Central Hauraki Gulf Habitat Mapping

Geospatial classifications and benthic geomorphology of legacy multibeam surveys HS53, HS54, and TAN1211

Prepared for Air, Land, and Biodiversity Team Research and Evaluation Unit (RIMU) Te Kaunihera o Tāmaki Makaurau / Auckland Council

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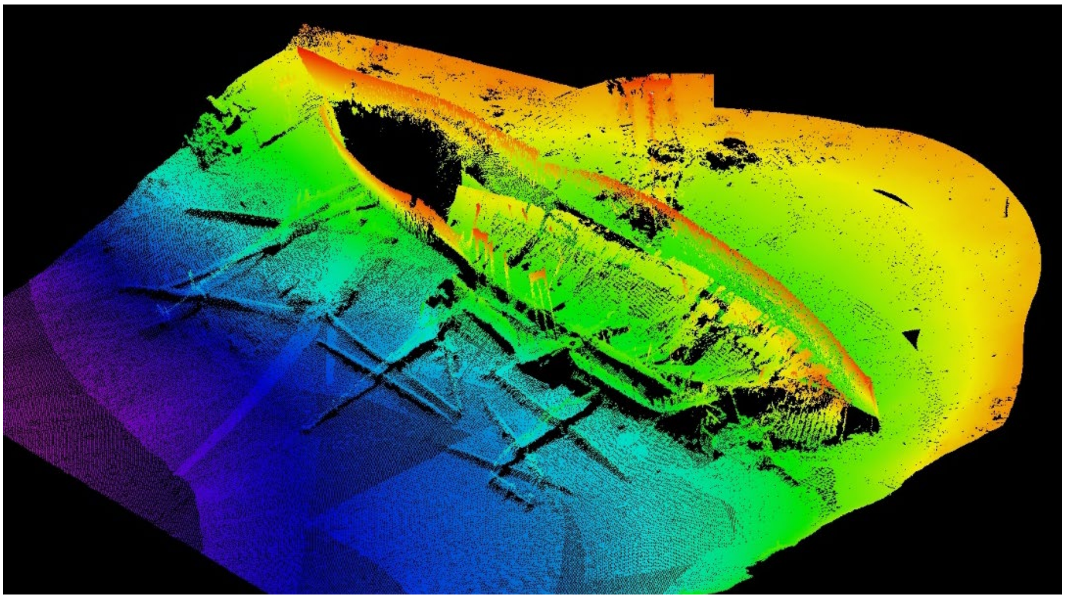

Prepared by:
Dr Susi Woelz
Dr Sally Watson
Dr Sam Davidson
Dr Erica Spain
Dr Tilmann Steinmetz

For any information regarding this report please contact:

Dr Susi Woelz
Principal Technician
Ocean Sediments
+64 4 386 0490
susi.woelz@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

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Executive summary

NIWA were tasked by Te Kaunihera o Tāmaki Makaurau / Auckland Council to produce a desktop habitat study of data collected for the Land Information New Zealand (LINZ) hydrographic surveys HS53 and HS54 from 2016/17 and a scientific dataset TAN1211 from 2012 within the Tīkapa Moana/Hauraki Gulf region.

To achieve the best outcome for scientific interpretation, NIWA reprocessed the bathymetry and seafloor backscatter datasets. Bathymetry, and derived products were used to classify the seafloor into benthic terrain attributes. Expert-driven interpretations led to a series of features of interest, based on morphological structure and backscatter signatures. These analyses revealed a range of areas that may represent important habitats including extensive rocky reefs, sediment bedforms, and seafloor seep sites. Additionally, the study identified numerous instances of human influence, such as wrecks, pipelines/cable networks, moorings, and anchoring impacts.

Furthermore, this report outlines recommendations for further data acquisition and analysis, emphasising the importance of legacy data processing, onshore-offshore connections using LiDAR datasets, and opportunities for advanced geophysical surveys for comprehensive substrate classification. The significance of ground-truthing through sediment cores or grab samples is also highlighted, alongside the need for resurveying high-priority areas to monitor changes over time.

Digital data deliverables comprise an ArcGIS project and several geodatabases containing bathymetric and backscatter products, along with accompanying geospatial derivatives, BTMs, and maps with features of interest. Additionally, an ESRI ArcGIS StoryMap has been created to summarise the highlights of the study and to allow for interactive exploration of the geospatial data for a more comprehensive understanding of the region's marine environment.

Overall, this project emphasises the importance of marine data acquisition in enabling a richer understanding of the diverse marine ecosystems and human impacts within the Tīkapa Moana/Hauraki Gulf. These datasets serve as a crucial resource to inform conservation and management efforts in the region.

1 Project scope

Nearly 70% of the area managed by Te Kaunihera o Tāmaki Makaurau / Auckland Council is marine. For this study, NIWA has been tasked by Te Kaunihera o Tāmaki Makaurau / Auckland Council to partially reprocess and to analyse pre-existing multibeam echosounder (MBES) data across the wider Hauraki Gulf region. This desktop study reuses existing data and did not involve any new data collection, sampling, or laboratory analyses. Additionally, the methodologies implemented during this study are identical to those undertaken by NIWA on the hydrographic multibeam survey HS52 – Approaches to Auckland dataset, presented in Pallentin et al. (2022).

Based in part on a previous assessment of legacy multibeam surveys across the Hauraki Gulf (Pallentin & Watson, 2021), the following surveys/voyages were identified as regions of interest for reprocessing (Figure 1-1):

- LINZ survey HS53 – Kawau Island (surveyed 2016-2017),
- LINZ survey HS54 – Tamaki Strait (surveyed 2016-2017), and
- NIWA voyage TAN1211 (surveyed as a part of the Oceans 2020 program in 2012).

Analysis of these existing MBES data is focused on building derivatives and classifying the bathymetry data, processing the seafloor backscatter data in a qualified way for feature detection and classification, and creating scientifically justified interpretations of the seafloor bathymetry and backscatter data. The workflow also included the production and delivery of bathymetric derivatives and Benthic Terrain Models (BTM) for all surveyed regions. Benthic Terrain Models (BTM) are an essential tool for seafloor classification studies worldwide. Derived from automated geospatial analysis of processed multibeam swath bathymetry grids, a BTM generates a comparable and repeatable seafloor morphometric classification. In addition to a BTM classification, specialist-driven interpretations of spatial derivatives and integration of seafloor backscatter further enhance modelled outputs. The outputs from a BTM may be used to identify areas of geological significance, regions which have been modified by human activity, and regions of potentially high ecological value without the requirement for towed cameras or other methods of direct sampling. Results from the BTM analyses provide a comprehensive overview of seabed morphology and activity within the Hauraki Gulf, covering a broad range of shallow marine environments. Features of interest identified across survey areas include rocky platforms, reefs, channels, sediment waves, and pockmarks. In addition to natural features, various impacts of human activity were also noted such as marine farm foundations, buried pipelines/cables, and anchor scour. Results from this study provide further insights into Hauraki Gulf benthic habitats and will assist in prioritising areas for management and future research. These outputs may now be used to identify areas of potentially high ecological value and to highlight areas for more detailed surveys and targeting sampling.

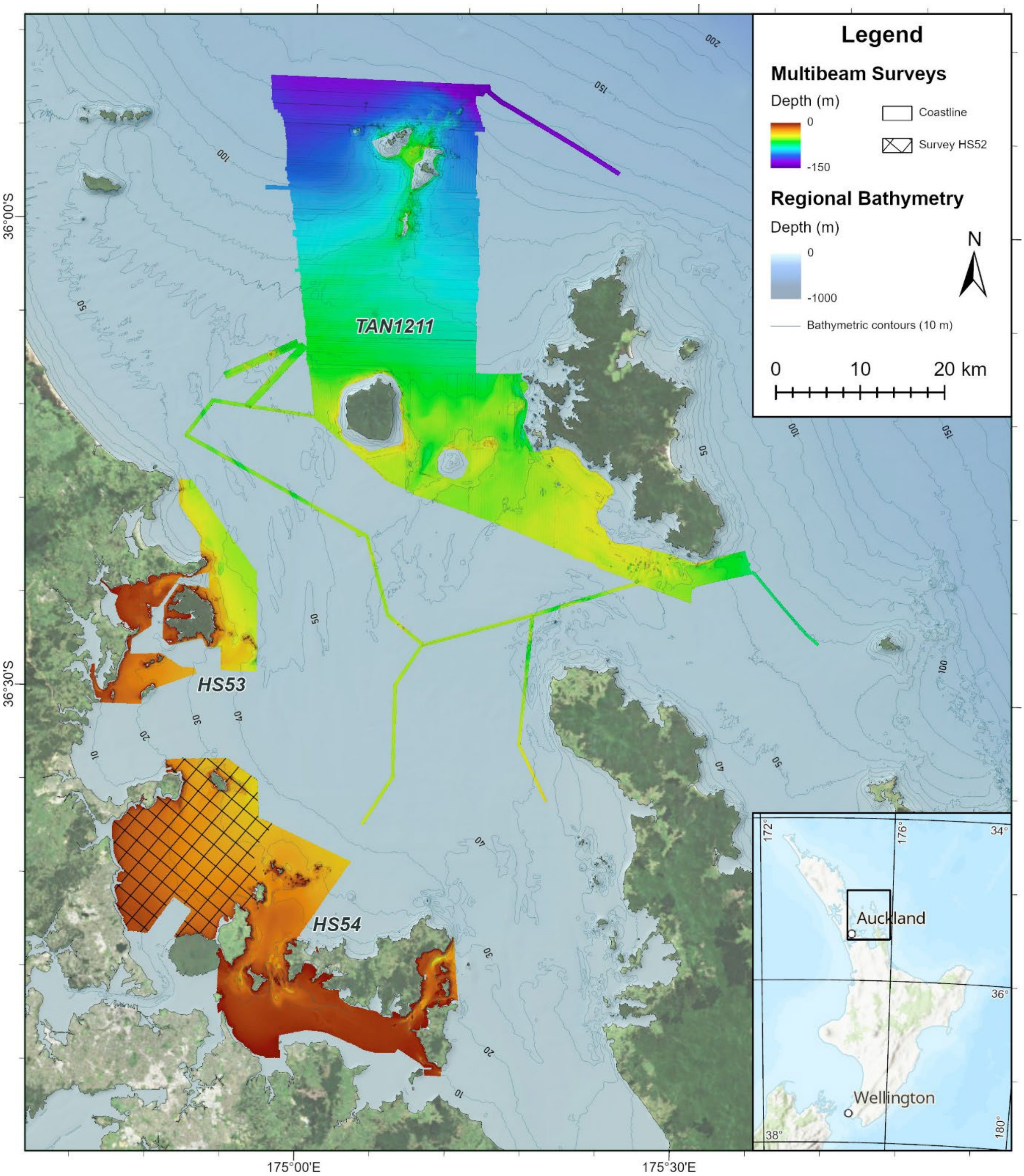


Figure 1-1: Overview of assessed bathymetry datasets across the Hauraki Gulf. Data assessed in this report include NIWA voyage TAN1211 and the hydrographic surveys HS53 and HS54. The hatched area is the adjacent area HS52 (Approaches to Auckland) from Pallentin et al., (2022).

Key deliverables of this project are:

- acoustic data layers and classifications stored in a GIS project (with supporting file geodatabase),
- a technical report outlining methods used, key findings, and recommendations for potential next steps (this document),

- an online ESRI® ArcGIS StoryMap integrating results from both this project and the already reprocessed HS52 dataset, and
- an online workshop hosted by NIWA upon completion of the project to showcase the results and deliverables from both this project and the previously analysed HS52 dataset.

2 Methods

The methods implemented during this project are identical to those developed during reprocessing of MBES survey HS52 (Pallentin et al., 2022), whereby raw MBES data and existing processed bathymetric products were assessed for:

1. Raw MBES survey data quality (i.e., data gaps or other survey acquisition artefacts), and
2. Optimal resolution of processed MBES products (median-surface bathymetric elevation models and processed backscatter grids).

2.1 Data collation

Land Information New Zealand (LINZ) provided NIWA with raw survey data for hydrographic surveys HS53 and HS54, assessed in this project. At a minimum, these hydrographic survey data contain processed soundings, backscatter images, and final processed shoal-biased bathymetry grids as provided by LINZ. In total, ~5.6 TB of survey project data from HS53 (~2 TB) and HS54 (~3.6 TB) were provided.

All raw data and processed bathymetric products from research voyage TAN1211 are held by NIWA's internal archives and were available for this project. In total, voyage TAN1211 contains 1.29 TB of survey data.

2.2 Data processing

For this project, NIWA undertook minor additional post-processing on the raw HS53 and HS54 survey datasets to produce median-surface bathymetric elevation models. Dataset-specific processing methods are outlined in the following sections.

2.2.1 TAN1211 – Great Barrier

Voyage TAN1211 was undertaken by NIWA's research vessel RV *Tangaroa* in 2012 as a part of the New Zealand Government's Oceans Survey 2020 program. In total, voyage TAN1211 collected 848 lines of MBES data to the south and west of Great Barrier Island using a Kongsberg EM302 MBES system (Figure 2-1). The total volume of raw survey data collected during TAN1211 was 1.29 TB.

As these data were not collected for hydrographic purposes, the TAN1211 dataset did not require any additional data-processing to remove artefacts associated with hydrographic chart production. However, acquisition artefacts are prevalent throughout the TAN1211 dataset, associated with reduced sounding density across the seabed (induced by exceeding optimal survey speeds and reduced overlap between survey swaths) and sound velocity artefacts inducing errors in seabed geometry across the outer acoustic beams.

Attempts were made to reduce the impacts of these artefacts through the implementation of sound velocity correction tools available within QIMERA software (e.g., TUDelft refraction residual corrections – Beaudoin et al., 2018); however, these attempts were unsuccessful in improving final processed surface quality (see section 2.2.5).

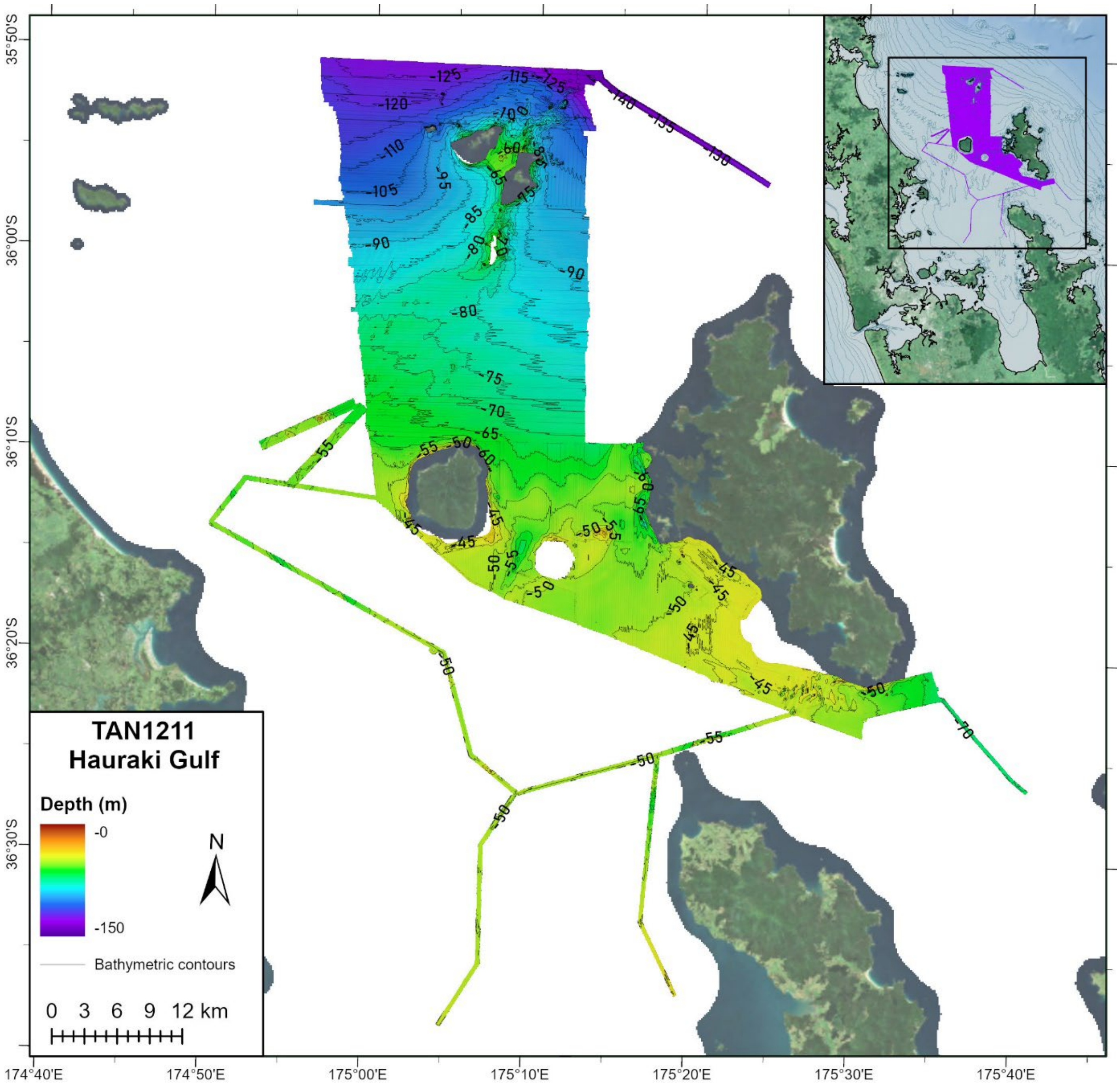


Figure 2-1: Depth colour-coded bathymetry of the TAN1211 area in the outer Hauraki Gulf. This area encloses Te Hauturu-o-Toi / Little Barrier Island, and its south-eastern part is adjacent to the south-west of Aotea Great Barrier Island. 5 m-depth contours are shown throughout the area. Inset shows the regional location of TAN1211 (shaded purple).

2.2.2 HS54 – Tamaki Strait

The dataset for HS54 – Tamaki Strait contains ~5364 individual lines of raw MBES data, collected using a Kongsberg EM2040C MBES system (Figure 2-2). The total volume of raw data collected during survey HS54 was 3.21 TB. Two types of data were processed from these MBES data – bathymetry soundings of the seafloor depth, and backscatter acoustic reflectivity. Because the HS54 survey was acquired using QPS QINSY software, processed data (.qpd format) and raw backscatter data (.db format) were directly imported into QPS QIMERA software (v2.5.3) for processing.

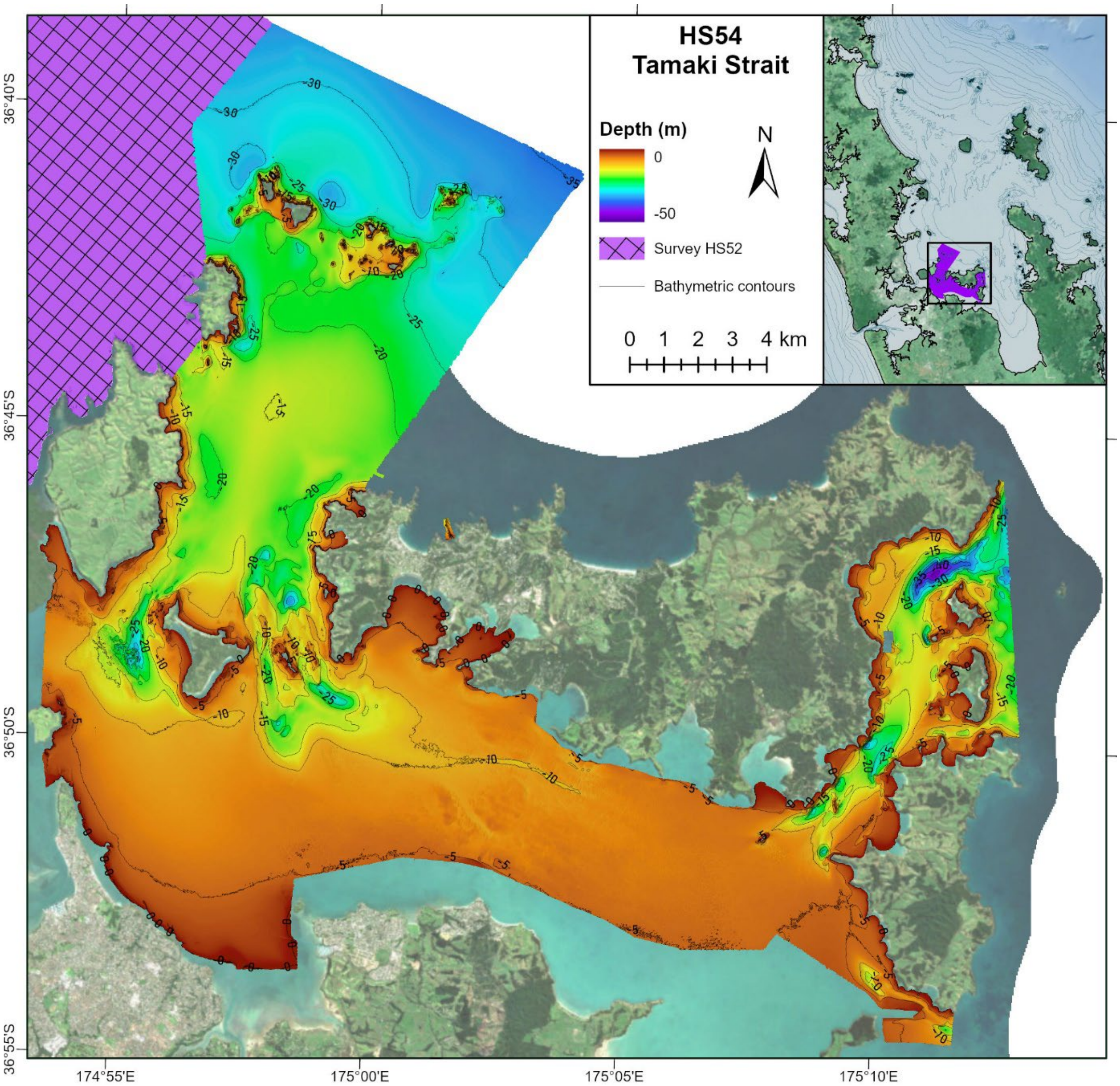


Figure 2-2: Depth colour-coded bathymetry of the HS54 area around Te Maraetai /Tamaki Strait.
5 m-depth contour lines are shown throughout the area. The hatched purple area shows adjacent HS52 – Approaches to Auckland. Inset shows the regional location of HS54 (shaded purple).

2.2.3 HS53 – Kawau Island

The dataset for HS53 – Kawau Island contains ~4049 individual lines of raw MBES data (Figure 2-3), collected using two different MBES systems:

- R2Sonic 2022 MBES sonar system, used in shallow water depths (< 10 m), and
- Reson SEABAT 7125 MBES sonar system, used in water depths exceeding 10 m.

In total, both MBES systems collected 1.24 TB of raw survey data during HS53. Two types of data were processed from these MBES data – bathymetry soundings of the seafloor depth, and backscatter acoustic reflectivity. Because the HS53 survey was acquired using QPS QINCY software, processed data (.qpd format) and raw backscatter data (.db format) were directly imported into QPS QIMERA processing software (v2.5.3), which NIWA uses to process MBES data.

