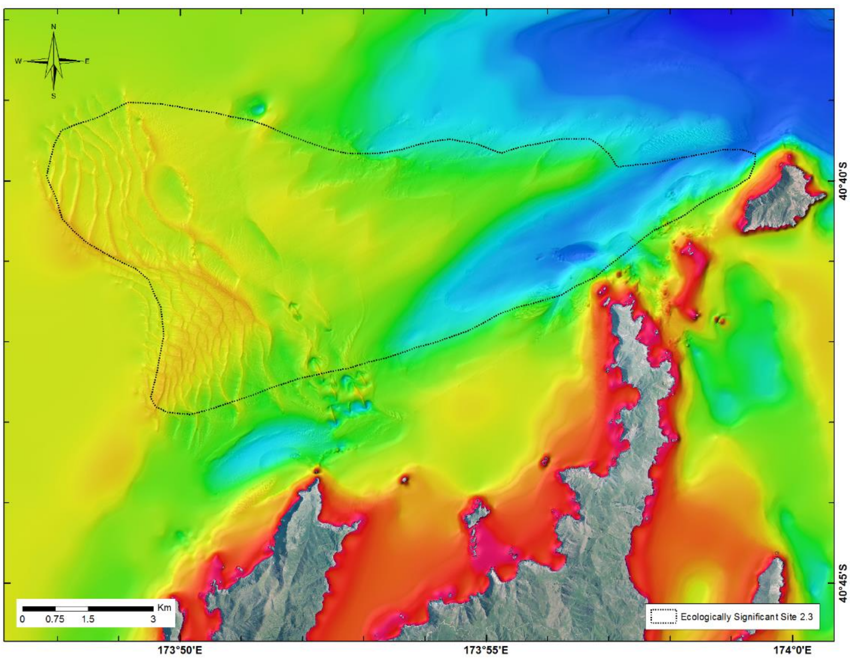
NIWA
Taihoro Nukurangi

Multibeam echo-sounder mapping to identify seafloor habitats northwest of D'Urville Island

Prepared for the Marlborough District Council

June 2015



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Executive summary

The Marlborough District Council (MDC) recently identified a number of ecologically significant marine sites from published literature, and historical and contemporary local knowledge. One site identified is a large area (~6000 ha) immediately northwest of D'Urville Island (MDC Significant Ecological Site 2.3) and is potentially habitat for bryozoan beds.

During May 2015 a joint mapping initiative between the MDC and NIWA using NIWA's Kongsberg EM2040 high resolution multibeam echo-sounder (MBES) was undertaken to map the seafloor and identify the diversity of physical habitats. The survey was co-funded by MDC, NIWA Core Funding ('Marine Physical Resources' programme, Coasts and Oceans Centre) and an MBIE Envirolink Grant ('Mapping reefs using MBES to identify habitats for marine biodiversity'). 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.

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. These data interpreted together reveal five marked geomorphic features: bathymetric depressions, strike ridges, sediment waves, disturbed seafloor and rocky reef. 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.

Bathymetric data from the survey were 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 classification scheme derived here classifies Significant Ecological Site 2.3 (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.

NIWA has produced a range of digital and charting products that can be used by the MDC to aid habitat demarcation and future sampling around D'Urville Island. 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 environment.

1 Introduction

The Marlborough District Council (MDC) recently identified a number of significant ecological marine sites from published literature, and historical and contemporary local knowledge (Davidson et al. 2011). One site identified is a large area (~6000 ha) along the northwestern coast of D'Urville Island and Stephens Island (Significant Ecological Site 2.3, hereafter referred to as Site 2.3). This area has not previously been surveyed and the boundaries and biological attributes summarised in Davidson et al. (2011) indicate the potential existence of bryozoan beds, based on information obtained from commercial fishers and a single scientific mention.

A joint MDC and NIWA mapping initiative was undertaken in May 2015 with co-funding from MDC, NIWA Core Funding ('Marine Physical Resources' programme, Coasts and Oceans Centre), and MBIE Envirolink Grant ('Mapping reefs using multibeam echo-sounder to identify habitats for marine biodiversity'). NIWA's high resolution multibeam echo-sounder (MBES) was used to map and identify seafloor types within Site 2.3. The multibeam survey mapped close to one hundred square kilometres of bathymetry consisting of over 200 million soundings which have been gridded at 2 m to 10 m-resolution.

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. Bathymetric data collected from the survey of Site 2.3 were 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.

2 Regional background

Cook Strait separates the North and South islands and is a 20-60 km wide passage shaped by climatic, oceanographic and tectonic processes. It is a dynamic and highly energetic sedimentary environment that receives sediment supply from nearby rivers, with sands and gravels subsequently transported by strong tidal flows and currents (e.g. Carter 1992, Lewis et al. 1994, Lamarche et al. 2011). During the last-glacial maximum, Cook Strait was closed by a land bridge that dramatically altered the oceanographic regime (Procter and Carter, 1989). Post-glacial sealevel rise formed a wave-based erosional platform, parts of which are now blanketed by a wedge of post-glacial sediment ranging from muds to tidal current-winnowed gravel, while other parts have been swept bare of post-glacial sedimentation, with erosional outcrops at the seafloor due to the strong wave and tidal environment (e.g. Lewis et al. 1994). Tidal currents coupled with sediment delivery have produced distinctive patterns of sedimentation and bedforms, in particular several sediment-wave fields have been recognised in the Narrows Basin (e.g. Carter 1992, Lamarche et al. 2011). Consequently, the seafloor geology and distribution of surficial sediments is complex and comprises relict and modern features.

Site 2.3, along the northwestern coast of D'Urville Island, is located within the wider Cook Strait region but is influenced by the strait's hydraulic regime. Sedimentary cover is broadly described as calcareous gravel to calcareous sand (Figure 2-1). Note that there are only 3 surficial samples proximal to, and one sample within, Site 2.3 (Figure 2-3) (samples from: Lewis and Mitchell, 1980; Lewis et al., 1994).

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 (Heath 1978, Heath 1982). 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 (Figure 2-2). These flows are sufficient to scour deep holes off headlands of the strait (e.g. Vennell 1994).

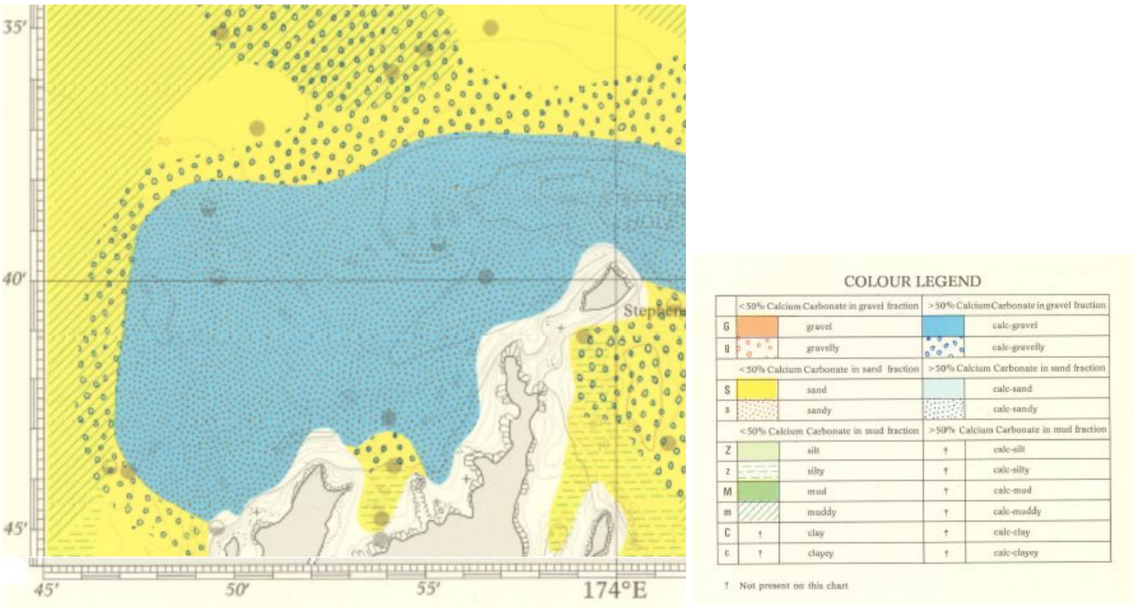


Figure 2-1: Interpretation of sediment distribution northwest of D'Urville Island. (From Lewis and Mitchell 1980).

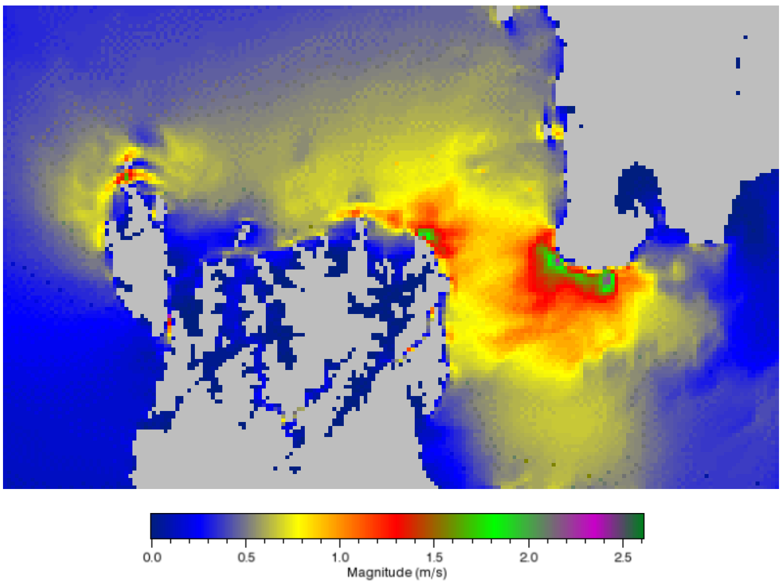


Figure 2-2: All-depth average modelled speeds of M2 tides in greater Cook Strait. (Mark Hadfield, NIWA).

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 was Site 2.3 off D'Urville Island and Stephens Island. Davidson et al. (2011) describe Site 2.3 as an area that has not been formally surveyed and the boundaries and biological attributes are based on information obtained from commercial fishers and a single mention in a scientific paper (Bradstock and Gordon, 1983). This site is reported to potentially support a bryozoan community dominated by the 'Separation Point coral' (Able Tasman), and therefore, is possibly the largest area of bryozoans in the Marlborough Sounds, however the quality and composition of the habitat is unknown.

NIWA's stations database archive of samples collected over the last 70 years, using a range of methods, shows that station information is sparse in this region. The single scientific mention of bryozoa in this region is sourced from Bradstock and Gordon (1983), which tabulates bryozoan species (93 spp.) at station D273 south of Site 2.3. Gordon (1989) produced a summary of bryozoa fauna in New Zealand which also documents the occurrence of 65 bryozoa spp. at station D272 within Site 2.3 (Figure 2-3). Bryozoa fauna at both these stations include *Celleporaria agglutinans* or 'Separation Point coral'. Substrates at both these stations were documented as predominately composed of dead shell material, i.e. calcareous gravel, in agreement with the earlier broad substrate classification of Lewis and Mitchell (1980).

Bryozoa fauna can be habitat forming when they dominate the seafloor substrate (so called 'bryozoan meadows'), such as at Separation Point (e.g. Saxton 1980, Bradstock and Gordon 1983, Grange et al. 2003), however the conditions required for habitat generation are poorly known. Habitat suitability models have been generated for the 11 most common habitat-forming bryozoan species by Wood et al. (2013). The greater Cook Strait region, including D'Urville Island, is one of the areas identified where bryozoans may occur, although it is important to note that predicting where bryozoans may occur is not the same as their occurrence at small scales.

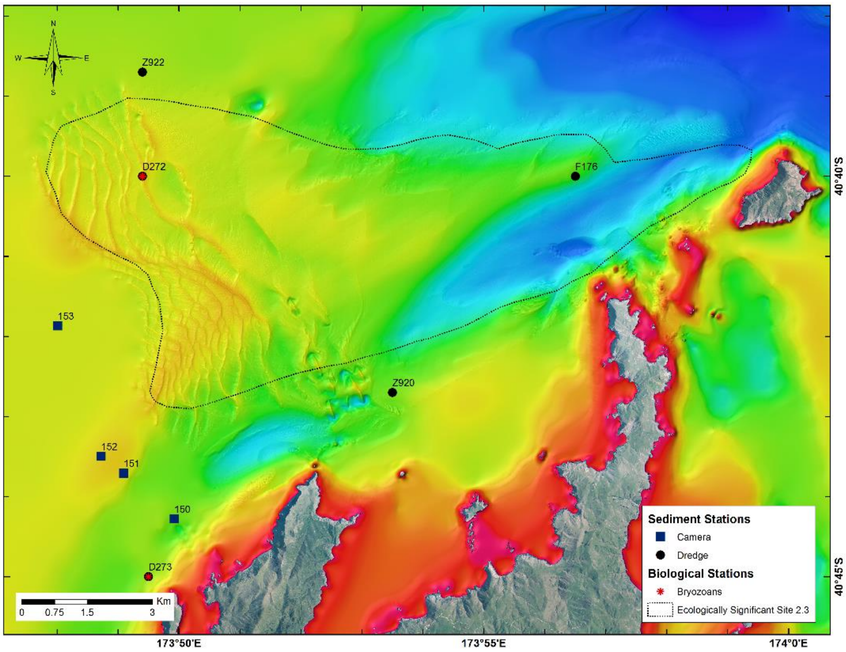


Figure 2-3: Archive sediment and biological stations in the vicinity of Site 2.3. Data sourced from NIWA archives. The extent of Site 2.3 is outlined by the black line.

3 Survey data collection and processing

3.1 Scope of Survey

The survey area was designed to provide 100% map coverage of the ~63 km^2 area of Site 2.3. The final MBES dataset covers ~93 km^2 (Figure 3-2).

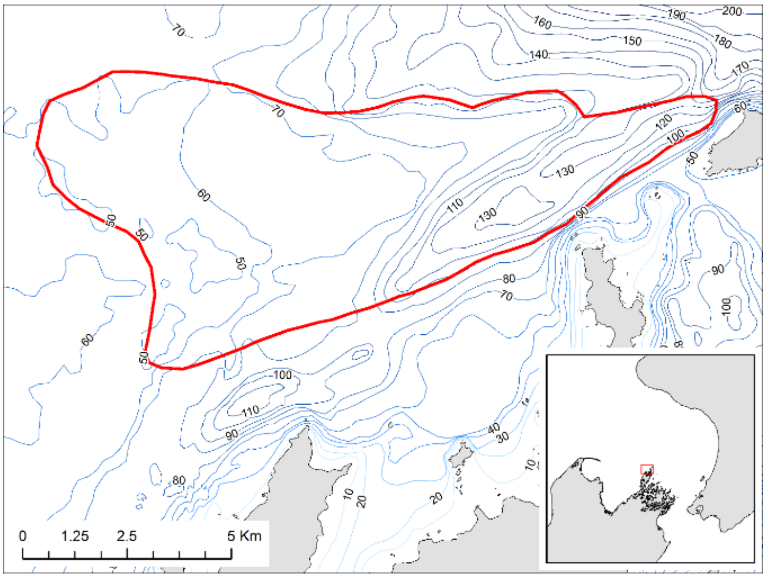


Figure 3-1: Map of the survey target area. Red area indicates the extent of the Site 2.3. The water-depth contours shown (drawn from pre-survey data) are sourced from NIWA's bathymetry archive.

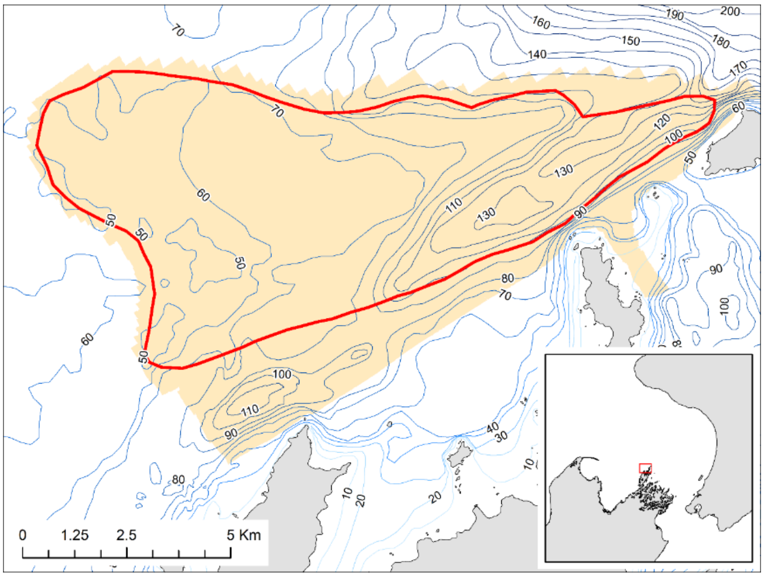


Figure 3-2: Swath coverage achieved (area of beige fill).

