depressions. Areas of high slope are also associated with the downslope (lee side) of sediment waves, strike ridges, slopes of seafloor depressions and nearshore rocky reefs and coastal regions. The direction of slope (aspect) illustrates the descent of the flat-lying seafloor into Stephens Hole and changing direction of the lee slope of sediment waves between the northern fields. Areas of increased seafloor roughness are associated with crests of strike ridges and nearshore rocky reefs, and to a lesser degree with the crests of sediment waves.

The resultant classification scheme derived here classifies Site2.3 (and the neighbouring surveyed area of Stephens Passage) as 74% flat plains, 17% broad slopes, 7% flat ridge tops, and 1% broad depression and rock outcrops (Figure 7). In the benthic environment, ecological diversity can be associated with complex environments, hence this classification scheme, combined with geomorphic features and existing archival sediment and biological data, can form the basis of a targeted photographic and sampling programme.

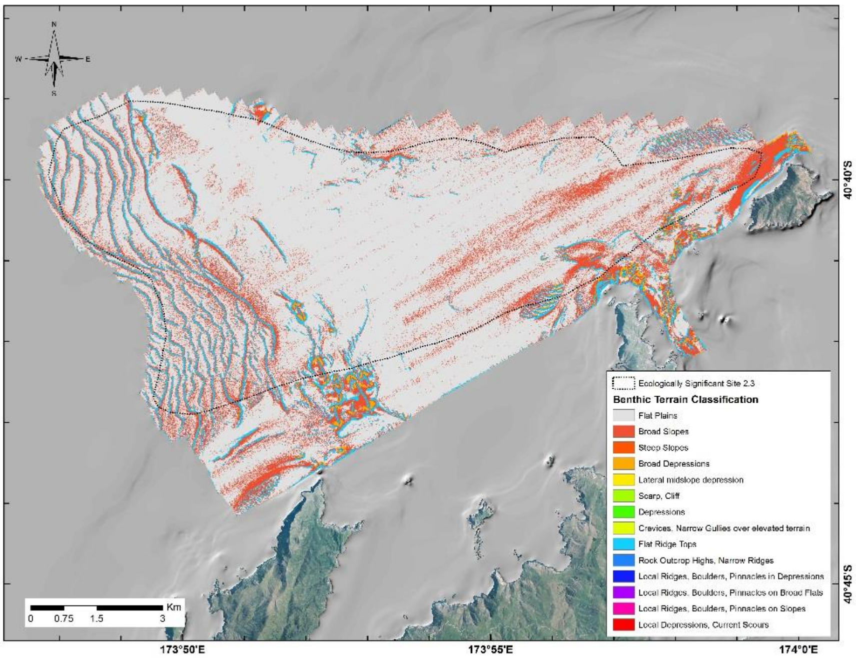

Figure 7 Benthic terrain classification of Site 2.3. This region of seafloor comprises 74% flat expanses of seafloor, 17% broad slopes, 7% flat ridge tops, and 1% broad depressions and rock outcrops.

4. CASE STUDY THREE - MULTIBEAM ECHO-SOUNDER MAPPING TO IDENTIFY SEAFLOOR HABITATS IN HIKURANGI MARINE RESERVE

The Department of Conservation (DoC) recently identified the need for a baseline survey of the new Hikurangi Marine Reserve, immediately south of Kaikoura. This baseline survey required multibeam bathymetry of the nearshore (~5–200 m depth), unmapped by previous shallow side-scan sonar and deeper multibeam surveys undertaken in the region by NIWA. The aim was to survey a portion of the coast to the north and south of the reserve to act as a control.

During June 2015 a mapping initiative using NIWA’s Kongsberg EM2040 high-resolution MBES was undertaken to map the seafloor bathymetry and identify the diversity of physical habitats. The multibeam survey mapped the bathymetry of ~ 7.5 km^2 of seafloor, consisting of over 385 million soundings. This density of soundings has been used to create a bathymetric grid at 0.5 m resolution (Figure 8). The shallowest depth able to be navigated and surveyed was ~1 m Lowest Astronomical Tide (LAT), with depths increasing to >300 m LAT in the east. The deepest seaward sections are associated with gullies at the head of the Kaikoura Canyon. The broader expanses of the shelf shoal against the coastline to the west.

