

Predicting seafloor habitats and their associated communities within Te Tapuwae o Rongokako Marine Reserve

Prepared for the Department of Conservation

By: Dr Tara J. Anderson¹, Enrique Pardo², Manon Broadribb³ and Jodie Robertson⁴

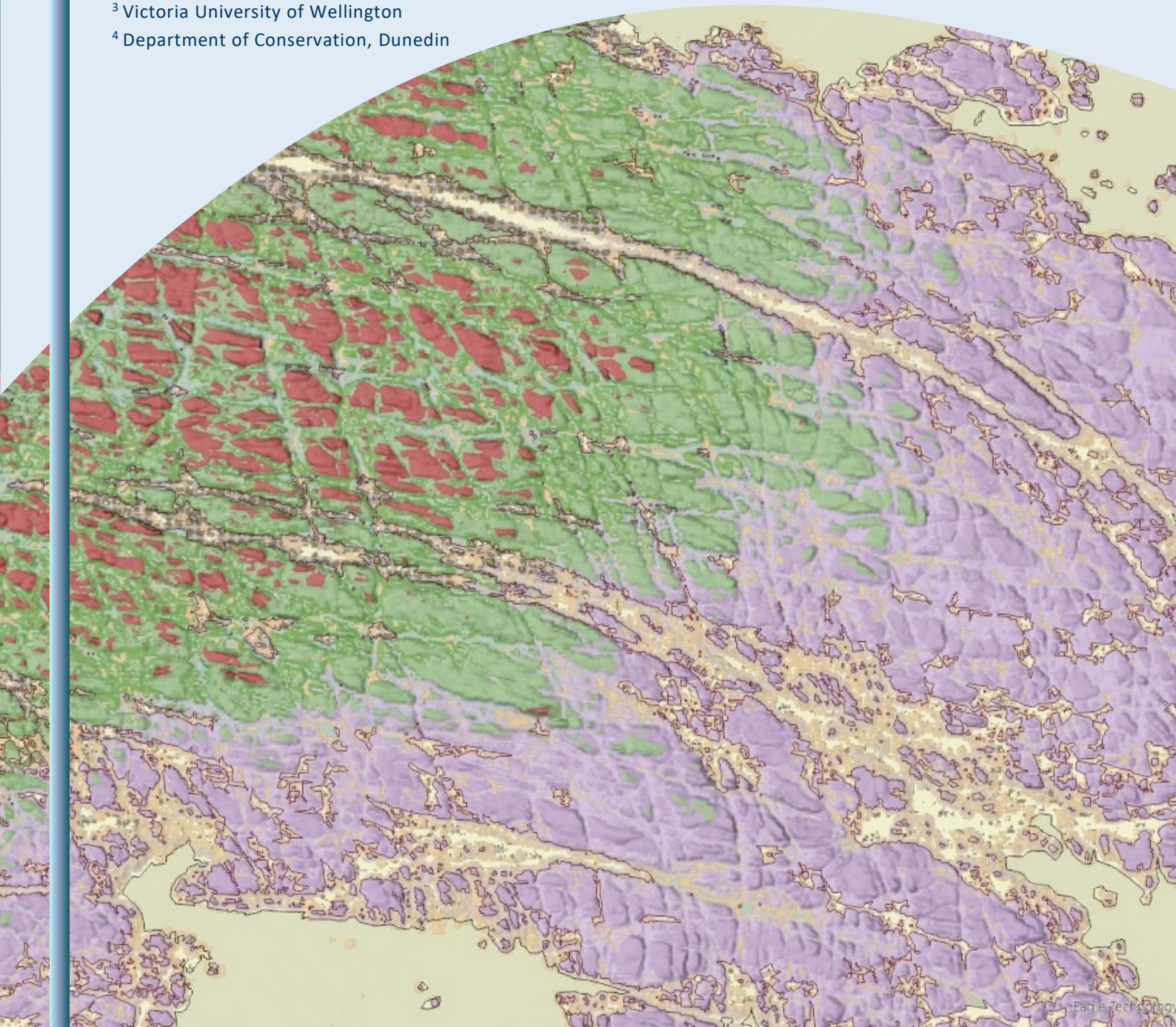
28 February 2025

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1 Background

Te Tapuwae o Rongokako Marine Reserve (TToR-MR) is a no-take marine protected area located on the east coast of the North Island, approximately 16 km north of Gisborne, in the rohe moana of Ngāti Konohi. The marine reserve was established in November 1999, under the provisions of the Marine Reserves Act (1971) as a collaboration between the local iwi Ngāti Konohi and the New Zealand government to protect an area of 2,452 hectares (24.52 km²) of coastal and marine habitats that are representative of the East Cape Region to help conserve the region's marine biodiversity and cultural heritage. As a marine reserve it prohibits fishing, and the removal or disturbance of any marine life within the marine reserve.

The marine reserve extends between 5 and 7.5 km alongshore (inshore and offshore boundaries, respectively) and between 3 to almost 5 km offshore (central and north locations within the TToR-MR, respectively). Baseline, monitoring and project-specific research surveys have found the TToR-MR to contain a range of benthic marine habitats that support a diverse marine flora and fauna, including rocky reefs, kelp forests, and sponge gardens, with a variety of marine taonga, such as pāua, kina, crayfish, and fish species like snapper and blue cod (e.g., Freeman 2001; Booth 2003; Freeman & Duffy 2003; Freeman 2005; Shears and Babcock 2007; Freeman and MacDiarmid 2009; review in Ross 2021). In the 2024 survey, the department of Conservation (DOC) used a small portable Splashcam drop camera system to explore and characterise seafloor habitats and their associated marine communities, generally associated with marine reserve baseline and monitoring surveys, including inside and outside comparisons.

2 Summary of Methods

2.1 Historical drop-camera survey 2003

2.1.1 Survey overview

In 2003, the Department of Conservation funded a spatially extensive drop camera survey undertaken by ASR Ltd, Marine Consulting and Research group (Led by Dr T. Haggitt). The 2003 survey area extended from just south of Makorori Point and 16.4 km up the coast to north of Whangara Island in water depth of 3 to 30 m, and included numerous sites out across Monowai Rocks. Within the survey area, 296 sites were sampled within an informal grid pattern, spaced circa ≥ 40 m apart (see Figure 1 and Figure 2). Sites were not sampled where water depth was too shallow (< 3 m) for safe vessel navigation over reefs. Of the 296 sites sampled, 88 sites were sampled within the TToR-MR, while 208 were sampled outside the marine reserve along the adjacent coastline. As no report was provided the specific methods are not available. However, all historic 2003 footage was post-processed recently for comparison with the newly collected 2024 video-transect survey. From viewing the video footage of the 2003 sites, it is clear that the camera was dropped over the side of the vessel and turned on once the seafloor was in view. The camera then recorded footage of the seafloor as the camera traversed the seafloor for 10's of seconds, then the camera was stopped and retrieved, and the vessel went to the next site.

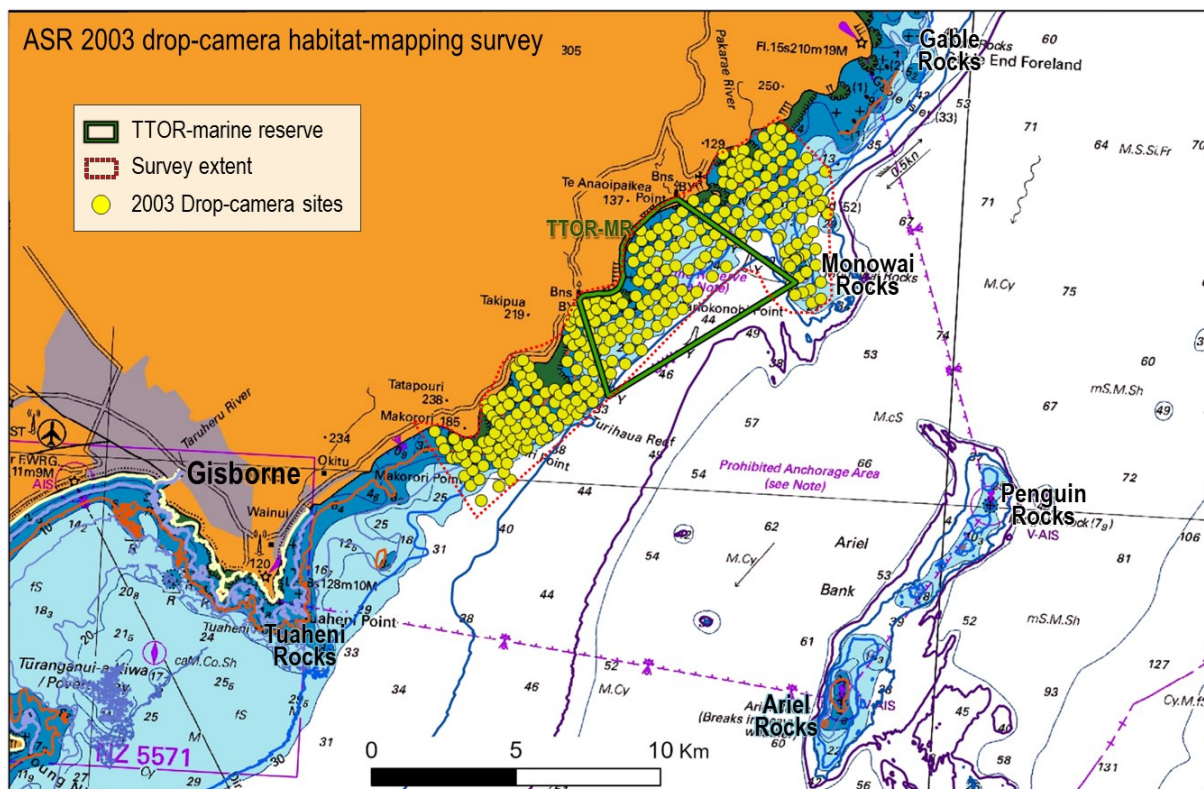


Figure 1. Regional location of the ASR 2003 drop-camera survey (296 sites). Green boundary = TTOR-MR; Sites were surveyed inside (88 sites) and outside (208 site) the TTOR-MR, with the survey area extending 16 km along the coast (9-25 km north of Gisborne), including Monowai Rocks.

In 2003, ASR characterised and delineated seven benthic habitats based on the drop-camera imagery. Although no report was produced on this research, maps (Figure 3) and raw imagery were provided to the Department of Conservation.

ASR 2003's seven benthic habitats were:

- 1) Shallow Carpophyllum,
- 2) Coralline algal-covered reef,
- 3) Mixed algae,
- 4) *E. Radiata* (kelp) forest,
- 5) Sponge garden,
- 6) Deep cobbles
- 7) Sand

To provide comparisons with the 2024 survey, all historic video footage from the 2003 video sites were reprocessed using DOC's Coastal and Marine Ecological Classification Standard (CMECS) habitat classification methodology (see processing methods below), with data recorded on substratum type, relief, sediment veneer and three taxonomic classification levels for the biota. As 2003 were dropped camera sites, where the camera was left to drift across the seafloor for several seconds, the video footage was characterised for a single data point per site. Both the ASR and DOC classifications were included in the 2003 dataset to provide comparative assessment between the classifications.

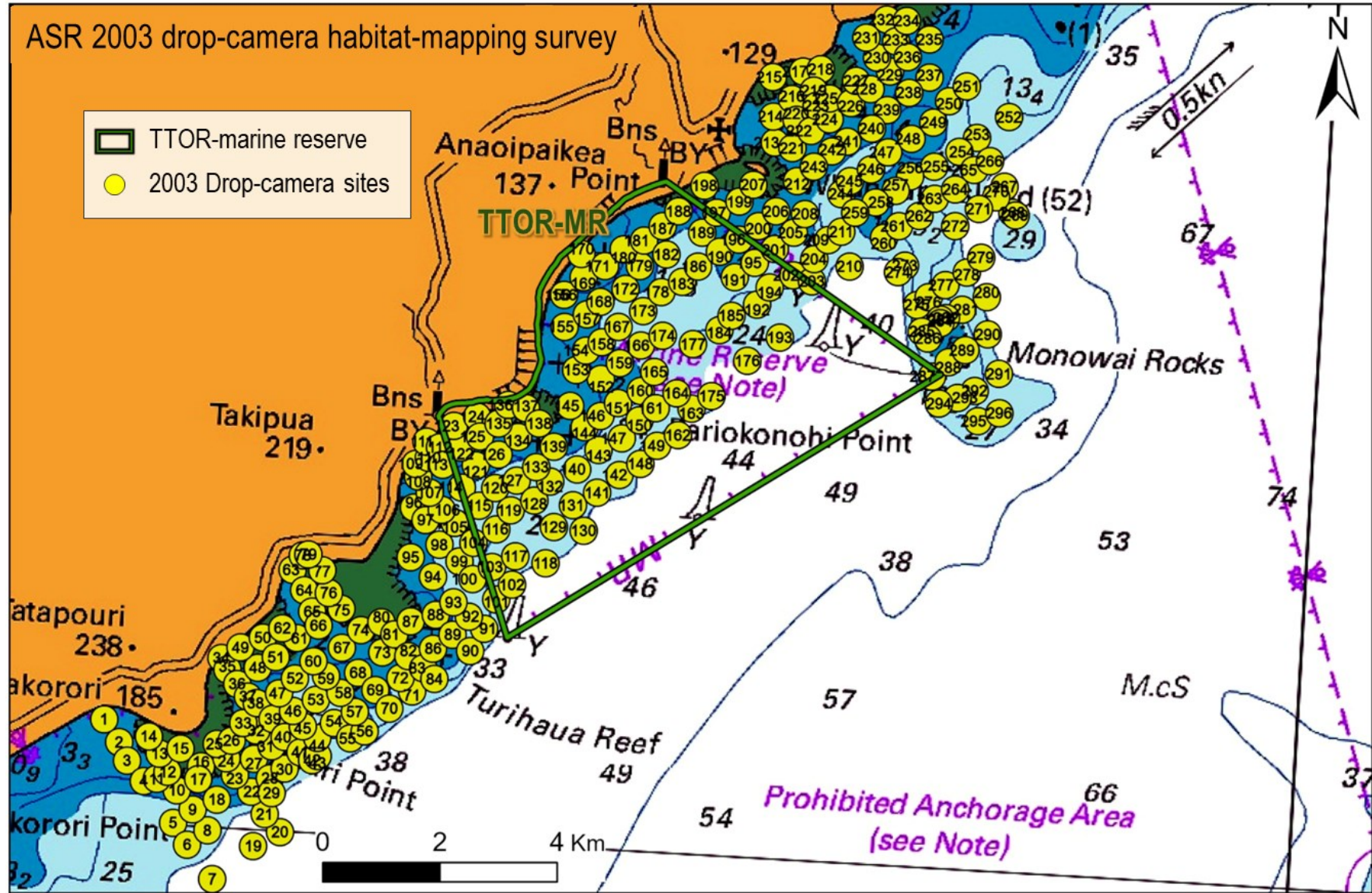


Figure 2. The 296 drop-camera sites (labelled by site numbers) surveyed 2003 by ASR inside and outside the TTOR-MR.