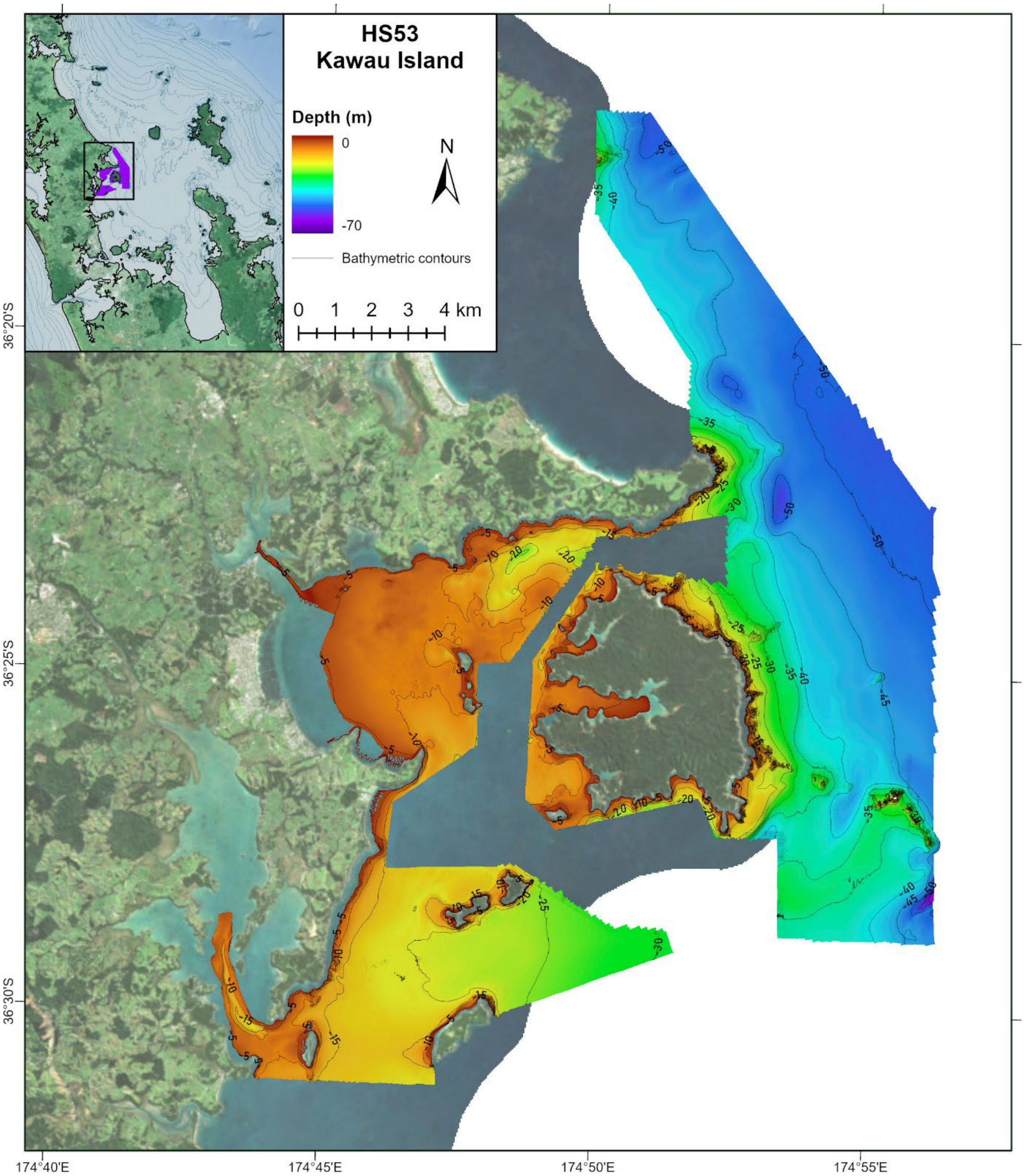


Figure 2-3: Depth colour-coded bathymetry of the HS53 area around Kawau Bay. 5m depth contours are shown throughout the area. Please note the sickle-shaped area immediately to the west of Te Kawau tumaro o toi / Kawau Island is not part of the LINZ HS53 data set, this region having been surveyed by the New Zealand Navy in 2015 during Operation Poseidon. MBES data associated with Operation Poseidon were not analysed as a part of this project. Inset shows the regional location of HS53 (shaded purple).

Spatial analysis of the seafloor bathymetry and backscatter data was performed using ESRI ArcMap (v10.8.2) and ESRI ArcPro (v3.1.3). Visual representation and inspection of data was done using ArcPro (v2.9.3) as this provides direct connectivity into NIWA's ESRI ArcEnterprise environment, supporting the StoryMap deliverable.

2.2.4 Spatial data and derivatives

All datasets presented in this report represent either processed bathymetric products from the raw MBES survey (i.e., bathymetry or seafloor backscatter), or geospatial derivatives of the processed bathymetric elevation model (i.e., slope, curvature, aspect, or rugosity). All spatial data and derivatives used for feature identification and analysis were generated as raster format files.

To generate bathymetry derivatives, exported GeoTiff grids were loaded into both ESRI ArcPro (v3.1.3) and ArcGIS (v10.8.2), both as native GeoTiff and ESRI FileGeoDataBase (FGDB) format – as different ArcGIS tools are optimised for different input formats. NIWA's in-house scripts generated a standard suite of bathymetric derivatives based on ESRI tools, including slope, aspect, curvature, and rugosity (roughness), described briefly hereafter.

Bathymetry

Bathymetry (shape and depth of seafloor) is illustrated as a digital elevation model (DEM). This is the processed layer that represents thousands of individual depth measurements collated to form a single continuous DEM (Figure 2-4). The resolution of each DEM depends on a range of factors including data quality, water depth, and echo sounder settings. The higher the resolution (grid cell size) of the DEM, the greater detail we are able to resolve on the seabed. From bathymetry data, other layers can be produced to assist in understanding key features of interest within the survey region. These layers are often referred to as derivatives, and they are described in detail below.

Backscatter

Seafloor backscatter data represent the acoustic reflectivity of the seafloor area insonified by each acoustic beam (Figure 2-4). This reflectivity is measured in decibels (dB) as the return of emitted acoustic energy, considering transmission loss in the water-column due to physico-chemical effects (e.g., salinity, temperature, and pressure).

NIWA used the QPS Fledermaus Geocoder Toolbox (FMGT) for seafloor backscatter processing. Processed .qpd files and their associated raw .db files were loaded into FMGT, integrating all processing steps and adjustments (e.g., tide, navigation, removal of bad pings). The data was geo-rectified, the backscatter signal extracted and filtered, and a backscatter grid produced. FMGT estimates the best possible resolution on several factors, however manual adjustment of the produced grid size is possible. Often the possible resolution of the seafloor backscatter grid is the same or better than that of the bathymetry grid.

Slope

Slope is the steepness of the seafloor gradient, attributed according to the angle (in degrees) from the horizontal. Values near zero (blue) are flat areas, while higher values (green and yellow) are areas that are increasingly steep (up to 75°). All data exhibit a wide range of slopes, but wider areas show low slope (< 0.5°, blue). Higher slopes are concentrated at nearshore areas, isolated reefs and high dynamic areas (e.g., in between islands). The effects of current scour and exposed rocky seafloor are clearly evident in slope images (Figure 2-4). Human impacts such as pipelines, anchoring footprints, wrecks, etc., are easily identified using the slope derivative, as they appear as high slope regions on otherwise flat seabed. The slope derivative also reveals linear striping due to data acquisition and processing artefacts across the survey areas, particularly visible in the TAN1211 dataset (e.g., Figure 2-5 and section 2.2.5).

Curvature

The curvature displays the shape or curvature of the slope and is calculated by computing the second derivative of the surface (the change of slope). Positive curvature at a location indicates that the surface is upwardly convex (e.g., a mound). Negative curvature indicates that the surface is upwardly concave (e.g., a depression). A neutral value of 0 (blue) indicates that the surface is flat. The colour gradient is symmetrical around zero curvature to emphasise curved versus flat seafloor (curved surfaces appear brown to orange). All data show wide flat areas with higher curvature occurring nearshore, at reefs, and artificial structures (Figure 2-4).

Aspect

Aspect is the direction of down-slope dip in value from each cell to its neighbours, with north at 0° (dark green), east at 90° (yellow), south at 180° (red), and west at 270° (light blue). Aspect can also be thought of as the slope direction. Aspect shows slope directions generally changing around landmasses, depressions, ridges, basins, in high dynamic areas, etc. (see example in Figure 2-4). Aspect can help to identify the orientation of ripples, sand waves, or geological formations.

Rugosity or terrain ruggedness

VRM – vector ruggedness measure, or rugosity is a measure of roughness and terrain complexity and is captured as bathymetric variation in three dimensions of grid cells within a neighbourhood, i.e., the ratio between the surface area and the planar area for each cell. This method effectively captures variability in slope and aspect into a single measure. Ruggedness values in the output raster can range from 0 (no terrain variation – blue) to 1 (complete terrain variation – orange) with typical values for natural terrains range between 0 and about 0.4. In the benthic environment, ecological diversity can generally be correlated with strong complexity of the physical environment. As such, rugosity can help identify areas where high biodiversity may exist on the seafloor. Low rugosity displays across all areas, and high rugosity is concentrated only in nearshore areas, reefs, sediment waves, pockmarks, or other geological or artificial features as see in an example in Figure 2-4.

Additional derivatives

In addition to the above derivatives, the following geospatial outputs were derived for interpretation purposes:

- **Depth range**; the difference between minimum and maximum depth within a selected spatial window of neighbouring cells.
- **Standard deviation of depth**; a statistical measure used to quantify variation in depth over a spatial window of neighbouring cells.
- **Standard deviation of slope**; a statistical measure that is used to quantify variation in slope over a spatial window of neighbouring cells.

For every geospatial derivative produced, different sampling windows were applied to the input bathymetric grid to assist in interpretation of broader-scale features which may be difficult to discern in the high-resolution datasets. The sampling windows used were based on neighbourhoods of 5, 15, and 25 cell kernels around each original input cell.

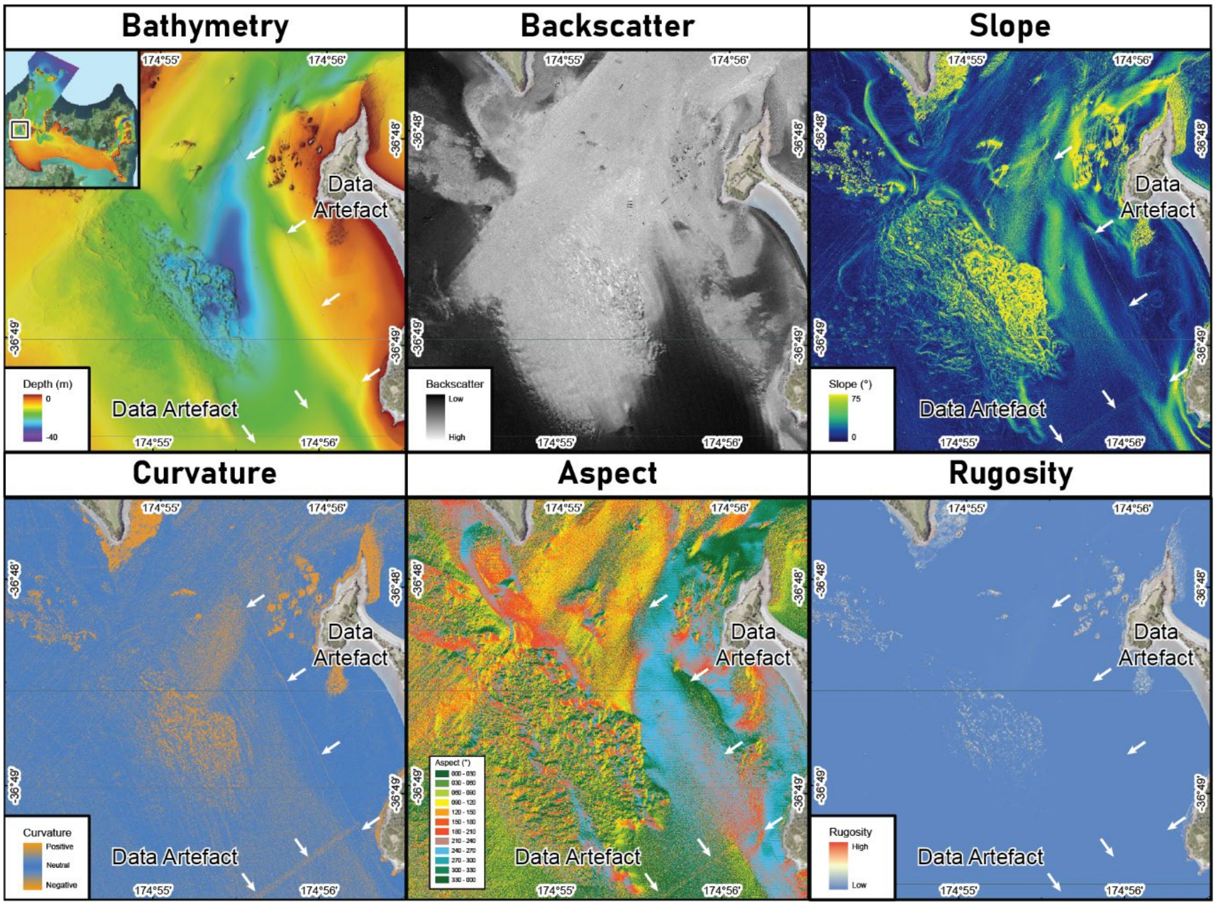


Figure 2-4: Examples of processed bathymetric products and geospatial derivatives (west of Motuihe Island/ Te Motu-a-Ihenga - survey HS54). Datasets illustrated include (clockwise from top left): bathymetry, backscatter, slope, rugosity, aspect, and curvature. Bathymetric data artefacts which may impact derivative datasets are illustrated by white arrows.

2.2.5 Data artefacts

Although all reasonable steps were taken to reduce the impacts of data acquisition artefacts during data processing, in many instances data artefacts can be identified in the produced geospatial products.

Seafloor striping - bathymetry

Due to the regular patterns undertaken for multibeam surveys, commonly referred to as "mowing the lawn," seafloor striping or the presence of abrupt steps in bathymetric depth which trend parallel to the surveyed path are the most common artefact in bathymetric data. Seafloor striping is caused by discrepancies in modelled depth values between the outer beams of surveyed lines. Due to their strong linear orientation and correlation with survey lines, these artefacts can be easily identified in processed outputs (e.g., Figure 2-5). All datasets assessed during this project display varying degrees of striping artefacts, however, they are all viewed as minor with respect to influencing interpretation confidence.

In addition to seafloor striping, sound velocity (SV) variations can produce significant artefacts in processed bathymetric products. Associated with incorrect water velocities applied to the MBES system during data acquisition, SV artefacts are commonly expressed as a parabolic seabed sounding cross-section in otherwise flat regions. Depending on the orientation of the parabola (i.e., concave up or down), artefacts in processed bathymetric products typically appear as a high density, strongly linear trend of irregular seafloor peaks/ridges (concave up SV artefacts) or depressions (concave down SV artefacts).

SV artefacts are prevalent throughout the TAN1211 dataset due to the survey conditions. In many regions across the TAN1211 survey area, SV artefacts reduce interpretation confidence compared to datasets HS53 and HS54, however, subtle underlying seafloor geomorphology could still be interpreted (see section 3). Finally, impacts of SV artefacts could be reduced in the TAN1211 dataset using coarser sampling windows for spatial derivatives (Figure 2-5).

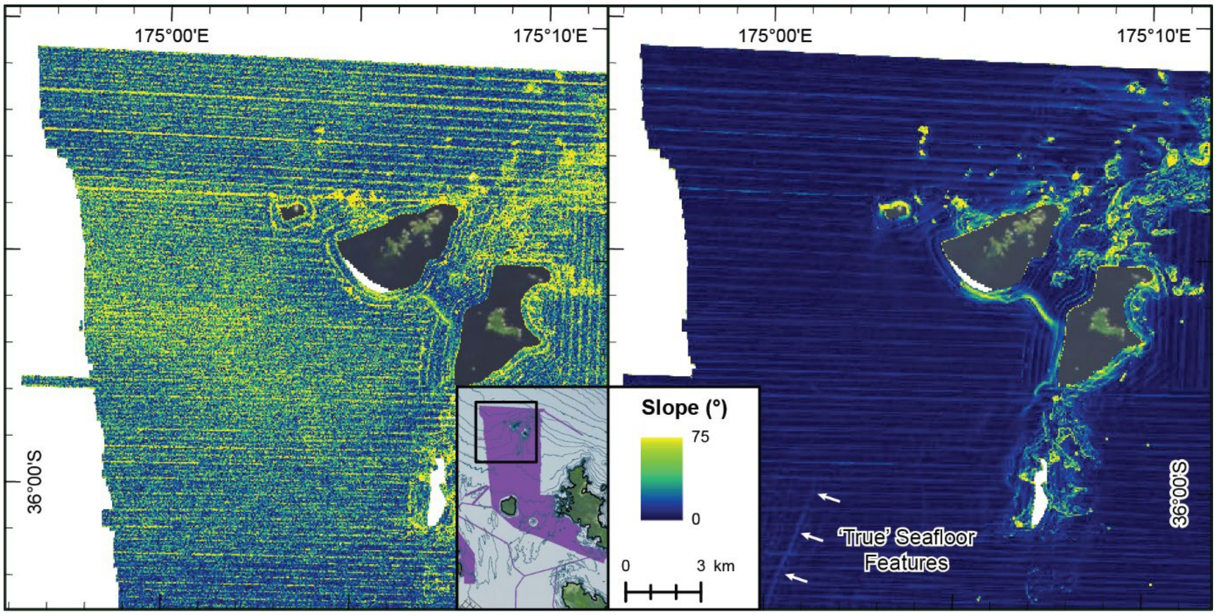


Figure 2-5: Example of sound velocity artefacts and resampling across survey TAN1211 - slope. Corrections to reduce impacts of sound velocity artefacts included processing geospatial derivatives with resampled intervals. The raw bathymetric surface-derived slope model (left) contains far more linear artefacts compared to the slope model derived from a 25-pixel spatial window neighbourhood (right).

MBES setting changes - backscatter

As seafloor backscatter presents the acoustic reflectivity of insonified seafloor during MBES acquisition, the absolute strength of the returned signal is dependent on the strength of the original transmitted beams. During MBES acquisition, it may be beneficial to vary the beam angle or beam strength to optimise the quality of the output bathymetric product (e.g., increasing beam angle width in shallow water to increase swath coverage).

If setting changes to the MBES system are not reliably captured during data acquisition, or multiple MBES systems are used during a survey, it can be difficult to reliably reconcile differences between signal return strength across a surveyed region. Setting changes to the MBES system typically manifest in processed backscatter products as abrupt colour band changes in the final processed output (e.g., Figure 2-6 A).

Compared to survey HS54 and voyage TAN1211 which both used a single MBES system, survey HS53 was acquired using two different MBES sonar systems (R2Sonic 2022 and Reson SEABAT 7125 systems), the difference in acquisition settings between the two systems is evident in the processed backscatter data (Figure 2-6 B). Across-track artefacts are present in all backscatter datasets, associated with either the formation of bubbles across the MBES transducers or swell impacting beam transmission. Across-track artefacts typically manifest as discrete strips of strong low backscatter signal (black regions) compared to the surrounding seabed (Figure 2-6 C).

Although backscatter artefacts are recognisable in the final output grids, backscatter is interpreted qualitatively only and is not used to derive any quantitative spatial products. As such, artefacts from backscatter processing are not deemed significant with respect to final interpretations.

A comprehensive summary of general and event artefacts of HS53 & HS54 has already been presented in Pallentin & Watson (2021).

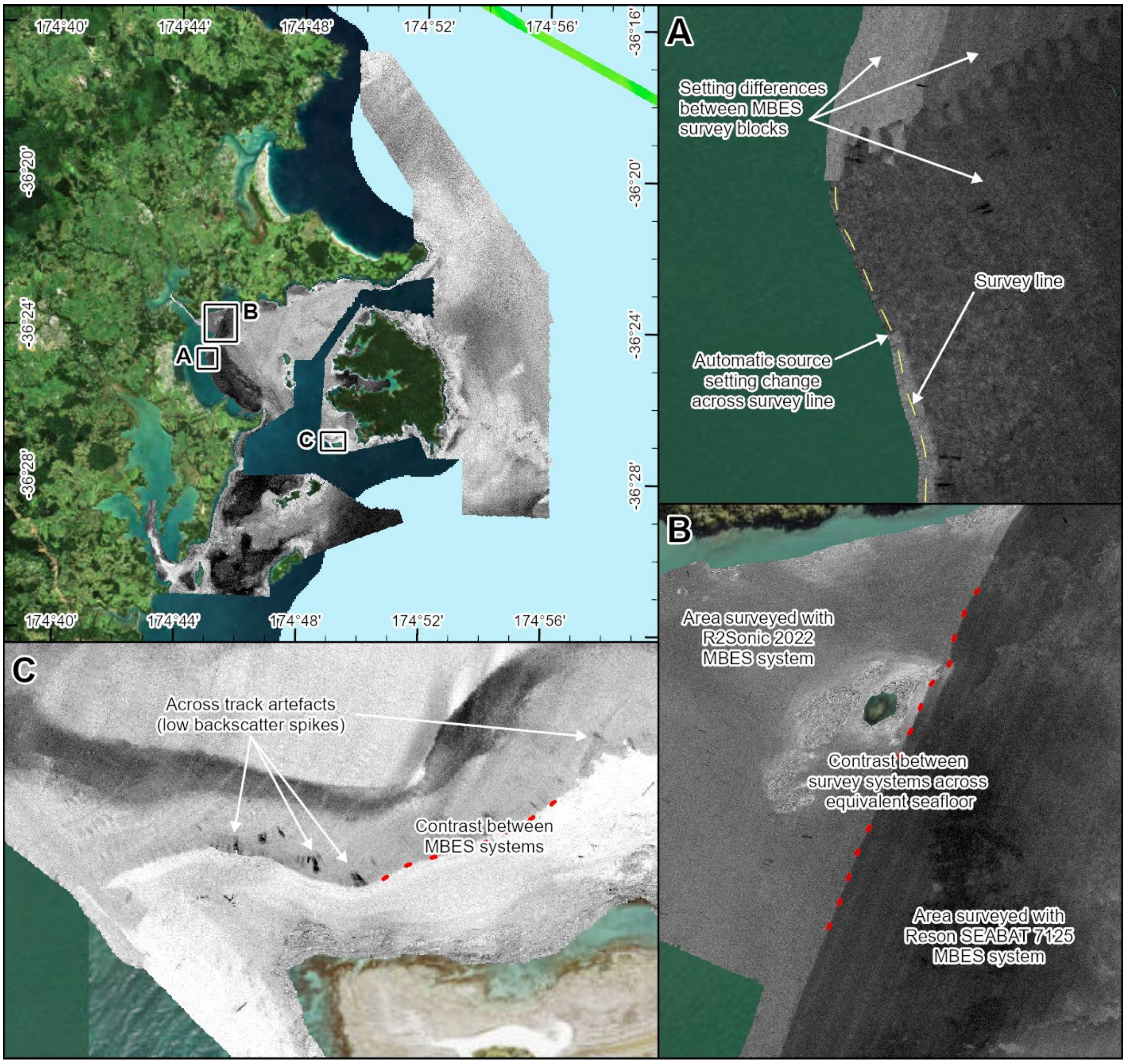


Figure 2-6: Examples of backscatter processing artefacts in the HS53 survey dataset. Different processing artefacts include variable MBES system settings between different survey blocks and along survey lines (A), contrast in backscatter due to use of different MBES systems (B), and across track artefacts (expressed as strong low backscatter strips) associated with vessel movement or under hull bubbles (C).

2.2.6 Benthic Terrain Model

MBES bathymetry data for HS53, HS54 and TAN1211 were processed in a Benthic Terrain Model (BTM) to classify the seafloor into zones based on bathymetric variability. BTM is a collection of ESRI ArcGIS-based tools developed for analysing and classifying the benthic environment based on bathymetric surface (e.g., Erdey-Heydorn, 2008; Lundblad et al. 2006). These BTM tools were applied to the combined bathymetric surface to provide assessment of and identify trends on the benthic terrain at a variety of scales, as well as to analyse fine- and broad-scale features.

Building on the work achieved from the HS51 Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au survey (Neil et al., 2018) and the HS52 Approaches to Auckland (Pallentin et al., 2022), terrain derivatives as described in section 2.2.4 were produced, including depth, depth statistics (standard deviation), depth range (difference between minimum and maximum depth), slope (angular units from the horizontal), slope statistics (standard deviation), 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. The information from the depth and derivative layers were then used to create a classification scheme for the terrain, or BTM.

Outputs from the BTM, other than those derivatives described in section 2.2.4, include:

- **Bathymetric Position Index (BPI).** BPI is principally a measure of where a referenced location is relative to the locations surrounding it. Hence positive values indicate features that are higher than the surrounding area (e.g., ridges), and negative values indicate features that are lower than the surrounding area (e.g., depressions or scours). Values near zero are either flat or areas of constant slope. The creation of BPI grids at two different scales is central to the methods behind the benthic terrain classification process. BPI is a derivative of the input bathymetric data set and is used to define the location of specific features and regions relative to other features and regions within the same data set (Figure 2-7). The standardized BPI data sets are classified to identify various benthic zones and/or structures.
    - **Broad-Scale BPI** is a broad-scale BPI data set that allows you to identify larger regions within the benthic landscape.
    - **Fine-Scale BPI** is a fine-scale BPI data set that allows you to identify smaller features within the benthic landscape.