3.2 Survey Mobilisation

The vessel used for the data collection was the 14m-long survey catamaran, RV *Ikatere*, owned and operated by NIWA. RV *Ikatere* was equipped with high-resolution Kongsberg EM2040 shallow water MBES and mobilised early April 2015 in preparation for the D'Urville Island survey. A full patch test completed prior to departure was to ensure the high performance of the system and to check the alignment of the transducers to the survey vessel reference frame. Subsequent to the successful patch test, a suitable weather window was forecast for the first few days in May 2015 and the vessel was readied by 29 April 2015. The boat departed from Wellington for the survey area on the morning of 30 April 2015.

3.3 Survey Conditions

Weather conditions during the survey were generally good for the time of year. A NW swell of ~1.0 m was accompanied by variable winds that freshened during each day, building 0.5 m of chop on top of the swell. Sea conditions in the very strong tidal flows close to Stephens Island and the approaches to Stephens Passage were marginal, but the system performed very well, even in the steep, 1.5-2.0 m seas. Maintaining prescribed survey tracts was challenging in these areas of strong tidal flows, and as a result line spacing had to be reduced, or additional fill lines run, to ensure sufficient multibeam overlap i.e. complete coverage (ensonification) of the seabed in the survey area.

3.4 Daily Survey Narrative

Thursday, 30.04.2015

Survey gear mobilisation, stores, fuelling, engine maintenance

Friday, 01.05.2015

On board: A. James, S. Harrison, A. Pallentin, T. Kane

0545 Departure checks

0630 Depart Evans Bay Marine, Wellington, for D'Urville Island. Strong Southerly swell at harbour entrance, but sea calming after passing Tory Channel.

0930 On site, system deployment and checks, SVP cast

1030 Begin lines

1630 End lines, scouting current patterns around Stephens Gap

1700 End survey day

1730 Arrive Catherine Cove (accommodation)

Saturday, 02.05.2015

On board: A. James, S. Harrison, A. Pallentin, T. Kane, K. Heyns (MDC)

0545 Crew readies RV *Ikatere*

0600 Survey on board, safety briefing K. Heyns

0615 Depart for survey area

0715 On site, system deployment and checks, SVP cast

0745 Start lines

1745 End of lines

1800 Depart survey area

1845 Refuelling at French Pass

2015 Departing French Pass

2030 Catherine Cove

2100 Boat crew finished

Sunday, 03.05.2015

On board: A. James, S. Harrison, A. Pallentin, T. Kane, K. Heyns (MDC)

0550 Crew readies RV *Ikatere*

0610 Survey on board

0630 Depart for survey area

0710 On site, system deployment and checks, SVP cast

0740 Start lines

1800 End of lines

1810 Depart survey area

1900 Catherine Cove

1915 Refuelling at French Pass and departure K. Heyns

2030 Crew back at Catherine Cove

Monday, 04.05.2015

On board: A. James, S. Harrison, A. Pallentin, T. Kane

0645 Crew readies RV *Ikatere*

0715 Loading gear, taking fresh water

0730 Depart for survey area

0820 On site

1315 End of survey, Depart for Wellington

1700 Arrive Evans Bay Marine, Wellington

3.5 Geodetic parameters

3.5.1 Horizontal datum

The horizontal datum and projection used in the D'Urville (Site 2.3) MBES survey were:

Datum	:	WGS84

Spheroid	:	World Geodetic System 1984 (WGS84)
Projection	:	Universal Transverse Mercator
Zone	:	59 South

3.5.2 Vertical datum

The vertical datum used for the MBES survey was:

Datum	:	LAT (NIWA tide model)

3.5.3 Tidal Data

Tide data for this survey was obtained from the NIWA tide model for the position: 173°51’20.0”E 40°40’30.0”S. All measurements are reduced to Lowest Astronomical Tide (LAT) in relation to the NIWA model (Walters et al. 2001).

3.6 Bathymetry Data Collection

The EM2040 MBES settings were optimised for the expected survey area water depth, and to maximise swath coverage to ensure accuracy and efficiency. The MBES was used with its standard frequency of 300 kHz in dual-swath mode. The angular coverage was set to the maximum of 70°/70°, giving a sea-floor coverage of up to 5 times the water depth. Line spacing was planned around ~20% data overlap between adjoining survey lines to maintain a high level of confidence in the bathymetric data. MBES seafloor bathymetry and backscatter, along with water column data were recorded concurrently. A more detailed description of survey systems and software used to complete this survey are contained in Appendix A.

To obtain accurate multibeam bathymetry water properties in the survey area are required. This was achieved by deploying an AML Minos.X sound velocity profiler (SVP) prior to the start of the survey data collection, and when needed during the survey day. This instrument gives a detailed profile of the speed of sound through the water column and is used by the MBES to correct for beam refraction due to changes in the physical properties of the water masses. In addition to the MBES data, detailed navigation and attitude data from the Applanix PosMV system was recorded. These data were used for post processing of the MBES data to reduce atmospheric distortions in the reception of the GPS raw signal. All survey data were archived at the completion of each day of surveying and backed-up.

3.7 Bathymetry Processing

3.7.1 Navigation & Attitude Data

The PosMV navigation and attitude data were post processed using Applanix PosPac software. High-precision GPS control station data and ephemeris data for the survey days were used to correct the received raw GPS data. This process results in positional data with accuracies in the centimetres range, improving on the real-time on-board positional accuracy in the decimetre range. The new position resolution for the MBES data were exported to SBET (Smoothed Best Estimate of Trajectory) files (Appendix A).

The SBET files are used in Kongsberg SISQA software to re-ray trace the raw MBES data. This more accurate MBES data were written to a new set of Kongsberg raw files, which are then used for post-processing as described in the following sections.

3.7.2 Bathymetry Data

The Kongsberg EM2040 data were imported into CARIS HIPS V9.0 software for initial processing and a standard CARIS hydrographic processing workflow was followed prior to the generation of the final data surfaces. The process involved the following steps:

- Import data: Import and convert Kongsberg *.all raw files to the CARIS HIPS format.
- Load tides: A tide file produced from the NIWA tide model was applied to the bathymetric soundings. This reduced water levels to LAT.
- Merge: The process of calculating final positions and depths for soundings, based on all relevant inputs such as observed depths, navigation information, vessel dynamics such as heading, heave, pitch and roll, and tide.
- Calculate TPU: Total Propagated Uncertainty (TPU), which is derived from a combination of all individual error sources, was calculated using error values specified in the RV *Ikatere* vessel file.

The bathymetry data were examined and cleaned on a line-by-line basis in the Swath Editor tool. Bathymetric soundings that represented gross errors and obvious spikes were rejected at this stage.

A surface was then created for the survey area. This bathymetry surface was gridded into a BASE (Bathymetry Associated with Statistical Error) surface using the CUBE (Combined Uncertainty Bathymetry Estimate) algorithm. The surface had a 1 m resolution for depth shallower 90 m, and 2 m for depths greater than 90 m. The CUBE derived BASE surface is a geo-referenced representation of the seabed derived from the processed bathymetry and computed uncertainty (error) values. When a CUBE surface is created, soundings are statistically weighted and contribute to surface grid nodes based on TPU values and distance from the nodes. The CUBE surface allows for multiple depth estimates or hypotheses to exist at a single grid node, depending on the variation of the sounding data. CUBE then uses a disambiguation process to determine which hypothesis at each node is statistically the most “correct”.

Further bathymetric cleaning was then completed using the CARIS Subset Editor tool. CUBE decisions were verified and, if necessary, overridden, in Subset Editor. Once any necessary edits had been made to the CUBE surface, the surface was recomputed. A 5x5 nearest neighbour interpolation was then run to fill any minor data holes in the CUBE-derived bathymetric surface. Once these data were fully cleaned and processed, the data were exported from CARIS in ESRI ascii grid format. This was read into ESRI ArcMap v10.2.1 and used for surface analysis and plot production.

The resulting data-set consists of over 185 million soundings. These were gridded at 1-2 m intervals resulting in a data density of approximately 4 data points per grid cell in the deeper parts of the survey area, and up to 150 per cell in the shallower areas.

Analysis of the system accuracies and survey conditions indicate that the multibeam accuracy for the LINZ MB-1 standard were met (Appendix B).

Bathymetry data revealing the shape and depth of the seafloor are illustrated as a hill-shaded digital elevation model (DEM), and as a 10 m bathymetric contours. Cross-sectional profiles were produced along with large format imagery and associated graphics.

3.7.3 Benthic Terrain Modelling

The BTM used here is a collection of ArcGIS-based tools developed for analysing and classifying the benthic environment. These tools include the creation of standardised bathymetric position index (BPI) grids, of which multiple scales are derived here: native or 01 resolution i.e. 1 x 1 pixel (2 x 2 m window), 05 resolution i.e. 5 x 5 pixels (10 x 10 m window), and 15 resolution i.e.15 x 15 pixels (30 x 30 m window). BPI is principally a measure of where a referenced location is relative to the locations surrounding it. Hence positive window values indicate features that are higher than the surrounding area e.g. ridges and negative window values designate features that are lower than the surrounding area e.g. depressions or scour. Window values near zero are either flat areas or areas of constant slope.

Terrain classifications used herein are depth (as described above), depth statistics (standard deviation over three windows), depth range (difference between minimum and maximum depth within each window), slope (angular units from the horizontal), slope statistics (standard deviation over three windows), curvature (a measure of the change of slope), aspect (direction of the downslope dip) and rugosity (ratio of surface area to planar area, roughness) or a measure of terrain complexity. In the benthic environment, ecological diversity can generally be correlated with complex environments, therefore rugosity is often used to help identify areas with potentially high biodiversity. Lastly, the information from the depth, slope, and other BPI data sets is used to create a classification scheme for the terrain.

3.8 Backscatter processing

3.8.1 Backscatter Data

The seafloor backscatter imagery was processed using QPS Fledermaus GeoCoder Toolkit (FMGT) software. Data were loaded from Kongsberg *.all files and the backscatter or imagery data extracted and automatically corrected for signal variations across the swath. The resulting corrected data were gridded into a 0.5-m resolution backscatter grid. The final seafloor backscatter grid was exported as an ESRI asci grid format and imported to ArcGIS Desktop software for analysis and plot production.

3.8.2 Water Column Data

To extract and process the water column backscatter component of the MBES data, the Kongsberg *.all files were imported into QPS Fledermaus water column data software FMMidwater. Ping data were normalised using the first ping (if using dual swath mode) to allow for an even backscatter water column image to be analysed. The data were screened on a ping by ping basis (across track), or as a curtain (along track) selecting the beam number to be viewed. Data were then exported as screen shots for display purposes, or as point data to be viewed in 3D-rendering software applications.

4 Results

Large format imagery is provided, in addition to this report, in an associated graphics portfolio (Neil et al. 2015a) and as two NIWA miscellaneous series charts (Neil et al. 2015b, Neil et al. 2015c). Digital data are delivered as a surface DEM at 2 m and 10 m resolution, and all digital data are included as a file geodatabase (see Appendix C for digital delivery products).

4.1 Bathymetry

Bathymetry data revealing the shape and depth of the seafloor at Site 2.3 are illustrated below in Figure 4-1. In addition, cross-section profiles of the survey area are also shown in Figure 4-3.

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 sections (>220m) are associated with Stephens Hole to the northeast. The wider region naturally shoals against the Stephen and D'Urville Island's coastlines to the south and east.

Two regional cross sections that span the extent of the surveyed area (Figure 4-4) illustrate regional morphologic features such as sediment current-generated bedforms (waves and ripples) in the west portion of Site 2.3, depressions proximal to D'Urville Island and pass nearby along strike features in the south. These features are described in detail in Section 4.4 below.

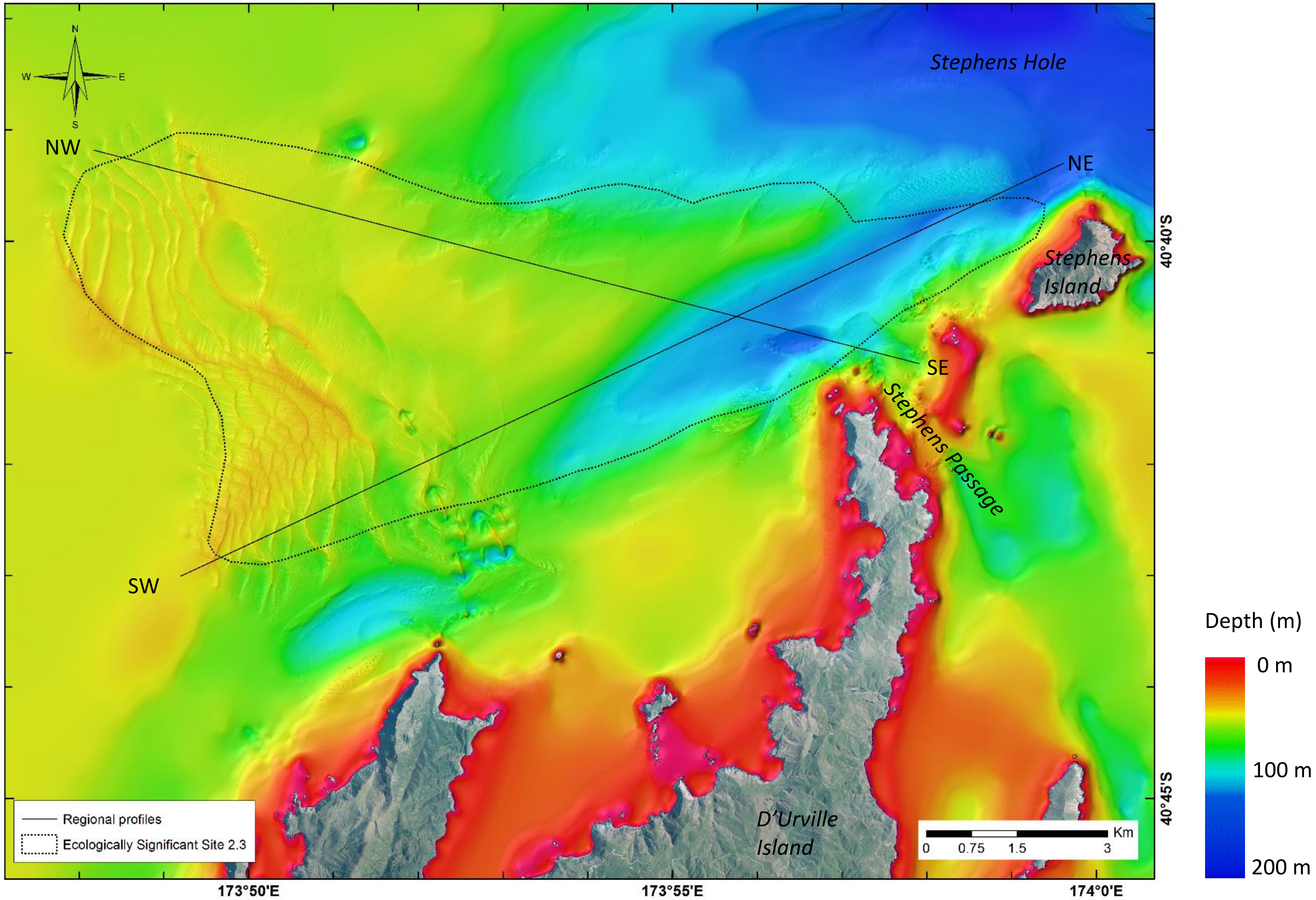


Figure 4-1: Sun illuminated digital elevation model (DEM) of Marlborough District Council Significant Ecological Site 2.3. Surrounding DEM sourced from NIWA's high resolution bathymetric database. The key shows the colour ramp used to depict bathymetry (water depth, in metres), with red shallowest and blue deepest. Location of regional profiles (Figure 4-3) also shown.