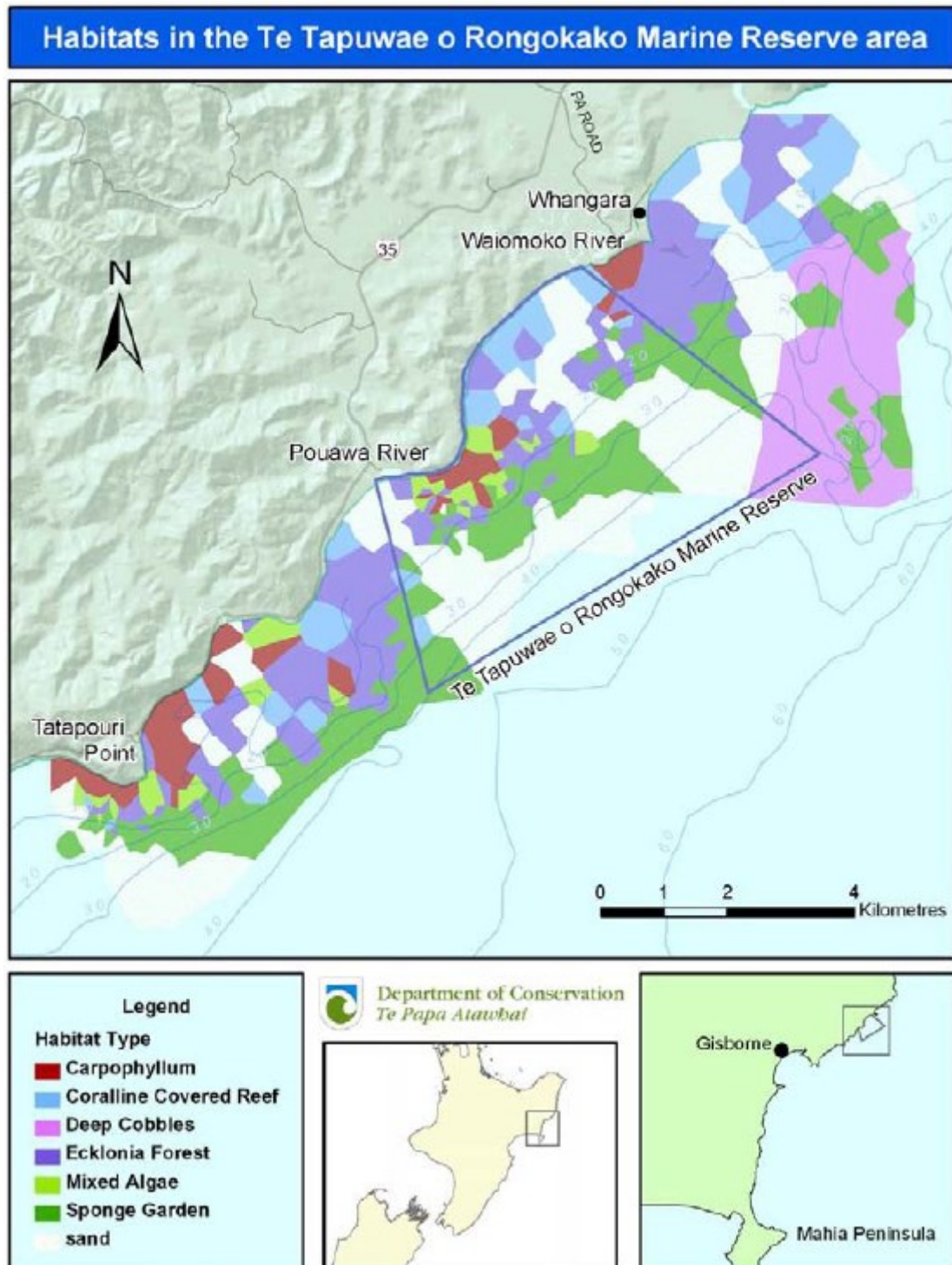


Figure 3. The seven benthic habitat types mapped by ASR inside and outside of the TToR-MR. Map from Wilson et al. 2007. ASR habitat boundaries were delineated around the site video-classifications, as no other physical mapping layers were available.

2.1.2 2003 positional errors

It is unclear how accurate the GPS site positions were for these 2003 historic sites, but for the most part site classifications appeared to align well with habitat features seen in the 2022 multibeam echo-sounder (MBES) data (described in section 2.4, below). In contrast, however, a few rare sites appeared to be very different habitats (e.g., extensive rippled sediments)

compared to those in the MBES layers (e.g., within extensive raised rocky reefs). Given the MBES maps have a vertical resolution of 0.3 m and a horizontal resolution of 2 m, these mismatches are likely due to either incorrect GPS marks, or the vessel drift well away from the reef prior to the seafloor coming into view. Either way, these were considered to be erroneous site positions, but provided good comparison with other soft-sediment sites adjacent to these reefs – suggesting these sites were more likely to have sampled nearby soft-sediment areas.

2.1.3 Reprocessing the 2003 video data

To provide comparison with the newly collected 2024 video data, all of the 2003 site video footage was reviewed and re-processed using DOC's CMECS habitat classification method. This however was undertaken by a different observer (DOC: Observer 1)¹. A description of the post-processing method is provided in section 2.3, below).

2.2 Video-transect survey 2024

2.2.1 Sampling design

Between February and April of 2024, ASR's 2003 drop-camera sites were resampled in and adjacent to the Te Tapuwae o Rongokako Marine Reserve (TToR-MR), as part of Department of Conservations marine reserve monitoring programme (Figure 4). As part of survey planning, priority was given to all sites within the marine reserve, then sites immediately outside of the TToR-MR to the NE and SW, with sites further away given lower priority. In 2024, a total of 154 sites were sampled across the survey area, with 92 transects (from 91 sites) surveyed within the TToR-MR and 63 sites were surveyed to the NE and SW outside the marine reserve boundaries (white circles in Figure 4), while a further 25 new sites were sampled to address uncertainties (orange circles in Figure 4). The new 2024 sites targeted key areas, including: i) Sites within complex raised reef areas; ii) The deep offshore zone within the TToR-MR not previously sampled in 2003, and iii) Sites offshore around deep reef outcrops – in the offshore south and north corners of the TToR-MR to characterise these deeper habitats (i.e., Monowai Rocks) (orange circles in Figure 4). Additional 2003 sites were also attempted, but failed due to no video being collected or zero visibility (i.e., no view of the seafloor). The summer of 2023-2024 had considerable rain and storm events which left coastal waters very turbid, and thus hindered good clarity days - so finding calm weather days where the water visibility was good was considerably limited. As a result, the survey was undertaken in two parts, between 16-19 February 2024, and the 28 March and 4 April 2024. As this was a mapping survey, no specific issues were caused by this sampling duration. Although the full 294 sites sampled in 2003 were not able to be revisited in the time available, all 2003 were re-processed using the CMECS habitat characterisation method by DOC (Observer 1) and 2024 sites were post-processed and combined for the purposes of mapping the seafloor habitats within the full survey area (details provided below).

¹ No comparative training was used to ensure that classifications between observers (and thus years) were the same for all substratum and taxon types. This should be a prerequisite for all future projects, as this caused substantial data comparison problems – where differences were due to observer-classification differences rather than real changes.

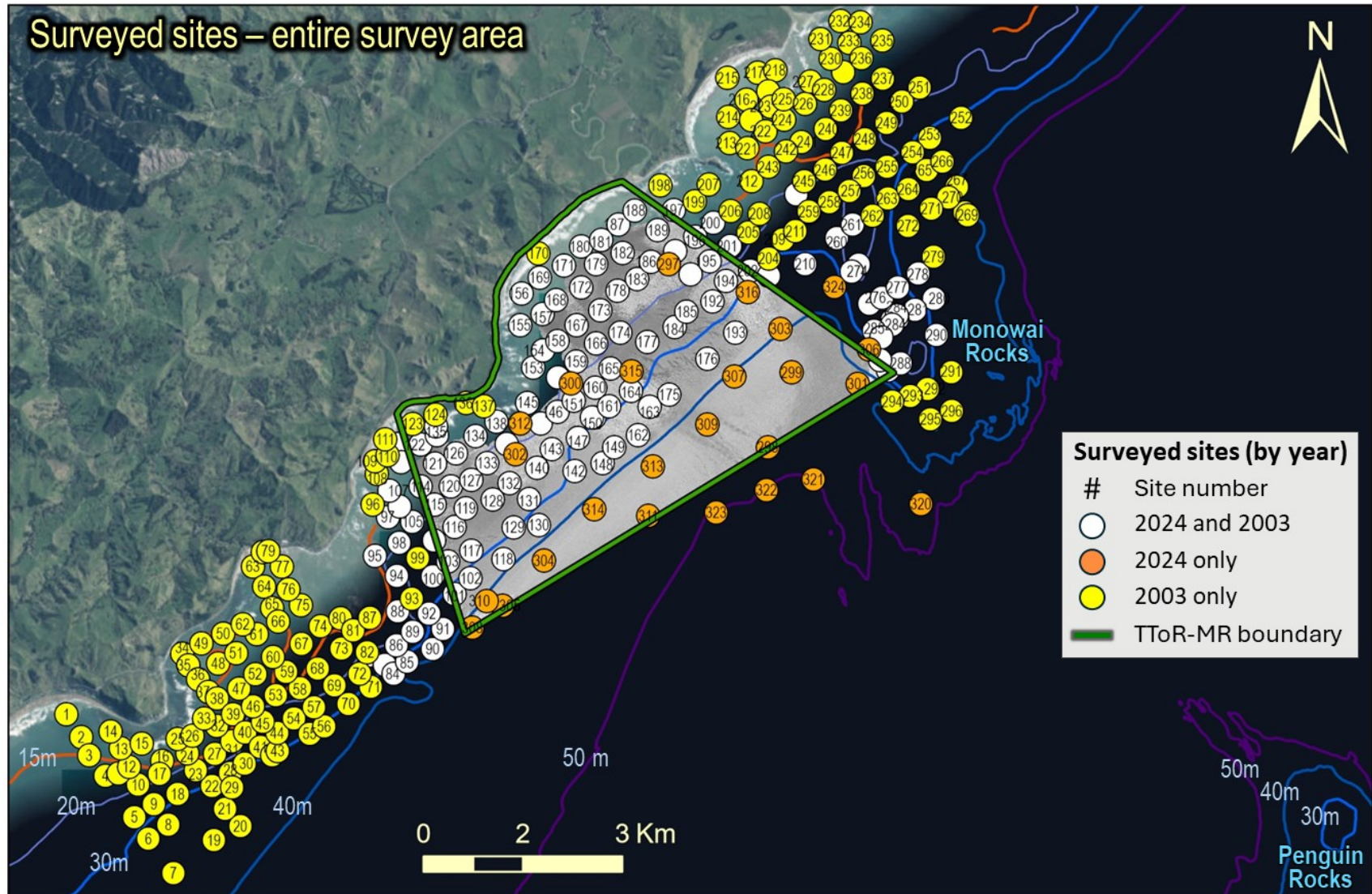


Figure 4. Drop-camera sites (labelled by site numbers) surveyed in 2024 and/or 2003 in and adjacent to the TToR-MR. Coloured circles denote the years each site was sampled: white and orange sites were sampled in 2024, while yellow sites were only sampled in 2003.

2.2.2 Video-transect survey

The 2024 benthic video-transect survey were undertaken using a DOC-custom modified Splashcam (from Delta Vision), hand-deployed from the side of the 5.8 m DOC vessel, the *Matahourua*. The high-definition underwater video-camera with a custom-made rectangular plate/frame (Figure 5) that reduces direct-tension on the camera during deployment and retrieval. The camera system is fitted with three underwater dive lights and two lasers, and is powered from the surface by a 100Ah lithium deep cycle battery that is connected to the Splashcam by a 150 m coaxial cable. The coaxial cable delivers real-time imagery of the seafloor via a portable topside monitor, which enables real-time manoeuvrability of the system - to ensure that the seafloor is in view during the video-transect, but also, so it can be quickly hauled up quickly to avoid collision with the seafloor, as and when required. All video footage is recorded to an on-board digital recording deck. The camera setup used in 2024 was considerably better than the standard definition camera setup used by ASR in 2003, which relied mostly on natural light. However, although three dive lights were strapped to the Splashcam they inadequately illuminate the seafloor to capture detail, especially in greater depths with less natural light. Additionally, lights were not diffuse enough to avoid 'burning out' parts of the video. This made identifying taxa difficult in some situations, but generally provided adequate information to characterise seafloor habitats across the study area. If additional information was required to identify features to species level, then this could be undertaken with future targeted research using more accurate and improved remote imagery and/or diver observations.

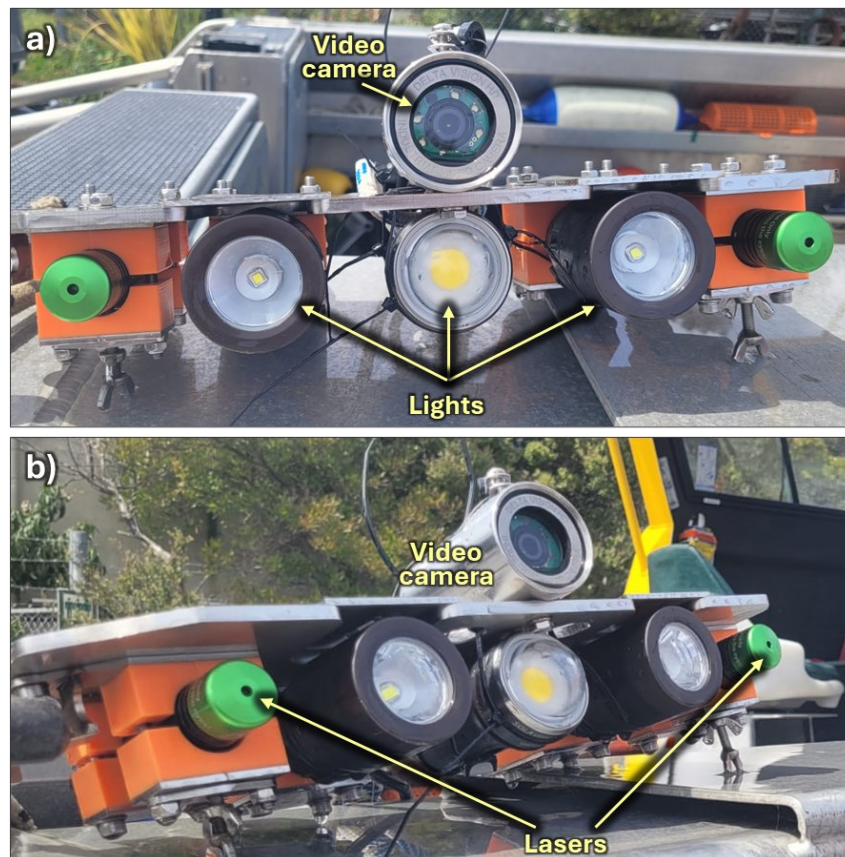


Figure 5. Department of Conservation Splashcam, used for the 2024 video-transect survey.

At each site, the date, start and end times, and depths were recorded to field sheets. Date, site number, and time was written on a whiteboard and held in front of the camera prior to deployment to ensure site details were recorded. The site waypoint was used as the start of line, where drop camera was hand-deployed over the side of the vessel, until the seafloor was in view on the topside monitor. The vessel then drifted with the camera's speed over ground between 0.5 and 1.5 knots. Video footage was recorded to hard drive. No USBL systems (ultra-short baseline) system was available for this survey (used to triangulate and log the position of the camera on the seabed). Consequently, the track-line for each underwater video transect was digitally logged every 1-3 seconds using the ship-board navigation. No layback was estimated or recorded. However, the direction of each transect can be determined from the sequential numbering along each track-line GPS data string. All track-line and video footage were backed up to hard drive in the evenings for post-processing and data archiving.

2.3 Post-processing video data (2024 & 2003)

2.3.1 *Within-transect classifications and data issues*

Both the historic 2003 video footage and the 2024 video footage were post-processed using DOC's CMECS methodology, a hierarchical classification standard developed by the National Oceanic and Atmospheric Administration in the USA, currently being lay out for Aotearoa New Zealand marine habitats. CMECS was applied using three out of the four components: Geoform, Substrate and Biotic components (water column was not included) defining the primary substrata and biota, and co-occurring elements (secondary substrata and biota) and a number of modifiers (incl. bedform structure, such as 'rippled' sediments, and/or vertical relief). The CMECS data were recorded every 5 m along each video transect. Percentage (%) cover estimates were entered in 10% categories for the primary and co-occurrent components.