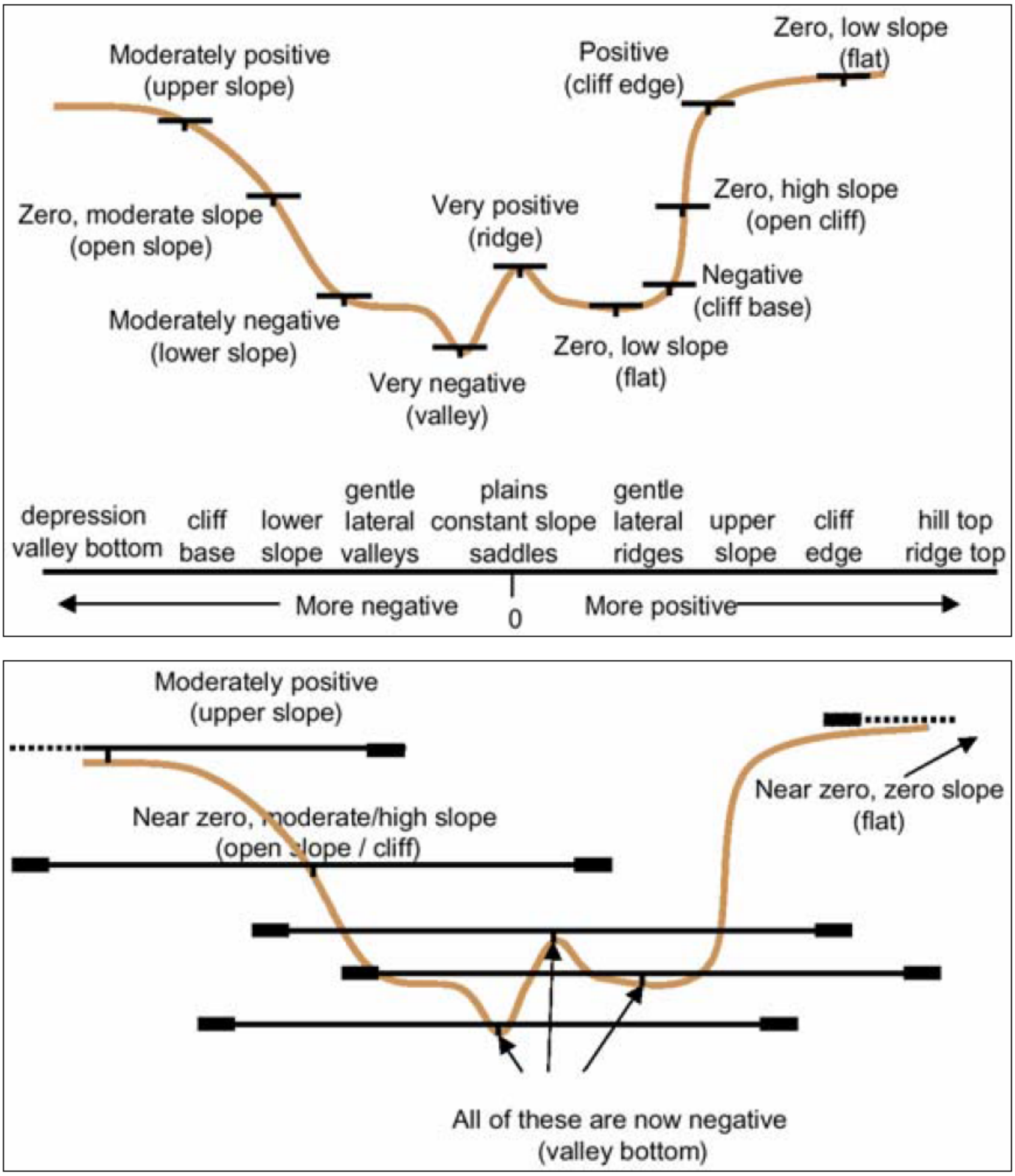


Figure 2-7: Fine-scale BPI (top) where subtle, small-scale (one to tens of metres) topographic features occur. Broad-scale (bottom) BPI result in broad-scale (tens to hundreds of metres) topographic features occur (modified after Weiss, 2001).

2.2.7 Geospatial classification

The benthic terrain classification is a user-defined benthic zones layer based on the combination of BPIs, slope, standard deviation breaks, and depth at each pixel location. Based on NIWA's standard classification library, developed for HS51 Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au bathymetric data (Neil et al., 2018), classification of the benthic structures in the output layer consist of 14 classes (Figure 2-8) which reflect different geomorphologic domains based on geospatial relationships between neighbouring pixels.

NIWA Benthic Terrain Model Classification			
1	**Flat plains** – variable BPI, but slopes no larger than 5°	9	**Narrow Slopes** – High positive broad BPI indicates that wider areas are deeper.
2	**Broad slopes** – like 1, but with higher slope values between 5° and 20°	10	**Rock Outcrop Highs, Narrow Ridges** – Broad and fine BPI high positive, indicating wider and closer neighbourhoods are deeper.
3	**Steep slopes** – like 2, but with higher slopes between 20° and 35°		
4	**Broad depression** – Broad BPI is low, so wider neighbourhood (broad BPI) is shallower	11	**Local Ridges, Boulders, Pinnacles in Depressions** – Broad BPI high negative (wider neighbourhood) is shallower, fine BPI (closer neighbourhood) high negatives values (small local highs as in boulders)
5	**Lateral mid-slope depression** – the wider neighbourhood can be deeper or shallower, but the closer neighbourhood is preferentially deeper. A slight slope is present.	12	**Local Ridges, Boulders, Pinnacles on Broad Flats** – negative to positive broad BPI with small (up to 5°) slope describing a wider/broad slope (similar to class 1 and 2), but with high positive fine BPI describing local ridges, boulders, and pinnacles.
6	**Scarp, cliff** – very high slope values dominate this class (<35°)		
7	**Depressions** – the wider and closer neighbourhood (broad and fine BPI) are shallower.	13	**Local Ridges, Boulders, Pinnacles on Slopes** – like class 12, but higher slope values
8	**Crevices, Narrow Gullies over elevated terrain** – The wider neighbour-hood (broad BPI) is deeper, but closer neighbourhood (fine BPI) is shallower.	14	**Local Depressions, Current Scours** – Similar to class 12, but the local / closer neighbourhood values are deeper (fine scour marks, dredge marks, etc.)

Figure 2-8: NIWA Benthic Terrain Model (BTM) classification scheme. This BTM scheme is standard across all NIWA BTM analyses and reflects a national standard for benthic terrain classifications.

Based on this classification, the surveyed areas of HS53, HS54, and TAN1211 (Figure 2-9, appendix figures, Figure A-1, Figure A-2Figure A-3) are largely comprised of flat plains (HS53 - 91.17 %, HS54 – 90.29 %, TAN1211 – 88.55 % of the seafloor). Other significant classes are narrow slopes (HS53 – 4.34 %, HS54 – 5.43 %, TAN1211 – 9.14 %), broad slopes (HS53 – 2.42 %, HS54 – 2.46%), broad depressions (HS53 – 0.92 %, HS54 – 1.11 %, TAN1211 - 1.52 %), and Rock outcrops (HS53 – 0.84 %, HS54 – 0.59 %, TAN1211 – 0.40 %) (see Table 2-1). Please note that the lower percentage of flat plains and the higher percentage of narrow slopes in the TAN1211 area is likely influenced by artefacts in the generated bathymetric elevation model (see section 2.2.5).

Table 2-1: BTM class coverage in % for HS53, HS54, and TAN1211.

BTM Zone	HS53	HS54	TAN1211
		Coverage (%)	
Flat plains	91.17	90.29	88.55
Broad slopes	2.42	2.46	0.32
Steep slopes	0.14	0.06	0.00
Broad platform or depressions	0.92	1.11	1.52
Lateral mid-slope platforms or depressions	0.02	0.01	0.01
Scarp, cliff	0.04	0.01	0.00
Broad depressions	0.01	0.00	0.02
Crevices, narrow gullies over elevated terrain	0.03	0.02	0.01
Narrow slopes	4.34	5.43	9.14
Rock outcrop highs, beach platforms, narrow ridges	0.84	0.59	0.40
Local ridges, boulders, pinnacles in depressions	0.00	0.00	0.00
Local ridges, boulders, pinnacles on flat plains	0.00	0.00	0.01
Local ridges, boulders, pinnacles on slopes	0.04	0.02	0.01
Local depressions	0.00	0.00	0.00

These classifications are in accordance with a national standard and can be used to compare with other regions.

Comparing the results from this report with the survey HS52 – Approaches to Auckland (Hatched area - Figure 1-1), assessed by Pallentin et al. (2022), survey areas HS53, HS54, and TAN1211 all appear to be morphologically more complex. Nearly 95% of the HS52 survey area comprises of seafloor with slopes <5° (Flat plains – 94.79%), while the remaining ~5% is morphologically more complex, predominantly occurring around shorelines.

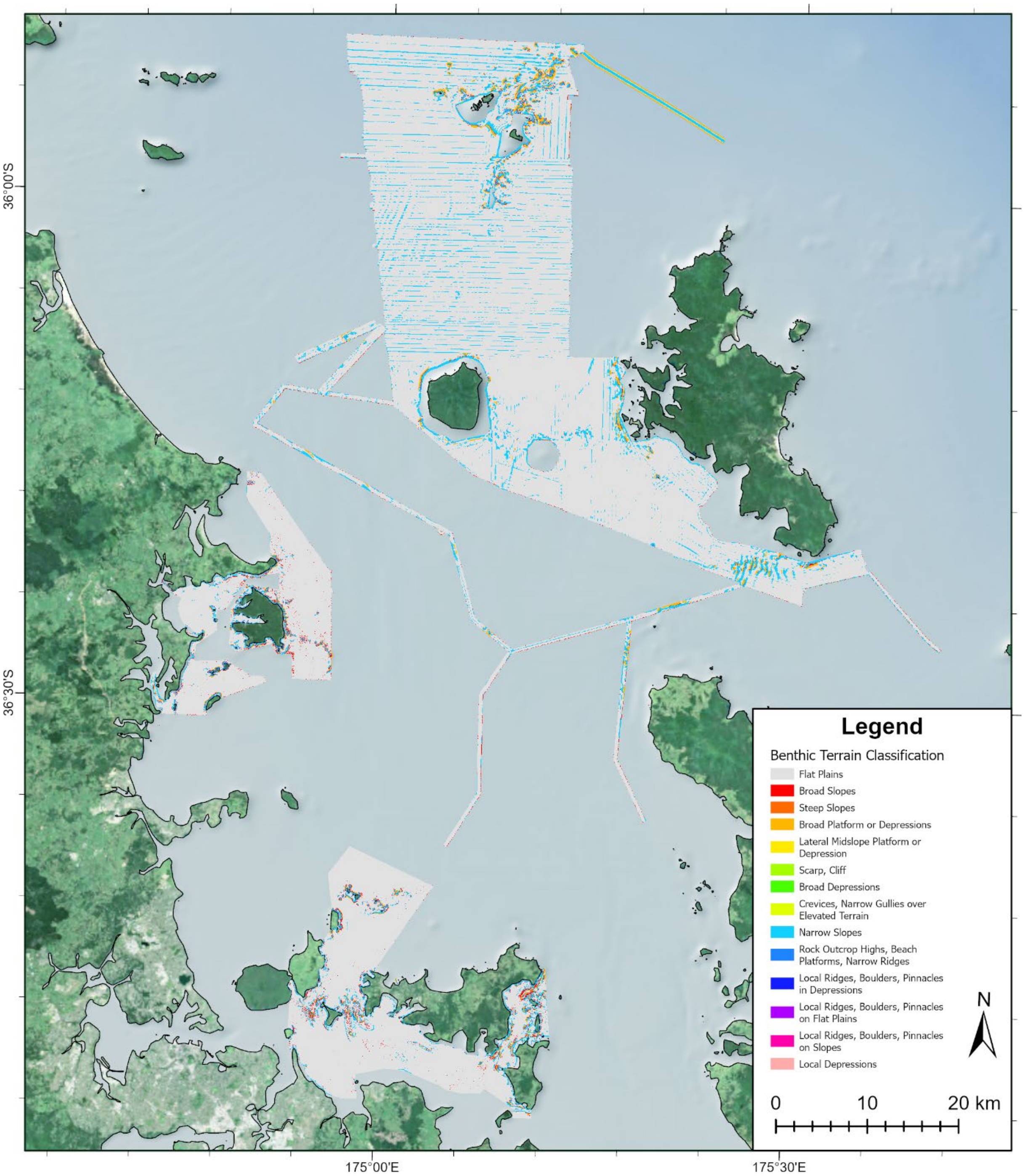


Figure 2-9: BTM classifications for HS53, HS54, and TAN1211. The areas are largely comprised of flat plains with other significant appearances of narrow slopes, broad slopes, and broad platforms. Please also see Figure A-1, Figure A-2, and Figure A-3 for close-ups.

2.2.8 Sediment and biological samples

Existing sediment and biological sample data can augment the analysis of bathymetry and backscatter. However, the low number of samples currently held by NIWA in the areas (Figure 2-10, Figure B-1, Figure B-2, Figure B-3), and lack of additional samples being accessible, allows no conclusions to be drawn from these for a habitat study.

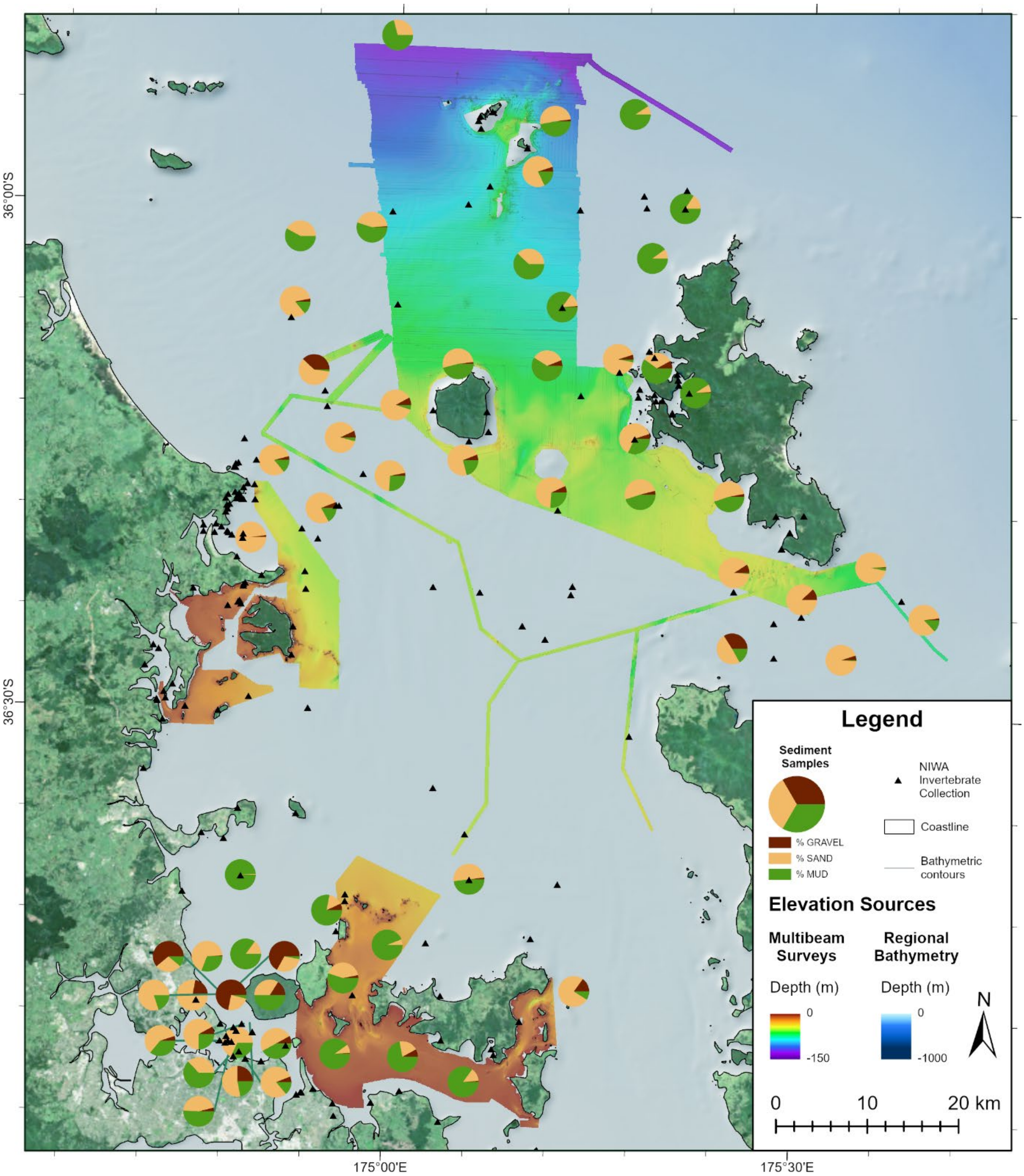


Figure 2-10: Sediment and biological samples across HS53, HS54, and TAN1211. Sediment samples are shown by percentage of gravel, sand, and mud. Biological samples from the NIWA Invertebrate Collection (NIC) are shown as black triangles. There are no sediments samples within the HS53 area and relatively few in the HS54 and TAN1211 area. Biological samples are sparse in all regions. Please also see Figure B-1, Figure B-2, and Figure B-3 for enlarged maps of each area.

3 Expert-driven interpretation

This report details three multibeam datasets, including two hydrographic surveys (HS53 and HS54), and one scientific survey (TAN1211). These datasets provide high resolution information about the depth, geomorphology, and nature of the seabed across three areas in Tīkapa Moana/Hauraki Gulf (Figure 1-1):

1. TAN1211 covering 1268 km^2 between Great Barrier Island/Aotea, Little Barrier Island/Te Hauturu-o-Toi, Flax, and Mokohinau Islands, with single swath lines extending farther south into Tīkapa Moana/Hauraki Gulf.

2. Tāmaki Strait (HS54) covering 310 km^2 between Waiheke, Motutapu and Motuihe Islands, the Noises, Mahurangi Peninsula, and the southern eastern shore of Tāmaki Makaurau/Auckland. This survey is adjacent to the HS52 – Approaches to Auckland survey, which was characterised in Pallentin et al. (2022).

3. Kawau Bay (HS53) covering 184 km^2 between Tāwharanui Peninsula, Mahurangi Peninsula and the region surrounding Kawau Island.

Figure 3-1 shows all three areas with Features of Interest (FOI) marked in white dashed lines and labelled according to Table 3-1, Table 3-2, and Table 3-3 following in section 3.4. For each feature of interest, where possible, onshore-offshore connections between observed seafloor geological features and the proximal onshore geological units mapped in the 1:1,000,000 (Appendix Figure D-1) and 1:250,000 (Appendix figures Figure D-2, Figure D-3, and Figure D-4) geological maps of New Zealand, published and regularly updated by GNS Science (Geological Map of New Zealand - GNS Science | Te Pū Ao). Specific geological units referred to in text cite these resources presented in Appendix D.

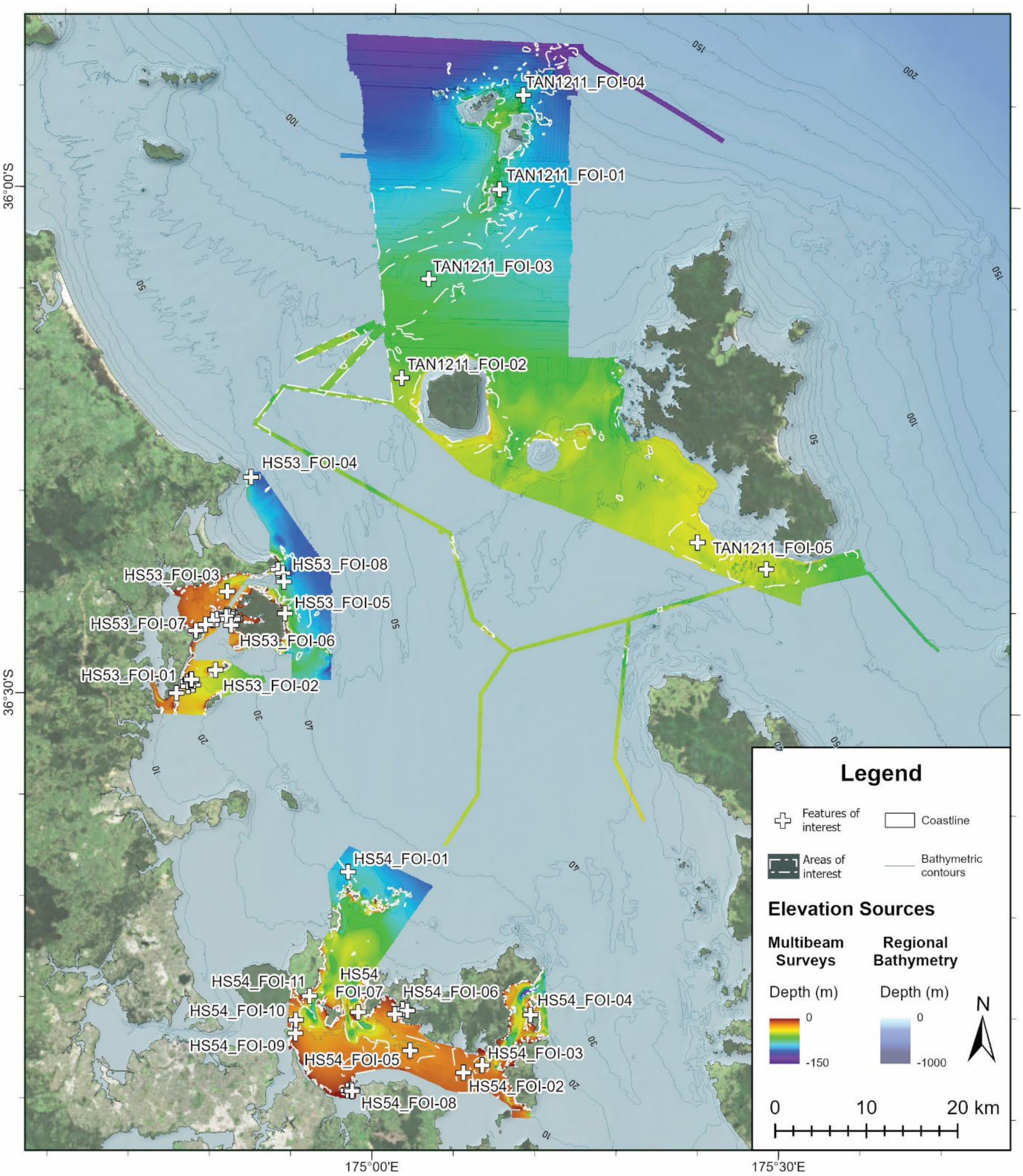


Figure 3-1: Areas HS53, HS54, and TAN1211 with Features of Interest (FOI) marked by white dashed lines and numbered. The numbering is according to the listing in Table 3-1, Table 3-2, and Table 3-3 in section 3.4.

3.1 Area description – TAN1211

The water depth within the TAN1211 survey ranges from ~20 m water depth in the waters around Great Barrier Island/Aotea and Little Barrier Island/Te Hauturu-o-Toi to ~140 m water depth in the northern portion of the surveyed area, near Flax and Mokohinau Islands.

Bathymetry data reveal the variability of the seafloor from rocky reef platforms, sediment bedforms, and broad flat seabed between the Hauraki Gulf/ Tīkapa Moana channels. Flax and Mokohinau Islands are characterised by extensive submerged rocky platforms with high rugosity seabed structures, and variable seafloor backscatter, and these may represent important habitats for benthic communities (Figure 3-1, Table 3-1, Feature: TAN1211_FOI-01). Onshore, the islands comprise Whitianga Group Rhyolite of the Coromandel Volcanic Zone, suggesting the offshore extension may also represent this unit (Appendix Figure D-2) (Edbrooke, et al., 2014; Heron, 2023; Rattenbury & Isaac, 2012).

Submarine bedforms are a common feature of the seabed, found near rocky reefs, particularly across the open flat seabed (Figure 3-1, Table 3-1, Features: TAN1211_FOI-02 and TAN1211_FOI-03) and on the western flanks of channel islands (Figure 3-1, Table 3-1, Features: TAN1211_FOI-01 and TAN1211_FOI-04). Sediment bedforms are extremely well represented in the seafloor backscatter mosaic as relatively high backscatter curvilinear ripples, over lower backscatter substrate (Figure 3-1, Table 3-1, Features: TAN1211_FOI-01 to TAN1211_FOI-03). The channel between Aotea/Great Barrier Island and Coromandel Peninsula is characterised by distinctive higher seabed backscatter signatures compared to the surrounding seabed indicative of a different, likely harder or larger grain-size sediment. This region also hosts a network of sediment bedforms (Figure 3-1, Table 3-1, Feature: TAN1211_FOI-05), which may reflect elevated ocean current speeds within these narrow channels. The seabed substrate is dominated by mud and sand with small proportions of gravels in some locations. Samples with higher proportions of sand are found in the southern region, south of Great Barrier Island/ Aotea. Larger grain sizes (sand) in grab samples are indicative of higher ambient current energy in this area (Figure 2-10).

Although only represented in transit lines, the sediment bedforms appear to be widespread within the Hauraki Gulf/ Tīkapa Moana, southwest of Aotea/Great Barrier Island.

The impact of human activities was notably absent from the TAN1211 dataset; however, this could be related to the finer scale of human activities typically observed in bathymetry data, the pervasive artefacts in the TAN1211 dataset, or the relative distance of the survey area from the mainland.

3.2 Area description – HS54

The water depth within the HS54 – Tāmaki Strait survey ranges from the coast to ~46 m water depth. Much of the enclosed waters between the Tāmaki Makaurau/Auckland and Waiheke Island are less than 10 m depth, with deeper troughs and scours in the channels between the Gulf Islands including Sergeant and Waiheke Channels. North and east of Waiheke, the water depths gradually increase to the central Hauraki Gulf/Tīkapa Moana.