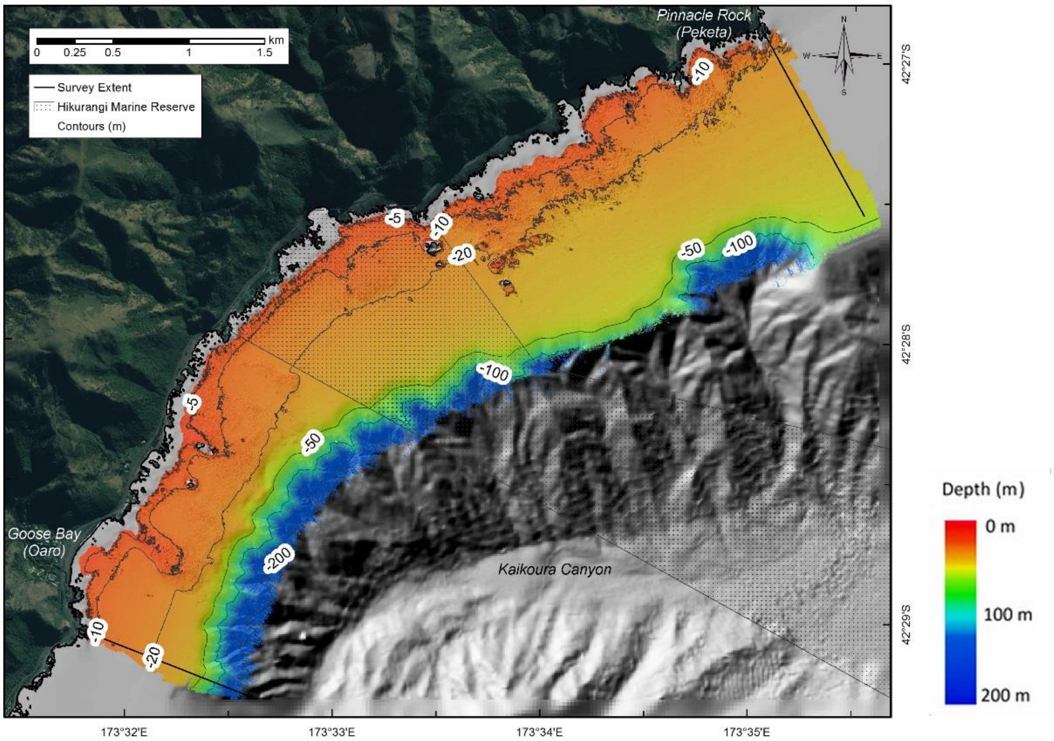

Figure 8 Sun illuminated digital elevation model (DEM) and bathymetric contours of the survey area from Pinnacle Rock (Peketa) to Goose Bay (Oaro). Surrounding DEM sourced from NIWA's high resolution bathymetric database. The key shows the colour ramp used to depict bathymetry (water depth, in metres), with red shallowest and blue deepest.

The seafloor backscatter data were gridded into a 0.25-m grid (Figure 9). The backscatter data from the area indicates that the region is predominately highly reflective seafloor (white) indicative of coarse-grained sediments (sands), and highly variable backscatter (speckled white to dark grey) indicative of indurated rock platforms, rugged rocky reefs, and/or boulders. Sediment ribbons, perpendicular to the contours, display low reflectivity, which are likely be related to finer grained sediment (mud).