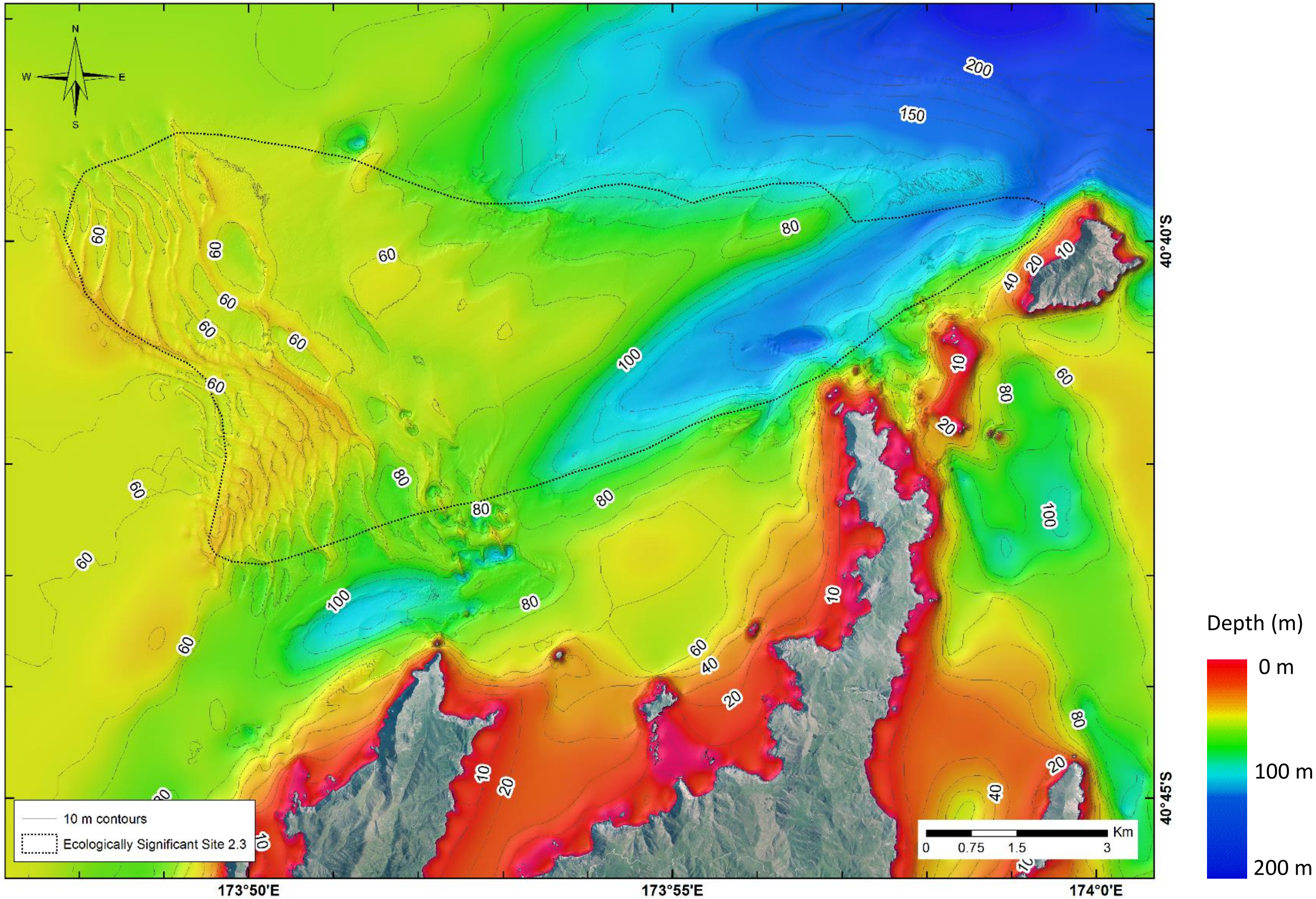
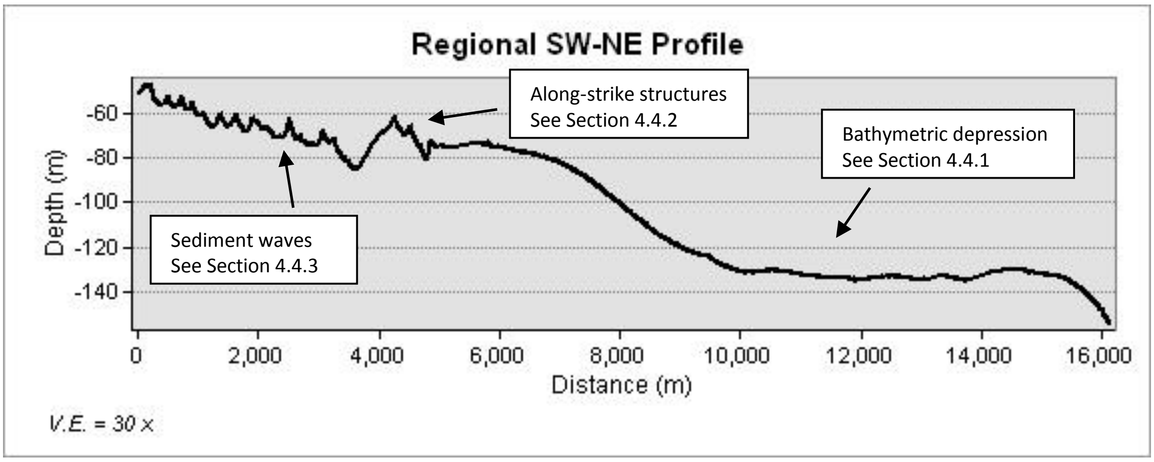


Figure 4-2: Bathymetric contours at 10 m interval for Site 2.3. Surrounding contours outside of Site 2.3 sourced from NIWA's high-resolution bathymetry database.



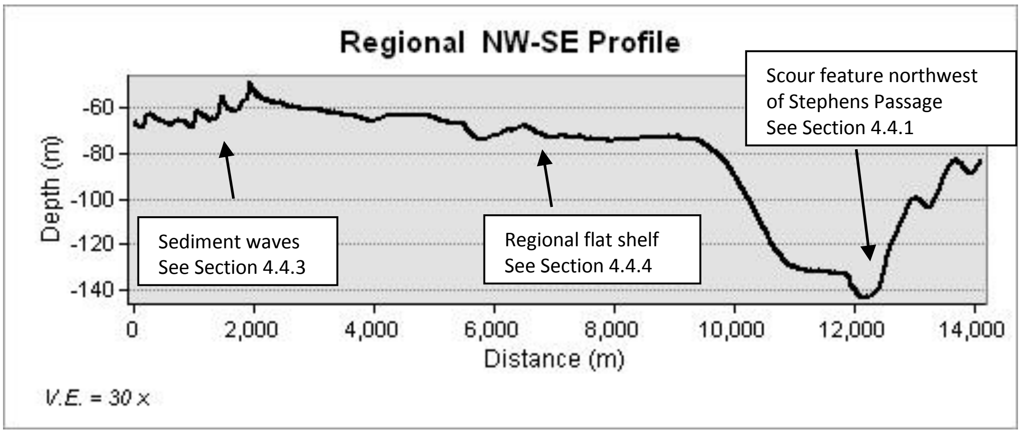


Figure 4-3: Bathymetric profiles from Site2.3. Location of profiles shown on Figure 4-1.

4.2 Backscatter Imagery

Backscatter imagery 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). Backscatter data are usually displayed using a grey-scale palette. Here, high reflectivity (coarse sediment) is represented by light grey or white and low reflectivity areas (muddy/fine sediment) as dark grey or black (Figure 4-4).

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).

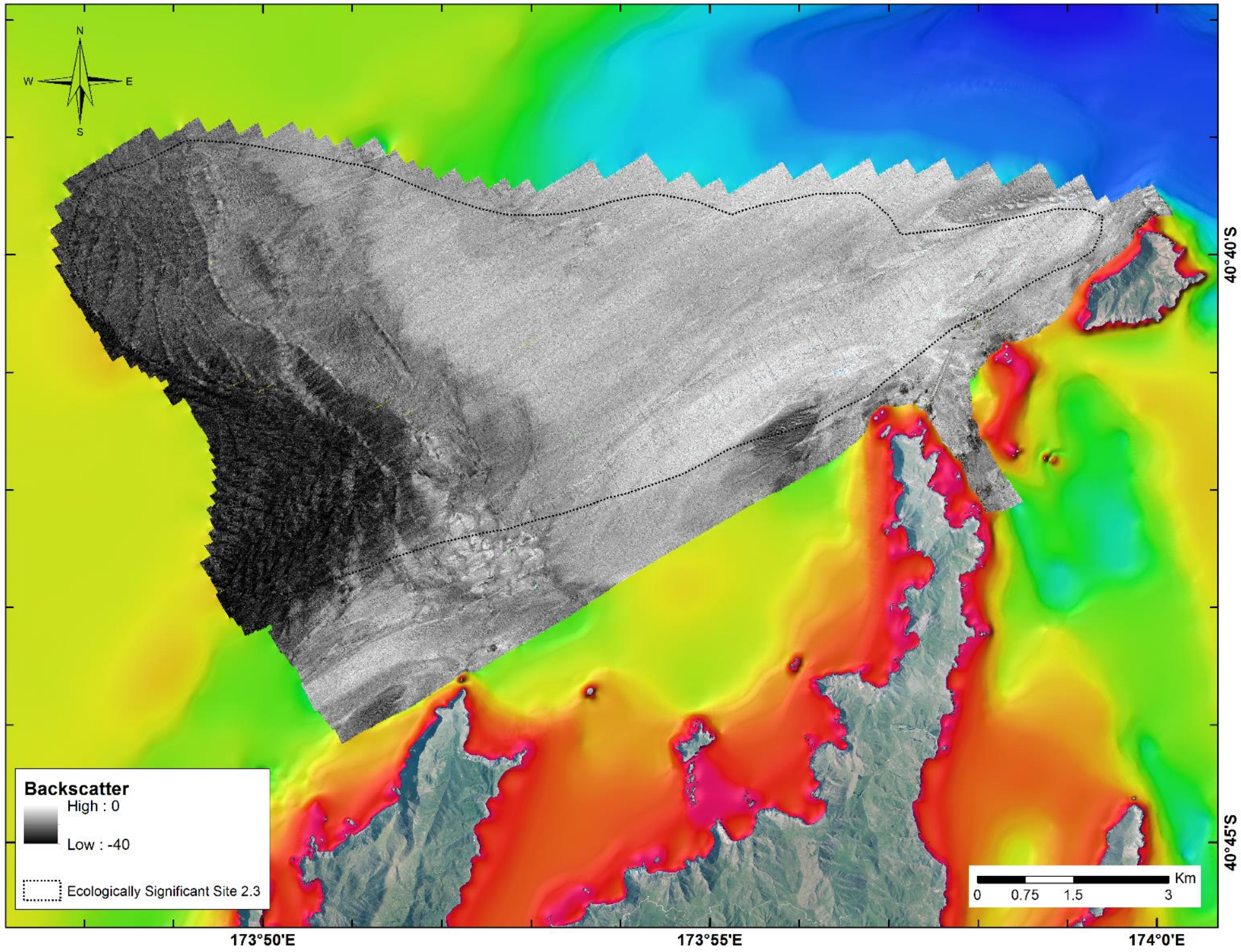


Figure 4-4: Backscatter imagery from Site 2.3. Areas of high reflectivity (coarse sediment) are represented by light grey and low reflectivity (muddy/fine sediment) are displayed as dark grey or black.

4.3 Water Column

Water column data collected at Site 2.3 predominately indicate the turbulent nature of the water column and the strong influence of tides. Stacked views of the water column data are illustrated in Figure 4-5 and show water turbulence in Stephens Passage and turbulence associated with ridges or nearshore rocky reefs (Figure 4-5A, 4-5B), as well as indicating the presence of a deep water mass and/or turbulence in the depression north of Stephens Island (Stephens Hole) (Figure 4-5C). A potential school of fish were identified only at nearshore rocky reefs proximal to Site 2.3 (Figure 4-5D).

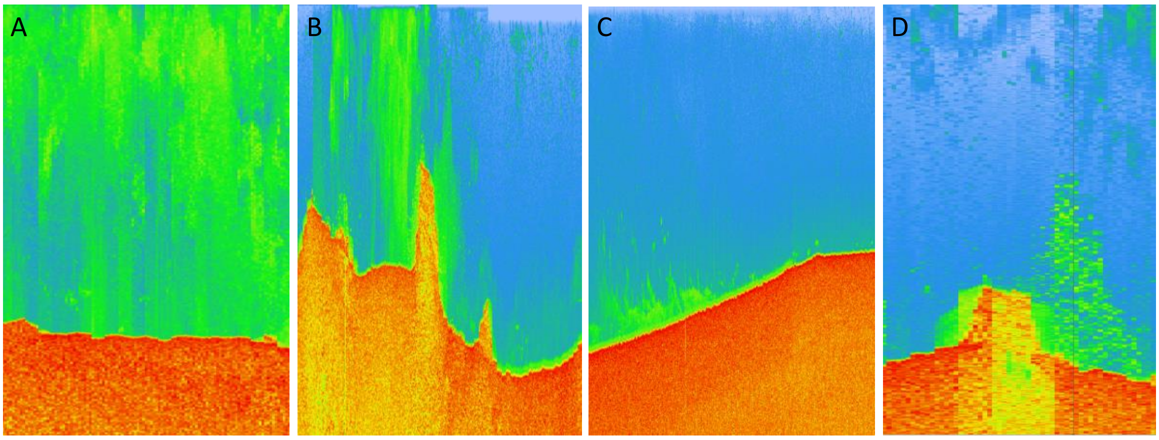


Figure 4-5: Examples of water column data from Site 2.3. A- Water turbulence in Stephens Passage; B- Water turbulence associated with ridges; C – Indication of presence of a deep water mass; D – Dotted mid water target indicating schooling fish.

4.4 Geomorphologic features

The bathymetry and backscatter data can be interpreted together to identify and describe a variety of geomorphic features within Site 2.3. These include bathymetric depressions, strike ridges, sediment waves, disturbed seafloor and rocky reefs.

4.4.1 Bathymetric depressions

Seafloor depressions form a natural boundary for Site 2.3 to the north (Stephens Hole) and east, offshore from the headlands of Stephens and D'Urville Island (Figure 4-6). The large depression to the northeast is ~9 km long and over 2 km wide and reaches depths of ~140 m (Figure 4-3). The backscatter data indicate that these depressions are predominately highly reflective seafloor and therefore indicative of coarse sediments. They are the result of erosion and scour of the seafloor as a consequence of accelerated tidal flows around the headlands. Here, all-depth average speeds are up to 0.8 ms^{-1} and sufficient to resuspend and transport very coarse sand (e.g. Tucker 1987).

Another scour hole occurs west of Stephens Passage. This feature is up to 1 m long, ~500 m wide and erodes ~40 m into the seafloor. This feature is likely the result of enhanced currents created by constriction over, and through, Stephens Passage. As currents and/or tidal flows relax with distance from the headlands and Stephens Passage sediment deposition occurs, evinced by a lobe of sediment ~ 1 km long and 40 m high immediately south of the seafloor depression and scour hole. The surface of this depositional lobe has irregular sediment megaripples with wave heights of up to 1 m and wave lengths (crest to crest) of 60–100 m (Figure 4-7). A depositional lobe is also associated with Stephens Hole north of Site 2.3

No seafloor photography is available within these depressions and holes, however NIWA archival photographs of the seafloor substrate to the south of Site 2.3, proximal to seafloor depressions, show gravel lag and winnowed underlying sediment. Here, the species richness suggests a developing invertebrate landscape including the encrusting form of the bryozoa *Cellaporaria agglutinans* or 'Separation Point coral'. Gordon and Bradstock (1983) and Gordon (1989) tabulate 93 spp. of bryozoan at station D273 to the east of these seafloor images, and proximal to a seafloor depression and accelerated tidal flows (Figure 4-8, and Figures 2-2 to 2-3).