However, no true absence records for any of the taxa were recorded. When modelling the relationship between species abundance and physical or environmental variables, having only presence data without corresponding absence data poses a significant challenge. The absence data are crucial for understanding the full range of environmental conditions where a species does not occur, which helps define habitat preferences and ecological limits more accurately. Without true absences, models may overestimate habitat suitability, as they cannot distinguish between areas where the species is truly absent and areas where it was simply not observed. Biota data were then integrated with the track-line data using date and time. The CMECS data were re-imported and data formatted using SAS and R programming to create a data matrix with site, substratum type, and three taxonomic classification levels for the Biota. Following a series of QA and QC, the raw within data were found to include numerous data issues; including:

- i. Key substratum types along with key habitat-specific taxa, were not recorded by the same classification codes. This meant that difference between habitats and sites between years was hard to distinguish from simple observer-classification difference. This was a very simple mistake to avoid, but the consequences were very problematic in the data analysis.
- ii. The positional uncertainty of the video camera (layback error/uncertainty) was unavoidable in this project as no USBL system was available. For many mapping projects this is inconsequential where habitat types have internal homogeneity: i.e., reefs and soft-sediment zones are compositionally consistent within their boundaries. However, the reefal habitats within this survey area were extremely heterogeneous, with very high fine-scale variation in both habitat composition (sand, rubble, rock) and

vertical height off the seafloor (low-lying reef in-amongst a series of steep-sloping pinnacles). The combination of the layback uncertainty of the video observations combined within this fine-scale seafloor heterogeneity meant there was an immediate mismatch between the video-data and the MBES-values along the track-line of each site. This meant that direct one-to-one point correlations were not possible. For example, sand observations aligned with high relief rock in the MBES data, while high relief rock habitats observed in the video aligned with soft-sediment gaps – making the biota-MBES correlations meaningless.

2.3.2 *Transect-level data corrections and analyses*

The 2024 within-transect data was imported in SAS. Due to the large number of data entry issues, several solutions were employed to streamline data corrections and subsequent analyses.

Step 1 - 2024 'text-descriptions' extracted as data

To capture the change in % cover over the gradient of habitat types, additional data were extracted from the notes section of the 2024 CMECS datasheet. As these taxa were systematically recorded, these extracted "text-descriptions" provided excellent information on the types of taxa seen and their % cover, and conversely (and crucially) their true absences.

Step 2 - Recoding variables to transect-level

To correct for subtle differences in substratum and taxa classifications, all substrata and taxa data from the 2024 survey were recoded to the transect (or site) level, with site means, standard error, upper quartiles and 90% Confidence Intervals (CI's) calculated. For example, 0 % cover in soft-sediment barrens, and 100% cover up on pinnacles (which was commonly seen) would result in a grand mean of 50% with very large errors bars – resulting in very little relationship with any habitat features. To improve upon this, we examined a range of summary statistics and found that the 90% confidence interval was the best approximation of the biota to capture strongly positive (or inversely strongly negative) relationship with the MBES values. Maximum values were not used as these are more prone to be driven by rare occurrences of high % cover. In contrast to other indices, we found that the 90% CI, represented realistic and characteristic relationships between key taxa and the different habitat types within the survey area.

Step 3 - Combining substratum types

Substratum types were combined together into 6 categories for ease of comparison: rock (rock, bedrock, megaclast); rubble (pebbles and cobbles); gravel (sandy gravels and slightly sandy gravels); sand (slightly gravelly sand, medium sand, fine sand); muddy-sands (sandy silt); and mud (silt and mud). This meant records called silt by one observer and mud by another were combined. A seventh category was coded as 'rock with sediment-veneer' to accurately capture rock habitats covered in sediment. Here both Observers inconsistently called these areas as either rock and/or muddy-sand. Given sediment cover is a critical factor driving community patterns, it was important to capture this habitat feature. Mean percent cover was calculated for each substratum type per site.

Step 3 - Recoding variables for ArcGIS mapping

For ArcGIS map layers, substratum types were recoded as primary ($\geq 50\%$ cover) and secondary ($\geq 20\%$ cover) types (as shown in Figure 12 and Figure 13). Relief and bedform types were extracted from the CMECS datasheets as maximum and minimum relief for hard substrata (i.e., high, moderate, low and flat) and bedform categories for soft-sediments (i.e., flat, rippled and

waved sediments. A relief/bedform category was then created following the CBed habitat classification methodology of Anderson et al. (2007); Nichols and Anderson (2009) - as shown in Figure 14 and Figure 15. Relief and bedform were not consistently entered in the DOC-CMECS dataset, so all sites with missing relief or bedform records were tagged for QA/QC, along with any site records with missing categories and/or % cover values for key taxa.

Step 4 - Reprocessing video data (Transect-level)

All transects with QA/QC issues were tagged for re-examination against the video-footage and corrected as required for the transect-level data. The full corrected transect-level data-matrix was then exported and mapped in ArcGIS, and plotted with the 2003 site-level data, for both mapping purposes and for between year comparisons. The combined (site-level) data resulted in 156 transects (from 154 sites) surveyed in 2024, with 72 sites located in the MBES-zone and 92 transects (90 site) within the within the TToR-MR. Given that there are multiple habitats, and not all key taxa occur in all habitats, the total number of data sites per habitat type or taxa/community type were often limited. To improve this ratio (and data input) the 296 sites surveyed in 2003 were merged with the 154 sites surveyed in 2024 – giving a total of 452 data points, with a combined 139 sites within the MBES-zone. Given that each site provides additional information (in terms of % cover and MBES characteristics) to model taxa-MBES relationship, extra sites were important.

Step 5 - Extracting MBES data for each site:

In ArcGIS Pro, site data were replotted over the corrected track-line data. A 30 m buffer was created around the entire track-line of each site surveyed in 2024 – to represent the possible location of the video at that site. Similarly, a 30 m buffer around the single GPS point was created around the single GPS point for each 2003 site – to similarly represent the location of the video relative to the vessel. MBES data (as described below) were then extracted for all points within each buffer zone for each site. This allowed the range of possible MBES features present at each site to be accurately summarised for each site in both the 2003 and 2024 datasets. All analyses were run using SAS and R to determine the relationships between habitat video characterisation, while conditional supervised raster modelling was undertaken using Python scripts written in ArcGIS. This was found to be the best approach given some of the data limitations (as described above). Zonal statistic (Mean, Stdev, SE, Max, Min, range and 90% confidence values) were then calculated for each raster layer for each sites' buffer zone.

Step 6 - Bio-physical analysis and modelling

The final merged 2024 and 2003 transect-level Bio-habitat dataset was then analysed in SAS using Proc CORR and Proc REG procedures to examine the correlation (and numerical relationships) between community taxa and the multibeam data layers. Bathymetry, backscatter, slope-std, ruggedness and benthic terrain classifications (at the broad-scale) were all important variables correlated with different benthic habitat and community types (Table 1; also see Table 9 to Table 16). Using these outputs in ArcGIS, models were built using Python script in ArcGIS (based on the correlative relationship with MBES data layers), to model the spatial distribution of the key habitat and taxa /community groups. Individual habitats (i.e., soft-sediment zones) and key taxa layers were then sequentially merged together, using the Dissolve edges processing functions in ArcGIS. These predicted habitat maps provided good alignment with the video observation, but would require independent data to validate the final maps, given there wasn't enough data that was linked with the MBES data, to split these data into testing and validation subsets. This wasn't because there weren't enough survey sites, rather the area mapped was only a subset of the large survey area. Video observations from Baited Underwater Video (BRUV) sites within this survey area may be useful for this purpose.

Table 1. Bathymetry, backscatter and derived-MBES variables used to predict community distributions within the TToR-MR. .

Zone	Kelp-all	Caulerpa	Mixed Inverts	Sed-tolerant taxa	Barren rubble	Sand gaps	Sand	Muddy-sand	Mud (+burrows)
n sites (taxa present)	109	37	51	46					
n sites (with MBES)	23	18	9	17					
Bathymetry	✓✓	✓✓	✓✓	✓			✓✓	✓✓	✓✓
Backscatter				<i>Too noisy</i>	✓		✓✓	*	✓✓
Slope		✓✓			✓				
Slope-std			✓✓	✓✓✓					
Ruggedness			✓✓						-ve✓
Raised reef polygon	✓✓	✓✓	✓✓						
Low-lying reef polygon				✓✓✓	✓✓				
Soft-sediment polygon							✓✓	✓✓	✓✓
Benthic Terrain Classifications									
Rock Outcrop Highs, Narrow Ridges	✓✓								
Flat Ridge Tops		✓✓	✓✓						
Scarp, Cliff		✓✓	✓						
Steep Slopes		✓✓	✓						
Broad Slopes		✓✓	✓						
Lateral midslope depression									
Local Ridges, Boulders, Pinnacles in Depressions			✓	✓					
Local Ridges, Boulders, Pinnacles on Broad Flats		✓	✓	✓					
Local Ridges, Boulders, Pinnacles on Slopes		✓✓	✓✓						
Broad Depressions				✓					
Depressions				✓					
Local Depressions, Current Scours				✓					
Crevices, Narrow Gullies over elevated terrain				✓✓					
Flat Plains							✓	✓	✓

2.4 2022 Multibeam Survey and MBES-derivatives

In 2022, LINZ Hydrographic Survey (HS76) collected 2013 hectares (20.13 km²) of multibeam echo-sounder (MBES) bathymetry and backscatter covering 82.15% of the TToR-MR in water depth >10 m water depth (Figure 6, also see Appendix A: Figure 34 and Figure 35, respectively). During this project, no coastal LIDAR² bathymetry for areas in or around the TToR marine reserve were available, so the nearshore area remains bathymetrically unmapped to date. Future LIDAR mapping could potentially fill in this near-shore gap, however, in the interim, satellite imagery from historical Google Earth images provides useful imagery to delineate nearshore rocky habitats (see Section 0, below).

The MBES Bathymetry (0.3 m vertical and 2 m horizontal resolution) and backscatter (1 m horizontal resolution) data were processed by Land Information New Zealand (LINZ), and provided as raster layers to Department of Conservation (Figure 6a-b, respectively). Derived MBES data layers (including: mean slope [Figure 6c and Figure 36]; the standard deviation of the slope [Slope-std; Figure 6d and Figure 37], Aspect and Curvature) were created from the 2 m bathymetry data, using a 3 x 3 m cell size analysis in ArcGIS Pro (v3.2.0). The standard deviation of the slope (Slope-std) is a statistical measure that quantifies how much the slope differs from the mean slope of the surrounding area, and has been shown to provide valuable fine scale information on seafloor variability/roughness. Slope-std, in combination with the seafloor ruggedness (described below), can help predict benthic habitats and associated communities. The Benthic Terrain Modeller (BTM) toolbox in ArcGIS (Walbridge et al. 2018; described in Wright et al. 2012), was used to delineate fourteen broad-scale 'benthic terrain classifications' (i.e., representing broad-scale geomorphic features across the TToR-MR)³. Seafloor Ruggedness (3x3 cell size), which also was calculated as part of the BTM, was also exported as an output raster layer (Figure 6e and Figure 38) along with the full BTM classifications (Figure 6f and Figure 39). Each MBES raster layer was clipped to the TToR-MR reserve boundary, to enable accurate calculations of the area of each and all mapped features within the marine reserve - within the depths where the MBES was collected and mapped (as presented in Figure 6 maps).

During this project a series of close-up satellite images were used to provide improved interpretation of where reefs occur. These images were imported and geo-rectified to the coastline in ArcGIS Pro. Polygons were systematically drawn around the visible reefs⁴. These reef polygons outside the MBES survey area (saved as Reef_drawn_noMBES.shp), are the best available boundaries we currently have.

These two mapping approaches, and their relative seafloor habitats, are examined separately relative to the respective areas:

- i) The area within the MBES mapping zone (MBES-zone), and
- ii) Areas not mapped by MBES (noMBES) occurring inside (nearshore zone, < 10 m water depth) and outside (SW and NW) of the TToR marine reserve.

² Light Detection and Ranging (LiDaR or LIDAR) is a remote sensing method, which uses pulsed laser light to measure determine land Topography and nearshore bathymetry (in shallow water depths where water clarity is sufficient to return light pulses).

³ Geomorphic features are characterised by the physical surface (seafloor) based on their physical attributes (i.e. size, shape, configuration and texture).

⁴ Future nearshore MBES or LIDAR mapping (the latter restricted to shallow nearshore zones) would be required to validate and/or improve these seafloor nearshore reef zones.

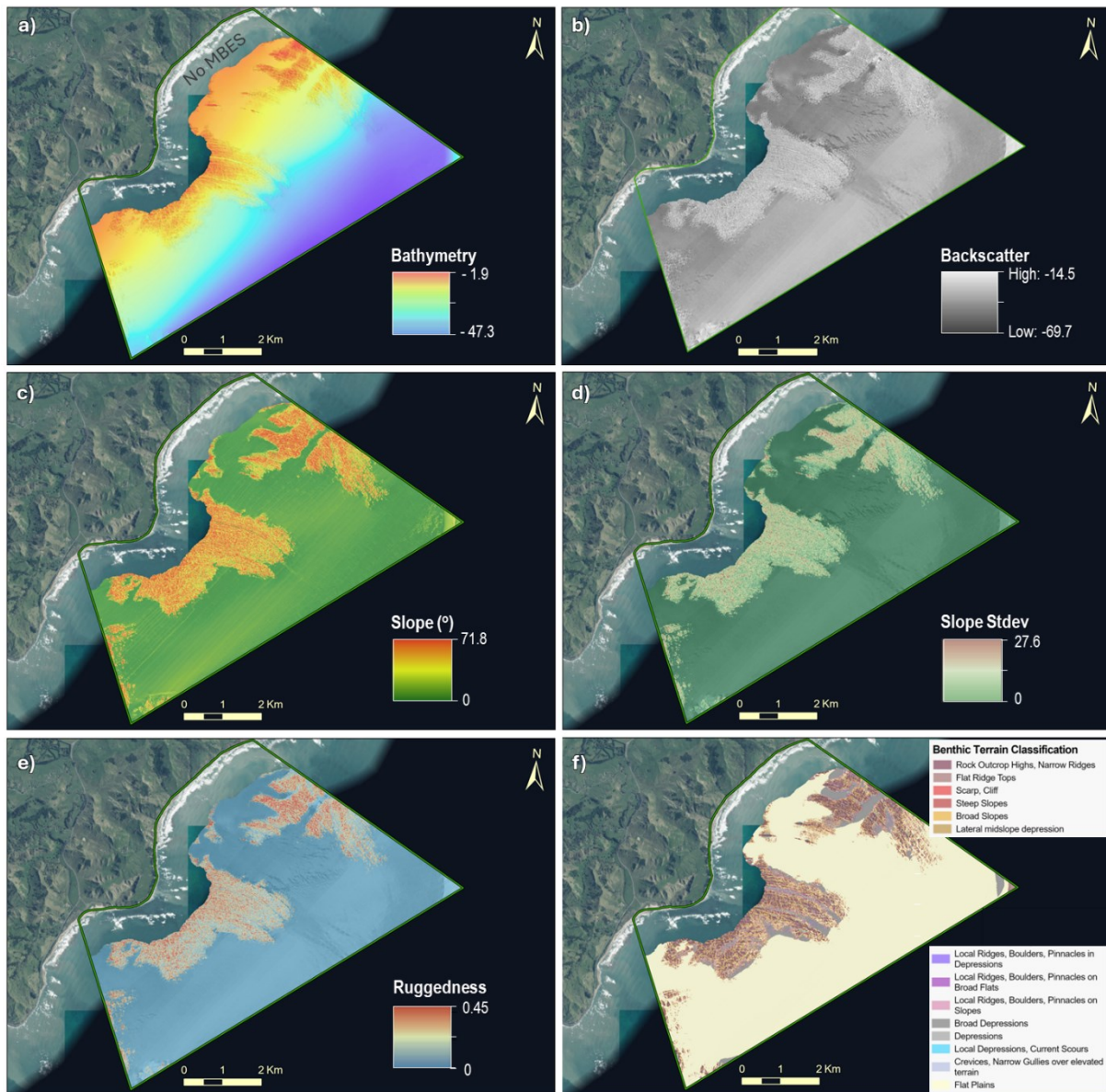


Figure 6. Multibeam echosounder data layers from LINZ hydrographic survey HS76, within the TToR-MR, 16 km north of Gisborne. These layers provided the input for modelling and creating the habitat suitability maps (see Appendix A: Figure 34 to Figure 39 for larger-sized maps).