The HS54 – Tāmaki survey lies adjacent to the HS52 - Approaches to Auckland survey, and many seabed features are observed across both datasets. One of the best examples of feature continuation across the HS52 and HS54 surveys is the linear array of pockmarks (Figure 3-1, Table 3-2, Feature: HS54_FOI-01) that was first identified in the HS52 survey. The pockmarks appear southeast of Tiritiri Maitangi Island (HS52) and trend to the southeast for ~9.1 km towards the Noises into the HS54 dataset. Across both datasets, the pockmarks are well expressed in seafloor backscatter as light circular dots on the darker seabed background. These pockmarks may represent sites of fluid escape and are recommended for follow-up surveys to evaluate seep activity and abundance of organisms in any benthic ecological communities. The strong linear arrangement of these pockmarks could also indicate they are structurally controlled (e.g., by a fault).

Unlike the shallow seabed region in the HS52 survey, the shallow water region within the Tāmaki Strait is highly variable, possibly related to the confined and high energy currents within the Waiheke, Motuihe and Sergeant channels (Chiaroni et al., 2010).

The eastern portion of the HS53 survey is characterised by numerous circular mounds that span the entire Tāmaki Strait (Figure 3-1, Table 3-2, Feature: HS54_FOI-02) from east of Duder Regional Park to south of Awaawaroa Bay. The mounds are characterised by high seafloor backscatter signature and variable surface morphology, from terraced to cratered in appearance. Determining the nature and origin of these features would require ground-truth information. These mounds may be important habitats and may be associated with specific benthic communities.

Northeast of the mounds is a cluster of circular depressions, morphologically similar to those observed in the HS52 dataset (Feature E in Pallentin et al., 2022), located next to an offshore pipeline in Mairangi Bay. In the Tāmaki Strait, these circular depressions (Figure 3-1, Table 3-2, Feature: HS54_FOI-03) are to the southeast of Passage Rock and are located within the Te Matuku Marine Reserve. These features may be indicative of relict or active seabed seepage and potential sites of sensitive ecosystems.

The western Tāmaki Strait deepens to the west towards Sergeant Channel, becoming more rugose and variable in backscatter intensity. For example, regions of low seafloor backscatter form ESE-WNW trending linear low relief channels, approximately 4 km in length and deepening westward (Figure 3-1, Table 3-2, Feature: HS54_FOI-05). These channels likely host a distinct seabed substrate, likely finer sediment, compared to the more variable moderate to high seafloor backscatter on the surrounding seabed. Sediment samples in this region mostly have a high proportion of mud and sand (Figure 2-10). Small percentages of gravel occur in the western Tamaki Strait and north of Sergeant Channel.

Similar to the HS52 dataset, the narrow channels between the mainland and Hauraki Gulf /Tīkapa Moana Islands display variable seafloor depth and texture (Figure 3-1, Table 3-2, Feature: HS54_FOI-07) and high seabed backscatter signature compared to adjacent seafloor, indicative of substrate boundaries. For example, lighter regions within the channel may be indicative of larger sediment grains, such as sand or gravel or even rock, compared to the flat plains with darker backscatter that could be dominated by muddy sediment. Compared to the Whangaparaoa Passage in the HS52 dataset, the Waiheke, Motuihe and Sergeant channels within the HS54 dataset, are comparatively narrower, more deeply scoured and host more variable seafloor morphologies, including rocky outcrops and widespread sediment bedforms (Figure 3-1, Table 3-2, Feature: HS54_FOI-11). These features may indicate high current speeds and therefore sediment mobility within the channels of the HS54 dataset.

Rocky reefs (Figure 3-1, Table 3-2, Feature: HS54_FOI-09) are widespread along the nearshore regions, particularly offshore headlands and within scoured channels. Rocky reefs were a prominent feature of the HS52 dataset as well, however, within the HS54 survey, the rocky reef outcrops show a distinctive morphology, likely related to the differing onshore rock units. On the eastern side of Browns Island/ Motukorea there is a unique rocky reef platform, mostly within 2 m water depth. The platform extends 500 m to the north of the island and up to 350 m east, and may represent the offshore extension of either the three volcanic rock units (of the Kerikeri Volcanic Group) or river deposits of Tauranga Group mapped onshore (Appendix Figure D-3) (Edbrooke, et al., 2014; Heron, 2023; Rattenbury & Isaac, 2012). Rocky reefs such as these may represent important habitats for benthic communities. Similarly, rough seabed is observed across many locations within the survey area characterised by increased rugosity and textured seafloor backscatter, and these areas may be important habitats associated with specific benthic communities.

The impact of human activities is observable on the seafloor across a range of locations within the HS54 survey region and is focused in the nearshore zone (Table C-1). These features are all sites of potential physical seabed disturbance, which may impact habitat distribution.

In northwest Cable Bay, offshore Rotoroa Island, there are a series of several high backscatter rounded features (Figure 3-1, Table 3-2, Feature: HS54_FOI-04) isolated to the region directly offshore from the western headland. The origin of these features is unknown, but due to their localised footprint, proximity to other human structures and scale, they are possibly related to a human activity (e.g., mooring of vessels, maritime operations, sediment disposal, dredging). North of Browns Island/Motukorea a similar suite of anomalous high backscatter features is visible covering ~1.5 km^2 (Figure 3-1, Table 3-2, Feature: HS54_FOI-10). Here, seafloor backscatter illuminates curvilinear markings with high intensity backscatter return, adjacent to localised mound and pit structures. Adjacent to the Pine Harbour Marina, a series of sub-10 m scale circular features are oriented in a linear array aligning with the dredged boat channel (Figure 3-1, Table 3-2, Feature: HS54_FOI-08). They appear to cluster in two main regions several hundred meters from the dredged channel and may represent sediments disposed of during the channel dredging process. These features (Figure 3-1, Table 3-2, Features: HS54_FOI-04, HS54_FOI_08, and HS54_FOI-10) are also presumed to represent human activity, but external verification is required to assist in determining their formative processes. The footprint of permanent vessel moorings (Figure 3-1, Table 3-2, Feature: HS54_FOI-06) is common within the enclosed bays around Waiheke Island (as well as within the HS53 dataset near Kawau Island). Mooring blocks manifest as sub-circular pits ~15 m diameter, often with leveed margins, where sediment has been displaced. They show variable (high and low) seafloor backscatter compared to surrounding moderate backscatter seabed and align well with the locations of moored vessels in satellite imagery.

3.3 Area description – HS53

The water depth within the HS53 – Kawau Bay survey ranges from the coast to ~61 m water depth, with an average depth of 28 m. The seafloor is shallowest within Kawau Bay and deepens eastward into the central Hauraki Gulf/Tīkapa Moana through the North and South Channels. Within Kawau Bay, away from the coast, the seabed morphology is generally gentle and undulating. One exception is a 5 m high bathymetric step, that lies almost equidistant between Karangatuoro Point and Pembles Island (Figure 3-1, Table 3-3, Feature: HS53_FOI-03).

Although the HS53 and HS52 survey boundaries are at least 7 km apart, there are many similarities between the two surveys in terms of seafloor morphology and features of interest. Like the HS52 survey, the HS53 survey hosts expansive rocky reefs along the coast, which manifest as tilted parallel rock units offset by faults (Figure 3-1, Table 3-3, Feature: HS53_FOI-01). The seafloor backscatter highlights that the rocky unit extends over 1 km seaward into Inner Channel, which is more subtle in bathymetry data, possibly related to a thin veneer of sediment overlying the rocky reef. Similar to the HS52 survey, these rocky reefs are likely the offshore extension of Late Oligocene Early Miocene-age deep-water mud and sandstones of the Waitemata Group that lies onshore in this region (Appendix Figure D-4). The rocky reef platforms are prevalent along the eastern margin of Mahurangi Peninsula and Kawau Island, Tāwharanui Peninsula and Cape Rodney, and less prominent on the western Kawau Island. East of Omaha and along the eastern margin of Kawau Island, adjacent rocky reefs display morphological differences that may reflect the geological contacts between mapped onshore units. For example, offshore Omaha the rocky reef (Figure 3-1, Table 3-3, Feature: HS53_FOI-04) to the north displays a subtly rugose morphology, with faint lineations that may represent stratigraphic units. To the south, the rocky reef is highly textured and fractured. Similarly, the Kawau Island eastern margin rocky reef (Figure 3-1, Table 3-3, Feature: HS53_FOI-05) is characterised by tilted stratigraphic sequences, with prominent fracturing and faulting to the north, and tessellated, highly rugose reef to the south. In both cases, onshore rock units vary along the coast between the Waipapa Terrain and Waitemata Groups (Appendix Figure D-4) (Edbrooke, et al., 2014; Heron, 2023; Rattenbury & Isaac, 2012).

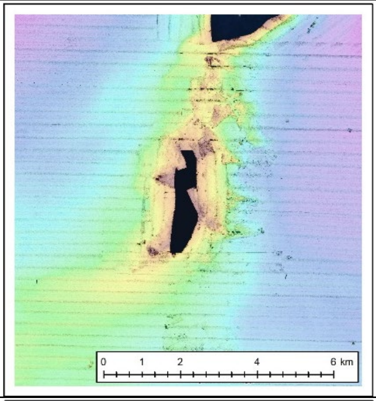
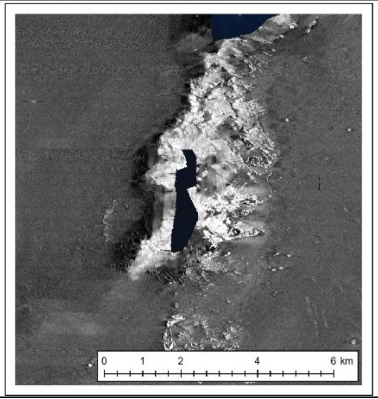
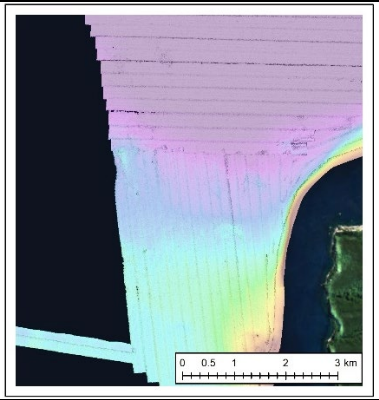
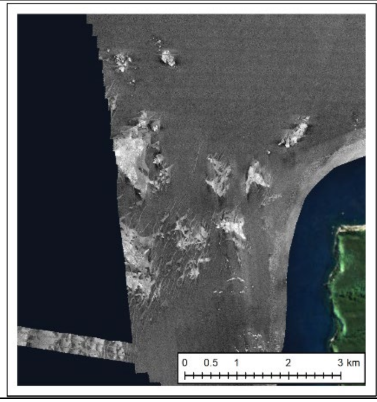
The North Channel between Kawau Island and Tāwharanui Peninsula shows exposed rocky reef outcrops, scouring and sediment bedforms (Figure 3-1, Table 3-3, Feature: HS53_FOI-08), like those observed within Whangaparāroa Passage mapped in the HS52 survey and the Sergeant and Waiheke channels in HS54. These observations are consistent with relatively high currents, as they flow around the islands of the central Hauraki Gulf/Tīkapa Moana. There are no sediment samples in this region (Figure 2-10).

The Kawau Bay dataset show a range of evidence for human infrastructure and activities impacting the seabed (Table C-1). These include: (1) numerous wrecks, such as the well-known *Rewa* wreck in Martins Bay on Moturekareka Island (Figure 3-1, Table 3-3, Feature: HS53_FOI-02), (2) the bathymetric imprint of pipeline or cable Goldsworthy Bay to Takangaroa Island and on to Kawau Island near Mansion house (Figure 3-1, Table 3-3, Feature: HS53_FOI-07), and (3) The central Kawau Bay west of Bon Accord Harbour shows subtle evidence of anchoring impacts (Figure 3-1, Table 3-3, Feature: HS53_FOI-06). Unlike the anchoring impacts observed in HS52, these are much smaller and therefore may be related to anchoring of smaller vessels. Some features, including these anchor footprints and much of the North and South Channels, cannot be characterised by seafloor backscatter due to the lack of coverage across parts of the Kawau Bay dataset.

3.4 Features of interest

In this section we tabulate Features of Interest (FOI) organised by survey area TAN1211 (Table 3-1), HS54 (Table 3-2), and HS53 (Table 3-3), respectively, as described in the previous section. Each table is sorted by FOI and illustrates a closeup of the bathymetry and backscatter data, the depth range of this closeup, and a description of the feature observed within the survey.

Table 3-1: Example Features of Interest (FOI) for TAN1211.

FOI	Example image (bathymetry and backscatter) of key features observed within surveys			Description of key features observed within surveys
	Bathymetry	Depth range	Backscatter	
		TAN1211		
01		Depth (m) 60 100		Rocky reef outcrop to the south of the Mokohinau Islands, surrounding Simpson Rock. These outcrops are dominated by high seafloor backscatter, indicative of harder, substrate, particularly on the eastern side of Simpson Rock to depths of 80 m. Rocky reef extends northward to Motukino/Fanal Island. Exposed rocky islands are composed of Whitianga Group Rhyolite of the Coromandel Volcanic Zone. Seafloor backscatter on the western and southern side shows alternating high and low reflectivity bedform structures.
02		Depth (m) 40 60		Reef and sediment ripples well represented in seafloor backscatter by high and moderate reflectivity, adjacent to lower reflectivity surrounding seabed in the channel west of Te Hauturu o Toi/Little Barrier Island. Linear sediment ripples trend to the northeast-southwest and extend from higher backscatter rocky structures. Varying backscatter is indicative of substrate/habitat boundaries. For example, lighter regions may be indicative of rocky or larger sediment grains such as sand, compared to darker backscatter which could be dominated by finer sediment.

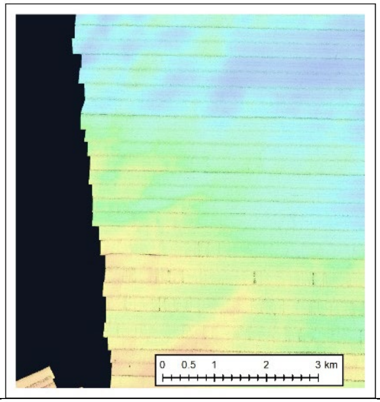
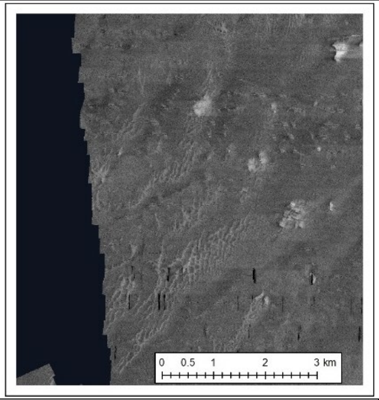
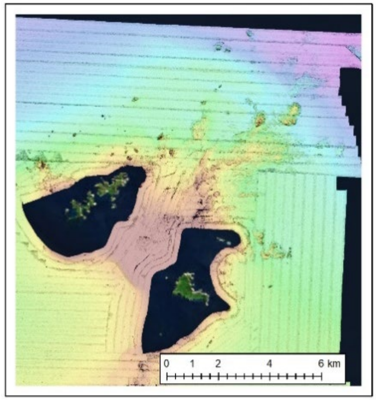
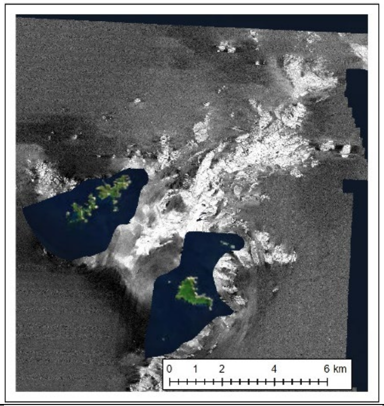
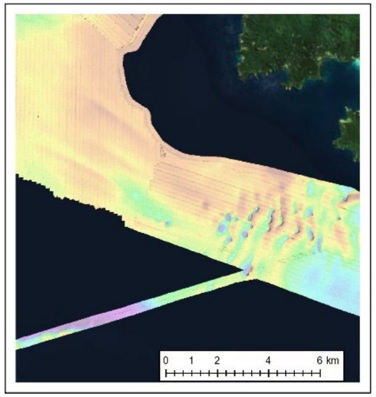
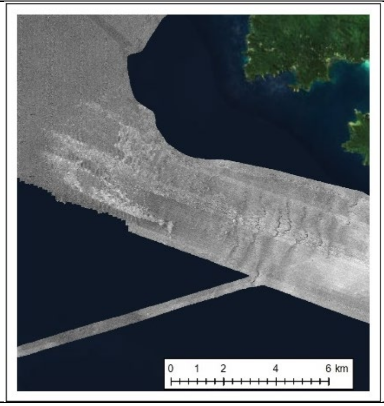
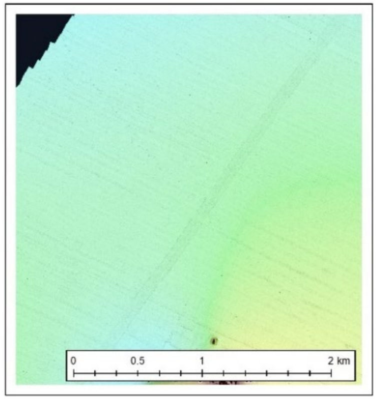
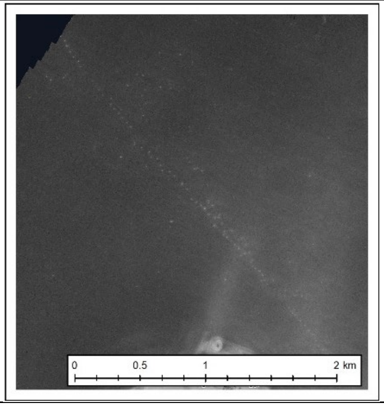
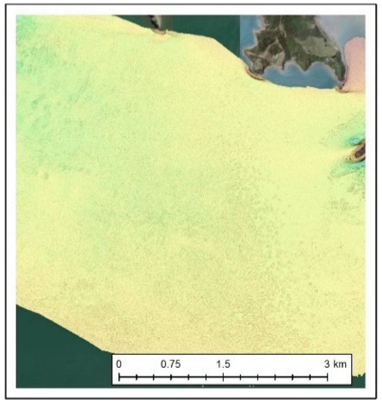
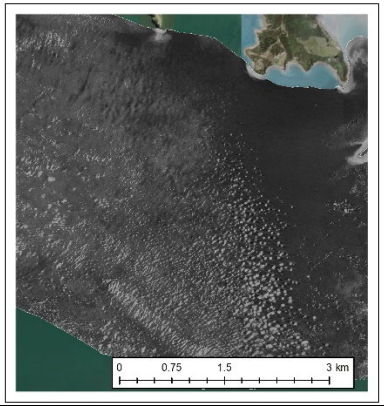
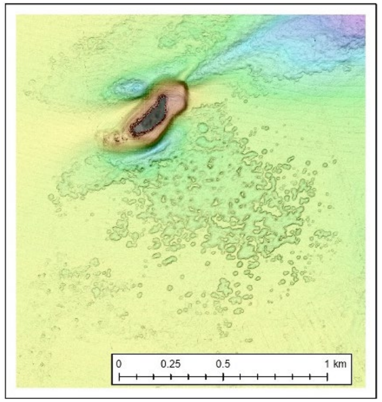
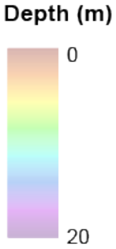
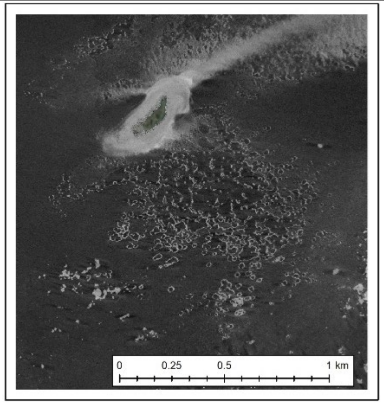
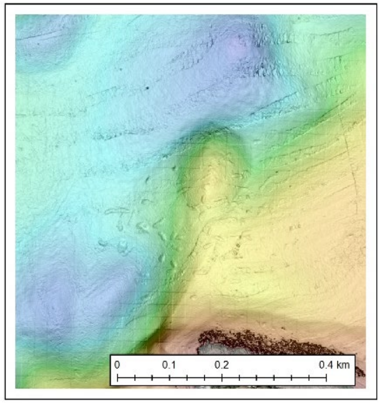
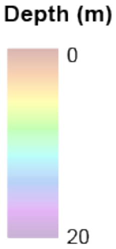
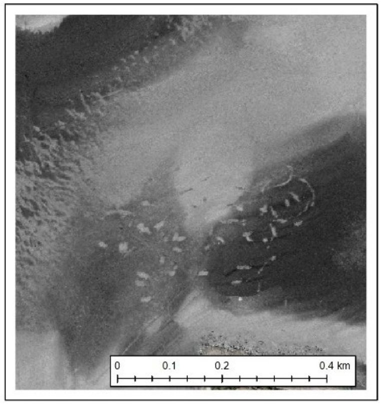
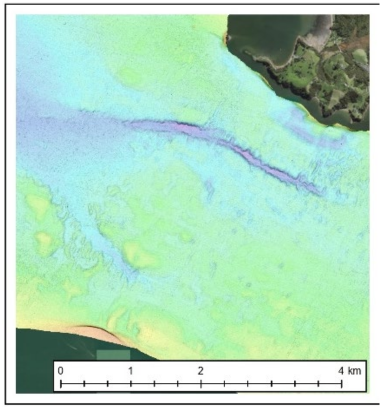
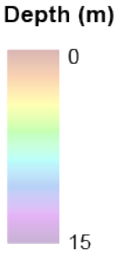
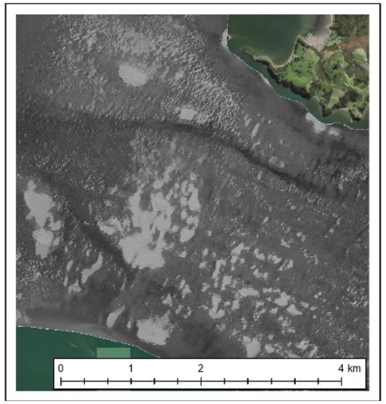
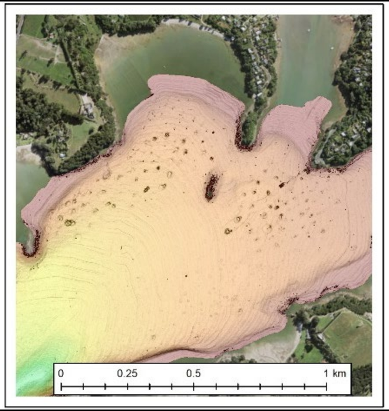
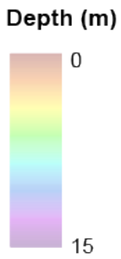
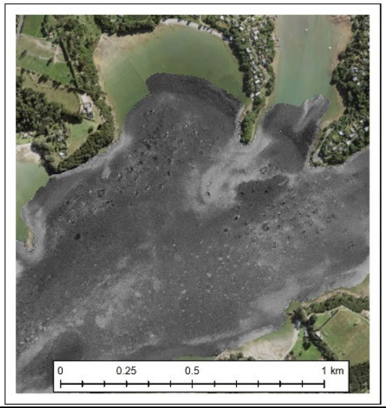
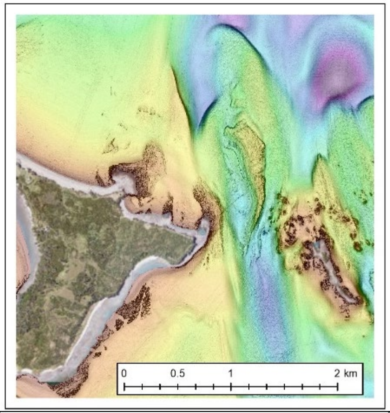
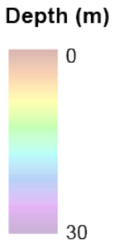
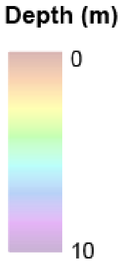
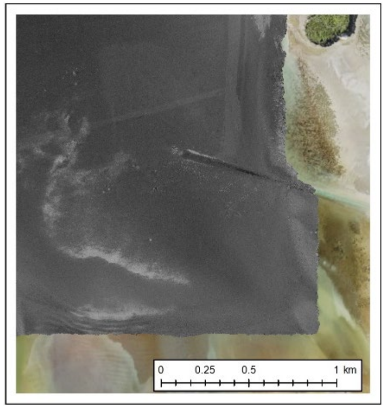
03		Depth (m) 60 80		Complex and irregular network of higher seafloor backscatter sediment ripples north of Te Hauturu o Toi/Little Barrier Island. Ripples are difficult to discern in bathymetric data, due to data quality and noise. Ripples extend at least 4 km and trend generally in a northeast-southwest direction, possibly reflecting dominant current flows.
04		Depth (m) 60 150		Extensive nearshore rocky reef characterised by increased seabed rugosity, and high seafloor backscatter between Mokohinau Islands and Flax Islands. Reef extends beyond survey, at least 11 km underwater to the northeast of the islands. Western side of the islands is dominated by relatively low backscatter, indicative of finer grained sediment and lower energy conditions.
05		Depth (m) 40 60		Sediment wave field between Aotea/Great Barrier Island and Coromandel Peninsula. Bedforms comprise a range of seafloor backscatter intensities, indicative of variable substrate grain sizes. To the east, bedforms are asymmetrical, with steeper lee slopes facing west, and larger, with heights up to 15 m and wavelengths of ~400 m. To the west, bedforms are more widespread, symmetrical, and smaller, with heights of less than 1 m and wave lengths of ~100 m.