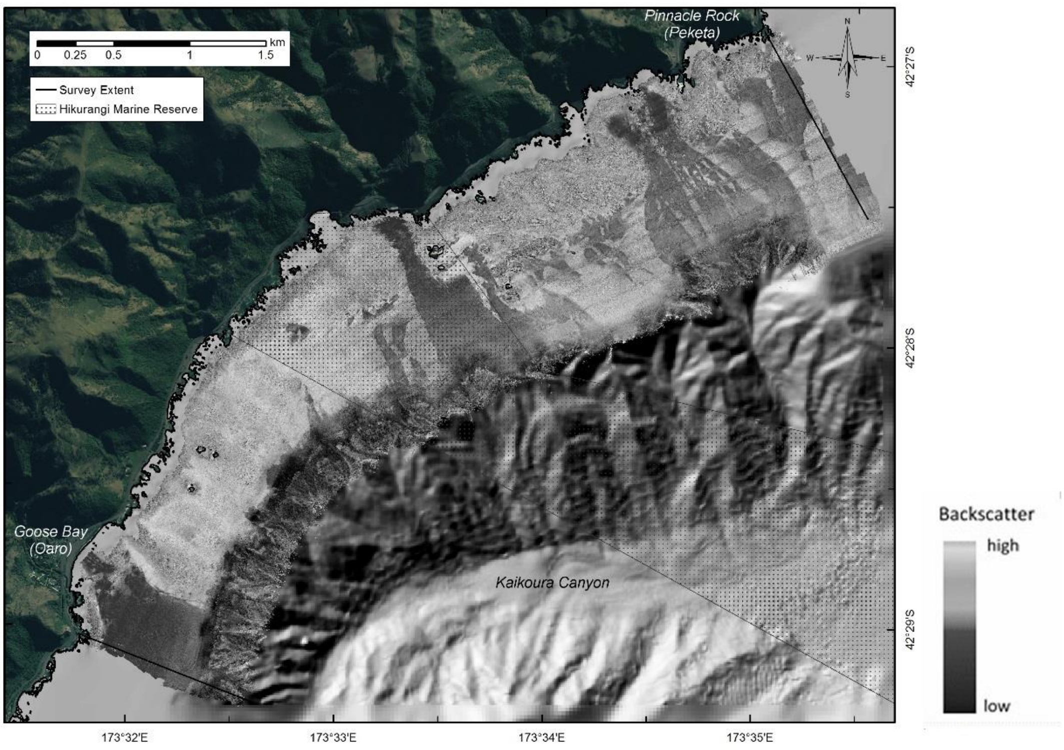

Figure 9 Backscatter imagery from the survey area, Pinnacle Rock (Peketa) to Goose Bay (Oaro). Areas of high reflectivity (coarse sediment) are represented by light grey and low reflectivity (muddy/fine sediment) are displayed as dark grey or black. Surrounding DEM sourced from NIWA's high resolution bathymetric database.

4.1 Seafloor Classification

4.1.1 Benthic Terrain Model

Bathymetric data from the survey were also processed in a benthic terrain model (BTM) to classify the seafloor into zones based on bathymetric variability. These zones form the basis of an ecosystem or habitat classification map that outlines distinct environmental conditions for subsequent targeted photographic and sampling programmes. The resultant BTM zones derived from NIWA's survey classifies the surveyed area 50% flat plains, 24% broad slopes, 10% narrow slopes, 7% broad and mid-slope platforms, and 6% rock outcrops, local boulders.

4.1.2 Geomorphic Feature Model

The bathymetry and backscatter data and the derivative benthic terrain model products can be jointly interpreted to identify and describe a variety of geomorphic features within the survey area. The classification derived here follows, wherever possible, the classification described in Lewis et al. (1998), and Lewis and Barnes (1999). These have been divided into two hierarchical groups.

Four first-order geomorphic domains describe the broad context of the survey area. These include rocky reefs-platform, flat seafloor with high backscatter reflectivity, flat seafloor with low backscatter reflectivity, and flat seafloor with medium backscatter reflectivity. Superimposed on these domains are three second-order geomorphic features, including boulder-rock apron, megarippled sediment, and canyon head (ridges and gullies). The map (Figure 10) shows the distribution of geomorphic environments throughout the survey area.