2.5 Delineation of reef features

2.5.1 MBES zone, within the TToR-MR (>10 m water depth)

To delineate areas of rocky reef, several methods were examined to get the best fit. First, a raised-rocky-reef polygon was delineated from the bathymetry. This provided good delineation of raised reef features when compared to the hillshade relief layer. However, when overlaid and compared to the backscatter (which can depict hard [high reflectivity] versus soft [low reflectivity] substrata), along with other presumed hard (lower-lying) areas had been missed – these features occurred both within the large reef matrices as well as around the edges of large reefs and isolated or smaller patch-reefs. These areas were identified as hard or soft based, at locations where there were video observations. To correctly capture the edge of these low-lying habitats, a supervised classification on the backscatter data was run using the Classification Wizard in ArcGIS. This layer delineated more of the low-lying hard-bottom habitat, missed by the first method, but did not delineate the outer edge of reefs very well, as some sections of raised features were completely missed (due to noisy sections in the backscatter), while other areas of soft-sediment were included as reef (mostly due to high NADIR noise⁵). Examination of the ground truthing data verified these errors. The Image Segmentation tool in ArcGIS Pro, was used to fine-tune the values to detect the hard-bottom boundary. Although this improved the output, this still wasn't accurate. A fourth method using the BTM output was also trialled, but outputs were similar to those of the backscatter wizard method (as both relied on the backscatter layer within the same NADIR noise). Finally, the "Raised-reefs" boundary (modelled using the bathymetry) and the "Hard-bottom" habitat boundary (modelled using the Backscatter: 'finer-tuned Segmentation' method) were imported into ArcGIS, and carefully assessed using all data layers available.

The "Raised-reefs" polygon was found to reliably capture the boundaries of "Raised reef" features. However, areas of the seafloor that were comprised of low-lying habitats (e.g., flat reef and/or rubble fields), which were common in video observations, particularly around reef edges and across the gulleys between pinnacle features, were not well captured. The 'hard-bottom' polygon in turn was found to distinguish these low-lying areas, but its boundaries also comprised two significant errors. First, some areas of raised reef were strangely and completely missed (Error-type 1) (Figure 7). Upon inspection of the backscatter data for these areas, this error appeared to be due to artifacts (noise) in the backscatter data. Second, some significant areas of soft-sediment were included in the hard-bottom boundary - due to NADIR noise along the track-line (Error-type 2) (e.g., Figure 7 and Figure 8).

Depth profiles were run over the 'Type 2 Errors' to examine their validity. The other MBES layers indicated there was no roughness or variations across these areas. Depth profiles run along and perpendicular to these predicted features found the seafloor across these areas to be flat and straight (indicative of soft-sediments), and found no changes in the bathymetry that would indicate any low-lying reef habitats (Figure 8). Examination of the Backscatter data, however, found that these regular spaced protrusions aligned with the centre of the MBES vessels track-line (or NADIR) – indicating that these were erroneous hard bottom habitats, due to NADIR noise (Error-type 2). While the data processing steps had removed much of NADIR-noise from open soft-sediment areas, the processing steps used were unable to remove the noise from around these reef edges, due to the inability to determine what was noise and what was reef. To correct the type-1 error, we used the erase tool in ArcGIS to

⁵ The NADIR is the track-line directly below the vessel. Areas of greater uncertainty are known to be associated with track-line artefacts along the centre line (e.g., NADIR), and can cause variations in the surface that can then incorrectly appear as areas of higher surface complexity, which, in turn, during post-processing analyses be classified as hard rugose surfaces.

extend the Backscatter 'hard-bottom habitat' polygon to include all of the raised reef habitats that were accurately predicted in the 'raised-reefs polygon'. The revised boundary was then examined in ArcGIS editing mode, with all type 2 errors manually removed using the reshaping tool. The combination of these final two layers provided excellent delineation of the raised reef features and all hard-bottom habitats, respectively, while a third "low-lying hard-bottom" layer was then created by subtracting the Raised-reef layer from the total hard bottom layer (see Figure 10). This was a critical important step as all subsequent modelling relied heavily on the accuracy of these three habitat layers.

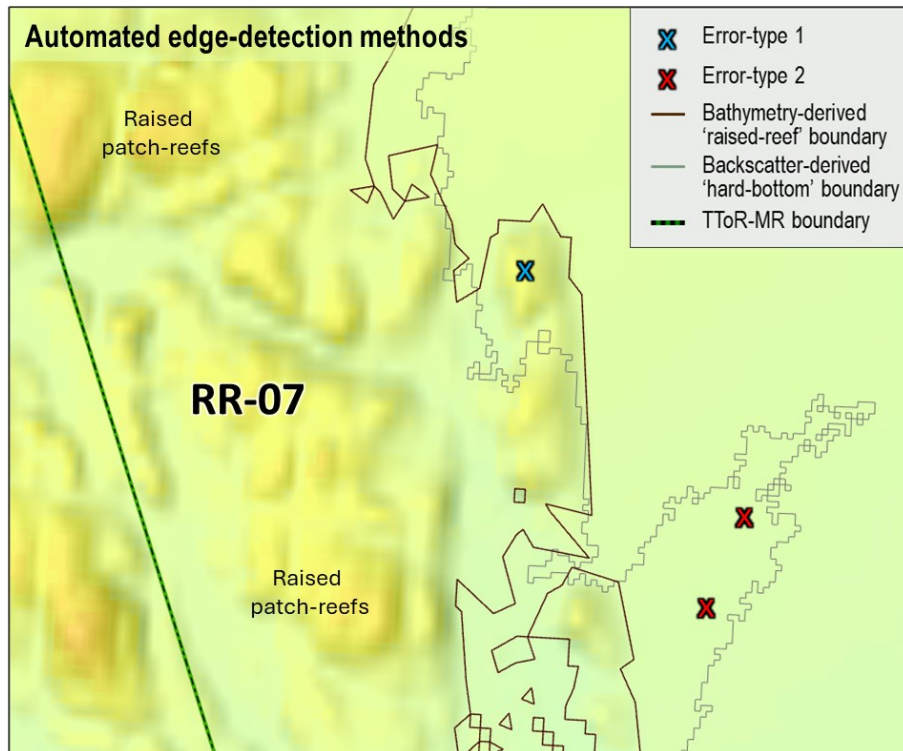


Figure 7. Assessment example of the two automated edge-detection methods. MBES bathymetry (brown line) reliably captured the boundaries of "Raised reef" features, but commonly missed low-lying hard bottom habitats. In contrast, the backscatter (thin green line) captured the low-lying habitats, but completely missed some raised reefs due to noise (Error-type 1) and erroneously included soft-sediments due to NADIR noise (Error-type 2). The location of these patch-reefs (i.e., RR-07) is shown in Figure 10).

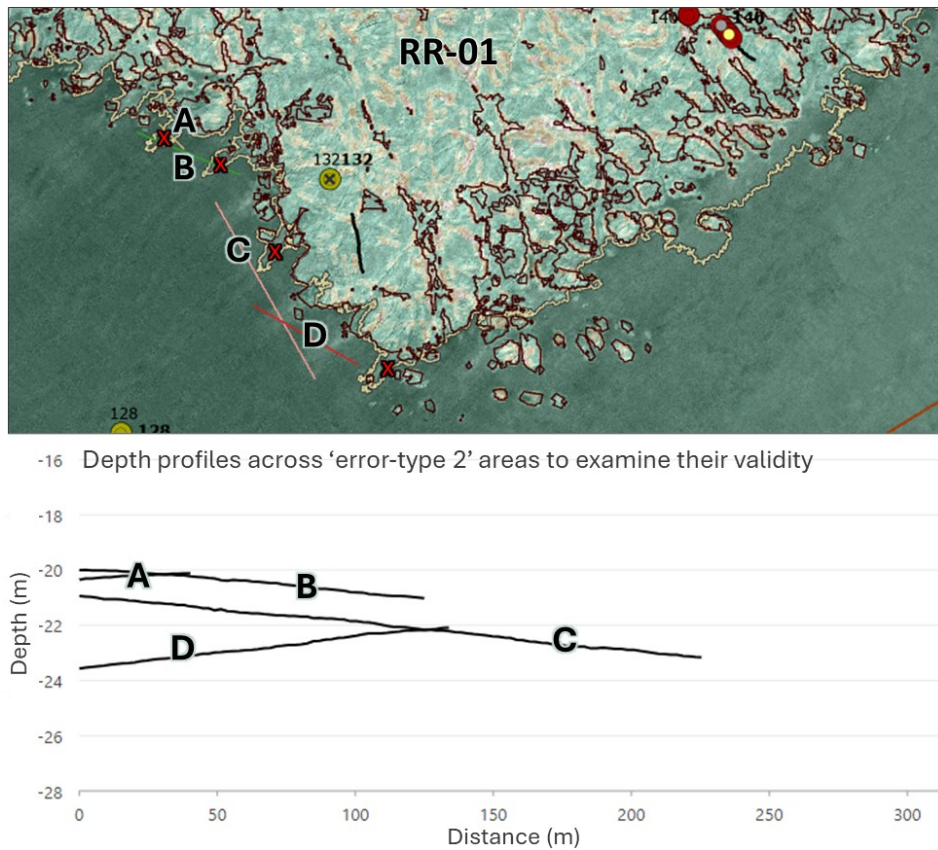


Figure 8. Examples of flat depth profiles (A-D) used to assess 'Type 2 Errors' in the backscatter edge-detection method. In the top image: Slope-std is draped over the backscatter and the hillshade relief. Bottom-image: Four depth profiles (locations in the top-image) identify that the bathymetry over these predicted features were flat and straight (indicative of soft-sediments), and were not low-lying reefs as depicted in the backscatter layer. Red crossed on these features indicate type-2 errors (due to NADIR noise). The location of this reef area (RR-01) is shown in Figure 10.

2.5.2 Nearshore TToR-MR, no MBES data (<10 m water depth)

Rocky reef areas without MBES maps, were hand-drawn using historic geo-rectified Google Earth imagery in combination with marine charts, national bathymetry contours and the 2003 drop camera and 2024 tow-camera survey substratum data (e.g., Figure 9a-b). To assist this process, we examined and exported historic Google Earth imagery where benthic features (such as rocky reefs and patch reef habitats) could be seen in the satellite imagery (e.g., Figure 9a). These images were imported into ArcGIS Pro, and geo-rectified to the coastal layers. The 2003 and 2024 video classification, along with marine charts and NZ bathymetric contours were used to delineate rocky reef features wherever possible. This combination of layers enabled the location and shape of inshore rocky reefs to be well estimated and drawn as polygons in ArcGIS Pro (Figure 12, Figure 13 and Figure 11). In contrast, in deeper water (outside the MPA), where no habitats could be seen in the satellite imagery, then estimated boundaries relied on the seafloor classifications from both the 2003 and 2024 video data, along with marine charts and NZ bathymetric contours.

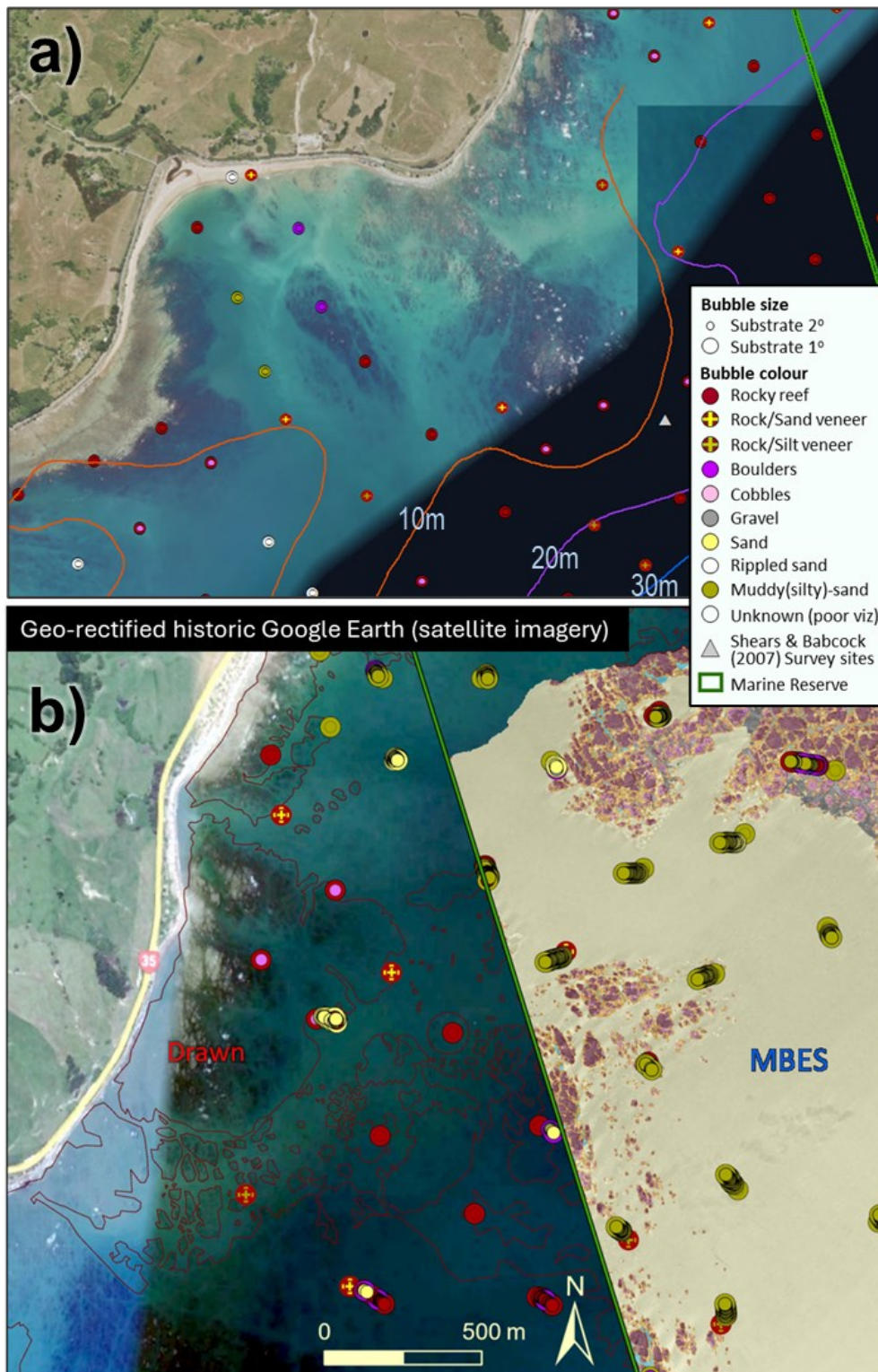


Figure 9. Examples of geo-rectified Google Earth imagery used to map inshore rocky reefs. Large circles= $\geq 50\%$ cover, smaller inner circles= 20% cover (Large and small circles with the same colour= 70%). Circle colours are provided in the legend.

3 Summary of Results

3.1 Mapping and delineating reefs

Seafloor habitats are examined relative i) the MBES-zone (~>10 m water depth), and ii) areas with no MBES maps, inside (<~10 m depth) and outside of the TToR-MR within the broader survey area.

3.1.1 Raised reef features

Raised reef features were located in several habitat configurations. The most abundant area of raised reefs, occurred within larger reef matrices (e.g., RR-01, RR-02 and RR-03 in Figure 10). These habitats contained a series of tall, rounded pinnacles (weathered smooth) that varied in height from several metres to over 10 m's in height. Raised reefs were also present as isolated patch reefs - located either directly adjacent to large reefs (i.e., RR-01b, RR-02b and RR-03b in Figure 10) or as part of a larger patch-reef zones along the southern boundary of the marine reserve (e.g., RR-06, RR-07 and RR-08) (Table 2 and Table 3; Figure 10).