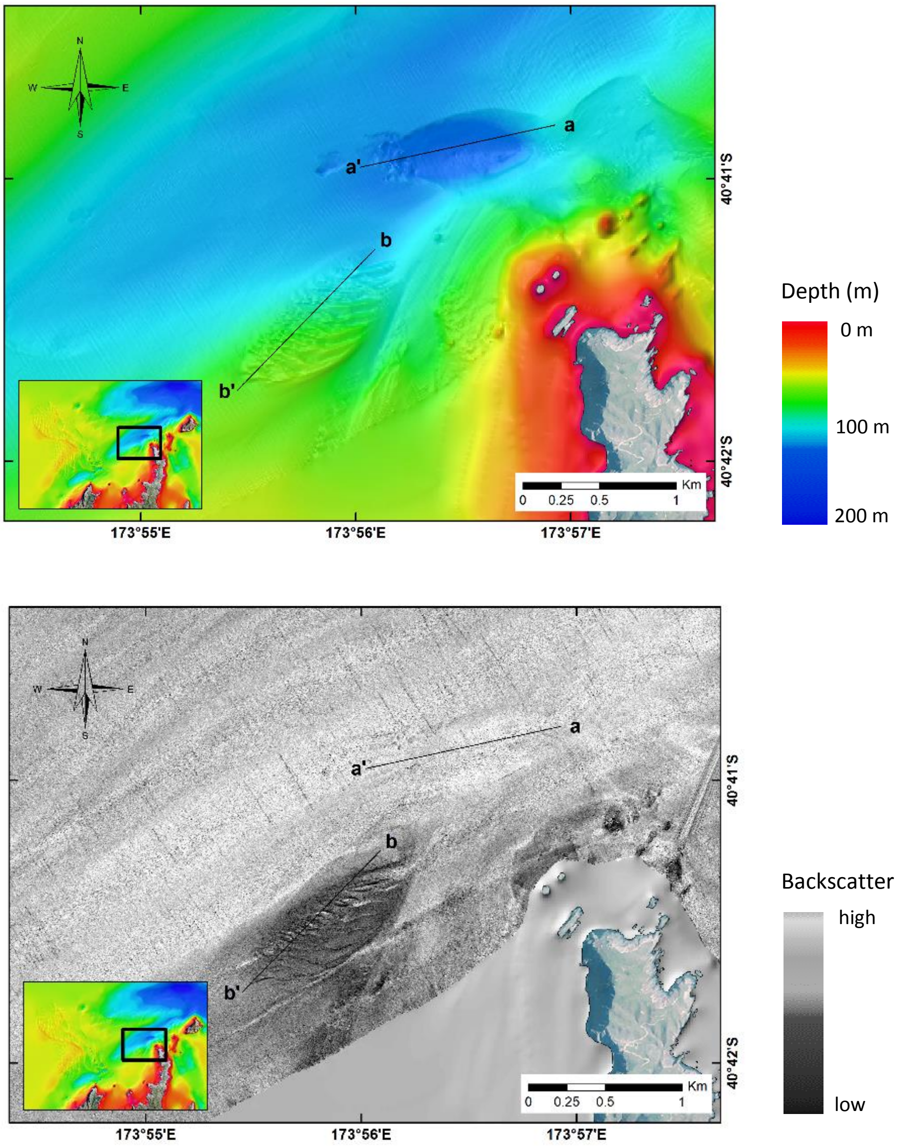


Figure 4-6: Bathymetry and backscatter imagery illustrating seafloor depressions immediately west of Stephens Passage and D'Urville Island.

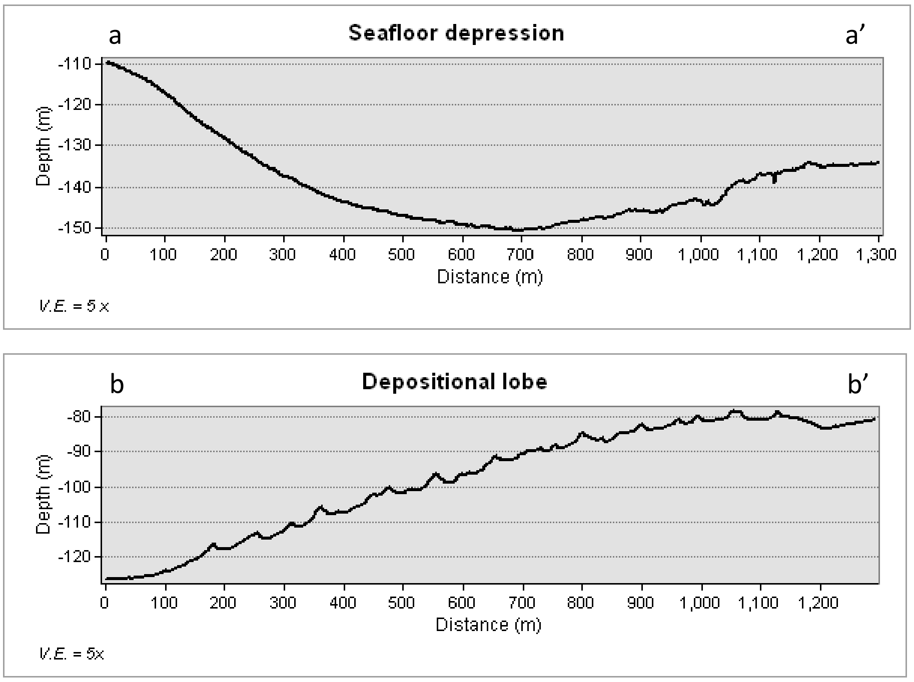


Figure 4-7: Bathymetric profiles from a seafloor hole within a wider seafloor depression west of Stephens Passage and D'Urville Island (top) and a depositional lobe of sediment illustrating irregular and asymmetric megaripples (bottom). Location of these profiles is shown on Figure 4-6.

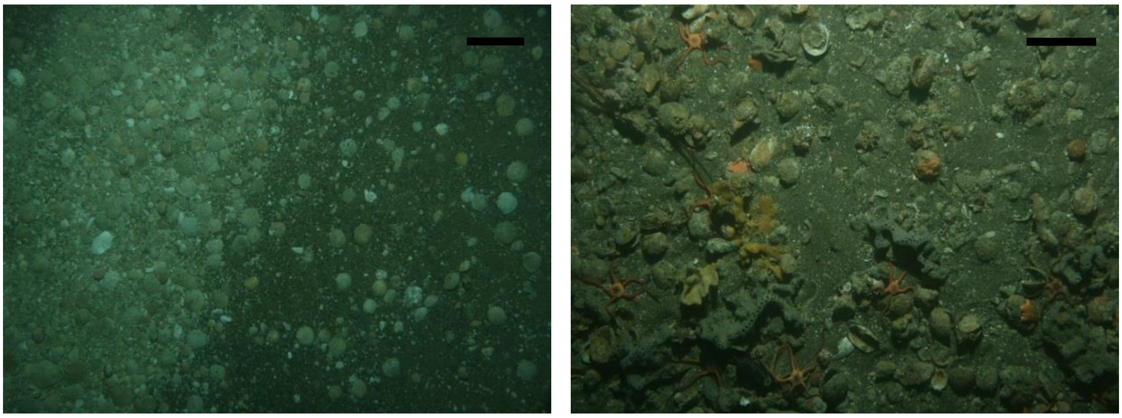
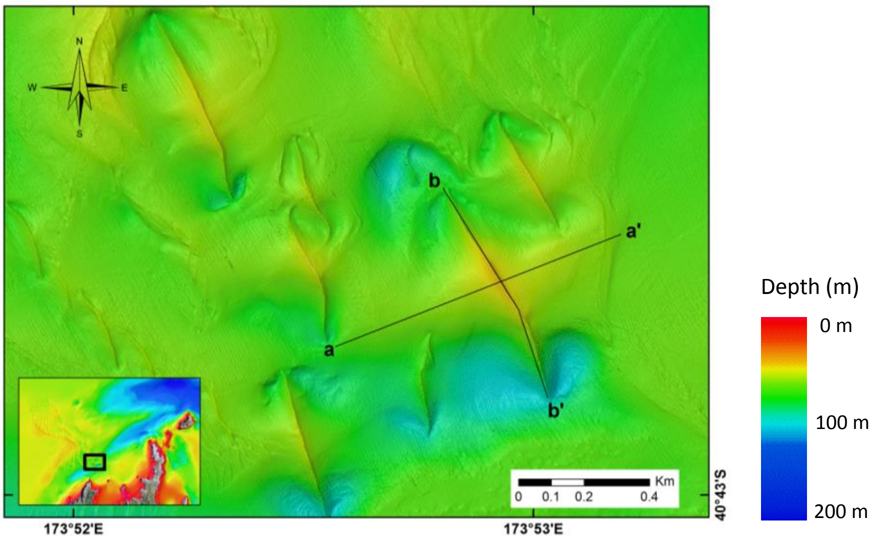


Figure 4-8: Selected seafloor photographs from Station 150 within a seafloor depression south of Site 2.3. Image on left illustrates a gravel lag and winnowed finer-grained underlying sediment. Image on right is indicative of a developing invertebrate landscape and illustrates visible fauna such as ophiroids, sponges, sea stars, turret shells, and the encrusting form of the bryozoa *Cellaporaria agglutinans*. Scale bars show 0.2 m. Location of Station 150 shown on Figure 2-3. *Images were collected as part of the Biogenic Habitats on the Continental Shelf project (Jones et al. unpublished).*

4.4.2 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. These strike ridges occur north of one of the major seafloor depressions identified in Site 2.3 (Figure 4-9) and protrude ~30 m above the surrounding seafloor and are ~ 600 m in length (Figure 4-10). Their along-ridge profiles are often concave as a consequence of erosion at their extremities (Figure 4-9). 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.



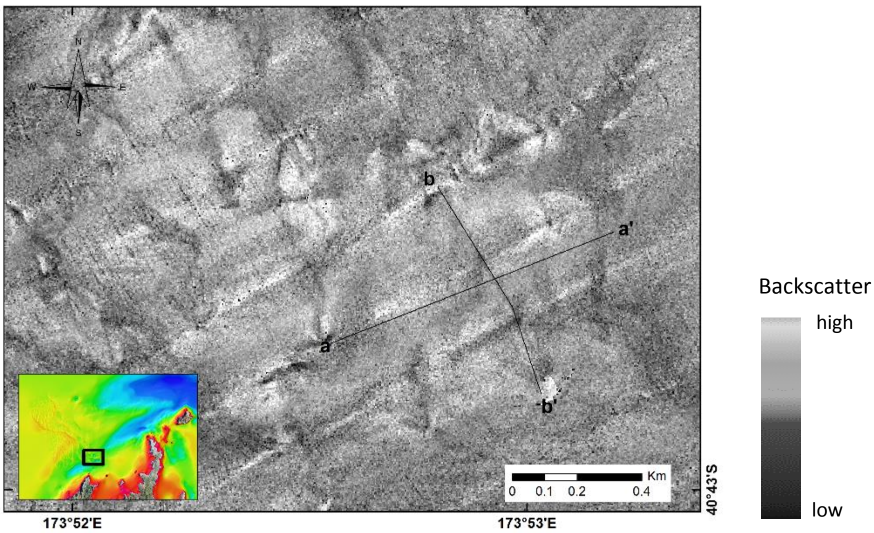
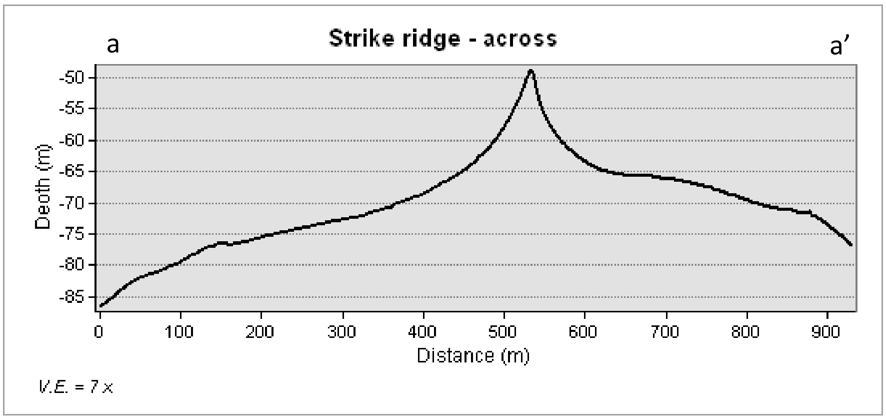


Figure 4-9: Bathymetry and backscatter imagery of strike ridges north of a major seafloor depression north Site 2.3.



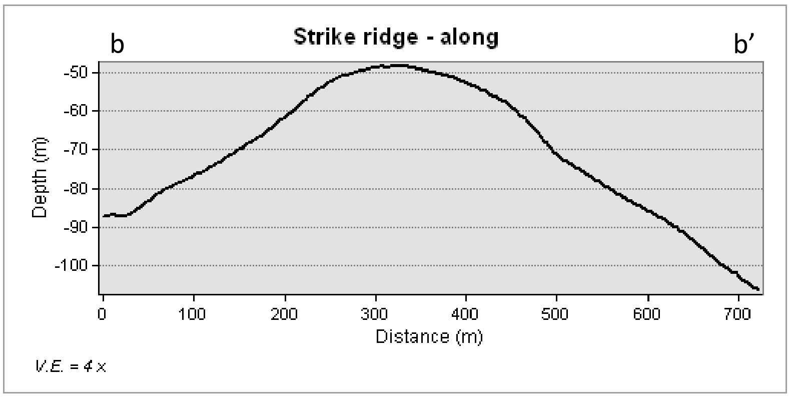


Figure 4-10: Bathymetric profiles across SW-NE (top) and along NW-SE (bottom) a strike ridge. Location of profiles are shown on Figure 4-9.

4.4.3 Sediment Waves

A prominent geomorphologic feature of Site 2.3 is an extensive sediment-wave field in the west and southwest (Figure 4-11 and Figure 4-12). 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 4-13). Sand waves can develop extensively with flows of up to ~ 0.7 ms^{-1}. Oscillating tidal flows can enhance the height (amplitude) of these features and generally result in symmetrical features, however a directional dominance of tidal flows or tidal asymmetry results in asymmetrical bedforms with the steeper lee slope facing downstream. Sediment is generally eroded from the shallower slope and transported to the wave crest, where an increase in turbulence and decrease in flow results in sediment falling out of suspension and being redeposited down the steeper slope. The asymmetrical nature of the bedforms is apparent in Figure 4-13. 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.

Smaller bedforms and megaripples, occur on top of the sediment waves (Figure 4-12 and Figure 4-13), with amplitudes of up to 1 m and wavelengths (crest to crest) of ~ 10 m. Megaripples frequently have smaller ripples on their backs. Consequently a lower backscatter reflectivity signal is returned, which may be related to finer substrate or a consequence of the complex nature of the seafloor roughness scattering the return signal (e.g. Lamarche et al. 2011) (Figure 4-11).While no seafloor photographs are available within the surveyed sediment-wave field of Site 2.3, images of the seafloor to the south of Site 2.3 considered to be an extension of the surveyed sediment-wave field, illustrate smaller sediment ripples with wavelengths of ~10-20 cm (Figure 4-14). This supposition of bedforms is considered to be a consequence of storm or fluctuating flows. One biological station (D272) is recorded in Site 2.3, located within the sediment-wave field, with 65 spp. of bryozoan reported to occur by Gordon (1989).

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.