Table 3-2: Example Features of Interest (FOI) for HS54.

FOI	Example image (bathymetry and backscatter) of key features observed within surveys			Description of key features observed within surveys
	Bathymetry	Depth range	Backscatter	
	HS54			
01		Depth (m) 20 40		Pockmarks following a distinctive linear arrangement, oriented NW-SE over ~3 km within surveyed region. This linear array of pockmarks aligns with those identified in HS52 (Approaches to Auckland), forming over 9 km of pockmarks with ~50 m spacing that extend from Tiritiri Maitangi in the northwest, to the Noises in the southeast. This lineation is parallel to known fault in the area, mapped onshore Tiritiri Maitangi. Pockmarks suggest fluid seepage, possibly along faults. The pockmarks are well expressed in seafloor backscatter as light circular dots on the darker seabed background.
02		Depth (m) 0 20		Hundreds of mounds at ~5 -10 m depth are scattered within the channel between Waiheke and the mainland, between Duder Regional Park in the east and Motukaraka Island in the west. The mounds are circular, and densely spaced, with some joining to form sublinear aggregations of high local relief towards the west. The eastern limit of the mounds is characterised by low surrounding seafloor backscatter (likely fine sediment) and an abrupt increase high backscatter mounds to the west, likely representing hard, rocky substrate. Mounds are less than 1 m in vertical relief, and individually ~ 50 m across. The surface morphology in the easternmost region of the mounds has distinctive circular terrace, below the rounded summit. To the north, the mounds host a central crater-like morphology, with notably high backscatter.

03				A cluster of rounded depressions is concentrated south of Waiheke Island in the Waiheke Channel. These features may represent relict or active seabed seepage and potential sites of sensitive ecosystems. Seafloor backscatter reveals that the sloping rim of these features may have a harder substrate compared to their base.
04				Several anomalous positive relief and high backscatter structures lie near Cable Bay, offshore the northern Rotoroa Island. These features are rounded and may represent the physical footprint of a human activity, due to their highly localised nature and relatively small scale.
05				A prominent linear bathymetric channel between Waiheke and the mainland. The channel is filled with dark seafloor backscatter (finer sediment) compared to surrounding seabed.

06				The seabed footprint of vessel moorings manifests as clusters of irregular mounds in shallow bays within Putaki/Putiki bays, Waiheke Island. Sheltered bays such as these are commonly where recreational vessels have fixed swing moorings. Satellite imagery supports this interpretation, showing numerous vessels moored in locations that align with the physical footprint observed in bathymetry data.
07				Strongly scoured and rugose bathymetry channel between Waiheke, Crusoe Islands and Motuihe Island/Te Motu-a-Ihenga. Deep scours are symmetrical about the narrowest section of the channel, likely forming due to increased current activity within the confined channel. Seafloor backscatter suggests that the substrate is relatively hard, or coarser grained compared to open flat seafloor. The base of channel scours host complex sediment bedforms and rocky reef outcrops. Rocky reefs show distinctive tilted parallel rock units dipping to the southwest. Adjacent onshore rock units include East Coast Bays Formation of Warkworth Subgroup (Waitemata Group) and Waipapa Group sandstone and siltstone (Waipapa Composite Terrane).
08				A series of small circular mounds lead into the dredged channel at the mouth of Pine Harbour Marina. Two dominant clusters of mounds lie to the south of the dredged channel, and likely represent the bathymetric footprint of human activity.

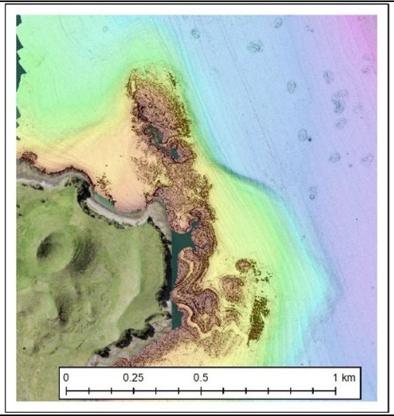
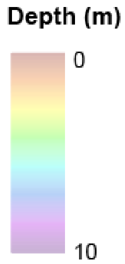
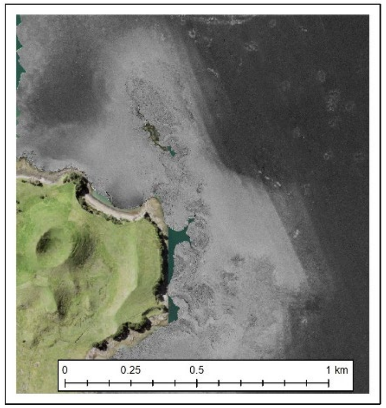
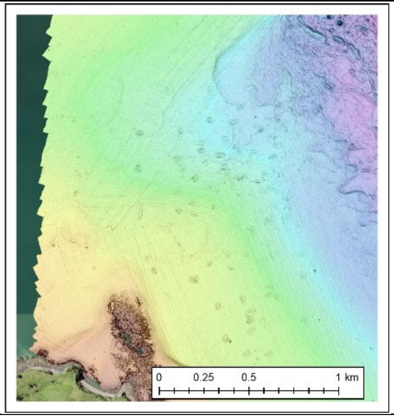
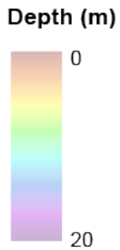
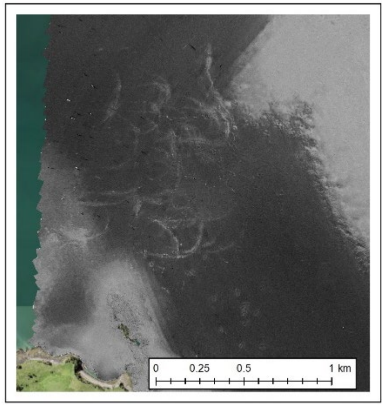
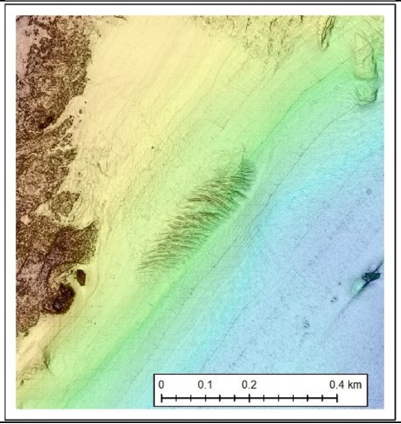
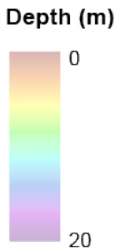
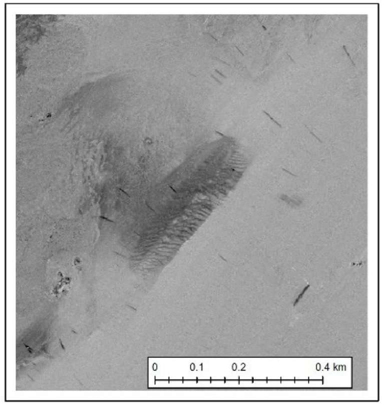
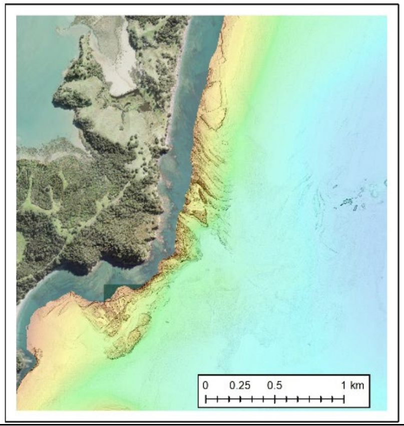
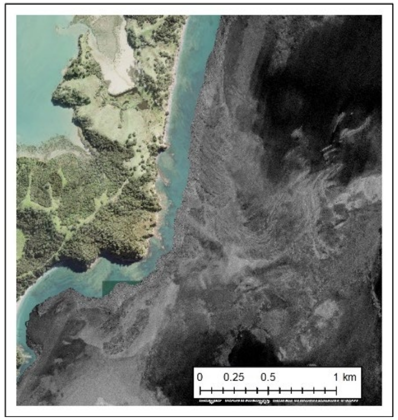
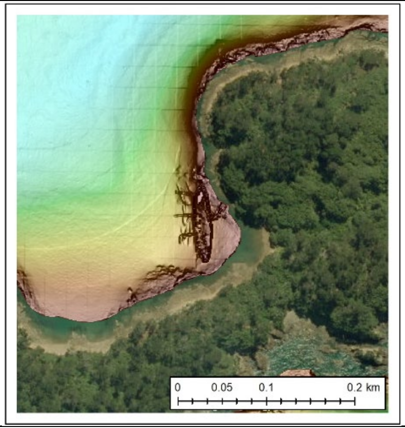
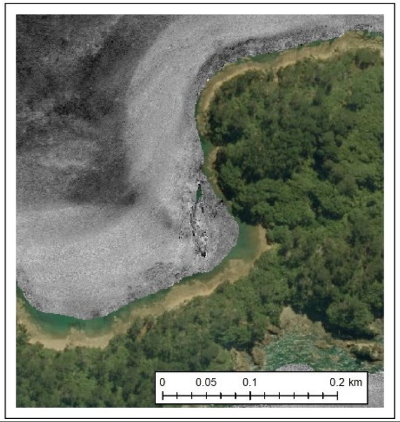
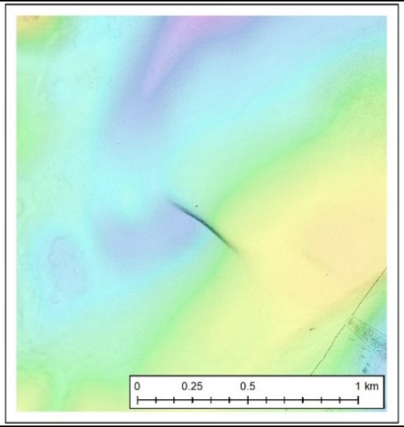
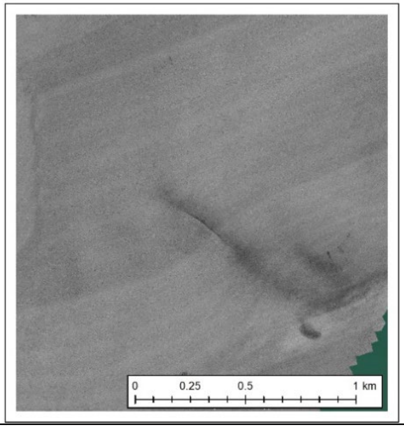
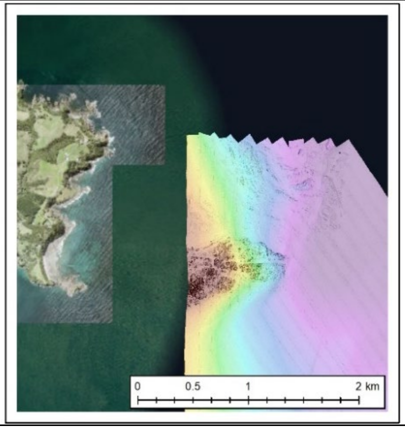
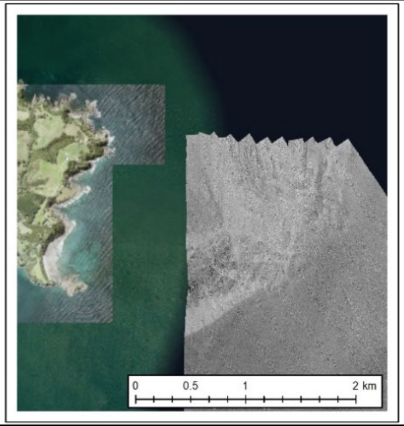
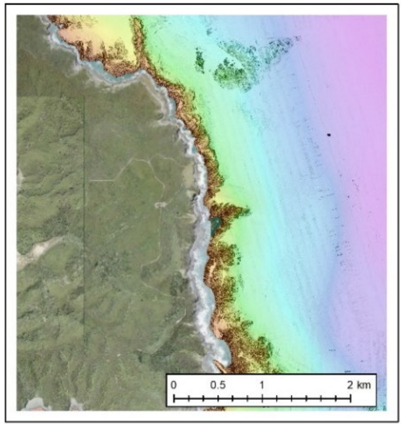
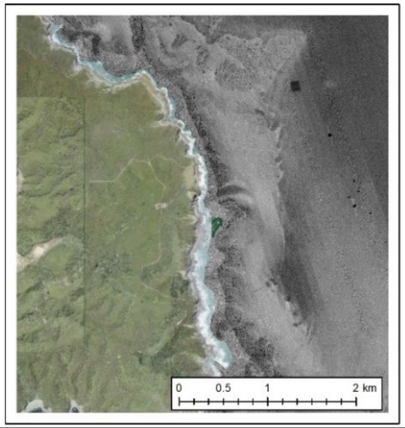
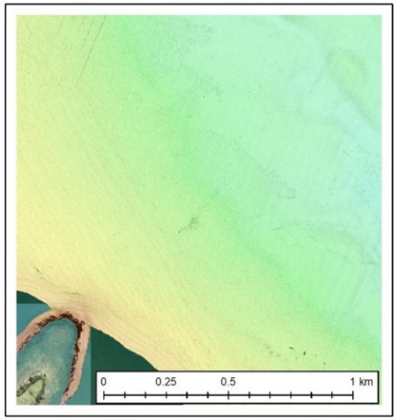
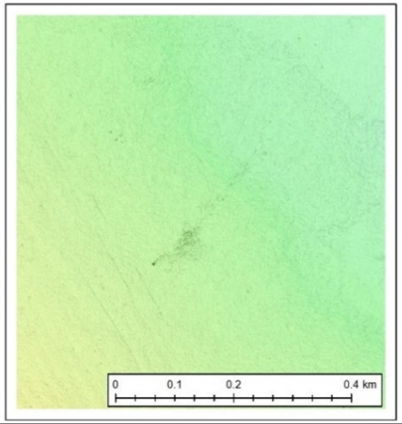
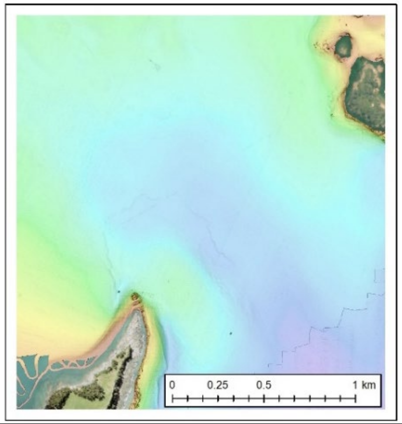
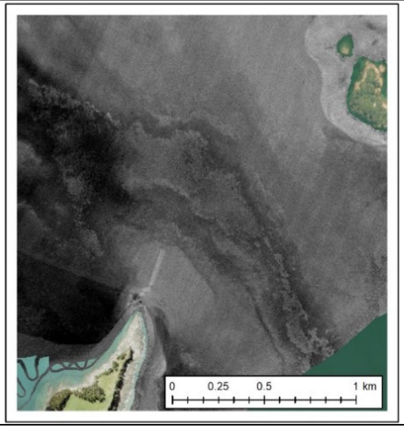
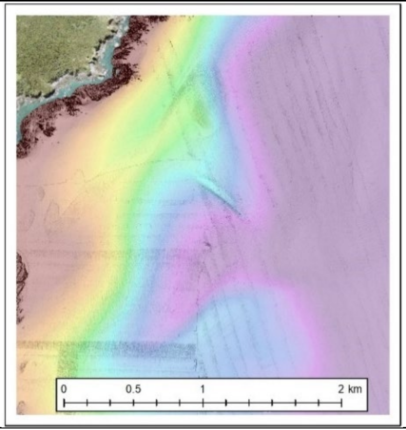
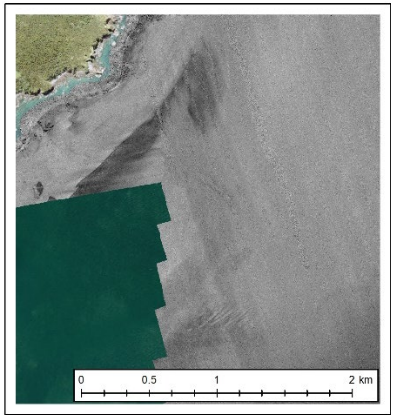
09				Highly distinctive curvilinear folds in a rocky reef unit that runs along the eastern margin of Motukorea/ Browns Island. The adjacent onshore unit is the Auckland Basalts tuff (Kerikeri Volcanic Group) of Auckland Volcanic Field. Backscatter imagery highlights the more textured hard rocky reef substrate (lighter) compared to the deeper and smoother soft sediment substrate (darker).
10				Rounded mounds and curvilinear high backscatter markings cover ~1 km^2 of seabed to the northeast of Motukorea/ Browns Island. Similar to those near Cable Bay offshore the northern Ponui Island/ Chamberlins Island. These features may represent the physical footprint of a human activity, due to their highly localised nature and relatively small scale.
11				An isolated oval-shaped region of linear-curvilinear sediment waves lies in channel between Motutapu Island and Motuihe Island/Te Motu-a-Ihenga. Sediment-wave crests are oriented approximately east-west and may be related to currents between the coast and the Hauraki Gulf Islands.

Table 3-3: Example Features of Interest (FOI) for HS53.

FOI	Example image (bathymetry and backscatter) of key features observed within surveys			Description of key features observed within surveys
	Bathymetry	Depth range	BS	
	HS53			
01		Depth (m) 0 30		Extensive rocky reef platform to the east of Mahurangi East Peninsula and Big Bay. The rocky outcrop shows tilted parallel rock units offset by faults. These outcrops are likely the offshore extension of Pakiri Formation of Warkworth Subgroup (Waitemata Group). Units show variable dip direction and angles, consistent with onshore observations. The rocky unit extends offshore, becoming less obvious in bathymetry data, but observable in seafloor backscatter as relatively high intensity substrate compared to surrounding seabed.
02		Depth (m) 0 30		One of many nearshore wrecks in these surveys. This wreck lies close to the beach at Martins Bay on Moturekareka Island. The *Rewa*'s three masts are clearly visible in bathymetric data as ~20 m straight poles lying perpendicular to the main hull of the ship.

03		Depth (m) 0 30		An isolated ~5 m high, 400 m long bathymetric step located in the channel between Kawau Island and Tāwharanui. The step faces to the SSW and is parallel to the orientation of form lines of the onshore Waipapa Group sandstone and siltstone (Waipapa Composite Terrane). The step is characterised as lower seafloor backscatter compared to surrounding seabed.
04		Depth (m) 30 50		This rocky reef offshore Omaha hosts two distinctive morphologies. The northern unit has less relief and shows subtle linear structures that may correspond to stratigraphic layers. The southern unit is highly textured with fractured and jointed surface texture. The two outcrops could represent the geological contact between Waipapa composite terrain (north) and Waitemata group (south), as mapped onshore. The nearshore region around Omaha, and Goat Island to the north has been mapped to a corresponding degree (1 m resolution) and overlaps with this survey. Seafloor backscatter shows variable intensity, across the textured, rugose regions, and lower backscatter over the surrounding flat featureless region.
05		Depth (m) 0 50		The eastern margin of Kawau Island hosts an extensive rocky reef. The onshore geological units comprise the Waipapa composite terrain and early Miocene Waitemata group. The offshore rocky reef shows two morphologically distinct rocky reef structures, to the north the bedded and fractured Waipapa terrain and to the south, the tessellated and highly rugose Waitemata group. The seafloor backscatter in this region shows a wide band of variable seafloor backscatter. Higher seafloor backscatter is characteristic of the rocky nearshore reefs, with adjacent seafloor backscatter showing complex high and low backscatter patterns, indicative of variable substrates/habitats.

06		Depth (m) 0 20		Anchoring footprint on the seabed in western Kawau Bay (~8 m water depth). Linear scours are caused by anchor deployment and feathering marks caused by gouging of the anchor chain scope whilst vessel swings (Watson et al. 2022). The zoomed in image shows distinctive feathering mark caused by the ships anchor chain swinging.
07		Depth (m) 0 20		Very faint lineation representing a pipeline or cable that runs from Goldsworthy Bay to Takangaroa Island and on to Kawau Island near Mansion house. The pipeline/cable is visible in satellite imagery and extends over 4.5 km within the surveyed region. The cable footprint is ~4 m wide.
08		Depth (m) 20 40		Sediment ripples in a channel opening between Kawau Island and Tāwharanui Peninsula. Sediment-wave crests are oriented approximately southeast-northwest and may be related to currents between the coast and the Hauraki Gulf Islands. Seafloor backscatter across the sediment waves shows lower backscatter return over the sediment waves, indicating finer grain-size substrate over the bedforms compared to surrounding area.

4 Recommendations for future data processing and collection

The features of interest highlight regions where we recommend further analysis and data collection, which are outlined in detail below.

4.1 Legacy data processing

As highlighted in Pallentin & Watson (2021), additional MBES data in the Hauraki Gulf is available for analysis. The hydrographic surveys HS6/HS15 (collectively survey HYDP1008 - Shipping Lane 1) and HS17/27 (HYD-2008/03 – Great Barrier Island, labelled HS17 in Figure 4-1). Unfortunately, only bathymetry data are available for these surveys (i.e., seafloor backscatter was not preserved during the survey).

All hydrographic surveys can be seen here:
https://storymaps.arcgis.com/stories/60af74f682bb40ed946a3c60d5cfa973

4.1.1 RNZN multibeam survey *Operation Poseidon* (2015)

The multibeam survey 'Operation Poseidon', undertaken by the Royal New Zealand Navy in 2015, collected MBES data in the nearshore areas surrounding Kawau Island. Additionally, the Poseidon survey undertook a shoal investigation over Tarapunga Rock to the east of Kawau Island on behalf of LINZ.

The purpose of *Operation Poseidon* was to provide support to the New Zealand Police in the search for a missing recreational vessel, rather than to undertake a dedicated seafloor mapping campaign for scientific or hydrographic purposes. As these data were not collected with a hydrographic purpose, the quality of these data differs to the surrounding hydrographic survey HS53 which was collected the following year. Although collected under different survey requirements, the *Operation Poseidon* dataset would be suitable for bathymetric terrain modelling, however, processing of raw survey soundings would be required.

The data from *Operation Poseidon* were not included in the analysis undertaken during this project.

4.1.2 Onshore-offshore connections – national LiDAR datasets

With improving access and coverage of high-resolution elevation datasets across both the terrestrial and marine environments, it is becoming increasingly beneficial to 'stitch' these datasets together into seamless elevation models. The greatest limitation to integrating topographic and bathymetric datasets has been the intertidal zone, where onshore Light Detection and Ranging (LiDAR) and offshore MBES systems can have difficulty reliably constraining elevation.

With the onshore Tamaki Makaurau / Auckland region now completely surveyed to a 1 m resolution, and the addition of a coastline-specific LiDAR dataset due for release in Q1 2024 (source – LINZ Elevation Aotearoa), it is possible to explore opportunities in generating high-resolution seamless elevation models in the region. New methodologies of generating seamless elevation models across tidal flats (e.g., Cao et al., 2023; Kang et al., 2023) can be implemented to provide further insights into how terrestrial processes may impact shallow benthic environments.

Near coastal features of interest, e.g. rocky reefs, near shore faults, would benefit most from these additional data.

4.2 New data opportunities

4.2.1 Multibeam surveys – improving data gaps

Although large areas of the Hauraki Gulf have been surveyed in the past using MBES systems, ~20 % of the Gulf remains unmapped (Figure 4-1). Additionally, many legacy surveys within the Hauraki Gulf were acquired between 15-20 years ago, presenting the possibility that components of these datasets are now out-of-date with respect to seabed morphology. Given the degree of variability in seabed morphology across nearshore surveys HS52 (Pallentin et al., 2022), HS53 and HS54 (this study), it is likely that the unmapped regions of the eastern Auckland city coastline also contain a highly variable seabed geomorphology which influences benthic environments.

Large data gaps exist between the survey area analysed by Pallentin et al. (2022) and this study (Figure 4-1). With future targeted MBES surveys of these data gaps, a seamless interpretation between coastal/shallow water benthic environments and the deeper offshore marine realm could be undertaken.