The marine reserve also captures the very corners of two offshore rocky features: Monowai Rocks a large raised bank in the north offshore corner of the marine reserve (RR-10: Table 2 and Figure 10), and a deep rock outcrop in the south offshore corner of the marine reserve (RR-09: Table 2 and Figure 10). Monowai Rocks was characterised by a mix of habitats. A scree-slope up onto a rubble bank with higher proportions of rock outcrop higher up the bank. However, the majority of Monowai Rocks, was characterised by broken rock and rubble. Although several large, raised reefs were mapped in the Bathymetry, only the lower edge of one of these was surveyed. It would be expected that the raised reefs would support higher abundance and diversity of mixed invertebrates. The Deep offshore rocky outcrops in the south corner, comprised two habitat types: an extensive buried reef characterised by moderate densities of sediment-tolerant invertebrates (see community descriptions below), and higher density mixed invertebrate communities on rock outcrops. Rock outcrops weren't very high (at least where the camera sites sampled), however, these outcrops were often covered in dense invertebrate communities, characterised by the most bryozoans of any other sites.

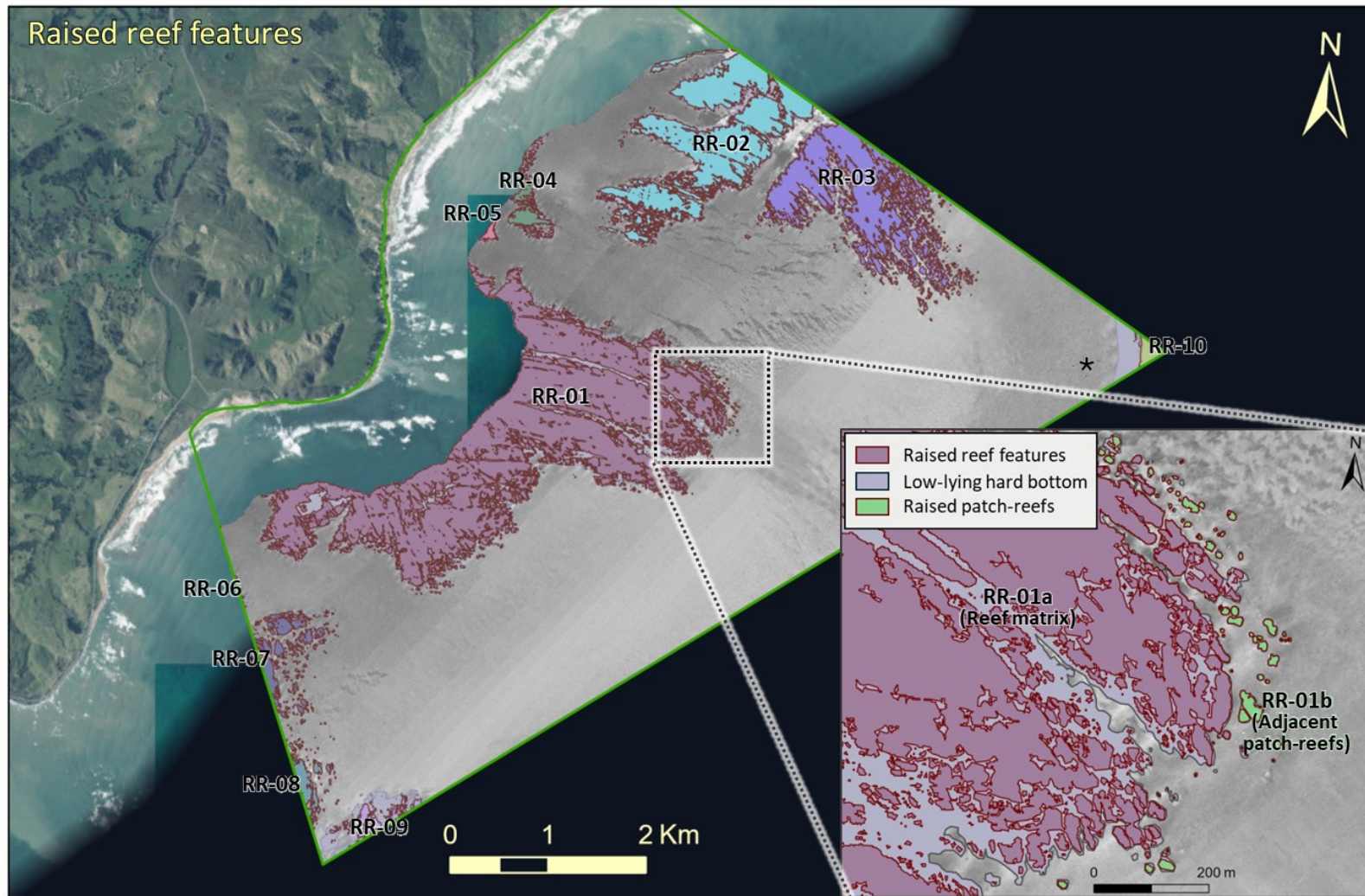
3.1.2 Low-lying and buried reefs

Most low-lying or partially buried hard bottom areas (i.e., beyond the raised reef features) were present within gulleys and depressions. Specifically, in flat plains (45%), broad depressions (32%) and depressions (18%), with less in mid-slope depressions or local depressions made by current scours (aerial values provided in Table 4 and Table 5)⁶.

Based on ground truthing data, these low-lying areas could be classed into three types.

- 1) **Low-lying rubble (mostly barren)** - mostly found within or at the base of a large reef matrix. These hard rubble habitats were characteristically clean of biota likely due to sediment-scouring. These habitats had varying amounts of sediment veneer (either due to fine depositional sediments or coarse sediments due to burial). These low-lying rubble zones occurred within inner-matrix gulleys, and had little to no biota present. Where biota was present it was generally limited to low %cover (<5-30% cover) of non-geniculate corallines, and occasional encrusting sponges (<1-5% cover).

⁶ Some additional Hard bottom values were recorded for other BTM categories associated with raised features, but upon close examinations these were residual edges of polygons rather than actual low-lying habitats – so these negligible values have been removed and are not included in here.



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Figure 10. Locations of the ten raised reef features (RR-01-10) within the TToR-MR, based on the HS76 MBES collected in 2022. Raised reef features occur within a larger reef matrix (e.g., RR-01, RR-02 and RR-03) or as isolated patch reefs - located either adjacent to large reefs (e.g., RR-01b, RR-02b and RR-03b) or as part of larger patch reef zones (e.g., RR-06, RR-07 and RR-08). The marine reserve also captures the very corners of two offshore features: large area of outcropping rock in the far south corner (RR-09) and a large Bank -in the north offshore corner (RR-10). Insert: The grey-line= the outer boundary of the reef matrix: with the areas of raised reef (maroon-fill) and low-lying hard substrata (grey-fill), with adjacent patch reefs (green-fill). "*" denotes the delineation of four very small, raised features on the lower sediment slope of the Bank.

Table 2. Areal size of raised reef features, either within a reef matrix or as separated patch-reefs, in the MBES-zone of the TToR-MR. Position alongshore and offshore are broad-scale classification to provide spatial references. The location of these raised reef features (RR-01-11) are provided in Figure 10.

Map ID	Raised reef feature	Feature-type (within)	Position alongshore	Position offshore	Area (km ²)	Perimeter (km)
RR01a	Large reef (inshore-centre)	Large reef matrix	South-central	In-mid-offshore	2.378756	189.32
RR01b		Adjacent patch-reefs	South-central	In-mid-offshore	0.017193	6.75
RR-02a	Large reef (inshore-north)	Large reef matrix	North	In-midshore	0.811625	67.69
RR-02b		Adjacent patch-reefs	North	In-midshore	0.006130	2.90
RR-03a	Large reef (offshore-north)	Large reef matrix	North	Deep midshore	0.668856	74.39
RR-03b		Adjacent patch-reefs	North	Deep midshore	0.034858	13.68
RR-04a	Small reef (inshore-north)	Reef (1 of 2, larger)	North	Inshore	0.058684	9.64
RR-04b		Patch-reefs	North	Inshore	0.006912	2.74
RR-05a	Small reef (inshore-north)	Reef (2 of 2, smaller)	North	Inshore	0.008644	0.96
RR-05b		Patch-reefs	North	Inshore	0.000205	0.35
RR-06	Patch-reefs (inshore-south)	Patch-reef zone	South-edge MPA	Inshore	0.006660	1.50
RR-07	Patch-reefs (midshore-south)	Patch-reef zone	South-edge MPA	Midshore	0.133029	21.83
RR-08	Patch-reefs (offshore-south)	Patch-reef zone	South-edge MPA	Offshore	0.070654	11.27
RR-09	Rock outcrop (offshore- south)	Rock outcrops	South-corner MPA	Offshore	0.056870	12.40
RR-10a	Monowai Rock (Extensive Bank offshore-Nth)	Large rock outcrops	North-corner MPA	Offshore	0.209570	9.79
RR-10b		Small rock outcrops	North-corner MPA	Offshore	0.006152	5.42
RR-11x	Tiny patch-reefs (x4)	(likely due to NADIR noise)	North corner	Offshore	0.000027	0.06
➤ All raised feature within reef matrix				subtotal	4.193005	364.19
➤ All patch reefs				subtotal	0.281794	66.44
Total raised reef features (within the Marine reserve)				Totals	4.474827	430.69

Table 3. Raised reef summary of Benthic Terrain / geomorphic categories in the MBES-zone of the TToR-MR.

Zone	Area (km2)	% of all low-lying hard substrata.
Rock Outcrop Highs, Narrow Ridges	1.157958	21.06
Flat Ridge Tops	0.345780	6.29
Scarp, Cliff	0.018937	0.34
Steep Slopes	0.199188	3.62
Broad Slopes	1.328650	24.17
Lateral midslope depression	0.201298	3.66
Local Ridges, Boulders, Pinnacles in Depressions	0.004518	0.08
Local Ridges, Boulders, Pinnacles on Broad Flats	0.100077	1.82
Local Ridges, Boulders, Pinnacles on Slopes	0.534455	9.72
Broad Depressions	0.456108	8.30
Depressions	0.252088	4.59
Local Depressions, Current Scours	0.061563	1.12
Crevices, Narrow Gullies over elevated terrain	0.004992	0.09
Flat Plains	0.831867	15.13
Grand Total	5.497479	100.00

Low-lying and buried reefs (continued)

- 2) **Partially or surficial buried reef (with sediment-tolerant taxa)** - were also common, but this habitat was generally found on low-lying deep reefs (due to sediment deposition) or at the reef-sediment interface of either large reefs or patch-reef, where the reef dips shallowly down under the sediment or where sediment burial up onto the reef has occurred. The habitats supported a suite of sediment-tolerant taxa, such as the native green alga, *Caulerpa* (inshore-midshore depths), and/or sponges such as *Polymastia crocea* (bright yellow dumpling-like sponge).
- 3) **Buried reef (no visible reef or biota)**: Buried reefs were defined as higher reflectivity detected in the backscatter, but no associated raised reef structure and no visible reef in the video footage. In some situations, buried reef habitats may simply be covered in sediments that are either too thick or temporally-persistent for biota to occur/survive, but shallow enough to reflect higher intensity backscatter signals. Alternatively, it may be that these buried reefs were at or closer to the surface when the MBES data were collected in 2022, but had been buried prior to the 2024 video surveys. Both of these factors may be occurring in different locations. Sediment habitats within the marine reserve appear to be dynamic, with sediment ripples occurring down to circa 40 m, while numerous sites had sediment build up within channels and along reef edges – indicative of storms or larger intensity water movement, that at these sites are able to move and deposit mobile sands up onto the reef. Ongoing sediment deposition is also high with most mid to offshore reefs having some level of sediment deposition present, with higher areal cover and thicker deposits present in lower-lying reef areas.

Table 4. Areal size of low-lying and partially buried hard bottom features, either within a reef matrix or as separated patch-reefs, in the MBES-zone of the TToR-MR. The location of these raised reef features (RR-01-11) are provided in Figure 10.

Map ID	Low-lying/Buried (within)	Feature-type (within)	Position alongshore	Position offshore	Area (km ²)	Perimeter (km)
RR01a	Large reef (inshore-centre)	Large reef matrix	South-central	In-mid-offshore	3.002176	30.48
RR01b		patch-reefs	South-central	In-mid-offshore	0.035122	8.57
RR-02a	Large reef (inshore-north)	Large reef matrix	North	In-midshore	0.989090	15.20
RR-02b		patch-reefs	North	In-midshore	0.013199	4.02
RR-03a	Large reef (offshore-north)	Large reef matrix	North	Deep midshore	0.864026	14.35
RR-03b		patch-reefs	North	Deep midshore	0.039199	13.51
RR-04a	Small reef (inshore-north)	Reef & patch reefs	North	Inshore	0.075054	3.46
RR-04b		(1 of 2, larger)				
RR-05a	Small reef (inshore-north)	Reef (2 of 2, smaller)	North	Inshore	0.010657	0.81
RR-05b		Patch-reefs	North	Inshore	0.019702	4.88
RR-06	Patch-reefs (inshore-south)	Patch-reef zone	South-edge MPA	Inshore	0.005043	1.20
RR-07	Patch-reefs (midshore-south)	Patch-reef zone	South-edge MPA	Midshore	0.141959	17.77
RR-08	Patch-reefs (offshore-south)	Patch-reef zone	South-edge MPA	Offshore	0.069245	5.55
RR-09	Rock outcrop (offshore- south)	Rock outcrops	South-corner MPA	Offshore	0.148057	5.74
RR-10a	Monowai Rock (Extensive Bank offshore-Nth)	Large rock outcrops	North-corner MPA	Offshore	0.093784	1.67
RR-10b		Small rock outcrops	North-corner MPA	Offshore	.	.
➤ All low/buried hard-bottom within reef matrix				subtotal	5.182845	71.690657
➤ All low/buried hard-bottom patch reefs				subtotal	0.323470	55.496911
Total low-lying/buried hard bottom (within the Marine reserve)				Totals	5.506314	127.19

Table 5. Low-lying hard bottom summary of Benthic Terrain / geomorphic categories in the MBES-zone of the TToR-MR.

Zone	Area (km2)	% of all low-lying hard substrata.
Flat Plains	0.613382	45.88
Broad Depressions	0.424087	31.72
Depressions	0.242963	18.17
Broad Slopes	0.052534	3.93
Lateral midslope depression	0.003284	0.25
Local Depressions, Current Scours	0.000723	0.05
Grand Total	1.336973	100%

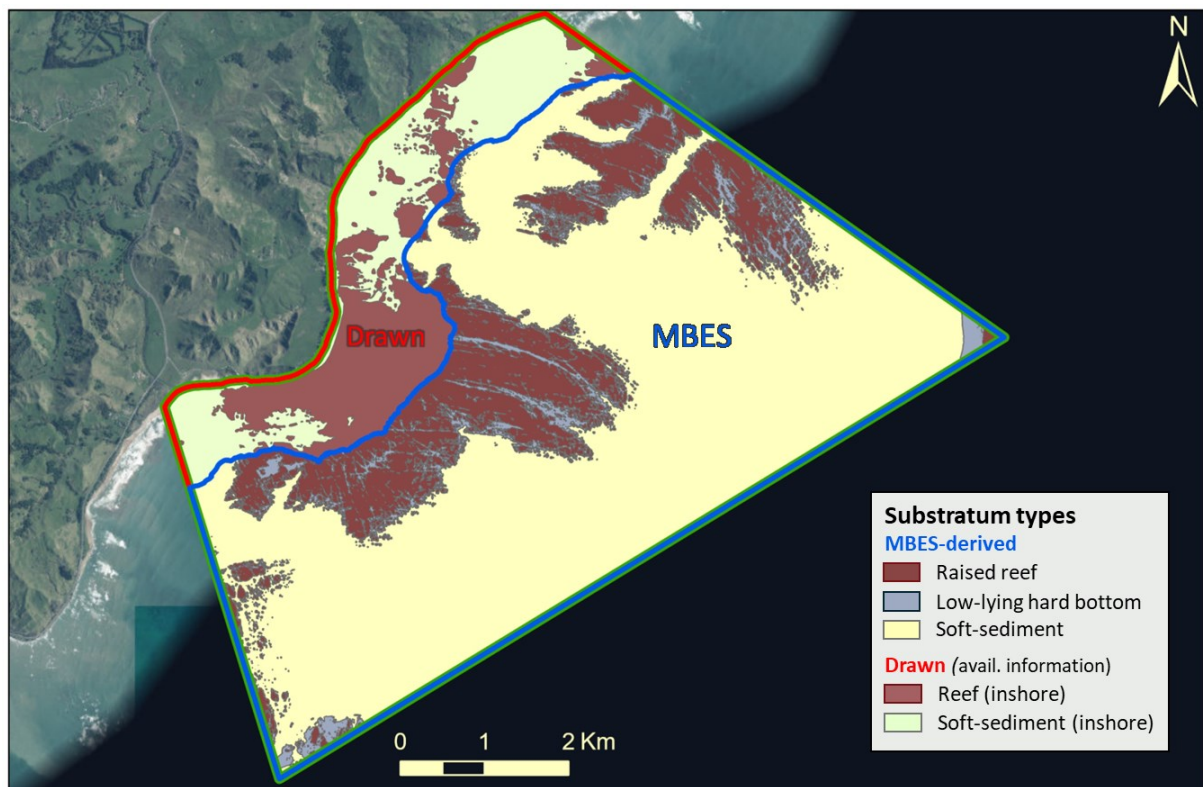


Figure 11. Substratum map for the TToR-MR. Rock reefs and soft-sediment were delineated based on the 2022 HS76 multibeam bathymetry and backscatter (i.e., within the MBES-zone, depicted by the blue boundary offshore); and hand-drawn from satellite imagery in the nearshore (no-MBES zone, depicted by the nearshore red boundary). Areal estimates for these habitats are provided in Table 6.