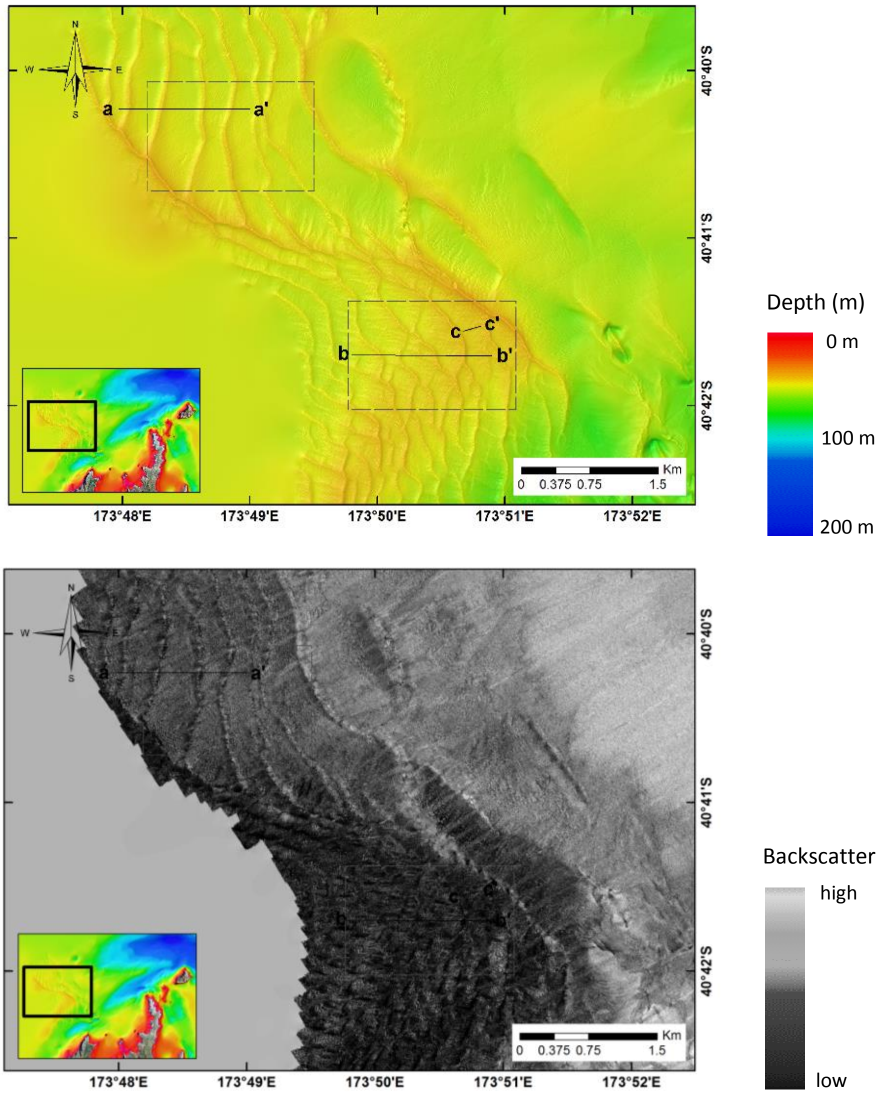


Figure 4-11: Bathymetry and backscatter imagery illustrating prominent sediment wave and ripple bedforms.

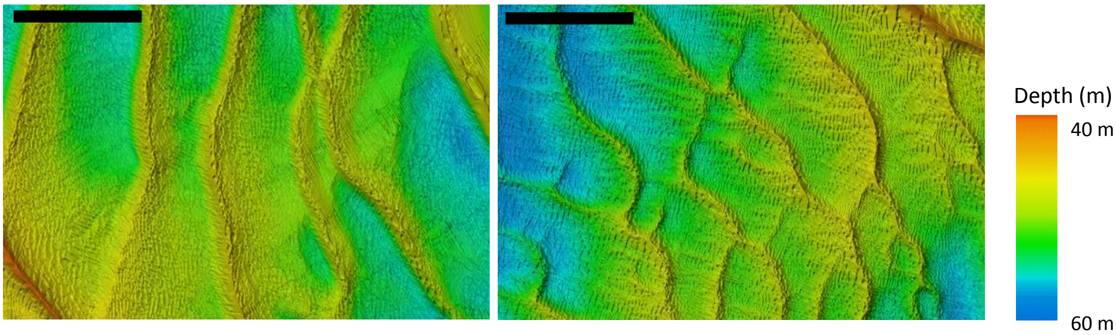


Figure 4-12: Close up MBES bathymetric images for the northern sediment-wave field (left) and southern sediment-wave field (right) illustrating the superposition of sediment waves, megaripples and ripples. Scale bars indicate 500 m. Locations shown on Figure 4-11.

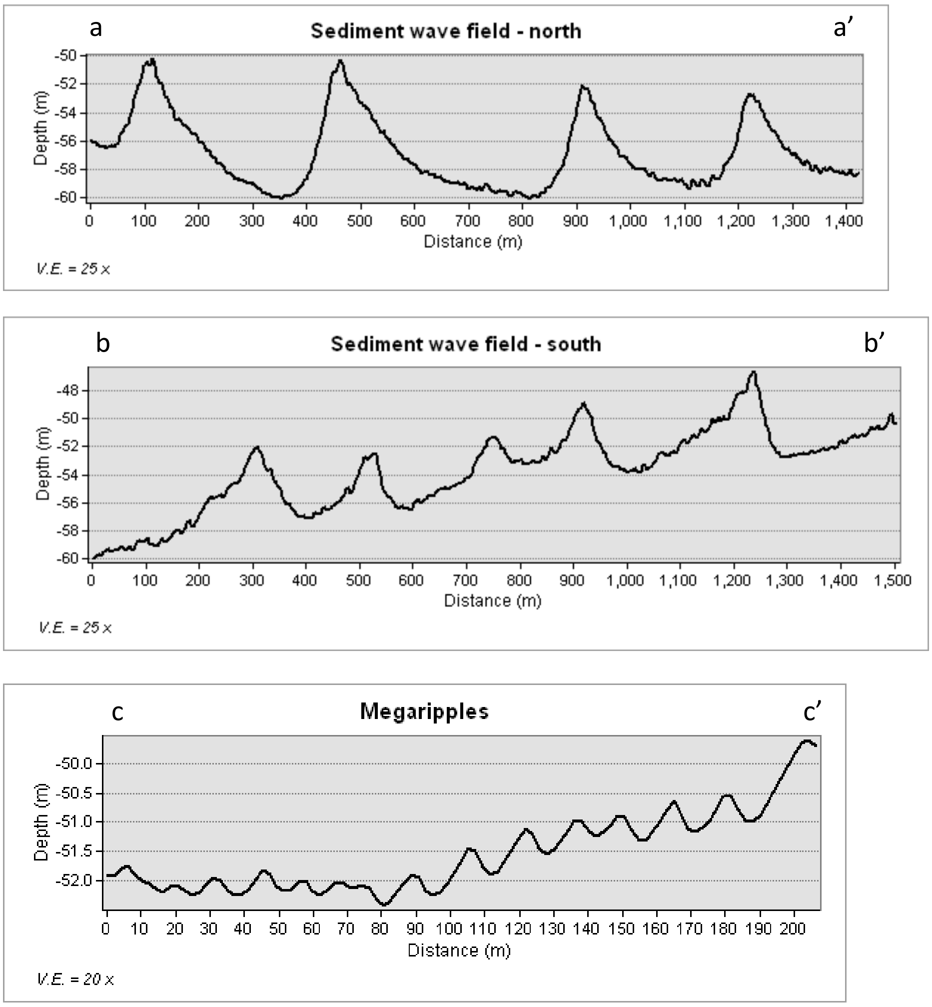


Figure 4-13: Bathymetric profiles across sediment-wave fields (northern - top and southern - middle) and megaripples (bottom). Location of profiles are shown on Figure 4-11.

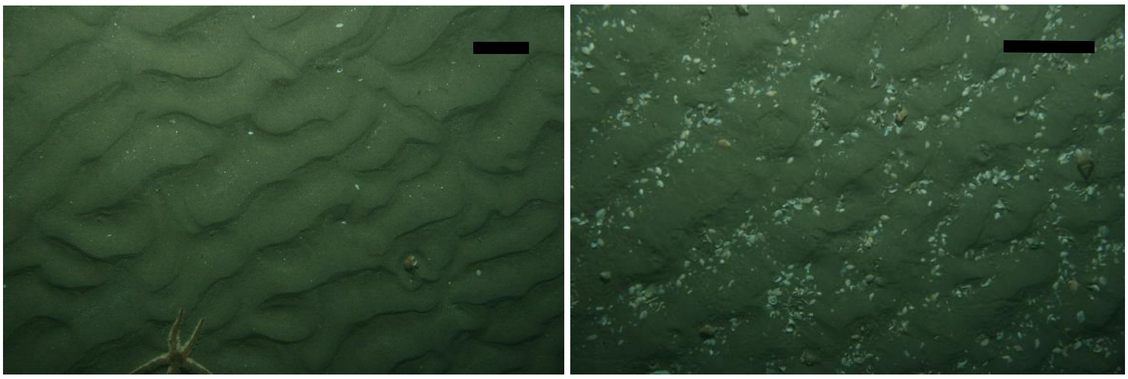
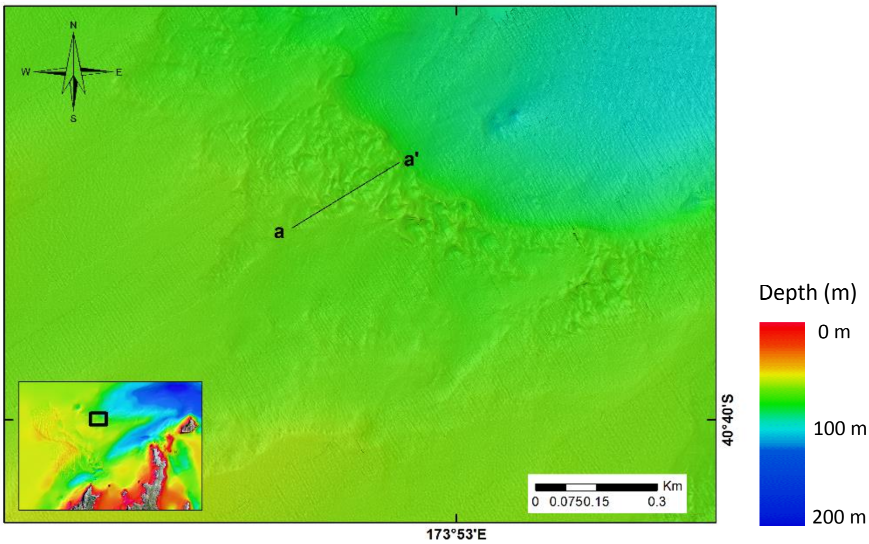


Figure 4-14: Selected seafloor images from Station 152 (left image) and Station 153 (right image), south of Site 2.3 illustrating sediment ripples. Image on left illustrates sediment ripples and biota (*Astropecten* sp. and hermit crab) upon a sandy substrate. Image on right shows sediment ripples upon a sandy substrate with a coarser grained shell hash (calcareous gravel). A hermit crab is again visible. Scale bars indicate 0.2 m. Location of stations is shown on Figure 2-3. *Images were collected as part of the Biogenic Habitats on the Continental Shelf project*.

4.4.4 Disturbed seafloor and irregular bedforms

The well-defined bedforms (e.g. sediment waves and mega ripples) that occur in the west and southwest of Site 2.3, pass into flat-lying seafloor and more irregular bedforms at depths of 60–80 m in the northeast of Site 2.3 (Figure 4-3), on the flanks of Stephens Hole (Figure 4-15). The occurrence of these irregular features spans several hundred metres and topography ranges from <1–3 m in height (Figure 4-16). They may form through a combination of enhanced downslope sediment movement (under gravity) and energetic oscillatory tidal flows on the slopes of Stephens Hole. Water column data shows turbulence associated with the steeper gradients around Stephens Hole (Figure 4-5C).



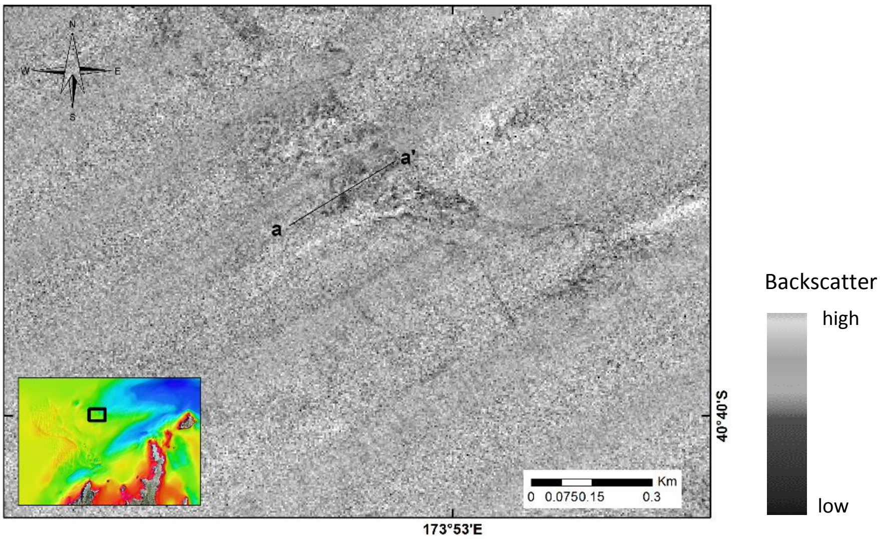


Figure 4-15: Bathymetry and backscatter imagery illustrating disturbed seafloor in the northeast.

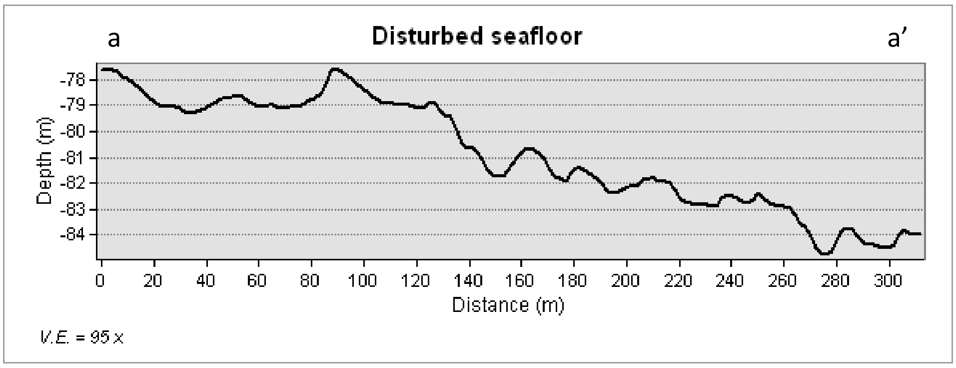


Figure 4-16: Bathymetric profile across disturbed seafloor in the northeast. Location of profiles shown on Figure 4-15.

4.4.5 Rocky reef

Vessel transits during the survey to and from Site 2.3 and the vessel mooring location were through Stephens Passage. Stephens Passage is a relatively shallow area (<50 m water depth) with enhanced tidal flows. The transit MBES data illustrates the nature of the rocky reef with low backscatter reflectivity as a consequence of the complex nature of the rocky seafloor topography scattering the return signal (e.g. Lamarche et al. 2011) (Figure 4-17 and Figure 4-18). Areas of seafloor surrounding the rocky reef and boulders returns high backscatter reflectivity indicative of coarse-grained sediments, and water column data record mid water targets potentially indicative of schooling fish. The substrate in this area were reported by Davidson et al. (2011) to comprise of rocky outcrops with common macroalgae (seaweed) (Figure 4-19) giving way to coarse sand, pebbles and cobbles below 18 m. It is also a region where high densities of small blue cod have been observed.