Due to the highly dynamic nature of the near coastal zone, we expect some features may change over time (channels, sediment bedforms, and areas with human impacts). To enable better understanding these temporal changes some features of interest would benefit from repeat multibeam surveys.

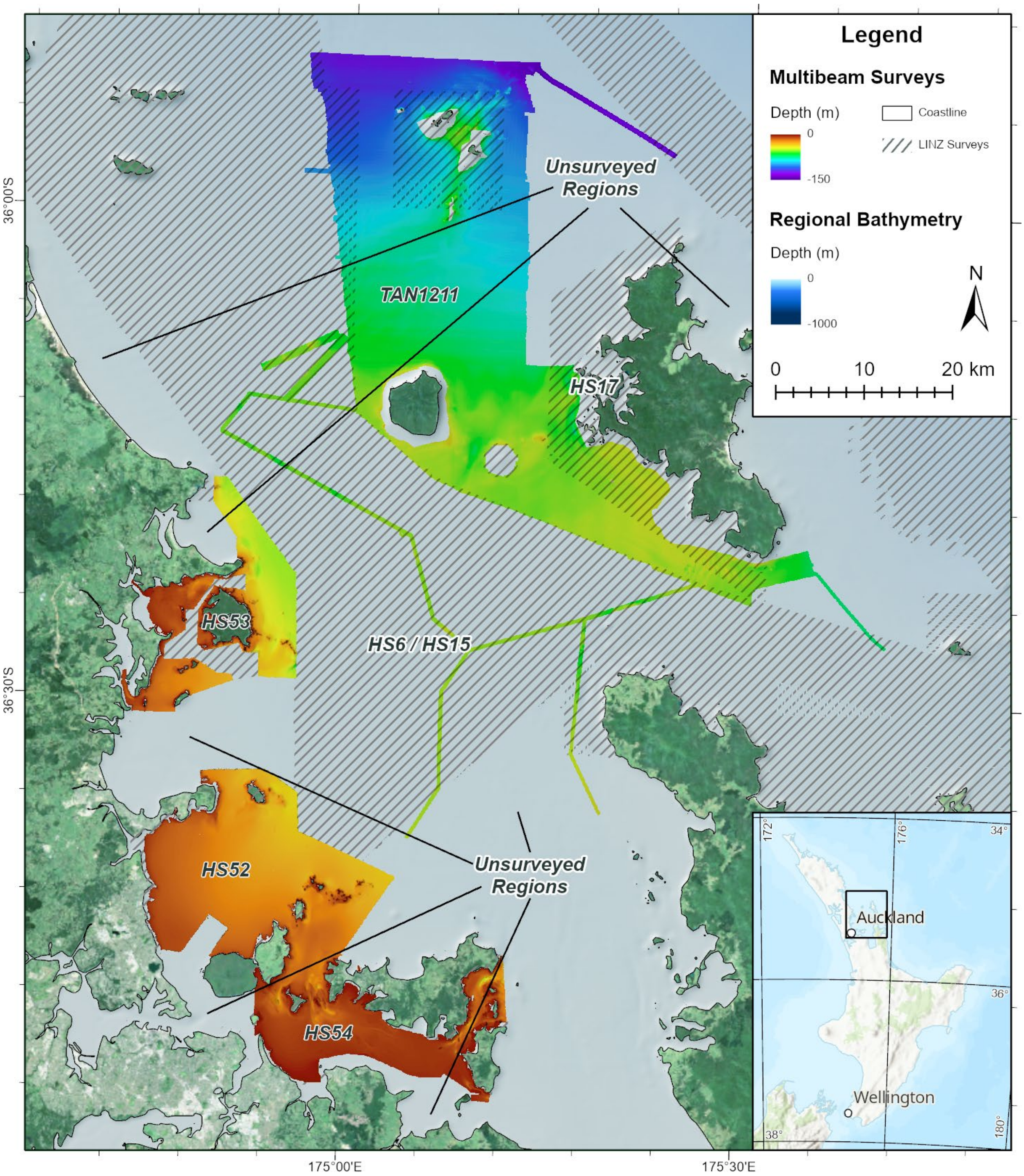


Figure 4-1: Data gaps in MBES coverage across the Hauraki Gulf. Processed bathymetric products from survey HS52 (Pallentin et al., 2022) and surveys HS53, HS54, and TAN1211 (this study) are shown in colour while regions which have been surveyed by MBES are shown by grey hatched regions.

4.2.2 Towed cameras – structure from motion modelling

With improvements in marine technology and imaging systems, new methods of data collection and processing are becoming increasingly used for detailed habitat assessment. One such method is the use of towed cameras and seafloor video transects. The use of towed cameras can allow large areas of seabed to be interpreted at ultra-high resolution (e.g., centimetre to decimetre) without the same depth limitations associated with human diving expeditions. This relatively new technique stiches still imagery together from towed, and diver-controlled, camera platforms, forming a continuous 3D model, with photo imagery overlain. 3D structure-from-motion models of the seabed (e.g., Figure 4-2) can now produce ultra-high resolution (cm scale) seafloor terrain models. With the ability to georeference structures-from-motion models, the interpretation and classification of ultra-high resolution benthic habitats coupled with geospatial analytical tools in GIS software packages may be possible.

All features of interest would benefit from video and camera imagery for habitat analysis.

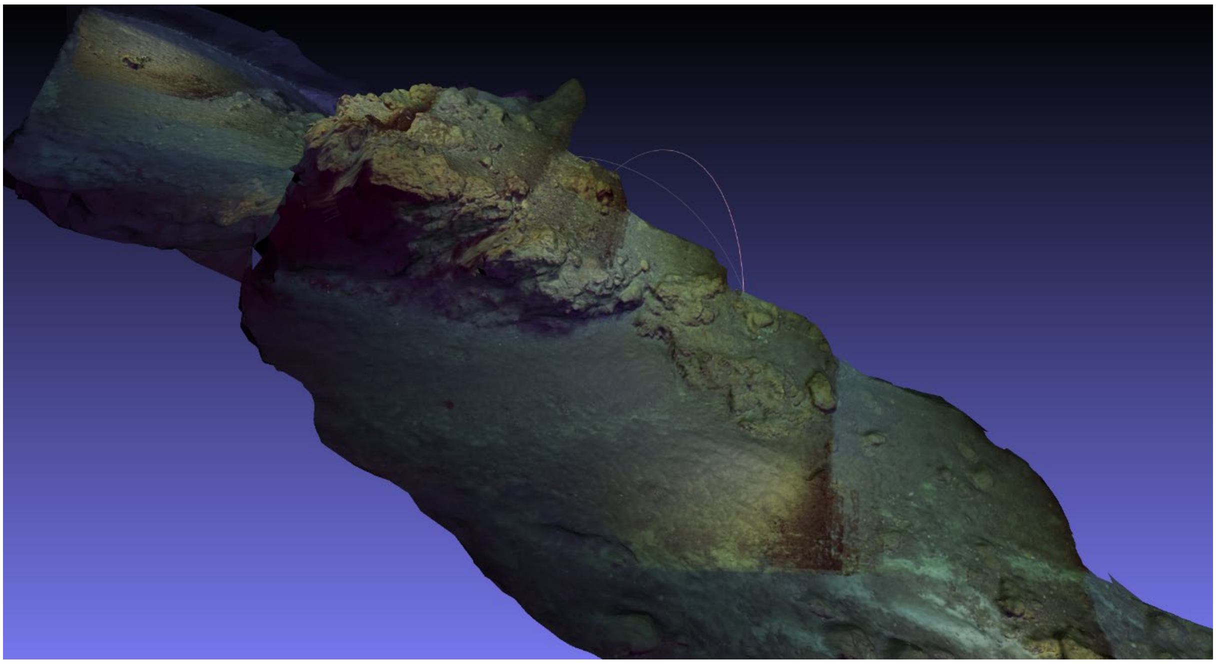


Figure 4-2: Example structure from motion 3D model. The model was generated from processed tow-camera imagery collected by NIWA.

4.2.3 Geophysical surveys – regional substrate classification

Various geophysical techniques can be employed for substrate classification in marine environments. Sub-bottom profiling, often conducted using techniques like seismic reflection and sub-bottom profiling sonars, provide information about the sediment layers and geological structures beneath the seafloor (e.g., buried reefs, faults, sediment layers). Other geophysical surveys include magnetic and electromagnetic surveys that measure the magnetic field and the electrical conductivity of the seafloor to identify volcanic rocks, sediment type and presence of minerals.

By employing these geophysical survey techniques, researchers can more effectively classify different substrate types, understand seafloor composition and dynamics, and delineate geological features beneath the ocean floor. This information can be used for marine habitat mapping, resource exploration, and the management of marine ecosystems and resources.

4.3 Ground truthing

4.3.1 Sediment cores or grab samples

Sediment grab samples at sufficient spatial coverage can aid in seafloor mapping and classification. By analysing the collected sediments, different seafloor regions can be categorised based on sediment types, which can provide valuable information about habitats and processes of the area.

The **composition** (texture, grain size, and composition) is crucial for understanding geological processes, and the influence of human activities, both of which can inform habitat analysis.

Biological and chemical analyses (organic content) can reveal the presence of microorganisms, nutrients, and pollutants. This can help in understanding the biological processes and environmental conditions of the seafloor ecosystem.

Understanding the sediment properties of habitats will be helpful for studying the biodiversity and ecological dynamics of marine ecosystems.

All features of interest would benefit from substrate sampling for habitat analysis.

4.3.2 Resurvey high priority areas

A better habitat analysis using the latest automated methods can be achieved in resurveying high priority areas following the GeoHab BSWG recommendations and including backscatter compensation lines.

4.3.3 Substrate distribution modelling

Substrate distribution modelling refers to the process of predicting the spatial distribution and characteristics of substrates, such as sediment compositions, or rock formations, within a specific geographical area. This modelling approach uses various data sources, including field observations, geophysical surveys, remote sensing data, and geospatial information, to create predictive models that describe the distribution patterns of substrates within a specific environment. The models are particularly important in understanding substrate distribution and are critical for studying habitat suitability and ecosystem dynamics.

4.3.4 Other data collection or analysis

Further data collection could include water-column data collection and analyses. This could include calibrated scientific split-beam echo sounder (SBES), MBES data, water-column physical and chemical data (CTD rosette sampling), and targeted video and biological sampling for selected features, such as pockmarks.

For areas where more than one bathymetric dataset exists over the same region of seabed, change detection analysis can be used to determine changes in bathymetry between the surveys.

4.3.5 Comparative studies – biophysical habitat modelling

Although comparative analyses of different biophysical habitat models within each assessed survey area was outside the scope of this project, additional insights through integration between different Hauraki Gulf-specific modelling studies and the benthic terrain habitat analyses undertaken here may provide further insights into regions of interest identified in this report. For example, biogenic habitats have been modelled by Bennion et al. (2023) to identify potential trawling corridors in water depths < 150 m. Additionally, Jackson and Lundquist (2016) undertook biodiversity prioritisation analyses across the Hauraki Gulf Marine Park to assess potential limitations of using different environmental variables (e.g., substrate, depth, coastal vegetation type) and demersal fish as biodiversity surrogates for habitat classification.

The integration of these varying habitat classification methodologies may provide a more refined perspective on the identified areas of interest in this report.

5 Conclusions

This report details the processing and expert-driven interpretation of bathymetry and seafloor backscatter data within hydrographic surveys HS53 and HS54, and a scientific survey TAN1211, with reference to nearby hydrographic survey HS52. Combined, these provide the foundational datasets necessary to understand the distribution and health of benthic habitats and the type, spatial extent, and potential consequences of human activities that coexist within the Central Hauraki Gulf marine environment. The three datasets presented here, as well as the HS52 data from a previous report (Pallentin et al., 2022), enable a highly detailed view of the seabed. A database of almost one thousand features of interest identified in all surveys is included in the accompanying GIS project. Highlights include:

- Extensive rocky reefs across all datasets, that are likely important shallow reef habitats or host sessile and ecologically important invertebrates, and the offshore extension of key onshore geologic rock units.
- Evidence for seafloor seepage (activity unknown) in the form of a linear arrangement of pockmarks within the HS54 and HS52 datasets. These pockmarks may be controlled by an underlying fault and host unique ecological communities that rely on the expelling fluids.
- Extensive sediment bedforms with variable morphology and complexity, indicating sediment mobility, possibly due to elevated ocean currents around the Hauraki Gulf Islands.
- Numerous locations where physical footprints of human activities (e.g., wrecks, marine litter, pipelines/cable networks, moorings, anchoring impacts) has been preserved on the seabed, which may actively enhance or degrade benthic habitats.

Across all datasets, the nearshore region shows relatively high seafloor complexity in the form of variable seafloor backscatter and BTM classes, high rugosity, and high slope. Seafloor complexity is commonly associated with higher biodiversity, and as such, we suggest further ground-truth work within the nearshore region in general. There are also several locations away from the coast (e.g., mounds in HS54 and bedforms in TAN1211) that would benefit from additional ground-truth information to fully understand their potential habitat characteristics.

The collection of these data for hydrographic or other scientific purposes and subsequent reprocessing for scientific interpretation demonstrates the range of potential end-uses for multibeam bathymetry and backscatter data, in line with the "map once – use multiple times" approach.

6 Acknowledgements

We would like to provide our gratitude to Auckland Regional Council for the opportunity of this work.

We would like to acknowledge the Hydrographic Authority team at LINZ, in particular Mr Bradley Cooper, for their assistance in providing all data associated with hydrographic surveys HS52, HS53, and HS54. Surveys HS52, and HS53 were undertaken by Discovery Marine Ltd (DML) and survey HS54 was undertaken by iXSurvey (now iXBlue), and we acknowledge the work of these companies and their hydrographic teams to acquire the original MBES datasets.

Our thanks also to NIWA contributors Kevin Mackay and Katie Maier for advice and review of this report.

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8 Data delivery

8.1 ArcGIS project

In addition to this report, all bathymetric and backscatter products, and subsequent geospatial derivatives produced for this project have been compiled and published in an ESRI® ArcGIS Pro project (filename "ARC23303_HaurakiBTM.aprx"). The published ArcGIS Pro project (v3.1.3) extracts data from 7 separate file geodatabases which contain the following datasets:

File geodatabase "ARC23303_HaurakiBTM"

- Identified features of interest across survey areas HS53, HS54, and TAN1211 (presented as both points and polygons),
- Overview points of wrecks and other objects identified by surveyors during surveys HS53 and HS54

For each surveyed region (HS53, HS54, and TAN1211), two file geodatabases have been produced (six geodatabases delivered for all surveys collectively). Each file geodatabase for the specific survey area is summarised below:

File geodatabase "SURVEYNAME_Bathymetry"

- Survey coverage polygon,
- Bathymetric contours (5 m and 10 m intervals),
- Bathymetric elevation model (spatial resolutions: HS53 = 1 m, HS54 = 1 m, TAN1211 = 2 m),
- Processed backscatter surface (spatial resolutions: HS53 = 1 m, HS54 = 1 m, TAN1211 = 2 m),
- Multidirectional hillshades derived from the bathymetric elevation model (at 3 x and 5 x vertical exaggeration at equivalent spatial resolution as bathymetric elevation models).

File geodatabase "SURVEYNAME_BathymetryDerivatives"

- Derived bathymetric products used for analysis (Aspect, Curvature, Range, Slope, Rugosity at equivalent spatial resolution as bathymetric elevation models),
- Derived bathymetric products at varying sample windows (Kernel sizes 01, 05, 15, and 25 pixels at equivalent spatial resolution as bathymetric elevation models)
- Survey-specific Benthic Terrain Model (at equivalent spatial resolution as bathymetric elevation models)

Each of the produced file geodatabases contains relevant metadata for geospatial products contained within.

Finally, supporting ArcPro compatible symbology templates (.lyrx file format) for each of the above geospatial derivatives have been provided in the delivered ArcPro project for quick implementation of NIWA's as-published symbology from the ArcGIS Online StoryMap.

8.2 StoryMap

An ESRI® ArcGIS StoryMap summarising the finding from this study, and results from the study by Pallentin et al. (2022), has also been produced for Te Kaunihera o Tāmaki Makaurau / Auckland Council. ArcGIS StoryMaps provide online users the ability to view and explore the derived geospatial datasets from this study in an online platform hosted by NIWA, without any requirements of the user holding the relevant software licenses. The StoryMap contains elements such as:

- high-resolution published images of identified features of interest from surveys HS52 (Pallentin et al., 2022), HS53, HS54, and TAN1211 (this study),
- online maps that present derived geospatial layers for the above study areas; and
- text elements and supporting figures which describe the methodologies implemented and observations from these studies.

The online maps published within the StoryMap allow for interactive zooming and panning in the project areas and investigation of the generated data in more detail than is possible in a traditional print format. The StoryMaps will be hosted on the NIWA ArcGIS Online account, providing access to the public for the duration of one year after completion.

The current URL for this StoryMap (at time of report delivery) is:

Benthic Habitat Analysis Across the Hauraki Gulf (arcgis.com)

Appendix A Benthic Terrain Models

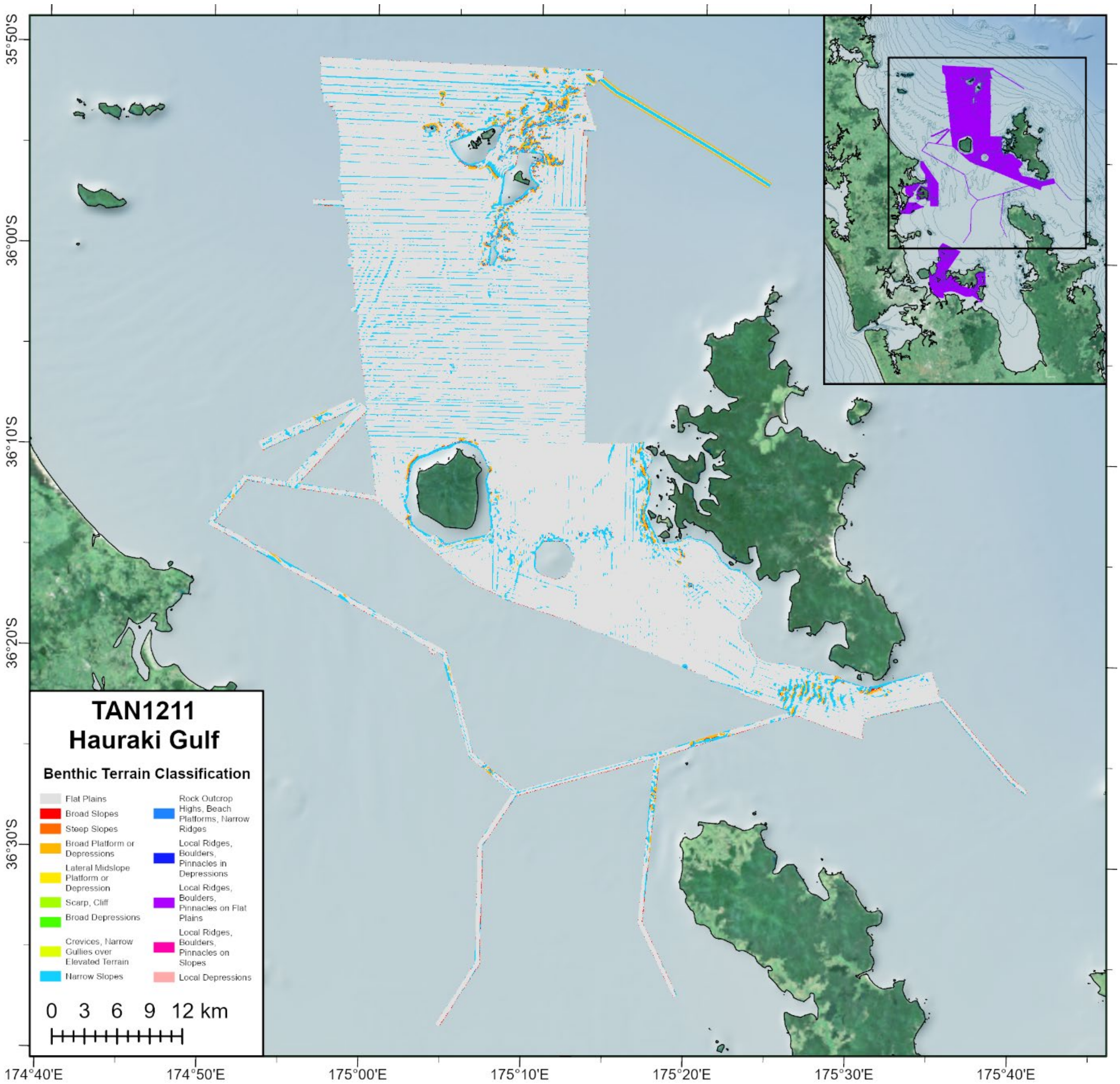


Figure A-1: Benthic Terrain Model for TAN1211.

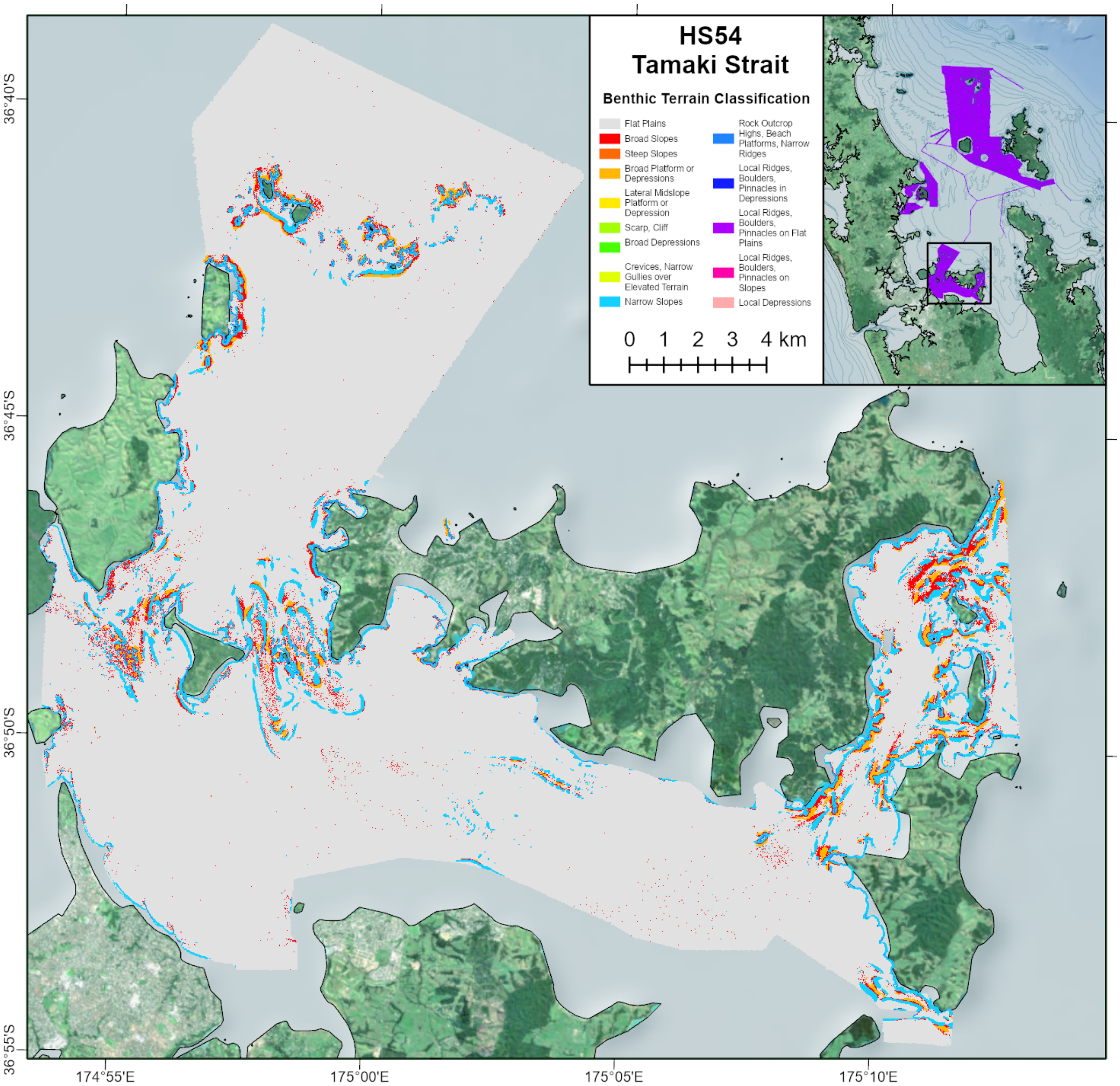


Figure A-2: Benthic Terrain Model for HS54.