Table 6. Areal amounts of reef and soft-sediment habitats within the TToR-MR. These substrata are mapped in Figure 11 and Figure 10.

Substratum feature	MBES available	Area (km ²)	% of total for TToR-MR (MBES zone)	% of total for TToR-MR (no-MBES)	% of total for TToR_MR (combined)
Raised reef	Yes	4.16	20.68 %	-	16.83
Low-lying reef	Yes	1.34	6.66 %	-	5.42
Soft-sediment (with MBES)	yes	14.62	72.66 %	-	59.14
<i>Subtotals</i>		<i>20.12 km²</i>	<i>100%</i>	<i>-</i>	<i>-</i>
Drawn reef (without MBES)	no	2.09	-	45.43	8.45
Soft-Sediment (no MBES)	no	2.51	-	54.57	10.15
<i>Subtotals</i>		<i>4.6 km²</i>	<i>-</i>	<i>100%</i>	<i>-</i>
Totals		24.72 km²			100%

3.1.3 Seafloor substrata classifications

The seafloor substratum classifications (substratum type and seafloor relief and bedform structure) correlated well with the MBES data both at large scale and zoomed in (Figure 12, Figure 13 and Figure 14). The 2024 classifications correlated well with those collected in 2003. Only a few sites (e.g., Site 133 in 2003) which classified muddy-sands, but was located on the large, raised reef (RR-01) with no nearby corresponding crevice or sediment gap. The same site sampled in 2024 recorded high relief rocky reef as would be expected from the high-relief bathymetry for this area. Obviously, the position of the 2003 Site is not correct in this situation. The nearest soft-sediment was 52 m away, so this is unlikely to be a small positional error; but a waypoint may have been taken prior to drifting in the current and recording video of the seafloor. Otherwise, 96.2% of the video footage was the same in terms of the substratum (hard vs soft) and general seafloor structure and configuration (high relief reefs; rocks and rubble; versus rippled sand).

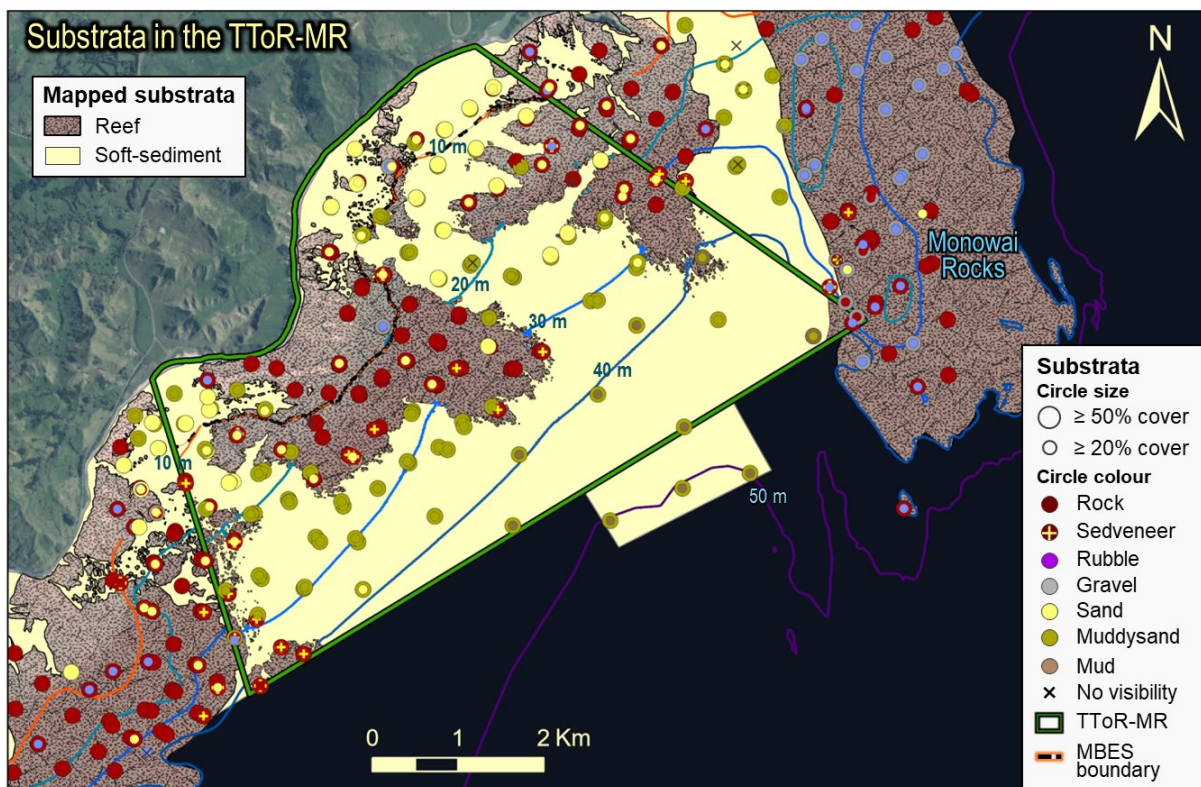


Figure 12. Seafloor substratum classifications (circles) from 2024 and 2003 video observations for the TToR-MR, overlaid on the delineated reef and soft-sediment maps. Reefs within the MBES-zone were delineated from MBES data, while reefs without MBES maps, were drawn in ArcGIS based on nearshore satellite imagery, marine charts and NZ bathymetry contours and these video data.

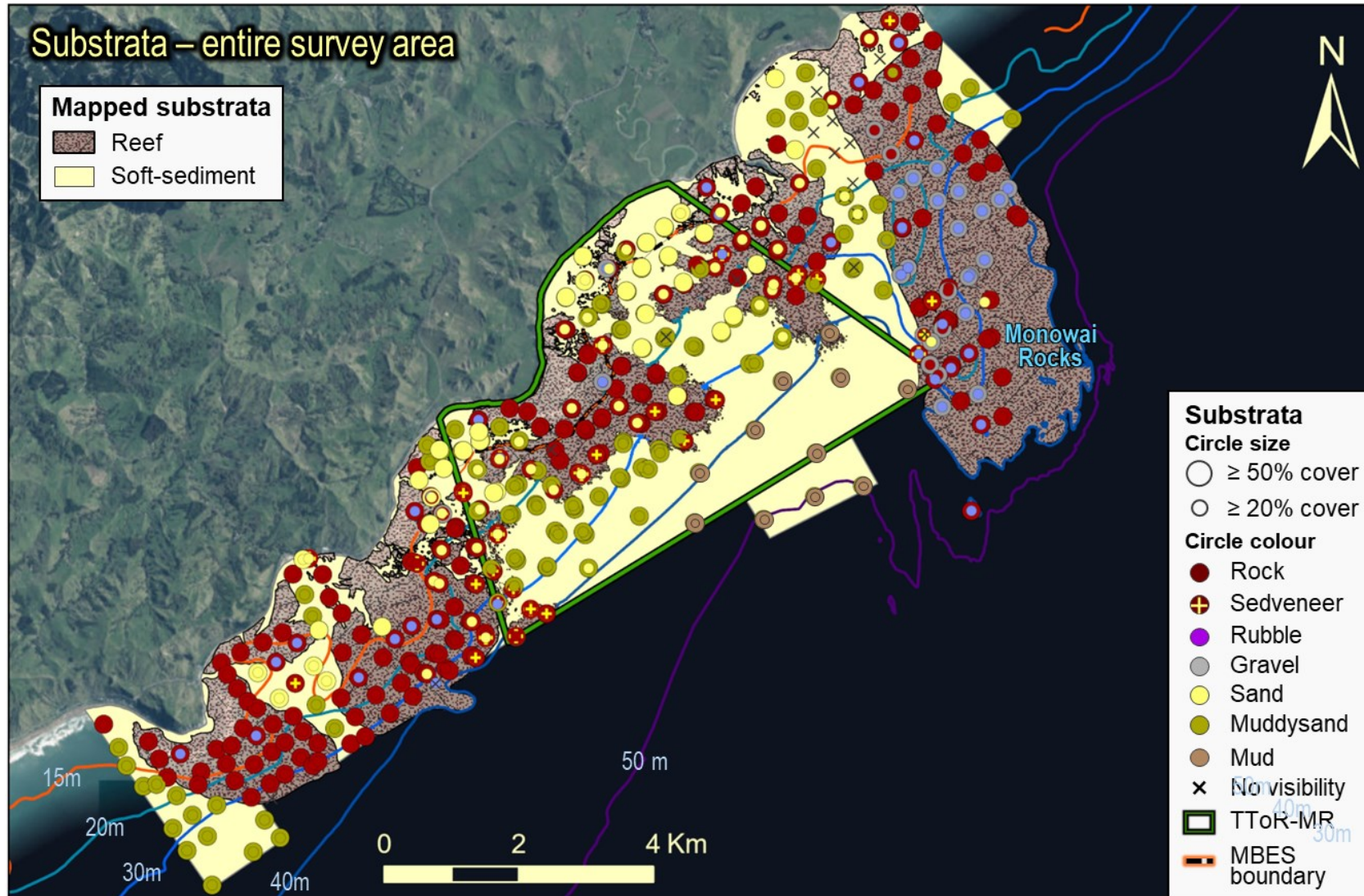


Figure 13. Substratum types (circles) from 2024 and 2003 video sites, for the entire survey area, overlaid on the delineated reef and soft-sediment maps. Reefs within the MBES-zone were delineated from MBES data, while reefs without MBES maps, were drawn in ArcGIS based on nearshore satellite imagery, marine charts and NZ bathymetry contours and these video data.

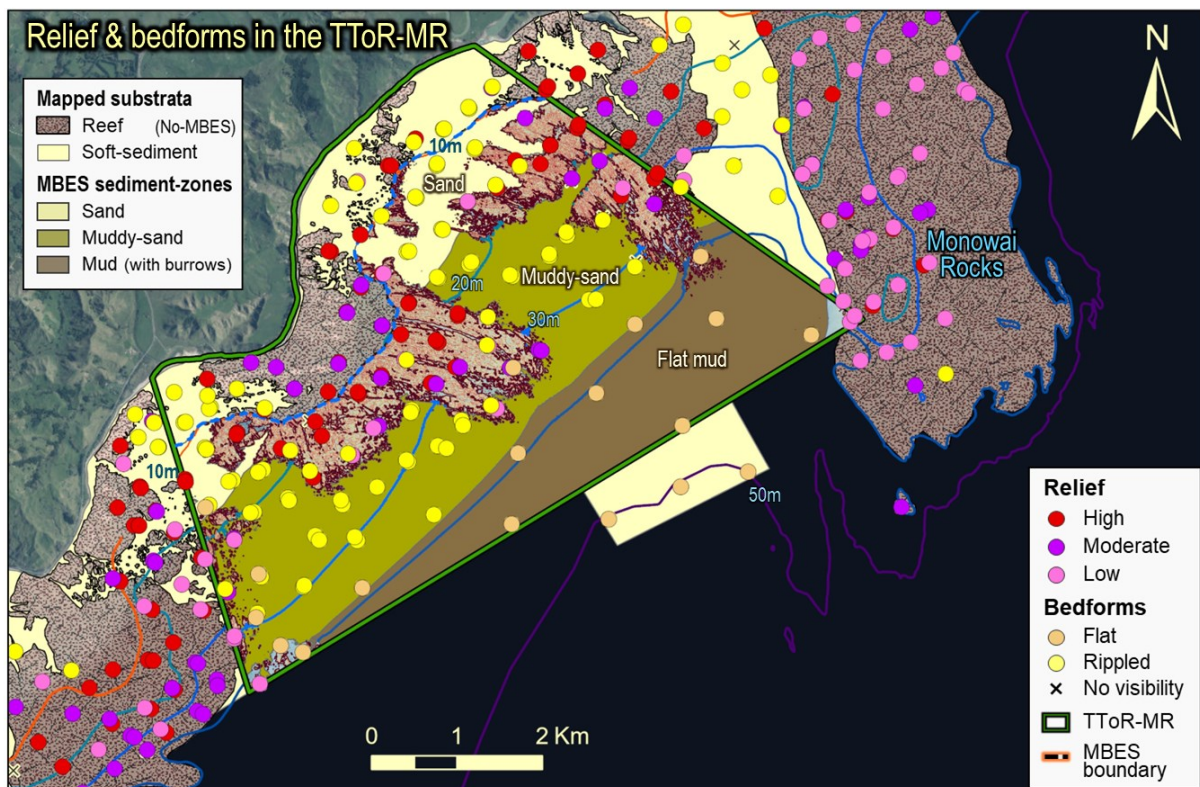


Figure 14. Seafloor vertical relief and bedform classifications (circles) from 2024 and 2003 video observations within the TToR-MR. Video data (circles) are overlaid on MBES-derived ruggedness clipped to the reefs or the three mapped soft-sediment zones (inside MBES-zone - >10 m) or the reef and soft-sediment maps (outside the MBES-zone).

Here the relief and bedform classifications identify that sand-inshore and muddy-sands in the midshore sediment zones, both had rippled bedforms, while deep muddier (siltier) sediments were flat (Figure 14). Within the muddy-sand zone rippled bedform intensity decreased becoming only subtly rippled with depth. In contrast, depth > 37 m had little or no impact from big swells, but likely received increased deposition of fine silts following storm events.

The spatial distribution of substratum types based on the video classifications from both years, identified that the highest relief reefs were generally found in water depths of 10 to 25 m, although some high relief reef (or 'raised reef') features were also found inshore, but these were often limited to smaller sized reefs (Figure 14 and Figure 15). Several large extensive reefs were mapped within the TToR-MR (i.e., Reefs RR-01, RR02- and RR-03 in Figure 10), along with similar sized reefs to the north and south of the marine reserve (Figure 15).