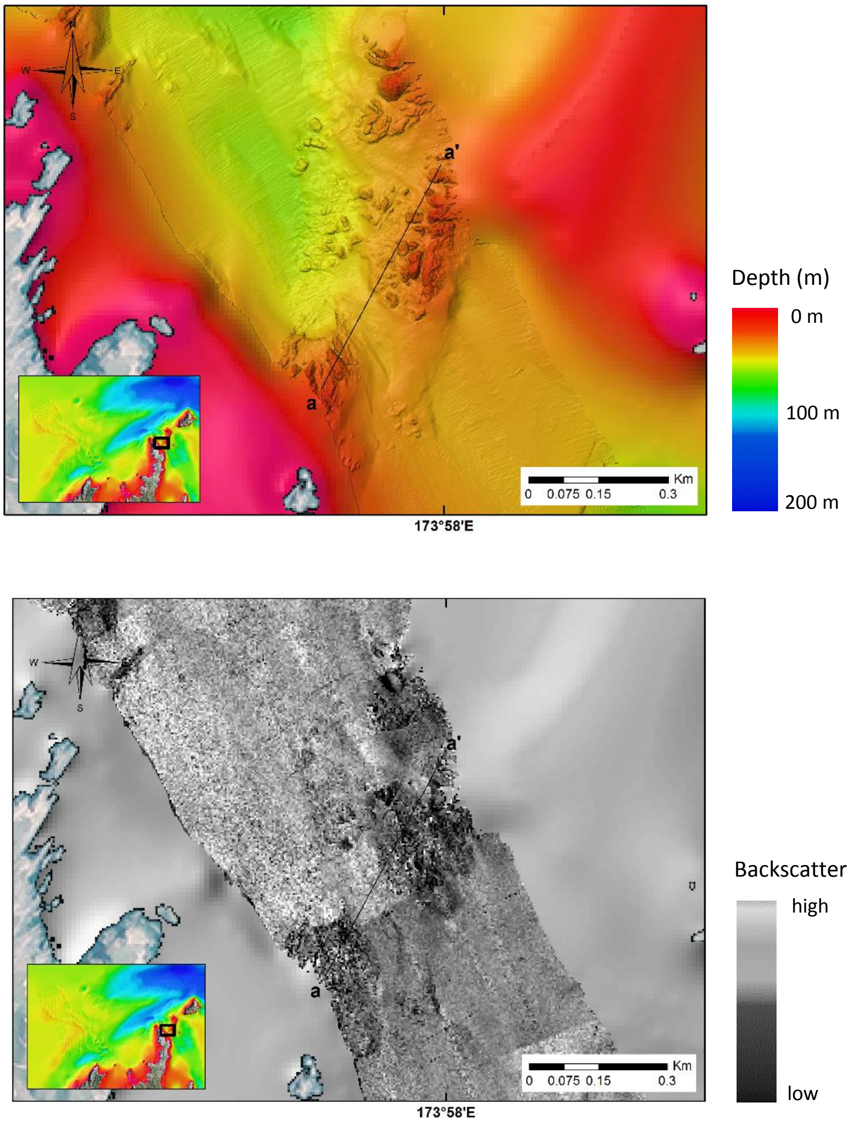


Figure 4-17: MBES bathymetry and backscatter imagery illustrating an indicative section of seafloor through Stephens Passage.

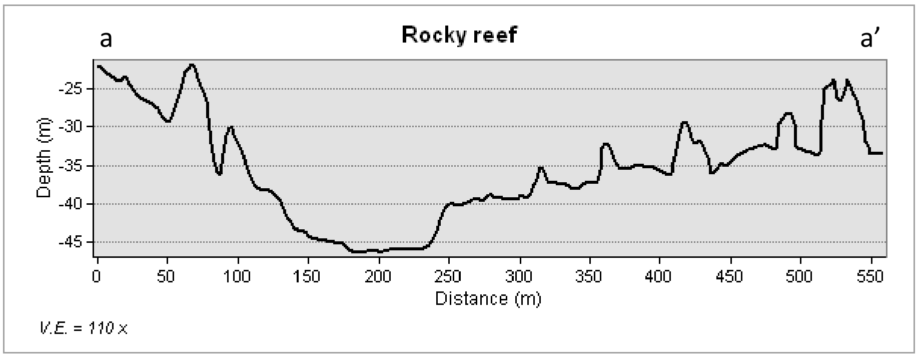


Figure 4-18: Bathymetric profile across Stephens Passage illustrating the rocky reef. Location of profile is shown on Figure 4-14.

Figure 4-19: Indicative image of macroalgae (*Marginareilla boryana,* seaweed) around the coastline of Stephens Passage. Image courtesy of Malcolm Francis, NIWA.

4.5 Comparison of Site 2.3 with Separation Point (Abel Tasman)

Biogenic habitats on the *Biogenic Habitats on the Continental Shelf* project collected a MBES transect off Separation Point, across a bryozoan bed area (known as the 'Separation Point coral'). Backscatter imagery showed patches of highly reflective seafloor, indicative of hard or coarse-grained substrate within a background of low reflectivity typical of finer sediments (mud) (Figure 4-20). This acoustic character is most likely due to patches of bryozoans (Jones et al. unpublished). Similar imagery is not observed within Site 2.3, however, this does not preclude the occurrence of bryozoans or *Celleporaria agglutinans* ('Separation Point coral') in particular. It likely illustrates the stronger contrast in substrate types at Separation Point: low reflectivity muds versus high reflective hard bryozoan patches. In addition, high reflectivity coarse sediments (sand and gravel) are more predominant at Site 2.3. Moreover, *Celleporaria agglutinans* growth form ranges from colony encrusting to erect, massive and foliose (Gordon, 1989); the latter has been documented at Separation Point (Bradstock and Gordon 1983; Grange et al. 2003) whereas the only available seafloor imagery proximal to Site 2.3 indicates only the presence of encrusting growth forms (Figure 4.8).

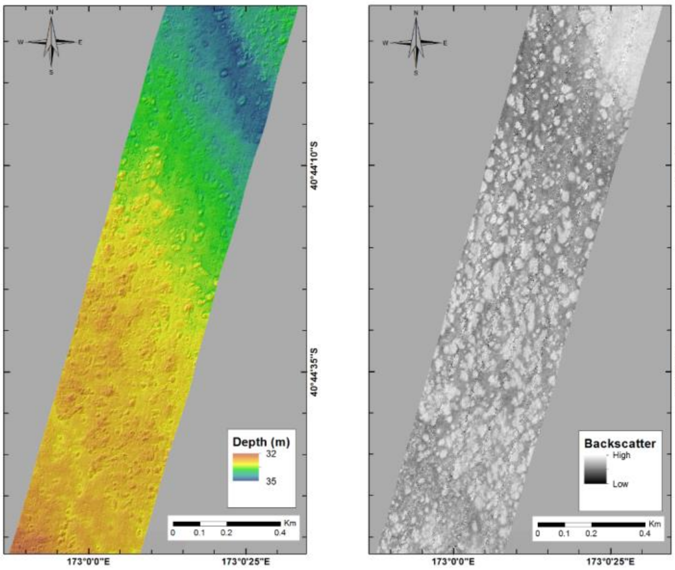


Figure 4-20: Bathymetry and backscatter imagery illustrating a section of the Separation Point transect. Bathymetry (left) and backscatter (right) illustrating the highly reflective patches considered to be composed of bryozoa. *Mulitbeam imagery was collected as part of the Biogenic Habitats on the Continental Shelf project* (Jones et al. unpublished).

4.6 Benthic Terrain Model

The digital elevation model (DEM) produced from this bathymetric survey can be used within a benthic terrain model (BTM) which classifies the seafloor into zones based on variations in the bathymetry. 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, and can form the basis of targeted photographic and sampling programmes.

Terrain classifications used here are illustrated below (Figure 4-21 to Figure 4-24) and a complete set are provided within a standalone A2 graphic portfolio. 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 4-25). 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.

Collection of imagery and/or samples across the five geomorphic features (depressions, strike ridges, sediment waves, disturbed seafloor) and four dominant BTM classifications (flat plains, broad slopes, flat ridge tops, and broad depression and rock outcrops) is recommended. The geomorphic features and seafloor classifications are not mutually exclusive, hence particular targets would be: the sediment-wave fields with their high slopes, rough crests and indication of species richness from a single archival sample site (D272); the slopes of, and seafloor proximal to, broad seafloor depressions with nearby seafloor photography, and a single archival sample site (D273), indicating these may be areas of developing invertebrate landscapes; the emergent strike ridges with increased seafloor roughness indicates these could be features with potential high biodiversity; and the flat-lying seafloor. Outside of Site 2.3 the nearshore rocky reefs are another potential target.

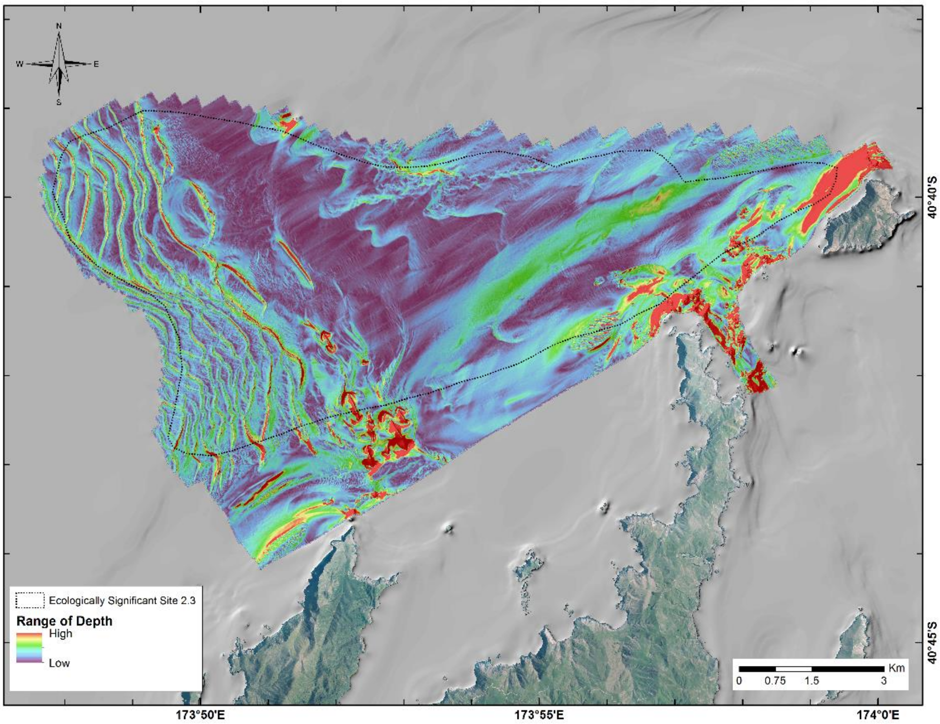


Figure 4-21: Depth range terrain classification. Areas of greatest difference between minimum and maximum depth within each 30 x 30 m window are associated with downslope (lee side) of sediment waves, strike ridges and the nearshore. More moderate difference occur on slopes flanking broad seafloor depressions.

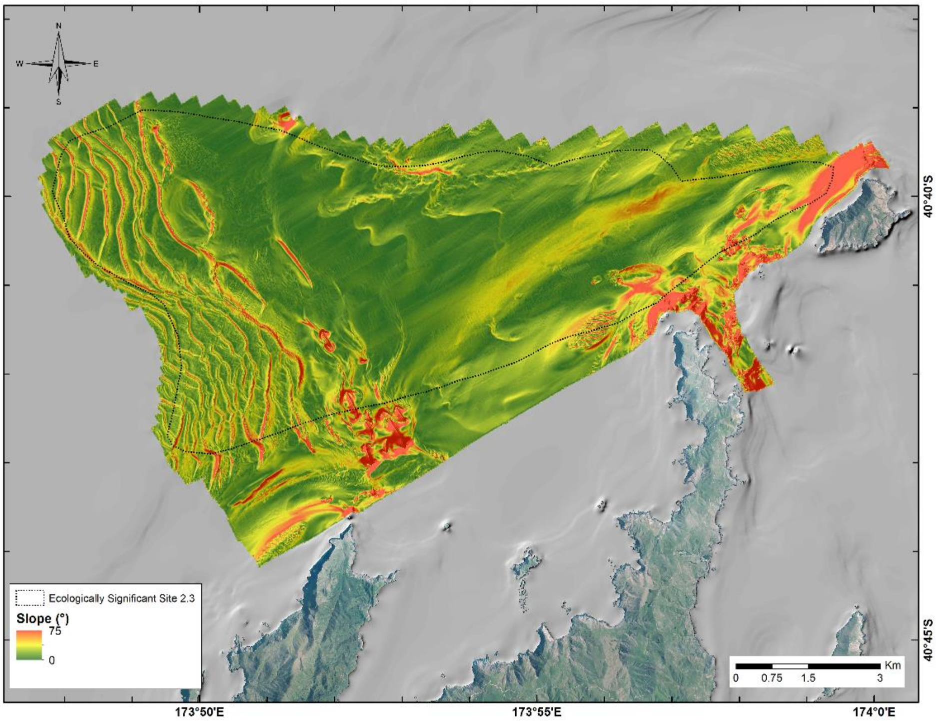


Figure 4-22: Slope terrain classification. Areas of high slope (greater angle from the horizontal of each 30 x 30 m window) are associated with downslope (lee side) of sediment waves, strike ridges and nearshore.

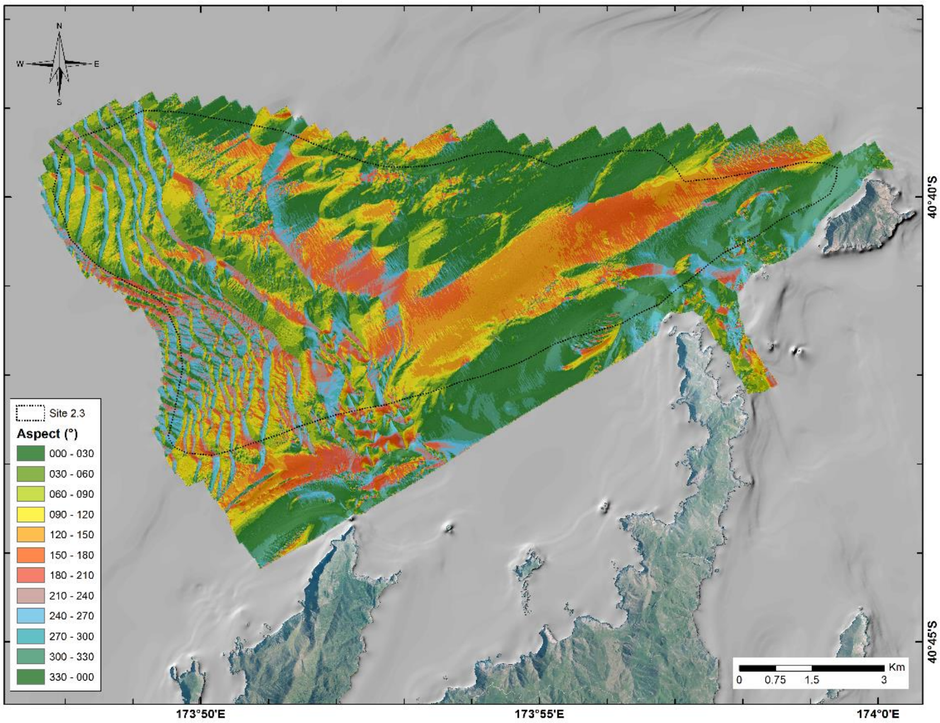


Figure 4-23: Aspect terrain classification. Direction of the downslope dip (within each 30 x 30 m window) illustrates the north-northeast descent into Stephens Hole and changing direction of the downslope (lee side) of sediment waves between the northern (240-300°, west) and southern (30-90°, east-northeast) fields.

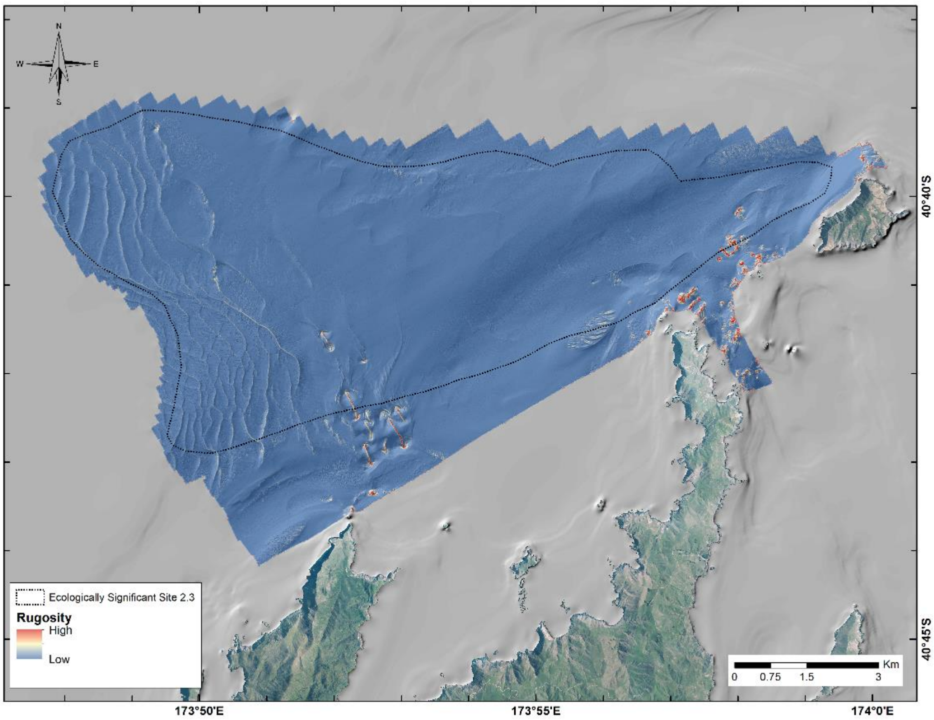


Figure 4-24: Rugosity terrain classification. Areas of high rugosity (red) or increased seafloor roughness (within each 30 x 30 m window) are associated with crests of strike ridges and nearshore rocky reefs, moderate rugosity is also associated with the crests of the sediment waves.