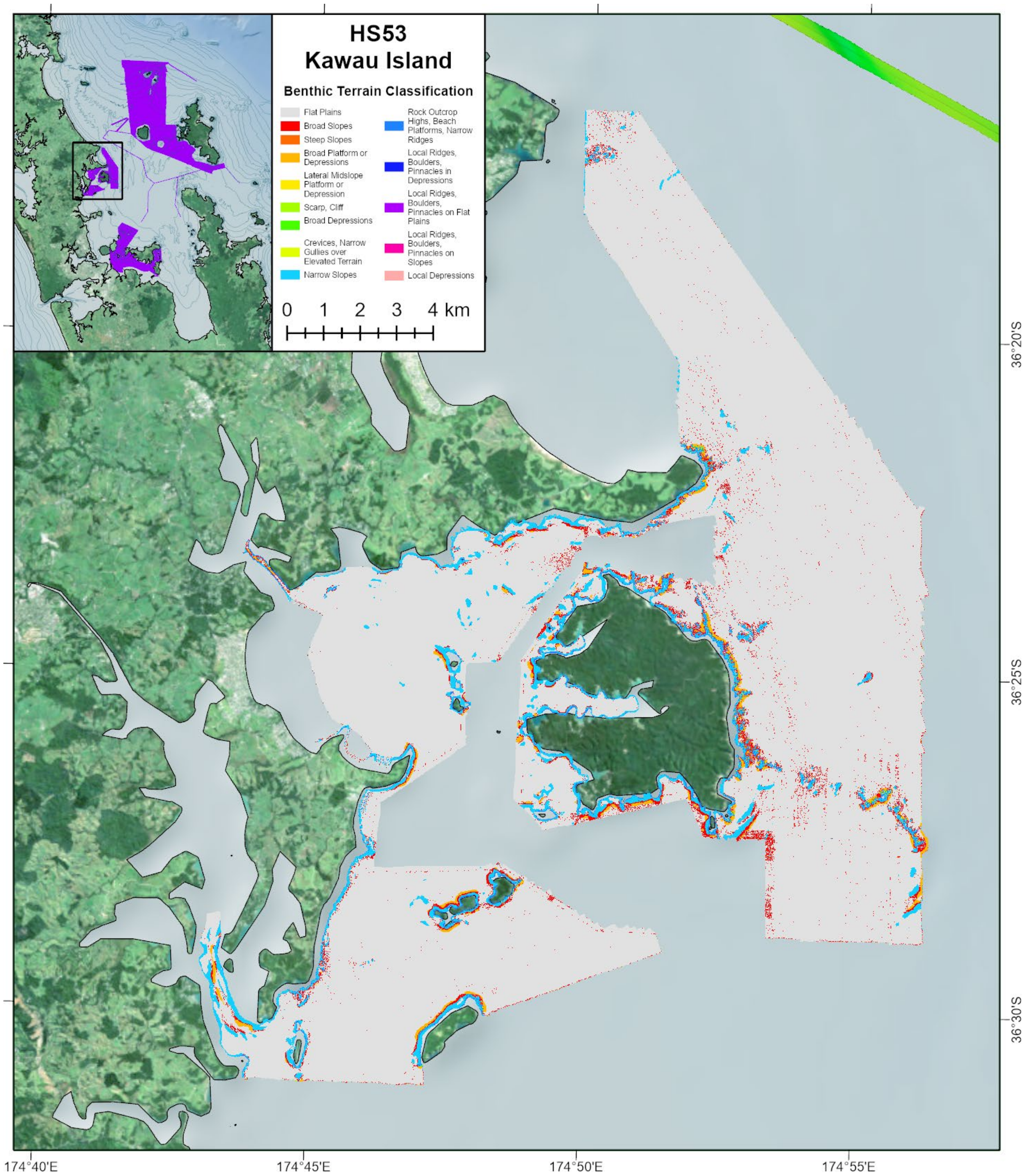


Figure A-3: Benthic Terrain Model for HS53.

Appendix B Sediment and Biological Sample Maps

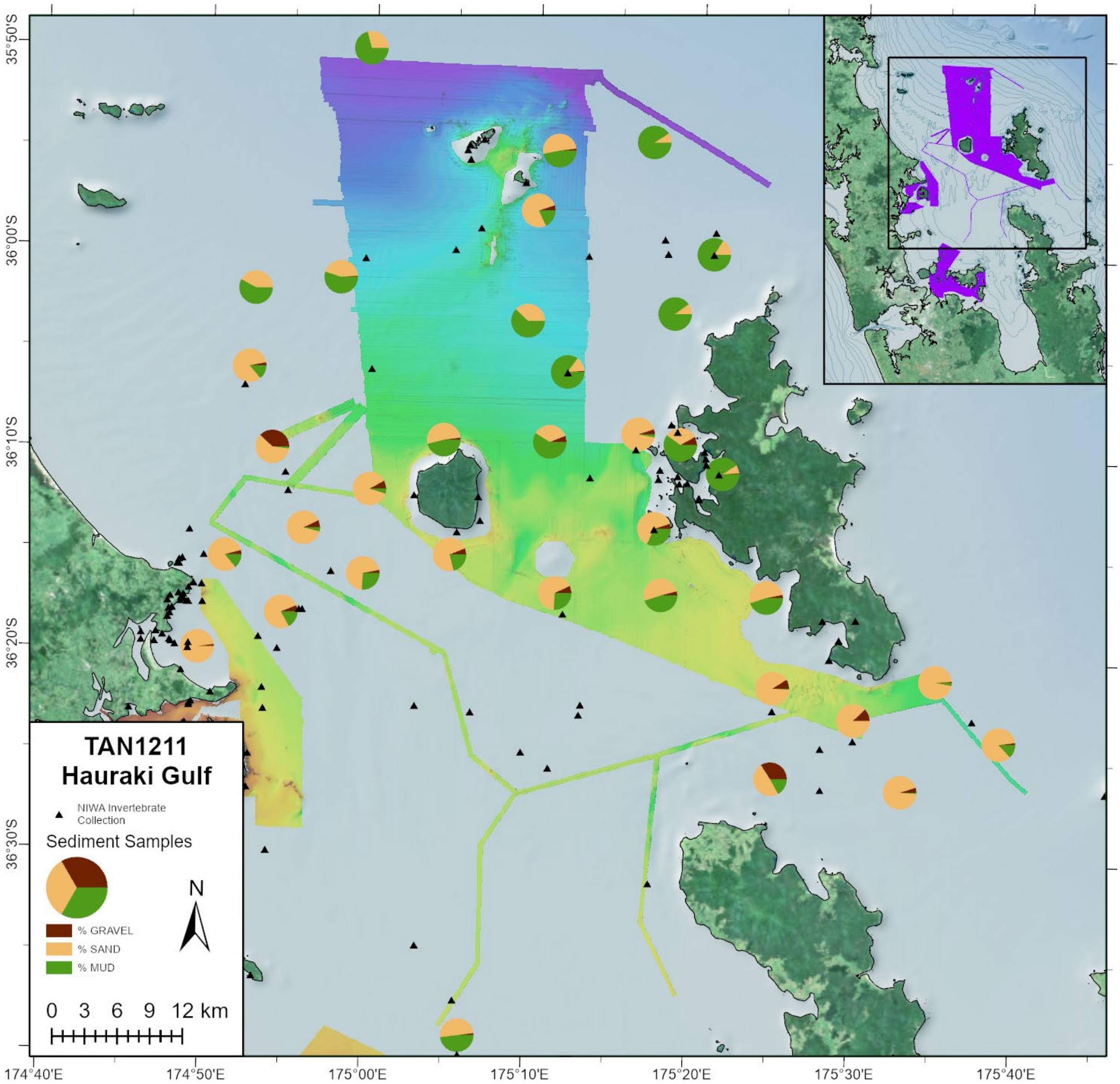


Figure B-1: Sediment and biological sample location in TAN1211.

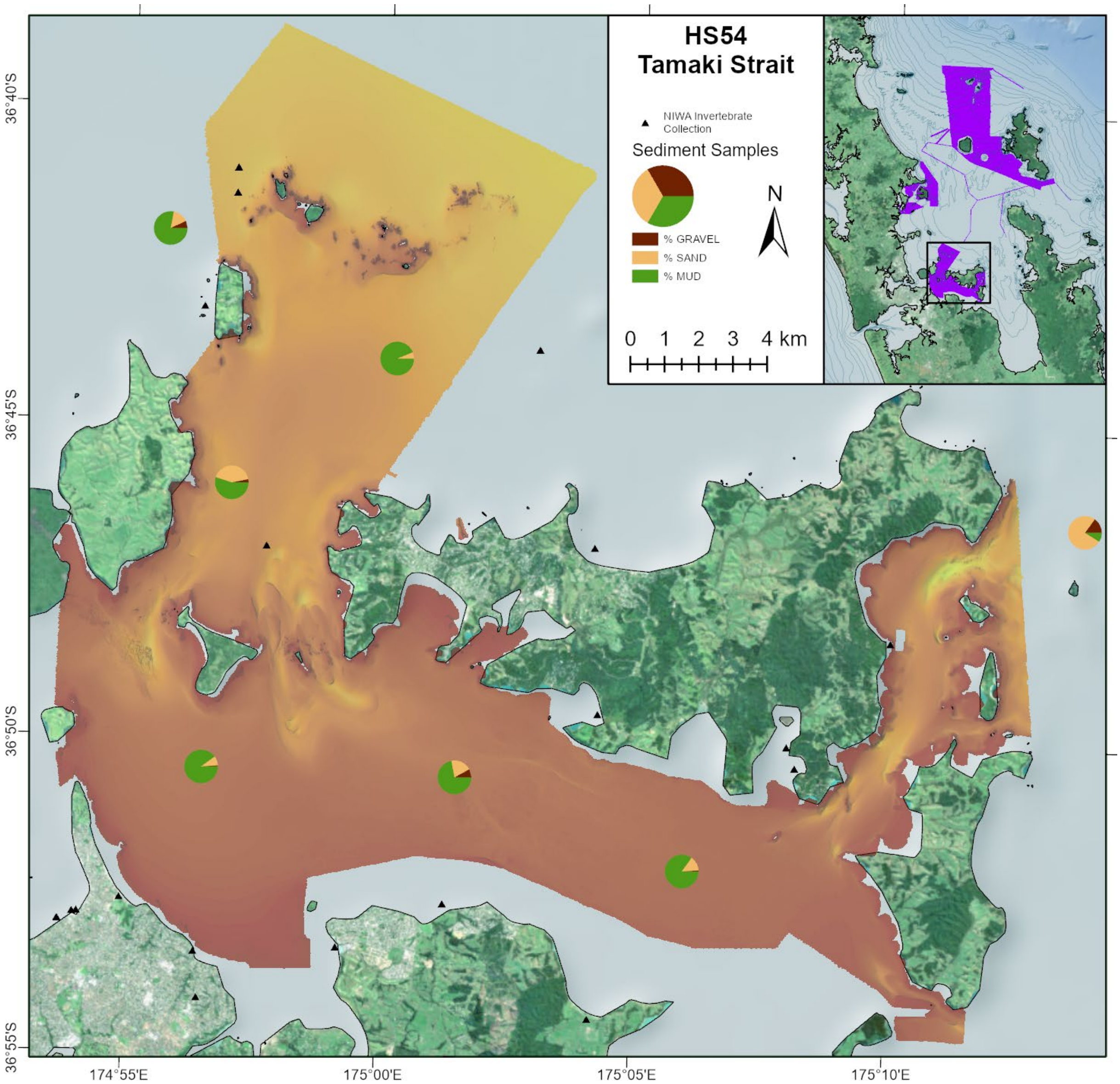


Figure B-2: Sediment and biological sample locations in HS54.

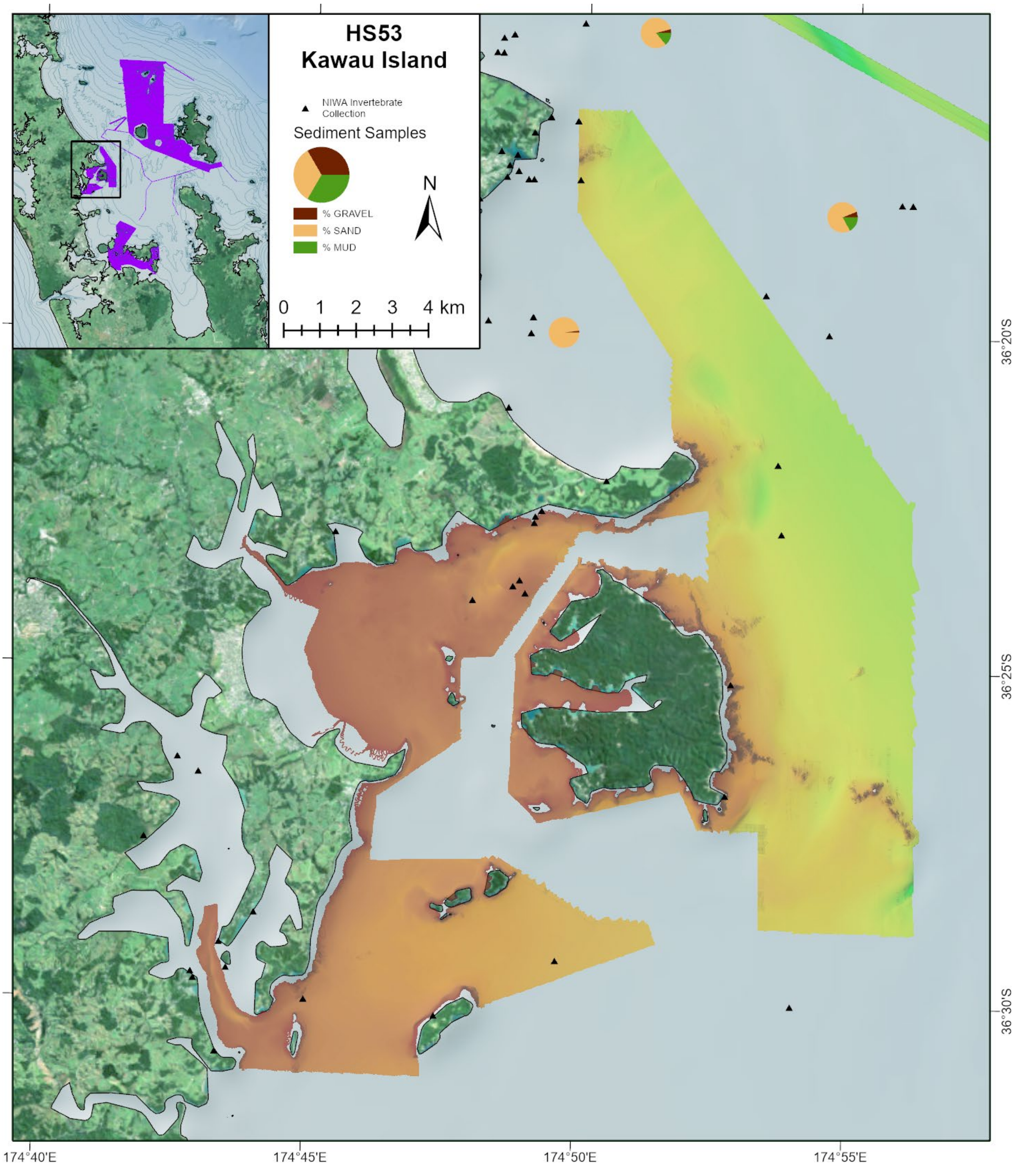
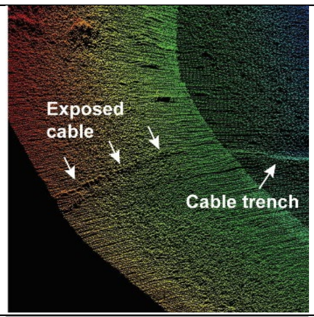
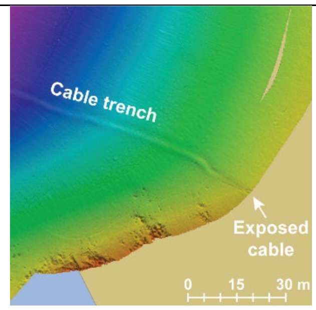
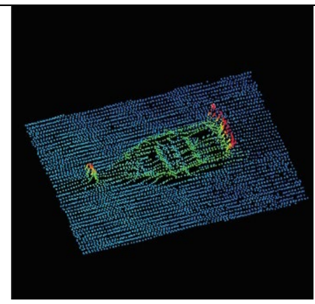
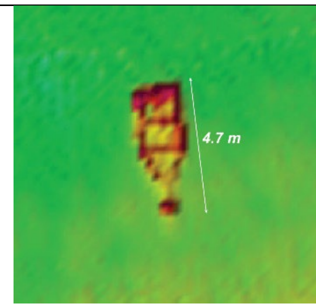
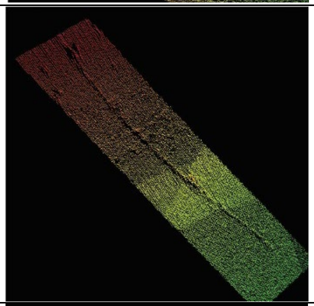
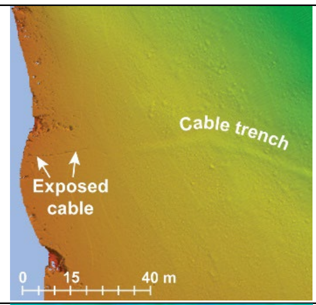
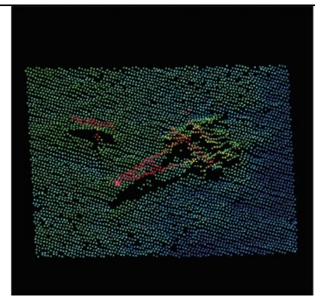
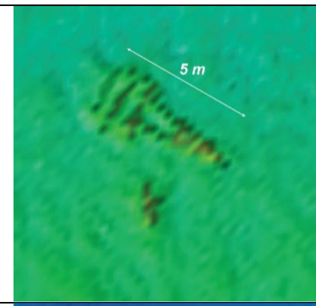
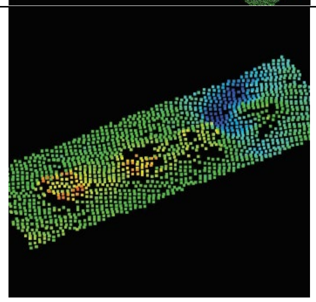
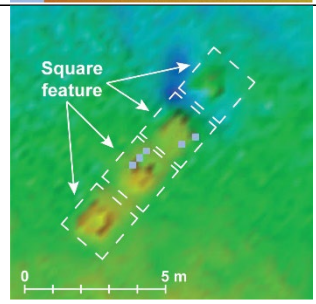
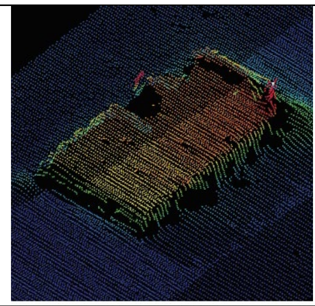
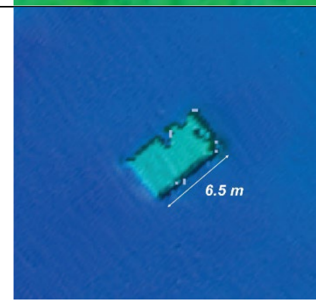
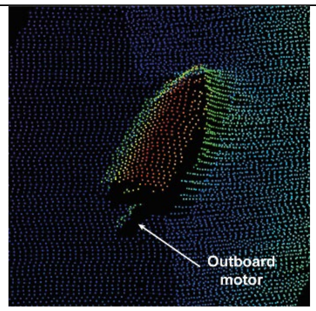
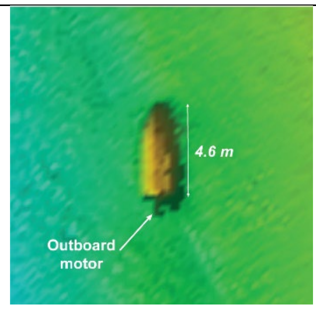
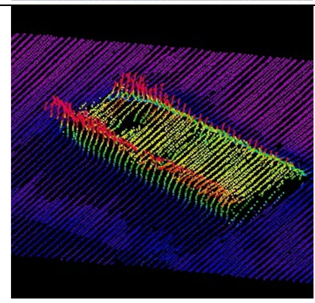
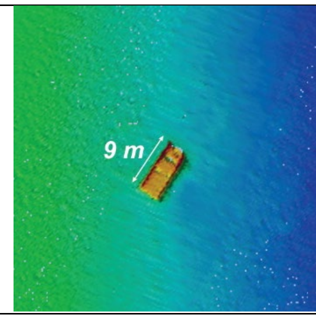
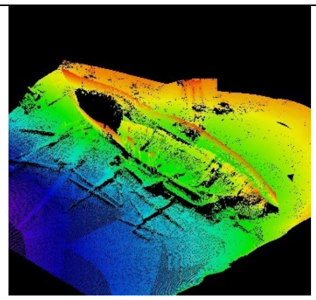
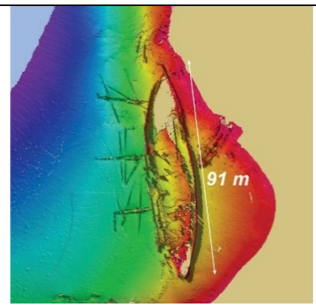
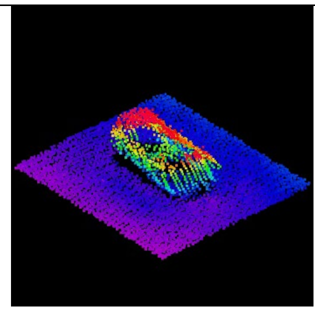
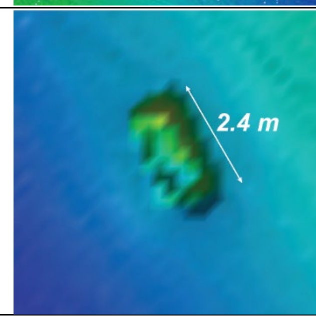


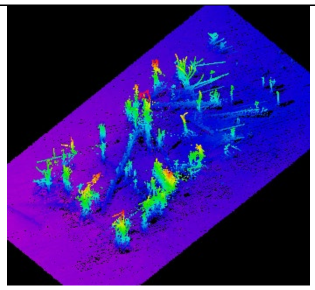
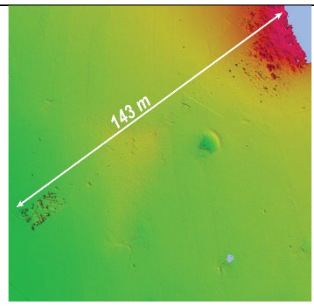
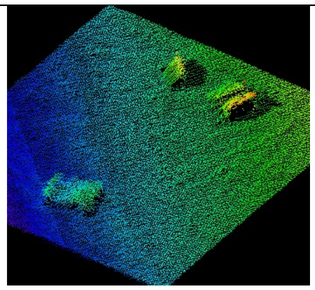
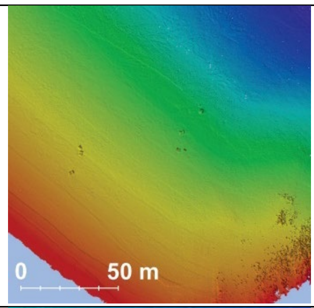
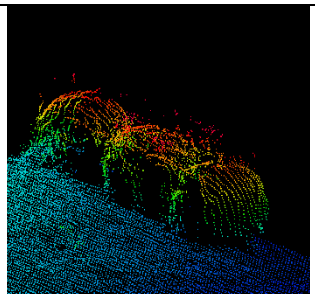
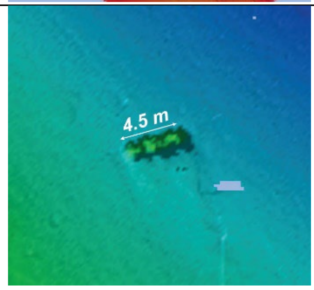
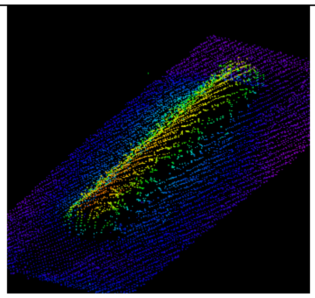
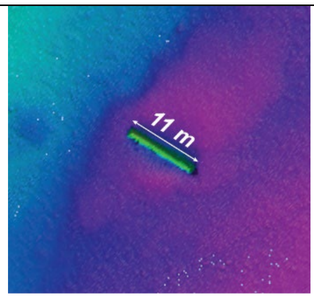
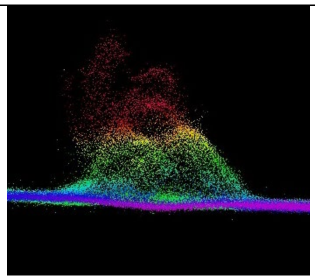
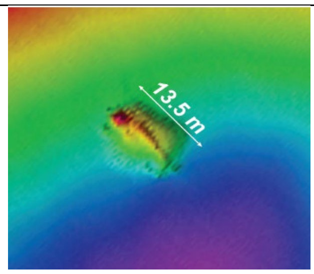
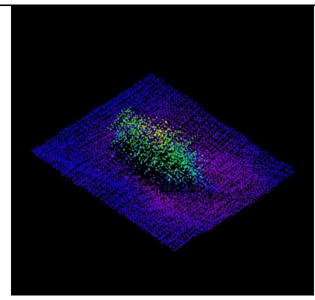
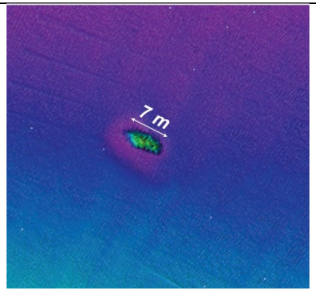
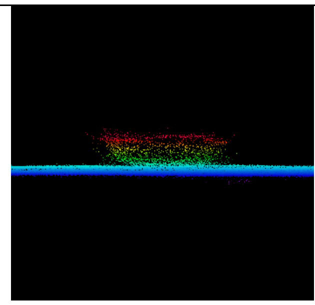
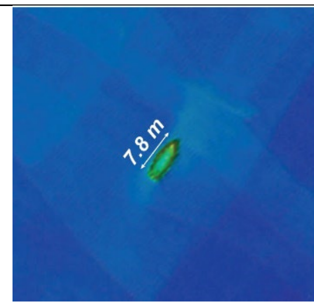
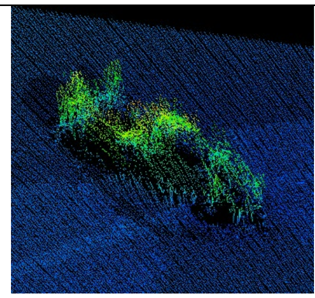
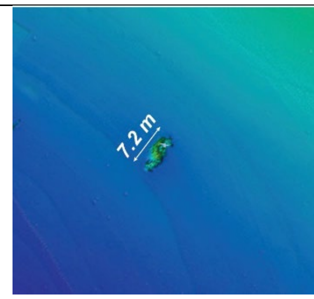
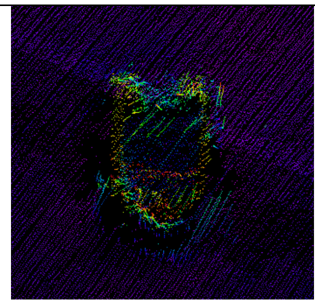
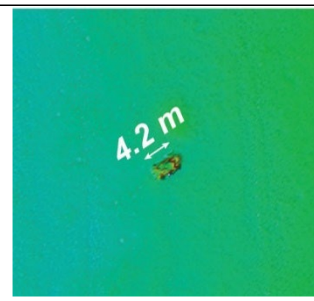
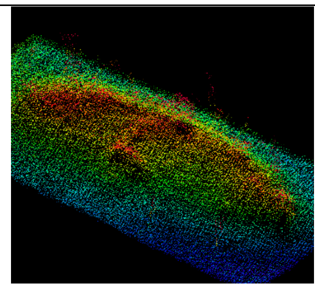
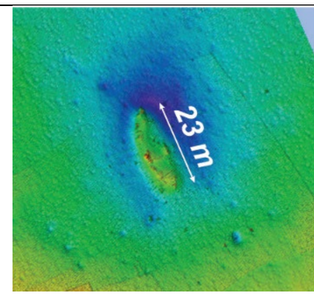
Figure B-3: Sediment and biological sample locations in HS53.