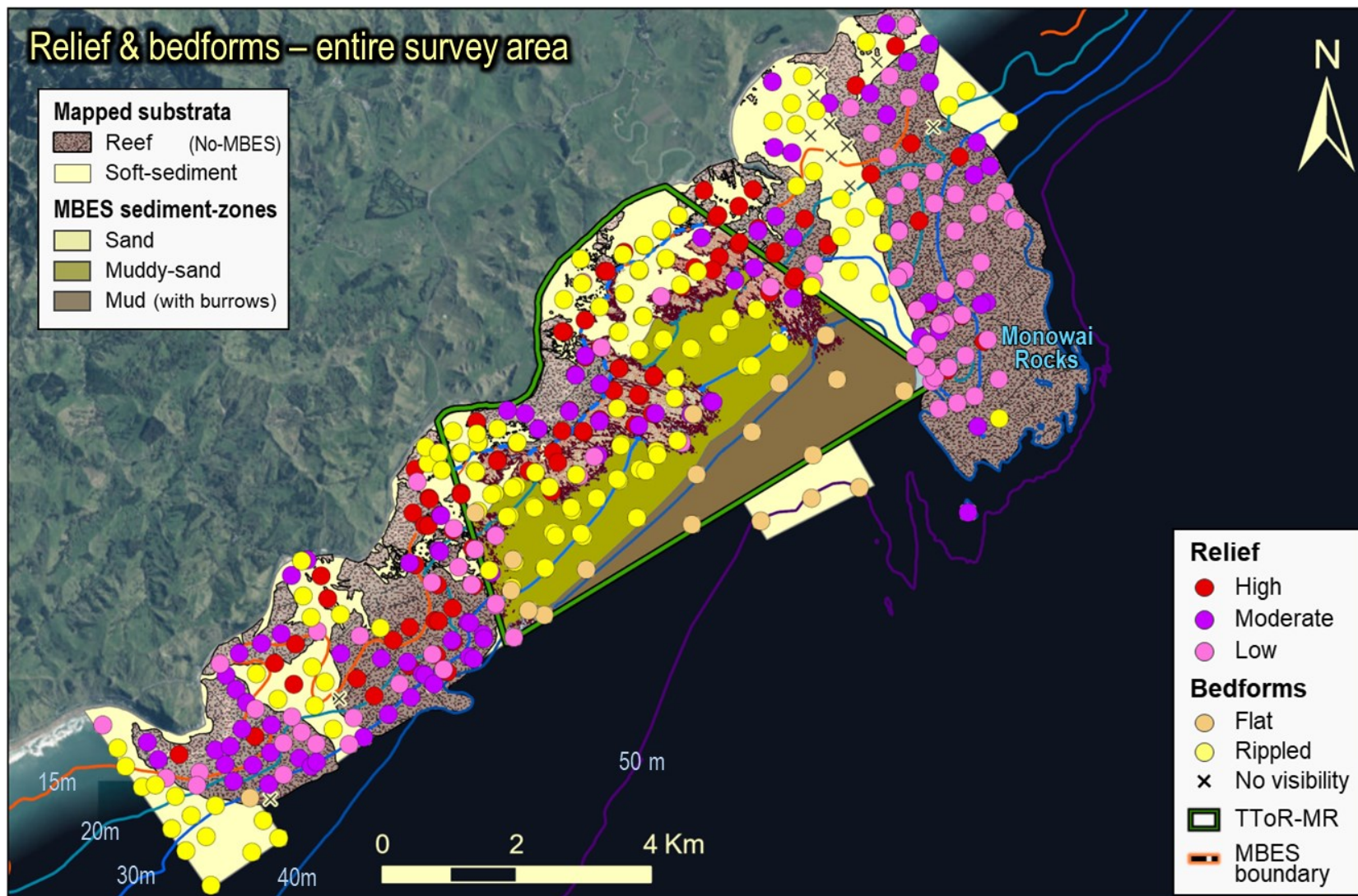


Figure 15. Seafloor vertical relief and bedform classifications (circles) from 2024 and 2003 video sites, for the entire survey area. Video data (circles) are overlaid on MBES-derived ruggedness clipped to the reefs or the three mapped soft-sediment zones (inside MBES-zone - >10 m within the TToR-MR) or the reef and soft-sediment maps (outside the MBES-zone).

3.2 Mapping soft-sediments

Soft-sediment polygons were created by combining all the hard-bottom polygons together in the respective i) MBES, ii) no-MBES zones within the TToR-MR, and iii) across the larger survey area beyond the marine reserve boundaries, both to the north and south of the marine reserve. To achieve this, three polygons were created in ArcGIS, one for the zone inside the TToR-MR with MBES data, another for the zone without-MBES data, the latter split into inside and outside of the marine reserve, and are presented below:

3.2.1 *Soft-sediments in the MBES-zone of the TToR-MR (>10 m water depth)*

To determine the amount of soft-sediment within the MBES zone, inside the marine reserve, all the hard-bottom habitats (i.e. the raised reef and low-lying reef) were combined into a layer of all hard bottom and subtracted from the MBES boundary polygon⁷ using the erase function in ArcGIS Pro, with the saved output called "Softsed_MBES_inMR.shp". The total amount of soft-sediment within the MBES zone was 14.62 km², representing 72.66% of the MBES-zone within the TToR-MR, and 59.14% of the entire marine reserve (Table 6 and Figure 11).

Video footage of the seafloor at sites within the TToR marine reserve identified three different soft-sediment zones, whereby sediment grain-size and bedform structure- based solely on video observations⁸ - decreased with distance offshore (Figure 16). The video data were plotted over each MBES layers. SAS Proc CORR procedure was used to examine the data structure of each sediment type and their correlation within the extracted MBES summary data from the buffer zones. Scatter point relationships were plotted and examined, along with summary statistics (see Appendix A: Table 14, Table 15 and Table 16). For soft-sediment, three depth zones⁹ were ample to define and delineate the observed spatial patterns. These were defined as:

- 1) Coarse mobile sand (inshore depths <~17m); mostly distinctly rippled bedforms.
- 2) Muddy-sand (midshore depths of ~17 to 35 m), mostly subtly rippled bedforms
- 3) Flat mud, with sparse burrows (offshore depths > 35 m)

All raster modelling was undertaken using Python scripts written in ArcGIS using a series of conditional statements. For soft-sediments, the bathymetry raster was used to extract the three depth zones, which were then coded to the relevant sediment classes, with a new habitat type descriptor field called "habtype" = "<sediment name>", then all three polygons were merged together using the 'dissolve boundaries' method saved as a shapefile, with the new variable "Area_km²" created and the amount of area calculated for each polygon.

We note here that this delineation fits well with observations (as seen in Figure 17), but the boundaries between these zones, are likely to be gradual transitions, reflecting diminishing hydrodynamic effects (waves and currents) on benthic sediments with increasing water depth. Geological sediment sampling would be required to formally document and validate grain size changes with increasing depth offshore.

⁷ Created by erasing the MBES bathymetry layer from Marine Reserves boundary polygon

⁸ Formal sediment grain size analyses from sediment grab samples would be required to verify and describe the grainsize distributions along and offshore within the TToR-MR.

⁹ Backscatter also supported these breaks but was itself too noisy to include directly into the conditional script

Of the total soft-sediment within the MBES zone, sand (coarse mobile sediments) covered an inshore area of 1.83 km², comprising 12.49% of the area within the MBES-zone. However, the inshore zone, inshore of the MBES-zone, also comprised coarse sands, so the total area of sand in the inshore will be represented by the combination of these two areas (4.34 km², representing 17.55% of the TToR-MR). Muddy-sands covered a midshore area of 7.36 km², representing 50.32% of the MBES-zone and 29.8% of the entire TToR-MR, while the deep offshore mud zone covered an area of 5.44 km², representing 37.19% of the MBES-zone and 22% of the entire TToR-MR (Table 7; Figure 17).

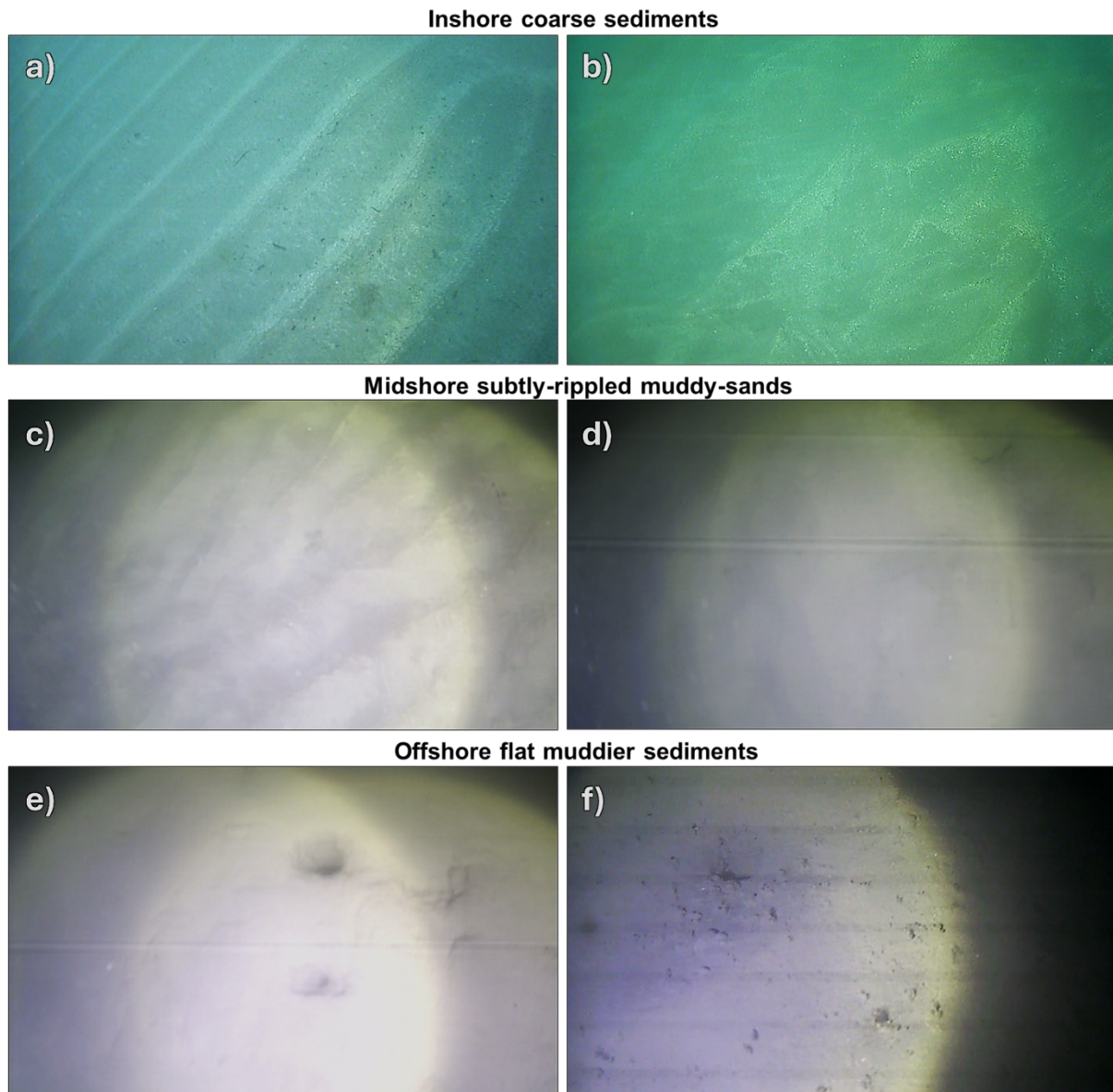


Figure 16. Examples of sediments changes with distance from shore, within the marine reserve. a-b) Inshore rippled sands, where sand grains and shell gravel are visible in the sediments (Sites 156 and 182); c-d) Midshore rippled muddy-sands (Sites 148 and 149); e-f) Offshore flat and muddier sediments (Sites 307 and 303) - depicting flatter sediments with occasional burrows. The latter two offshore sites were not sampled in 2003, but were strategically added to determine what habitats were present in the offshore zone of the marine reserve.

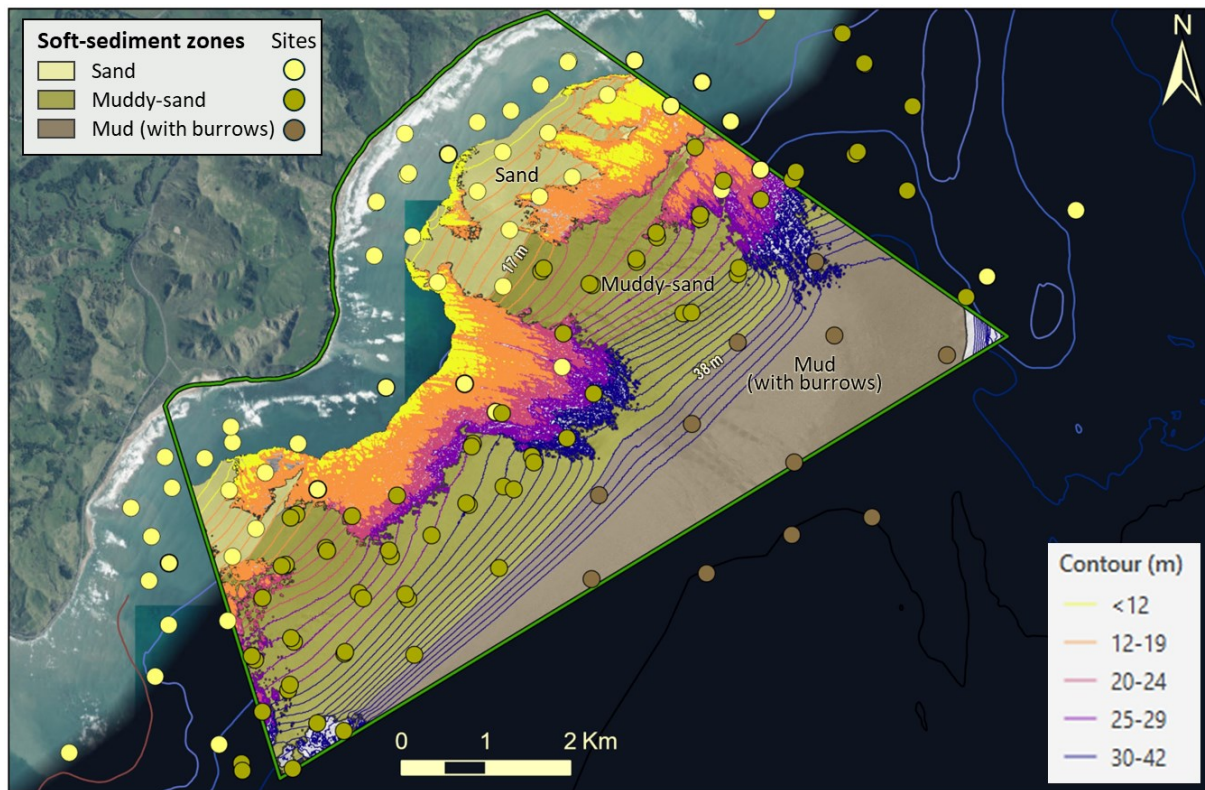


Figure 17. Soft-sediment zones within the TToR-MR, defined by MBES bathymetry. Sediment grain-size decreased with distance offshore, with three sediment zones delineated: Coarse mobile sand inshore of ~17m; rippled Muddy-sand between ~17 and 35 m, and flat mud, with sparse burrows, in depths > 35 m were identified and delineated. Areal estimates for these soft-sediment habitats are provided in Table 7.

Table 7. Areal amounts of the three soft-sediment zones within TToR-MR. These soft-sediment zones are mapped in Figure 17.

Soft-sediments	Area (km ²)	% of total sediment within MBES zone	% of total for entire TToR-MR
Inside the TToR-MR (no MBES)			
Sands (inshore, no MBES)	2.51	-	10.15%
Inside the TToR-MR (with MBES)			
Sand (coarse mobile sediments)	1.83	12.49%	7.40%
Muddy-sands (rippled)	7.36	50.32%	29.77%
Mud (with sparse burrows)	5.44	37.19%	22.01%
Outside the TToR-MR (no MBES)			
Soft-sediment (all)	16.56	-	-
Grand Total	14.62	100%	69.34%

3.2.2 *Soft-sediments in the TToR-MR, but no MBES maps (>10 m water depth)*

Soft-sediment polygons were created by subtracting all the hard bottom habitats (hand-drawn reefs) inside the marine reserve beyond the MBES-zone (i.e. no MBES maps), using the erase function in ArcGIS Pro, with the output saved as "Softsed_noMBES_inMR.shp". Within the near-shore unmapped section of the TToR-MR (i.e. no-MBES), there was 2.51 km² of soft-sediment representing just over half (54.57%)¹⁰ of the total area in this TToR-MR (no MBES) zone (Table 6). When combined with the adjacent inshore sand zone (with MBES) the total area of coarse sand comprised 4.34 km² – and represents ~ 17.56% of the total area of the marine reserve (Table 7; Figure 17).