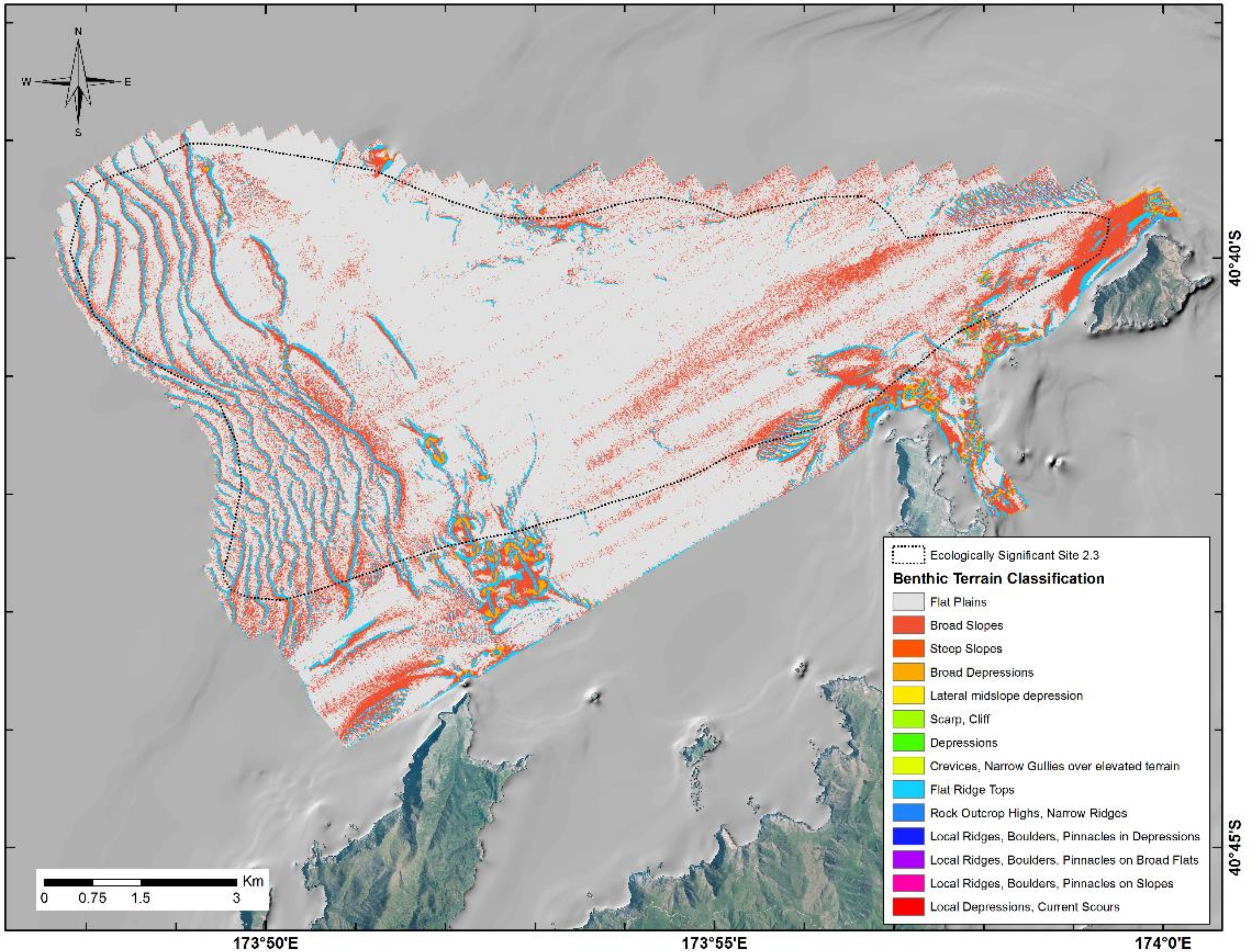


Figure 4-25: Benthic terrain classification of Site 2.3. This region of seafloor comprises 74% flat expanses of seafloor, 17% broad slopes, 7% flat ridge tops, and 1% broad depressions and rock outcrops.

5 Summary

- The MDC recently identified a number of ecologically significant marine sites, with Site 2.3 occurring as a ~6000 ha area to the northwest of D'Urville Island.
- A joint mapping initiative between MDC and NIWA using NIWA's shallow-water, high resolution MBES was undertaken to map the seafloor and identify habitat types.
- The MBES survey area encompassing Site 2.3 collected ~93 km^2 of new multibeam bathymetry, consisting of over 200 million soundings to produce a bathymetric surface with a 2 m and 10 m grid resolution.
- The bathymetry, backscatter and water column data were interpreted together to describe a variety of geomorphic features within Site 2.3. These features include bathymetric depressions, strike ridges, sediment waves, disturbed seafloor and rocky reef.
- BTM's were 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.
- The BTM classification and geomorphic features can form the basis of targeted photographic and sampling programmes. Specific targets within Site 2.3 could be the sediment-wave fields, the slopes of the broad seafloor depressions, the emergent strike ridges and the flat-lying seafloor. Outside of Site 2.3 the nearshore rocky reefs are another potential target.
- The resultant map scheme derived from NIWA's survey classifies Site2.3 (and the adjacent surveyed area through Stephens Passage) as 74% flat plains, 17% broad slopes, 7% flat ridge tops, and 1% broad depression and rock outcrops.
- NIWA has produced a range of digital and charting products that can be used by the MDC to inform habitat types and future sampling in this location near D'Urville Island.
- 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 environment.

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Tidal model from Mark Hadfield, NIWA.

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Legacy data sourced from NIWA data catalogue.

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7 References

Bradstock, M.; Gordon D.P. (1983). Coral-like bryozoan growths in Tasman Bay, and their protection to conserve fish stocks. *New Zealand Journal of Marine and Freshwater Research* 17: 159-163.

Carter, L. (1992). Acoustical characteristics of seafloor sediments and its relationship to active sedimentary processes in Cook Strait, New Zealand. *New Zealand Journal of Geology and Geophysics* 35: 289-300.

Carter, L.: Lewis, K.B. (1995). Variability of the modern sand cover on a tide and storm driven inner shelf, south Wellington, New Zealand. N*ew Zealand Journal of Geology and Geophysics* 38 (4): 451-470.

Davidson, R. J.; Duffy, C.A.J.; Gaze, P.; Baxter, A.; DuFresne, S.; Courtney, S.; Hamill, P. (2011) *Ecologically significant marine sites in Marlborough, New Zealand.* Co-ordinated by Davidson Environmental Limited for Marlborough District Council and Department of Conservation.

Gordon, D.P. (1989). The marine fauna of New Zealand: Bryozoa: Gymnolaemata (Cheilostomida Ascophorina) from the western South Island continental shelf and slope. *New Zealand Oceanographic Institute Memoir* 97: 1–158.

Grange, K.R.; Tovey, A.; Hill, A.F. (2003). The spatial extent and nature of the bryozoan communities at Separation Point, Tasman Bay. *Marine Biodiversity Biosecurity Report 4*, 22 p.

Heath, R.A. (1978). Semidiurnal tides in Cook Strait. *New Zealand Journal of Marine and Freshwater Research* 12: 87-97.

Heath, R.A. (1982). Generation of the M4 tide in Cook Strait, New Zealand. *Ocean Dynamics* 35: 261-270.

Hughes Clarke, J.E.; Mayer, L.A.; Wells, D.E. (1996). Shallow-water imaging multibeam sonars: A new tool for investigating seafloor processes in the coastal zone and on the continental shelf. *Marine Geophysical Researches* 18(6): 607-629.

Jackson, D.R.; Briggs, K.B. (1992). High-frequency bottom backscattering: Roughness versus sediment volume scattering. *Journal of the Acoustical Society of America* 92(2): 962-977.

Jones, E.G.; Morrison, M.A.; Davey, N.; Mills, S.; Pallentin, A.; George, S.; Kelly, M.; Shankar, U. (unpublished). Biogenic habitats on New Zealand’s continental shelf. Part II: National field survey and analysis. New Zealand Aquatic Environment and Biodiversity Report.

Lamarche G.; Lurton X.; Verdier A-L.; Augustin J-M. (2011). Quantitative characterisation of seafloor substrate and bedforms using advanced processing of multibeam backscatter – Application to Cook Strait, New Zealand. *Continental Shelf Research*, 31: S93-S109.

Lewis, K.B.; Carter, L.; Davey, F.J. (1994). The opening of Cook Strait: interglacial tidal scour and aligning basins at a subduction to transform plate edge. *Marine Geology* 116(3/4): 293-312.

Lewis, K.B.; Mitchell, J.S. (1980). Cook Strait sediments. 1:200,000 *New Zealand Oceanographic Institute Chart, Coastal Series*.

Neil, H.L.; Pallentin, A.; Mitchell, J. (2015a). Northwest D'Urville seafloor habitat maps: A2 map folio series. NIWA Client Report WLG2015-40.

Neil, H.L.; Pallentin, A.; Mackay, K.A.; Mackay, E.J.; Mitchell, J.S. (2015b). Beneath the waves: Northwest D’Urville. NIWA Miscellaneous Chart Series 96.

Neil, H.L.; Pallentin, A.; Mackay, K.A.; Mackay, E.J.; Mitchell, J.S. (2015c). Northwest D’Urville. NIWA Miscellaneous Chart Series 97.

Procter, R.; Carter, L. (1989). Tidal and sedimentary response to the Late Quaternary closure and opening of Cook Strait, New Zealand: results from numerical modelling. *Paleoceanography* 4:167-180.

Saxton, F.L. (1980). Coral loss could deplete fish stocks. *Catch '80* 7(8): 12–13.

Tucker, M.E. (1987). Sedimentary petrology. *Geoscience texts: Vol. 3*. Blackwell Scientific Publications (first published in 1981), Oxford, 252 pp. ISBN 0-632-00074-0.

Tuckey, B.J.; Gibbs, M.T.; Knight, B.R.; Gillespie, P.A. (2006). Tidal circulation in Tasman and Golden Bays: implications for river plume behaviour. *New Zealand Journal of Marine and Freshwater Research* 40: 305-324.

Vennell, R. (1994). Acoustic Doppler current profiler measurements of tidal phase and amplitude in Cook Strait, New Zealand. *Continental Shelf Research*, 14(4): 353-364.

Walters, R.A.; Goring, D.G., Bell, R.G. (2001). Ocean tides around New Zealand. *New Zealand Journal of Marine and Freshwater Research* 35(3): 567-579.

Wood, A.C.L.; Rowden A.A.; Compton T.J.; Gordon D.P.; Probert P.K. (2013). Habitat-Forming Bryozoans in New Zealand: Their Known and Predicted Distribution in Relation to Broad-Scale Environmental Variables and Fishing Effort. PLoS ONE 8(9): e75160. doi:10.1371/journal.pone.0075160

Appendix A Systems and Software Used

Kongsberg EM2040 Multibeam Echo-Sounder

The Kongsberg EM2040 is a multibeam echo-sounder system that measures the relative water depths across a wide swath perpendicular to the vessel's path. In its current configuration on the RV *Ikatere*, it uses one pair of transducers (sonar heads), the Tx and Rx respectively.

There are four main components of the basic EM2040 system: a pair of transducers, a Processor Unit, a video display, and an acquisition Operator Station computer. The transducers are mounted firmly underwater using a pole that descends through a moon-pool (Figure A-1). The other three components are placed inside the vessel for the operators use (Figure A-2).

The system operates by transmitting a sound, or a "ping" from the transducer head (Tx). The sound travels through the water column and is reflected by targets, the seabed, or any object that it "hits". The reflected signal is received through independent transducers (Rx), digitised and then sent to the processor unit, where the signal is converted to soundings.

The EM2040 operates over three (user selected) frequencies of 200, 300, and 400 kHz, has a very high ping rate of up to 50 Hz and a large number of measurements per ping (up to 800) The system beam width is 0.4°x0.7° or 0.5°x1.0° depending on frequency selected and has full electronic pitch, yaw and roll stabilisation (Table A-1). One hundred percent coverage of the bottom is achievable at vessel speeds of about 10 knots in shallow waters, with across track coverage of up to five times depth.

Depth vertical resolution is strongly variable depending on frequency used and pulse length. In inspection mode (400 KHz, very short pulse) 18 mm can be resolved, while in normal survey settings 5-50 cm (depending on depth) are realistic. The horizontal resolution of depth depends on the footprint of the beams (the area of seafloor insonified by one beam), and depends on the angular opening of the beams (Table A-1). For the EM2040 exemplary values are listed in Table A-2.

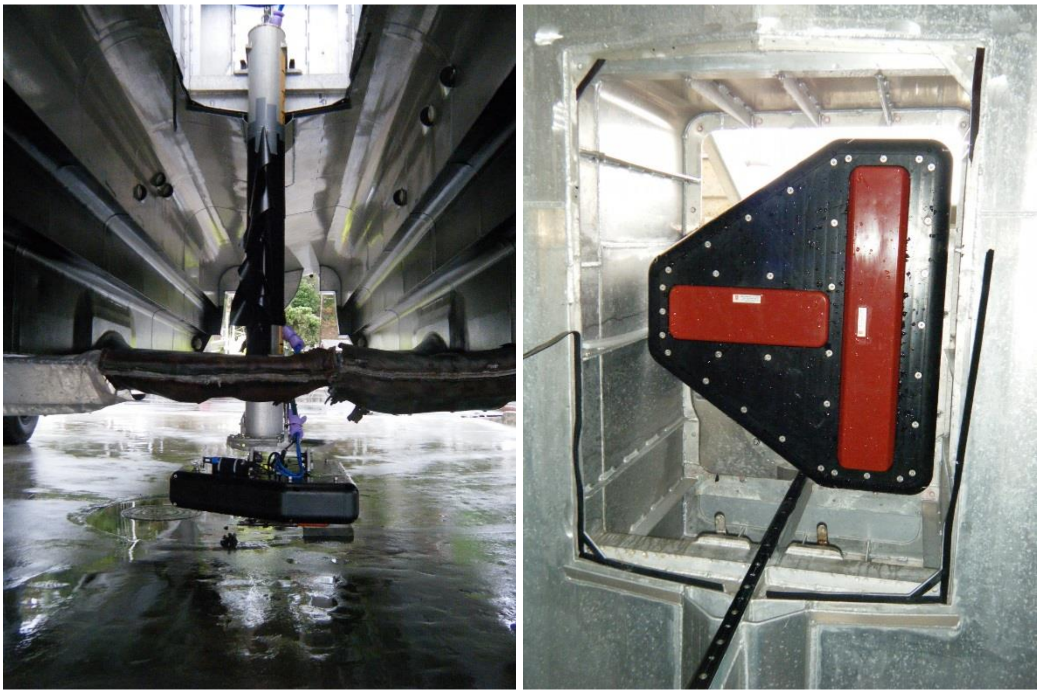

Figure A-1: Kongsberg EM2040 installation on the RV *Ikatere*.

Table A-1: Kongsberg EM2040 multibeam echo sounder (MBES) technical specifications.