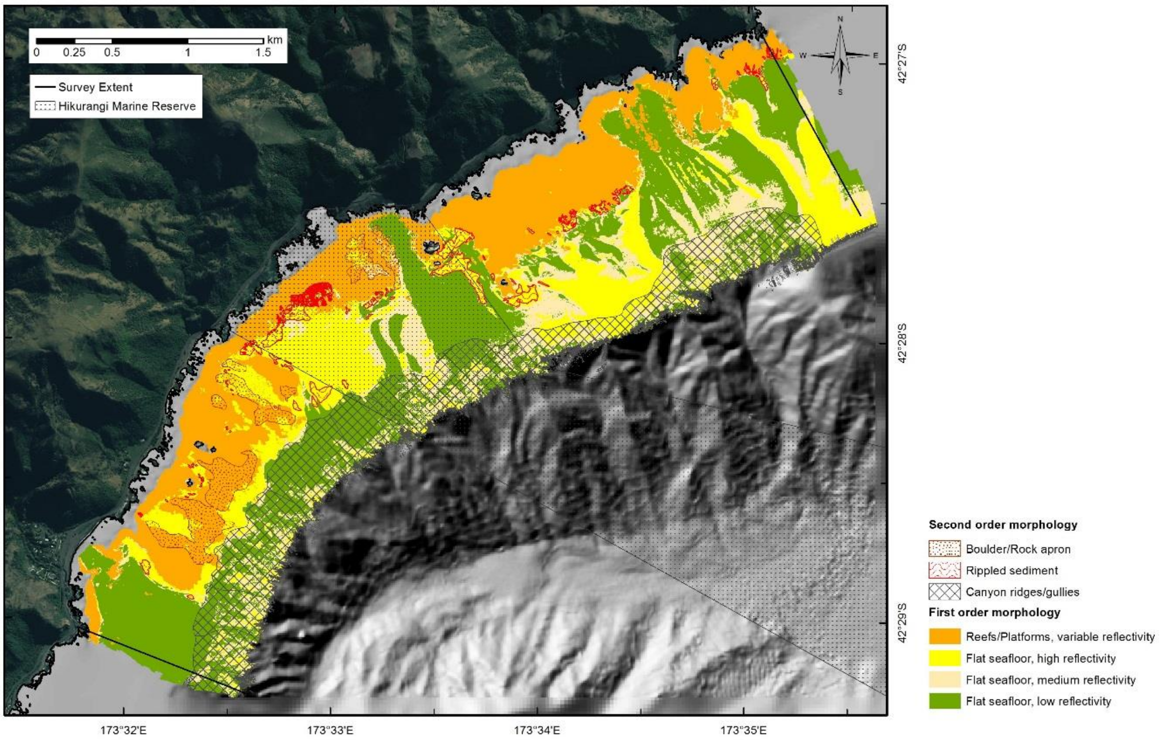

Figure 10 Seafloor classification of the survey area from Pinnacle Rock (Peketa) to Goose Bay (Oaro).

4.2 Regional Coverage

The survey data, mapping from ~5–200 m water depth, was combined with existing multibeam data from two previous NIWA surveys, to produce a single regional coverage gridded at 10 m resolution (Figure 11). The deep-water (>200 m deep) portion of the marine reserve had been previously surveyed using a hull-mounted Kongsberg EM300/302 MBES on the NIWA research vessel RV *Tangaroa*. The combined dataset yields a single 100% regional coverage of the ~104 km^2 area of the Hikurangi Marine Reserve. These high quality MBES baseline data were gridded at 10 m resolution to produce a bathymetry DEM, bathymetry hillshade and a Benthic Terrain Model (Figure 12).

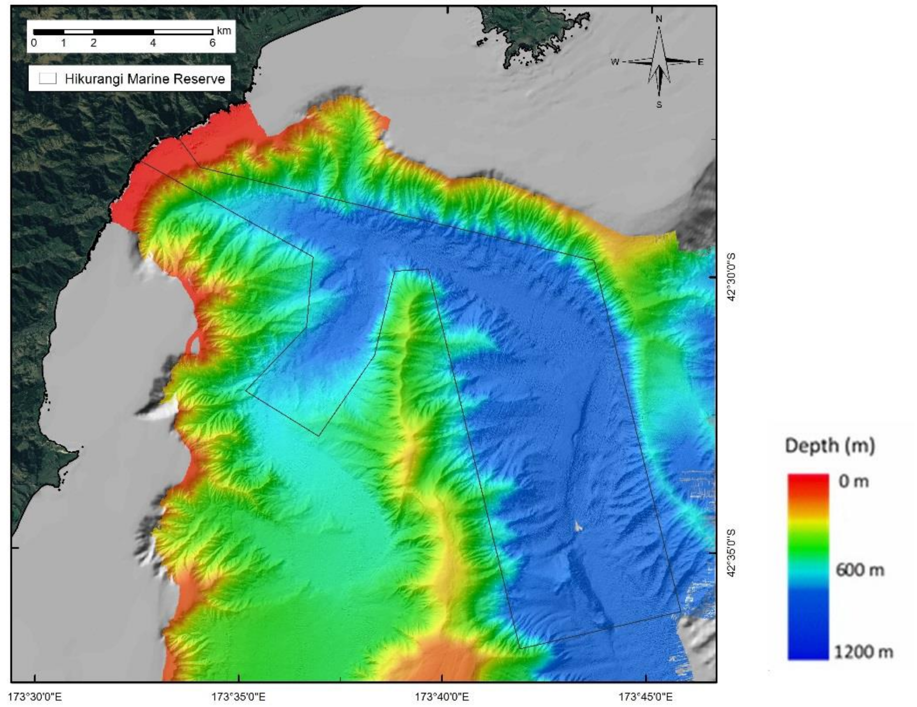

Figure 11 Bathymetry imagery illustrating the Hikurangi Marine Reserve.