Appendix C Human impacts

Table C-1: Examples of human impacts.

HS53 – Kawau Island									
ID	Example image (raw soundings and bathymetry) of key features observed within surveys			Description of key features observed within surveys	ID	Example image (raw soundings and bathymetry) of key features observed within surveys			Description of key features observed within surveys
	Raw soundings	Depth range	Bathymetry			Raw soundings	Depth range	Bathymetry	
		Depth (m) 0 8		Transition zone of cable crossing onto western shoreline of Mansion House Bay. Cable appears to be buried at a depth of 2.4 m, with a pronounced ~1.5 m wide trench extending into deeper water. The exposed cable approaching the water mark is visible in raw soundings, high-resolution bathymetric data (25 cm grid), and satellite imagery.			Depth (m) 4.5 5.0		Sunken boat trailer in ~4.7 m water depth located in the central Bon Accord Harbour. Boat trailer dimensions are 4.7 m long x 1.6 m wide. Trailer has no clear impact on local seafloor sediment distribution
		Depth (m) 0 13		Western continuation of cable expressed at shoreline of Mansion House Bay. Transition zone of cable crossing shoreline of northern Takangaroa Island. Exposed cable approaching water mark visible in raw soundings and high-resolution bathymetric data (25 cm grid).			Depth (m) 4.5 6.0		Sunken boat trailer in outer School House Bay. Boat trailer is ~5 m long by 2.3 m wide. An unknown smaller object (~1.6 m x 0.5 m) is also noted 2.5 m to the south of the trailer.
		Depth (m) 7.8 8.2		Four subdued square features aligned to the NE-SW along the western margin of Mahurangi Inlet. Features are less than 40 cm tall above the surrounding seabed, suggesting features could largely be buried. Features could be related to the nearby anchorage sites in Jamieson Bay and Opahi Bay.			Depth (m) 0 5		Wrecked barge located in inner North Cove mooring area. Barge dimensions are 6.5 m long by 3.9 m wide. The wreck is surrounded by mooring blocks and seabed impacts of anchoring. Barge appears to be in a degraded condition.
		Depth (m) 6 9		Overturned powerboat in 7.5 m water depth on the eastern side of the Mahurangi Inlet channel, ~200 m west of Casnell Island. Vessel is 4.6 m long and appears to still have an outboard motor attached. Unknown if fuel system is still present or intact.			Depth (m) 11 12.5		Wrecked barge located in ~13 m water depth, 500 m east of Mullet Point. The barge appears upright on the seafloor and is 9 m long by 4 m wide. Seafloor surrounding barge appears undisturbed.
		Depth (m) 0 12		Wreck of the 91 m long tall ship *Rewa*, located on the northeastern shoreline of Moturekareka Island. The vessels masts and evidence of a wrecked jetty alongside the vessel are also evident.			Depth (m) 5 7		~2.4 m long by 1.1 m diameter cylindrical object located west of Momona Point. No evidence of additional man-made objects is present surrounding this object, suggesting the object is not a part of a larger feature (e.g., boiler from a shipwreck).

HS54 – Tamaki Strait

ID	Example image (raw soundings and bathymetry) of key features observed within surveys			Description of key features observed within surveys
	Raw soundings	Depth range	Bathymetry	
A		Depth (m) 0 – 4		Dismantled wharf located in Putiki Bay, Waiheke Island. Feature is comprised of abandoned jetty beams and piles. Original jetty was approximately 150 m long by 12 m wide and is a known charting hazard. Small anchor impact features are also prevalent around the wharf.
B		Depth (m) 0 – 10		Collection of seven angular features on the seabed near the coastline of Awakiriapa Bay, Waiheke Island. All features are in <10 m water depth and have a typically rectangular footprint (~2.0 x 1.5 m). May be mooring blocks.
C		Depth (m) 0 – 6		Three ~1.5 m wide spheres nested alongside one another in Awakiriapa Bay, Waiheke Island. Features may be associated with the nearby Waiheke Mussel Farm (<100 m to the east).
D		Depth (m) 4 – 6		Approximately 2 m diameter by 11 m long pipe in 6 m water depth, offshore of Poroaki Bay, Ponui Island. Pipe does not appear to be linked to any other seabed feature, with both ends clearly exposed above the surrounding seafloor. Undetermined if pipe is hollow or has closed ends.
E		Depth (m) 25 – 28		Unknown feature on seabed located approximately 280 m due west of Kauri Point, Ponui Island. Feature is 13.5 m long by 9.2 m wide with pronounced long-axis geometry. Surrounding seafloor morphology suggests object may be a deformed/partly buried shipwreck, rather than a natural feature.
F		Depth (m) 27 – 29		Shipwreck located in 29 m water depth approximately 4 km northeast of The Noises islands. The vessel is 7 m long with a 3 m beam and appears to be inverted on the seabed. A sediment moat extends around the wreck.
G		Depth (m) 18 – 19.5		Intact wreck located in 19 m water depth mid-channel between Motutapu and Waiheke Islands. Wreck appears in good condition in raw soundings and bathymetric models, sitting upright on the seafloor.
H		Depth (m) 0 – 2		Shipwreck located near the coastline of a major mooring site in Putaki Bay. Wreck is 7.2 m long by 2.9 m wide, likely a recreational vessel.
I		Depth (m) 2 – 3		Wreck of a small dinghy or powerboat, located in 2.5 m water on the eastern side of Putiki Bay. Vessel located to the southwest of major anchorage area.
J		Depth (m) 12 – 14		Shipwreck located in the south Motuihe Channel, equidistant from Motukorea/Browns and Motuihe Islands. The shipwreck is lying on its starboard side in ~13 m water depth. The shipwreck has formed a sediment moat around the vessel, the deepest part of which (13.7 m) is across the vessels bow.

Appendix D Regional geological maps (QMap)

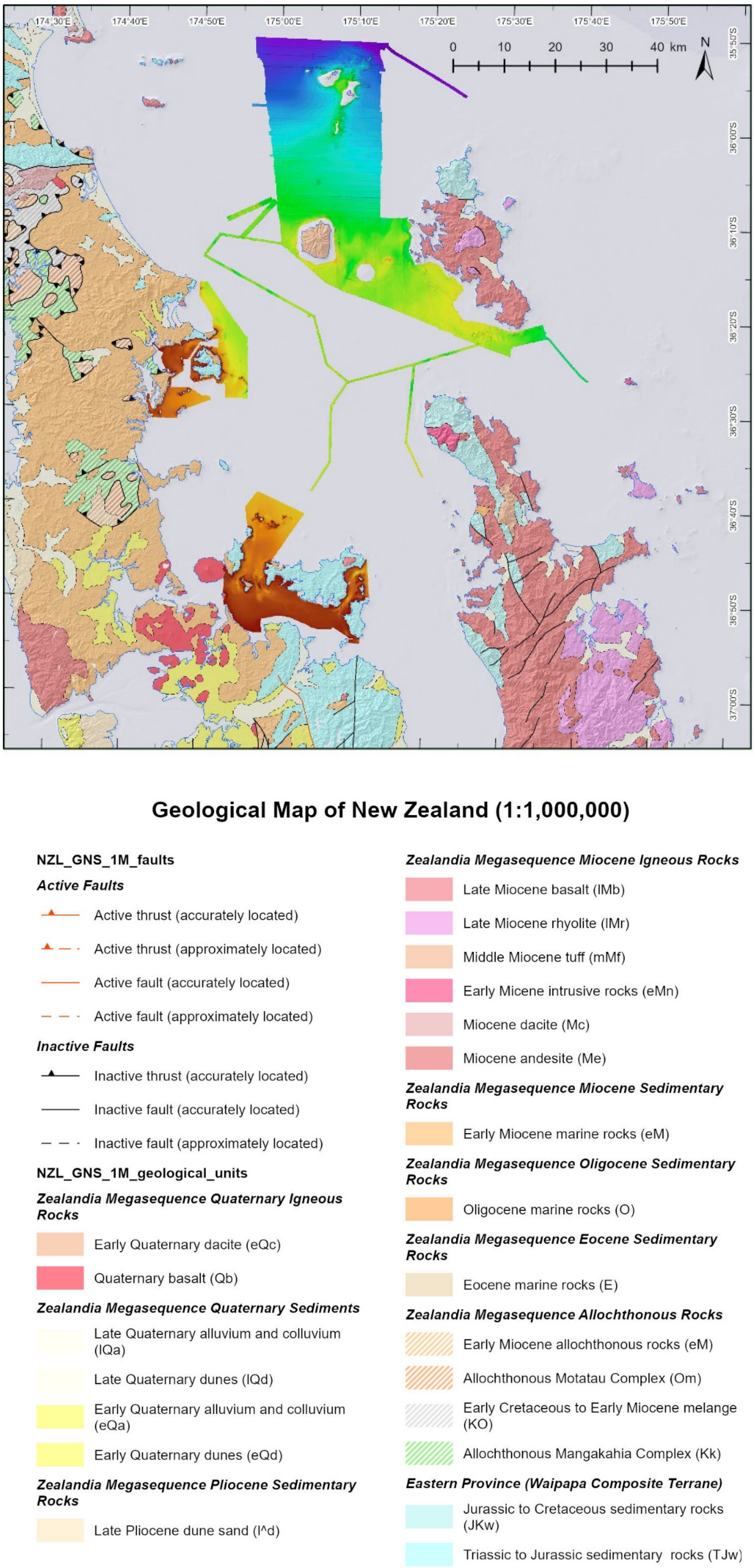


Figure D-1: Interpreted bathymetric datasets in relationship to onshore geology. Regional geological units extracted from the 1:1,000,000 geological map of New Zealand (QMap), produced/maintained by GNS Science.

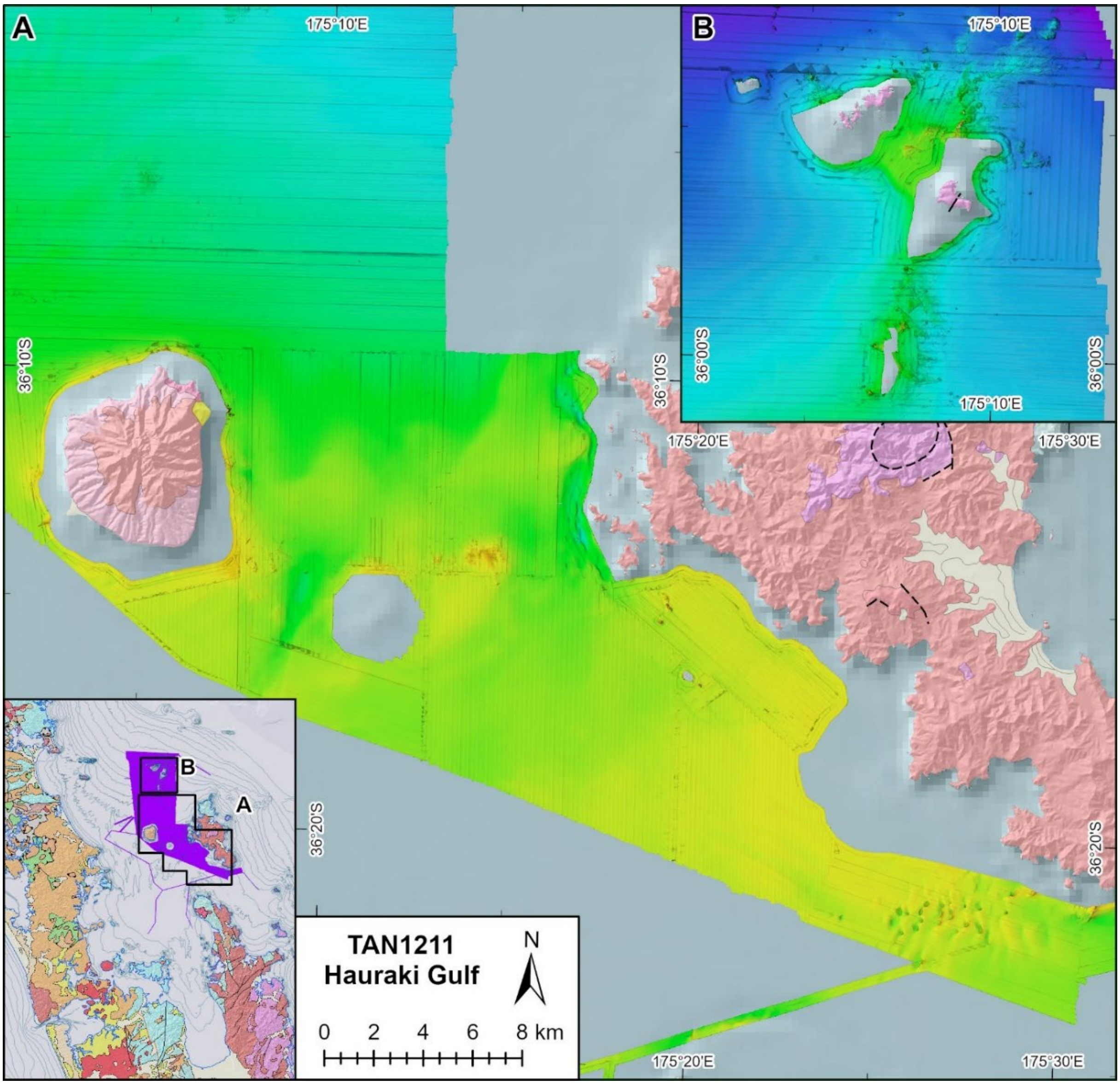


Figure D-2: Onshore-offshore relationship between TAN1211 bathymetry and regional geology. Regional geology extracted from 1:250,000 scale geological map of New Zealand, published/maintained by GNS Science. Legend of onshore geologic units found in appendix Figure D-1.

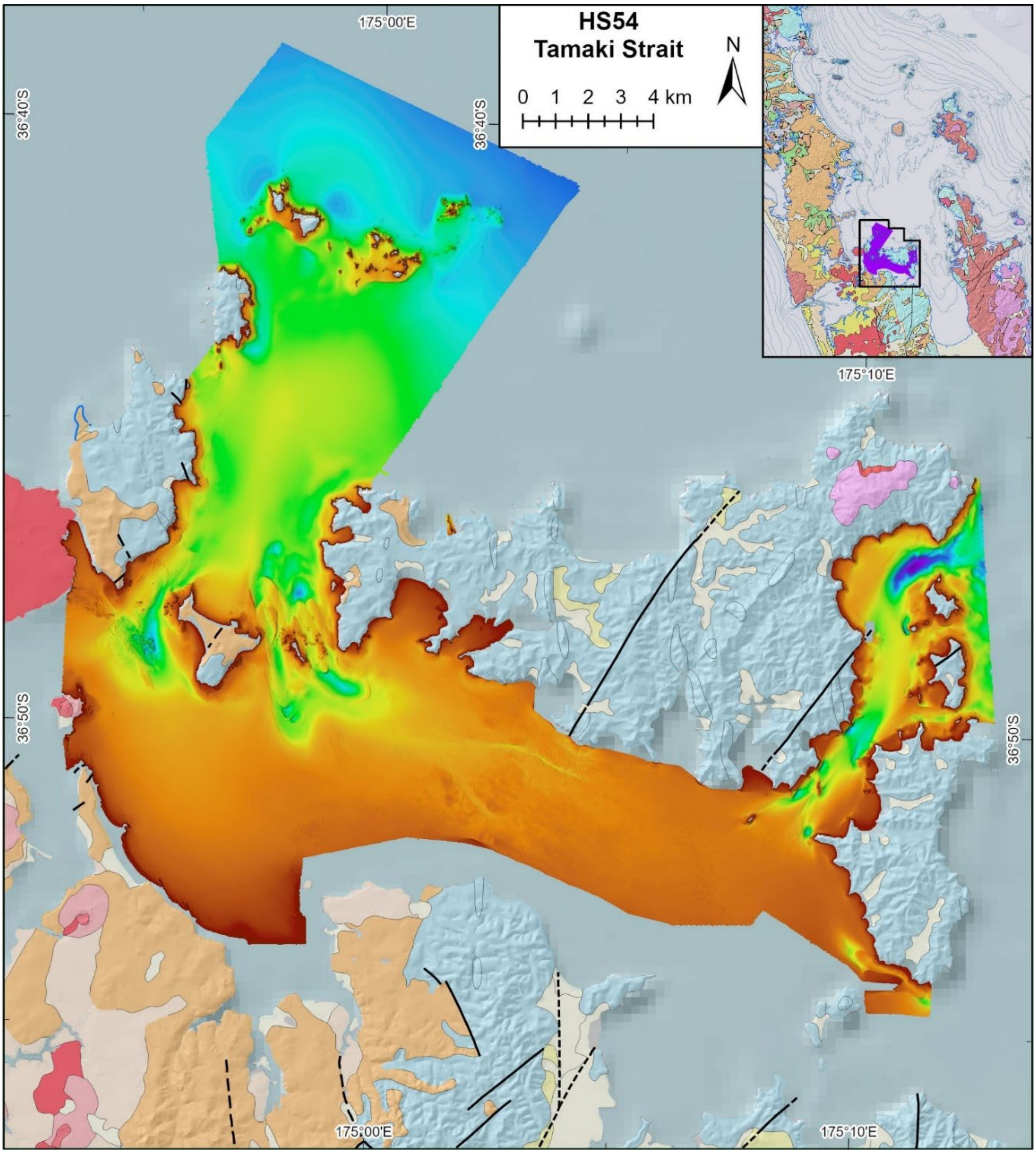


Figure D-3: Onshore-offshore relationship between HS54 bathymetry and regional geology. Regional geology extracted from 1:250,000 scale geological map of New Zealand, published/maintained by GNS Science. Legend of onshore geological units found in appendix Figure D-1.

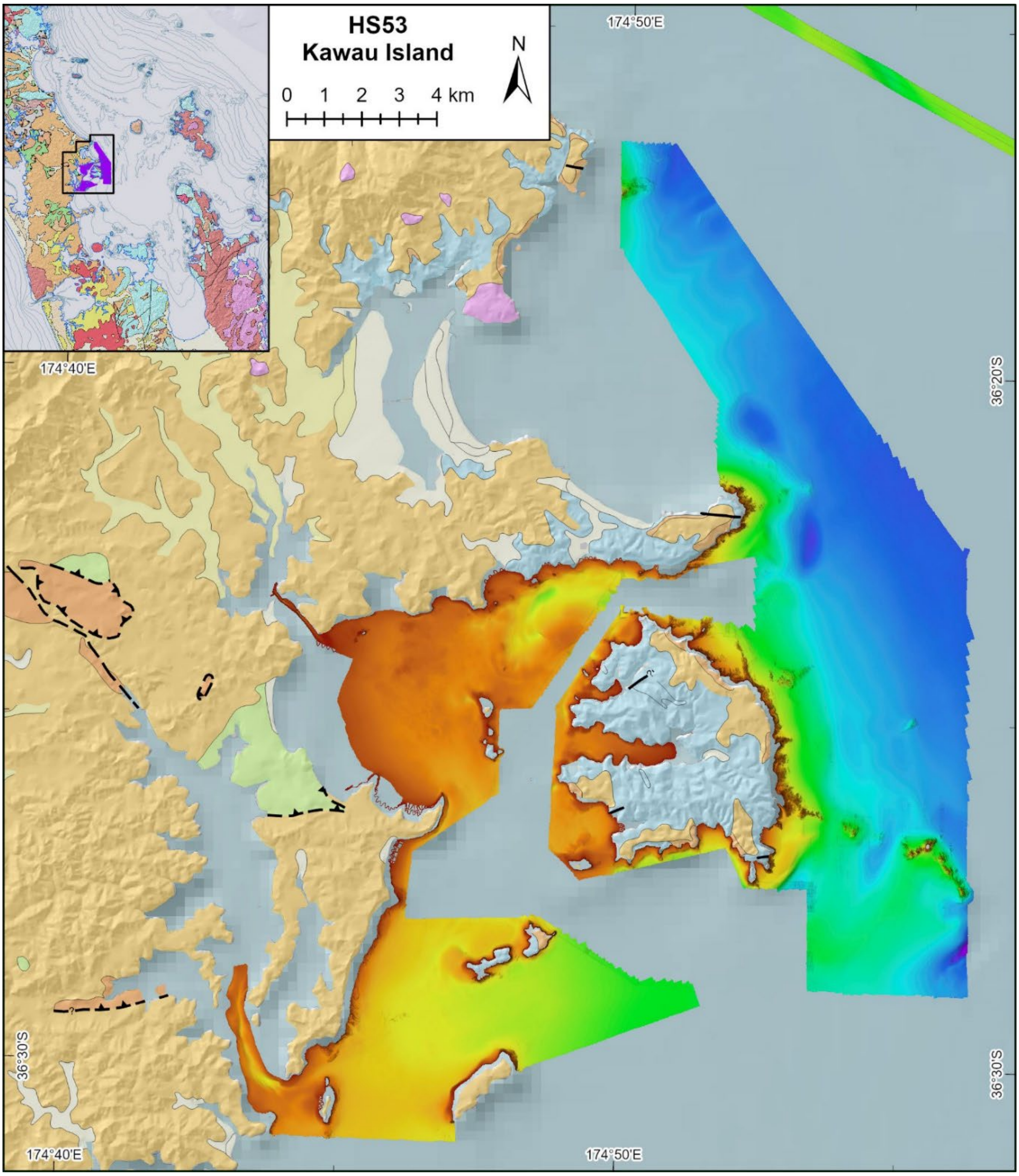


Figure D-4: Onshore-offshore relationship between HS53 bathymetry and regional geology . Regional geology extracted from 1:250,000 scale geological map of New Zealand, published/maintained by GNS Science. Legend of onshore geologic units found in appendix Figure D-1.