Frequencies	200, 300, 400 kHz
Beam opening	400 KHz: Tx 0.4 degrees, Rx 0.7 degrees 200 & 300 KHz: Tx 0.5 degrees, Rx 1.0 degrees
Number of beams	256
Max ping rate	50 Hz
Number of soundings	400 Single Swath, 800 Dual Swath
Max swath width	140 degrees (200 & 300 kHz), 120 degrees (400 kHz)
Pitch stabilisation	yes (+/-10 degrees)
Roll stabilisation	yes (+/-15 degrees)
Yaw compensation	yes (+/-10 degrees)
Heave compensation	yes (greater of 5cm or 5% of heave)
Depth range	0.5 - 450m
Depth resolution	Raw range resolution (cτ/2) is 18 mm
Transducer geometry	Mills cross

Beam pattern	Equidistant, Equiangular, or High Density
Beamforming	Dynamically, nearfield focussed
External sensors	Position, heading, pitch, roll, heave, sound velocity profile, sound velocity at transducer
Clock synchronisation	1PPS from GPS

Table A-2: Typical Footprint of Beams at Nadir.

Water Depth	400 kHz	200 & 300 kHz
10	0.07/0.12 m	0.09/0.17 m
20	0.14/0.24 m	0.17/0.35 m
50	0.35/0.61 m	0.44/0.87 m
100	0.7/1.2 m	0.87/1.75 m
150	1.05/1.83 m	1.31/2.62 m
200	1.4/2.4 m	1.75/3.49 m

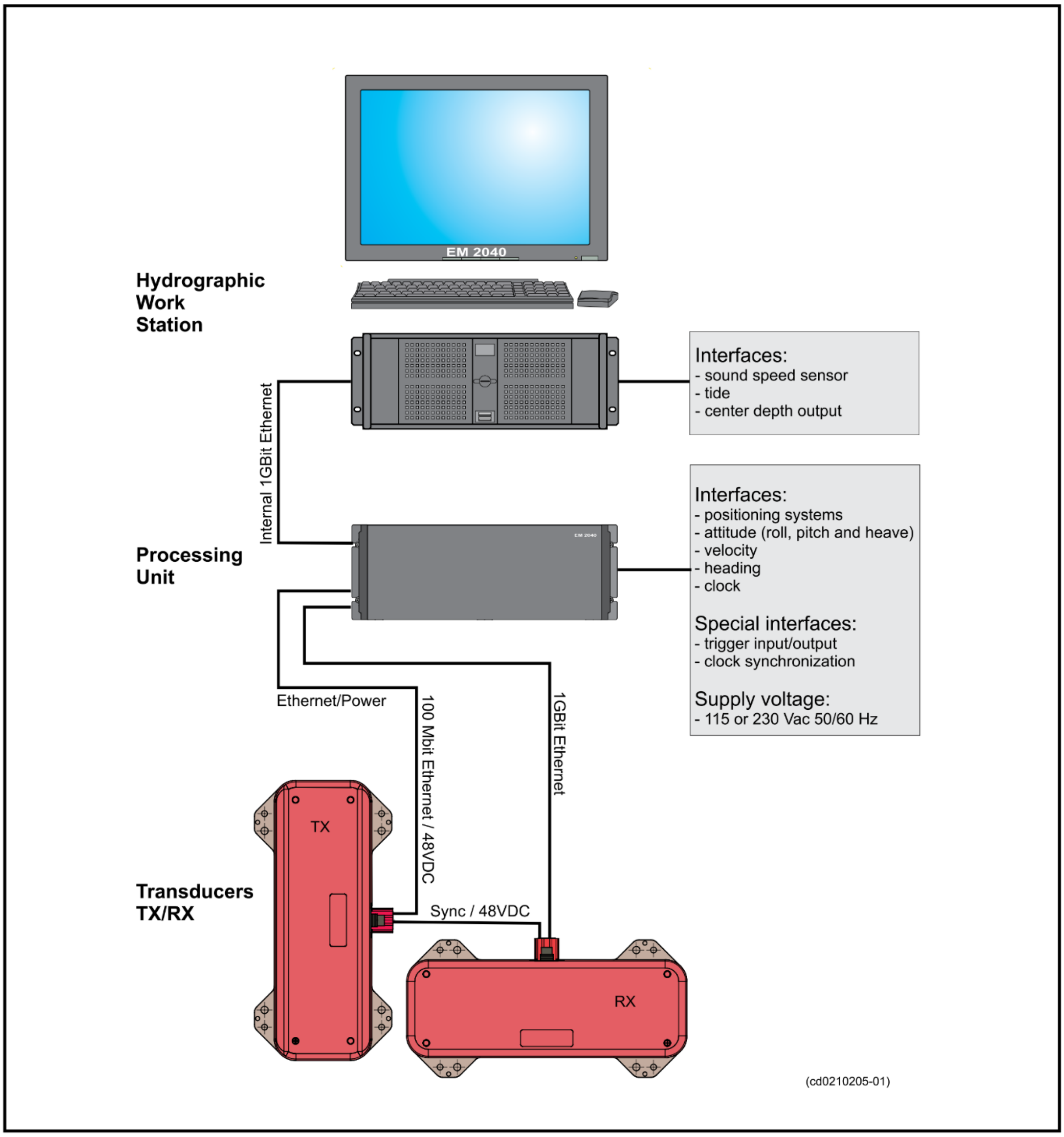

Figure A-2: Typical EM2040 system configuration with desktop operator station, Processing Unit and Sonar Heads.

SIS - Seafloor Information System

The Kongsberg Seafloor Information System, SIS, is a real time software designed to be the user interface and the real time data processing system for hydrographic instruments produced by Kongsberg Maritime. SIS operates under the Windows operating system. The SIS installation on the RV *Ikatere* also provides geographical displays to a remote screen for the helmsman to steer by (Figure A-3).

SIS provides the surveyor with the functionality needed for running a survey with functions such as line planning, sound velocity editing and real time data cleaning of bathymetric data. SIS includes algorithms for automatic flagging of soundings that should be eliminated from the survey. The soundings are not removed, simply flagged as invalid, so it is always possible to reverse the decision easily. For the majority of user needs, this processing will be satisfactory so that further processing is either not necessary or at least substantially reduced. The digital elevation model is generated in real-time from input of all soundings available in one area, not just the current soundings, but all previous soundings in that area. The processing algorithm automatically chooses the best cell size, and then defines a curved surface through the majority of the soundings in that cell.

The gridding algorithm updates a multi-resolution display grid which makes it possible to select a grid with the best fit resolution to the selected map scale. Large areas can then be displayed with low resolution, but still important details can be shown.

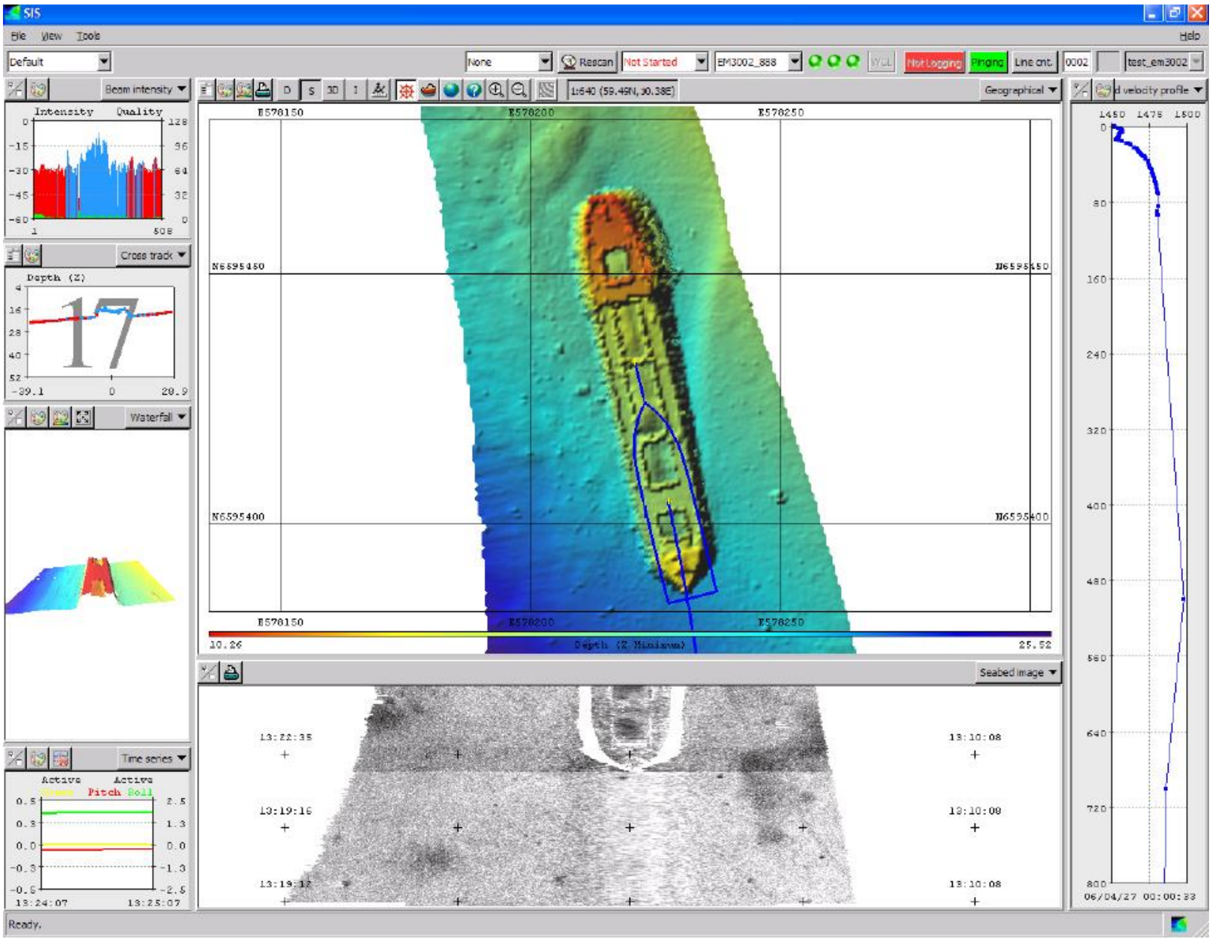

Figure A-3: SIS display during data acquisition.

CARIS HIPS

The CARIS HIPS software product is a comprehensive bathymetric data cleaning and validation tool integrated with vector product creation and is the hydrographic industry's preferred software for processing of hydrographic data. HIPS can take the raw sounding data from ship to chart with support for over 40 industry standard sonar data formats. Automated data cleaning filters and algorithms coupled with the ability to produce vector products, such as contours and selected soundings, assist in bathymetric processing.

Applanix POS/MV 320 Motion Sensor

POS MV is a tightly-coupled system using Inertially-Aided Real-Time Kinematic (IARTK) technology (Figure A-4). The system provides accurate attitude, heading, heave, position and velocity data, representing the latest in state-of-the-art inertial/GPS technology. The system maintains positioning accuracy under the most demanding conditions, regardless of vessel dynamics (Table A-3). With its high data update rate, POS MV delivers a full six degrees-of-freedom position and orientation solution to provide the following:

- Position (latitude, longitude and elevation)
- Velocity (north, east and vertical)
- Attitude (roll, pitch and true heading)
- Heave (real-time, delayed)
- Acceleration Vectors
- Angular Rate Vectors

POS MV is designed for use with multibeam sonar systems, enabling adherence to IHO (International Hydrographic Survey) standards on sonar swath widths of greater than ± 75 degrees under all dynamic conditions.

Figure A-4: Applanix POS/MV components.

Table A-2: Performance Summary - POS MV 320 accuracy.

POS MV 320	DGPS	RTK	Accuracy During GNSS Outage
Position	0.5 - 2 m	Horizontal: +/- (8 mm + 1 ppm x baseline length) Vertical: +/- (15 mm + 1 ppm x baseline length)	~ 6 m for 60 s total outages (DGPS) ~ 3 m for 60 s total outages (RTK) ~ 2 m for 60 s (post-processed DGNSS) ~ 1 m for 60 s total outages (IAPPK)
Roll & Pitch	0.02°	0.01° (0.008° with post processing)	0.02°
True Heading	0.01° with 4 m baseline 0.02° with 2 m baseline	-	1° per hour degradation, negligible for outages <60 s
Heave TrueHeaveTM	5 cm or 5% 2 cm or 2%	5 cm or 5% 2 cm or 2%	5 cm or 5% 2 cm or 2%

Applanix POSPac MMS post-processing software

POSPAC 5 utilizes Post Processed Virtual Reference Station (PPVRS) and the tightly coupled Inertially Aided Post Processed Kinematic (IA-PPK) techniques. The PPVRS technique makes use of GPS network stations to compute corrections for survey rovers within the network. The IA-PPK mechanization uses an integrated inertial navigator for prime positioning and uses the PPVRS corrections with GPS in tightly coupled mode to control errors. Together they offer a method for conducting Marine surveys with the necessary precision to eliminate the need for establishing dedicated GPS reference stations. Centimetric level positioning accuracy is possible even when the nearest base station in the network is 100 km away.

The workflow includes:

- Import of PosMV recorded data
- Import and check base stations
- Compute Virtual Network (PP-VRS)
- Recompute positioning and attitude solution (IA-PPK)
- Export SBET file for use in MBES post-processing software

Appendix B Error table for EM2040.

	Source of Error		Depth in Metres							
			5	10	20	50	75	100	150	200
		Note	Metres							
a.	Draught Setting	1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
b.	Variation in Draught	2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
c.	Velocity of Sound	3	0.06	0.07	0.1	0.17	0.23	0.29	0.41	0.53
d.	Spatial Variation in SV	4	0.05	0.05	0.1	0.1	0.1	0.25	0.4	0.5
e.	Temporal Variation in SV	5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
f.	Application of Measured SV	6	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
g.	Depth Measurement	7	0.05	0.1	0.2	0.5	0.75	1	1.5	2
h.	Heave	8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
i.	Settlement and Squat	9	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
j.	Roll, Pitch and Seabed Slope	10	0.01	0.01	0.02	0.05	0.08	0.1	0.15	0.15
k.	Co-tidal Readings	11	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
l.	Tide Corrections	12	0	0	0	0	0	0	0	0
Total Standard Error: $\sqrt{(a^2 + b^2 + \ldots)}$			**0.21**	**0.23**	**0.31**	**0.57**	**0.82**	**1.09**	**1.62**	**2.14**
Required accuracy:										
IAW TH Standard 31 for MB-1			0.38	0.39	0.44	0.68	0.92	1.19	1.73	2.28
IAW TH Standard 31 for MB-2			0.51	0.52	0.58	0.9	1.23	1.58	2.3	3.1
IAW TH Standard 31 for MB-3			0.63	0.65	0.73	1.13	1.54	1.98	2.88	3.8

1 Based primarily on ships' drawings and draught readings at W/L
2 Very little change throughout survey
3 Based on SV Plus accuracy.
4 Spatial Variation could be significant
6 Used during data acquisition
7 Estimates from MBES trials and rated accuracy of system.
8 POS/MV manufacturers specifications apply
9 Based on squat trials
10 Errors minimised through patch testing
11 Estimate.
12 Not Applicable.

Appendix C Digital Data Delivery

Accompanying this report is an external hard drive that contains digital data sets arising from the survey voyage and other deliverables, including: raw, processed and interpreted data, and electronic versions of this report. The main components are listed below.

Deliverables

\MDC Data Delivery\Reports
- Report
- Portfolio
- Charts

MDC Digital Data

\MDC Data Delivery\MBES
Raw Bathymetry, Backscatter & Water Column
Kongsberg *.all files

\MDC Data Delivery\SVP
Sound velocity profiles

\MDC Data Delivery\Navigation
PosMV navigation files

\MDC Data Delivery\Tides

\MDC Data Delivery\GIS
\MDC Data Delivery\GIS\File Geodatabase\WLG2015_38
Bathy grids 2m, 10m, 100m Cook background
Hillshade 2m, 10m, 100m Cook background
Contours 5m
Backscatter grid
\MDC Data Delivery\GIS\File Geodatabase\Benthic_Terrain_Modeller
Benthic Terrain Models

\MDC Data Delivery\GIS\Other layers
Bathymetry geotiffs
Backscatter geotiff
Land geotiff
Coastline
Benthic Terrain layers
Sediment & Biology stations layer

\MDC Data Delivery\GIS\Mxd
ArcGIS Mxd for the report

\MDC Data Delivery\Water Column
\MDC Data Delivery\Water Column\DUrville_WCD_final.fmproj
FM-Midwater project including processed gwc files

\MDC Data Delivery\Metadata listing