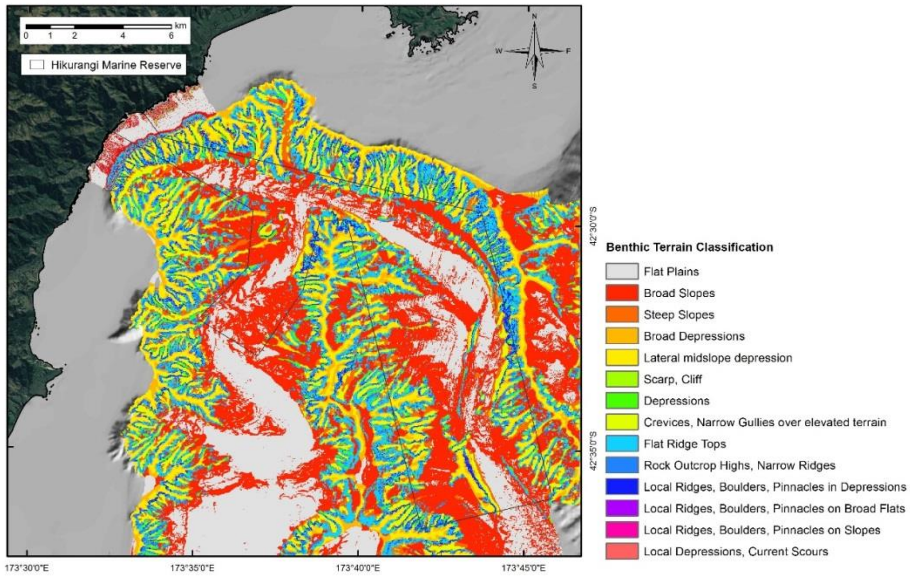

Figure 12 Benthic Terrain Model imagery illustrating the Hikurangi Marine Reserve.

5. SUMMARY

- A mapping initiatives using both NIWA’s shallow-water and deep-water, high-resolution multibeam echo-sounders have been undertaken to map the seafloor bathymetry and identify habitat types.
- Bathymetry, backscatter, water column data and derivatives of bathymetry (benthic terrain models) can be interpreted together to describe a variety of geomorphic features.
- Benthic terrain models are used to classify the seafloor into mappable zones based on metrics that describe variations in bathymetry. These zones are interpreted to have distinct environmental conditions, and by implication, distinct benthic ecosystems.
- NIWA has produced a range of digital and charting products that can be used to define habitat types, aid habitat demarcation, and inform future sampling around New Zealand.
- The approach used herein can help endusers to better characterise marine areas and plan for the preservation of indigenous biodiversity. Identifying and characterising important habitats for biodiversity will improve ongoing monitoring of the state of the coastal and marine environment.

6. ACKNOWLEDGEMENTS

The D’Urville survey was co-funded by MDC, NIWA Core Funding (‘Marine Physical processes and Resources’ programme, Coasts and Oceans Centre) and an MBIE Envirolink Grant (‘Mapping reefs using MBES to identify habitats for marine biodiversity’).

The Hikurangi suvey was funded by New Zealand Department of Conservation. Legacy multibeam data (TAN0616 & TAN1111) used in the Hikurangi survey were sourced from NIWA data catalogue and were originally collected during voyages funded by New Zealand Foundation for Research, Science and Technology and Oceans Survey 20/20 RV *Tangaroa* days funded by Land Information New Zealand.

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BIOGRAPHICAL NOTES

Dr Helen Neil is a sedimentologist and palaeoceanographer specialising in seabed mapping and identification of sediment and biological distributions. She has undertaken research in the subtropical and subantarctic oceans surrounding New Zealand and has lead or participated in over 16 research voyages, five of which included international collaboration with USA, Australia, and the EU. Her work focuses on the geological, sedimentological, oceanographic and biological processes that affect the seafloor, in particular that associated with deep water transport, impact of currents on sediment systems and depositional processes, geological resources, and habitat mapping. Her expertise has been applied to seabed surveys, telecommunication cables, marine infrastructure, and ocean exploration. She manages NIWA's Ocean Sediments group and geological isotope facilities, and is NIWA's National Projects Manager.

Kevin Mackay is a Principal Technician and Marine Database Manager with wide experience in marine surveys, hydrographic mapping, data management and GIS. Kevin has 14 years seabed surveying experience in the data acquisition and processing fields including multibeam surveying with Kongsberg EM300 and EM3000D and EM2040 MBES. He has taken part in over 36 bathymetric surveys during this time, ranging to inshore coastal to deep-water surveys. Kevin has experience with processing multibeam/single beam survey data with CARIS HIPS/SIPS, MBSystem, Kongsberg Neptune, Fledermaus Professional; as well as experience in deploying and processing sediment cores and grabs. With over 14 years experience in the GIS industry with ESRI, GMT, Genamap, QGIS, PostGIS, MapInfo products Kevin also holds the role of Programme Leader with NIWA's Environmental information Centre.

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