3.2.3 *Other soft-sediments habitats (within reefs) in the TToR-MR*

Soft-sediments were also present within the large reef matrices, in three forms reflecting different processes:

- 1) Coarse sediments burying reef edges in shallower inshore depths. High energy environments appear to wash sands up onto the reef, or are dumped onto the reef during high energy storms. Sediments seen in these environments, were mostly coarse sands with shell gravel visible.
- 2) Coarse mobile sands in large gulleys within the reef matrix. These sediments were generally rippled sands or muddy sands, depending on the depth of the seafloor, with siltier sediments found in deeper depths.
- 3) Sediment veneer: In depths > ~25 m, finer depositional sediments were a common feature of deeper low-lying reefs. Low-lying reefs and the gulleys within raised reefs had thicker and more extensive areas of sediment veneer than higher standing reefs. Deeper reefs also had extensive sediment deposition that in part buried the lower-lying reefs and especially reef-edge and patch reef habitats.

These habitats are difficult to define from MBES data. This is because these habitats give off much high backscatter-reflectivity than their sediment type alone would produce. This higher reflectivity is due to the presence of the underlying hard substrata. Low-lying bathymetry and edge habitats can be depicted in the bathymetry, however, many of these areas contained hard abiotic rubble (various combinations of boulder, cobbles, gravels and sometimes shell debris) so the location of these crevices, gulleys and low-lying areas alone are not enough to determine the composition of the substrata within them (this is also discussed below in further detail). However, it is important to note here that these sediment-veneer and sediment-scouring conditions are important factors determining what taxa are able to live in these sediment-impacted zones. Based on the prevalence of these within-reef sediment-veneer and sediment-scouring conditions, and the depth profiles of the sediments adjacent to the large reefs, sediment impacts are a natural and dynamically variable part of this coastal environment. However, additional inputs from coastal erosion and inland forestry run-off, particularly after large storms and cyclones, are likely to negatively contribute to this impact, and may result in the burial of more reefal habitat within the marine reserve. However, many of these species living on these reefs will already be tolerate to sediment cover, although the frequency and intensity of these runoff events may be important. We would recommend an estimate of sediment deposition across the TToR-MR be calculated to determine the rates of sediment-deposition, and reef-burial over time. While the accretion rates of sediment occur in

¹⁰ Noting that these inshore polygons are drawn-polygons based on satellite imagery of the nearshore, and while good in many shallow areas, are best-available knowledge, but are not exact maps.

geological time scales, the burial of reefs can be important over years to decades. When examining the effects of having a marine reserve in place over many decades, loss of reefal habitat can become an important consideration.

3.3 Survey area outside of the TToR-MR

The 2003 survey area, extending beyond the TToR-MR boundaries, both to the north and south of the marine reserve), comprised a total area of 58.85 km², of which soft-sediment comprised 14.05 km² (23.87%) with the remaining 76.03 km² representing hard bottom habitat (Table 1 and Table 6). This is a much higher proportion of reef to sand than that found inside the TToR marine reserve – which was 69.29% soft-sediment and 30.70% hard bottom habitat (Table 6). This is important when considering the representativeness of the TToR-MR relative to the adjacent coastline, as well as assessment of comparative impacts from sediment scouring and depositional processes, which are likely to be higher in areas with smaller reefs and higher proportions of reef-perimeters impacted by sediment mobility, and less in areas where reefs are more expansive. However, we note that the estimates within the marine reserve are based on high-resolution maps that accurately depict where the reefs are along with the hand-drawn reefs in the inshore that are visible in satellite imagery – and as such will be far more accurate than those outside the marine reserve, which although also based on nearshore satellite imagery, they have no MBES maps offshore and are therefore reliant on less precise delineation methods. This is because in the nearshore, drawn reefs are determined from satellite imagery, which although will have some level of drawn boundary errors, this is likely to be far less than areas offshore where satellite imagery cannot detect deeper reefs. These offshore reefs were drawn based on the drop camera video characterisation plotted over marine charts and national depth contours (which help identify the locations and boundaries of foul grounds and raised bathymetric areas), but are still likely to be considerably less precise. However, these newly drawn maps provide the best information available, and are an improvement on the previous knowledge and maps for this section of coast. This inverse pattern of soft-sediment to reef is however large and unlikely to simply be due to errors in mapping.

3.4 Mapping Key taxa/community types

Habitats and communities varied at very fine spatial scales within both the very extensive rocky reef zones/matrices, and across small and large patch-reef zones. The extensive inshore and midshore rocky reefs were characterised by an extremely undulating terrain, that traversed over a series of steep sloping rounded pinnacles, whereby the terrain varied from rubble or sand crevices up onto the tops of steep and 10 m high pinnacle-features and back down again, with a single video-transect traversing up and over many of these features. The key habitats modelled are described in summary here:

3.4.1 Kelp on reef tops (≤ 15 m)

At the tops of these reefs in water depth ≤ 15 m were kelp forest comprised of various mixes of *Ecklonia radiata*, *C. maschalocarpum* and *Carpophyllum flexuosum* – generally in low to moderate densities (Figure 19, Figure 20, Figure 21; with summary statistic provided in Table 9). Bathymetry (depth) profiles across this shallower section of reef, depicted a series of 2-10 m high pinnacles (e.g., Figure 18), while video-transect observations identified a series of rolling raised reef that were weathered and rounded in appearance that supported “kelp” on the tops of the pinnacles; with “*Caulerpa*-meadows” down the slopes of these same pinnacles; and sediment-tolerant taxa (incl. *Caulerpa*, and sessile invertebrates [see Sections 3.4.3 and 3.4.4, below]). Although *Carpophyllum maschalocarpum* was a key habitat / common feature of shallow rocky reefs, most sites with high % cover of *C. maschalocarpum* lay inshore of the MBES-zone, leaving only 7 *C. maschalocarpum* sites inside the MBES-zone. Obviously, this was too few to build a model on. Consequently, all Kelp Forest species recorded during these surveys (i.e., *Ecklonia radiata*, *C. maschalocarpum* and *Carpophyllum flexuosum*) were combined to improve survey numbers. Although these kelp species have differing, albeit overlapping, depth and spatial distributions, in this region and on these reefs, they regularly co-occurred together whereby all three kelp species were found on the tops of pinnacle features, either within a ‘mixed kelp assemblages’ or if separated were only within metres of each other. Their spatial co-occurrence along this particular coast, likely reflects the undulating pinnacle (or “rolling reef”) structure of these reefs, whereby depth zonation is contracted into much closer confines. As a consequence, pooling % cover of “all Kelp”, was deemed to be an appropriate approach to improve data-density for this key habitat-forming taxa. Both bathymetry (≤ 15 m) and benthic terrain classifications (Rock outcrops, category 10) were important in predicting the distribution of mixed-kelp distributions, with the final predicted kelp-zone comprising a 0.62 km² area within the MBES-zone of the TToR-MR (Table 8 and Figure 30, also see: Figure 31 and Figure 32).

Species found in the ‘Kelp-zone’, include:

- Non-geniculate coralline algae (NGC, commonly up to 60-90% cover), as well as
- *Zonaria* ($\leq 40\%$ cover, at some shallow sites, e.g., Figure 19c; Site 145),
- Filamentous red algae (≤ 5 -18% cover at some sites, e.g., Figure 19a),
- Encrusting sponges (≤ 5 -20% cover, mostly orange coloured, and occasional yellow ones).
- Geniculate coralline algae (≤ 5 -45% cover, e.g., Figure 19a,b) - although their occurrence was generally associated with the presence of *C. maschalocarpum* in shallower depths (e.g., Site 297, 312).

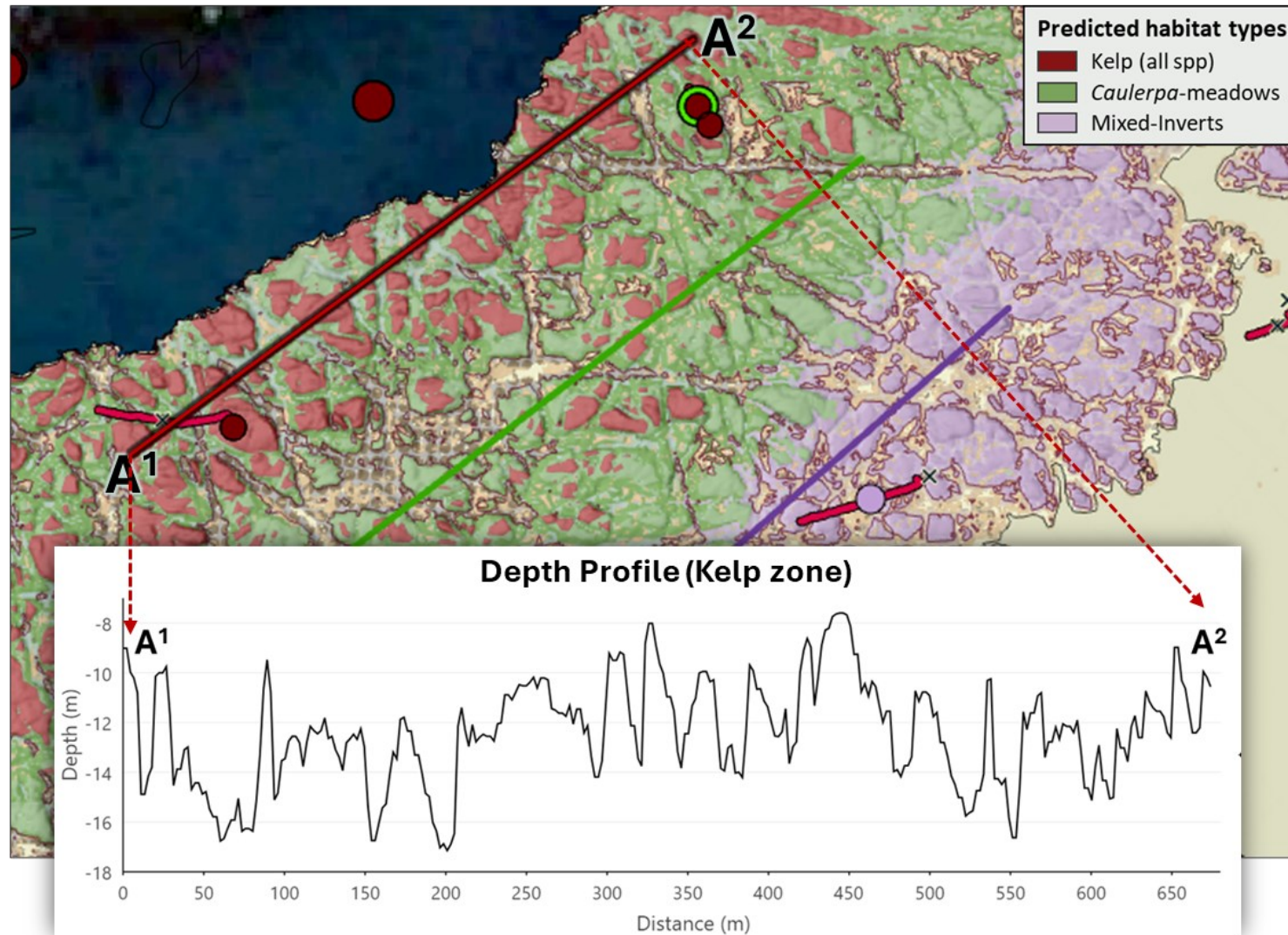


Figure 18. Bathymetry (depth) profiles depicting the pinnacle/rolling reef configuration (~2-7 m high) across the shallower reef (RR-01). A1-A2 denote the start and end of the alongshore depth profile. Red map areas = “kelp” on the tops of the pinnacles (photos in Figure 19); green = “*Caulerpa*-meadows” down the slopes of the same pinnacles. See Figure 30, for full legend.

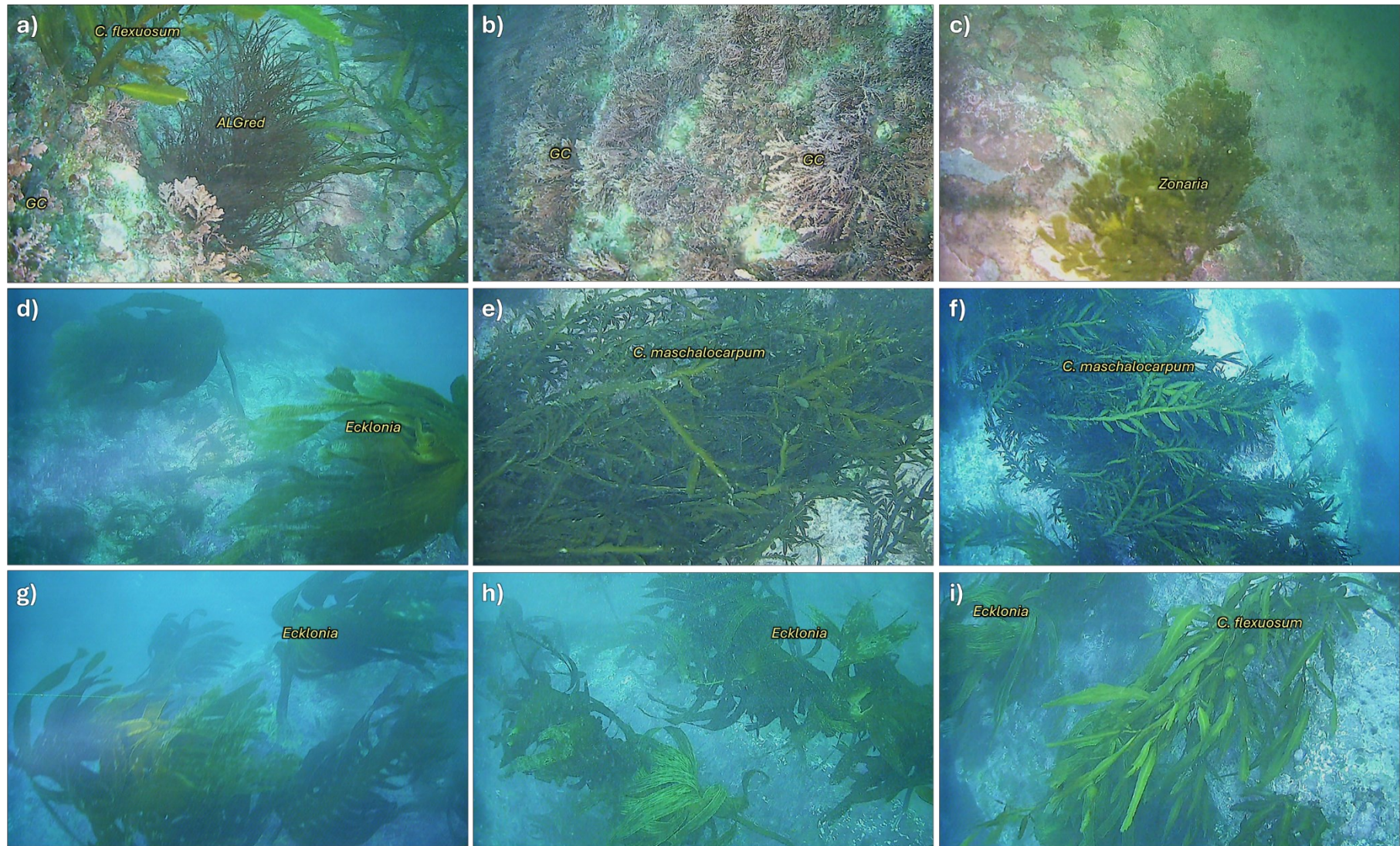


Figure 19. Examples of Mixed kelp assemblage on the tops of rock pinnacles in depths ≤ 15 m (species dependent) and characteristic subcanopy species (a-c).

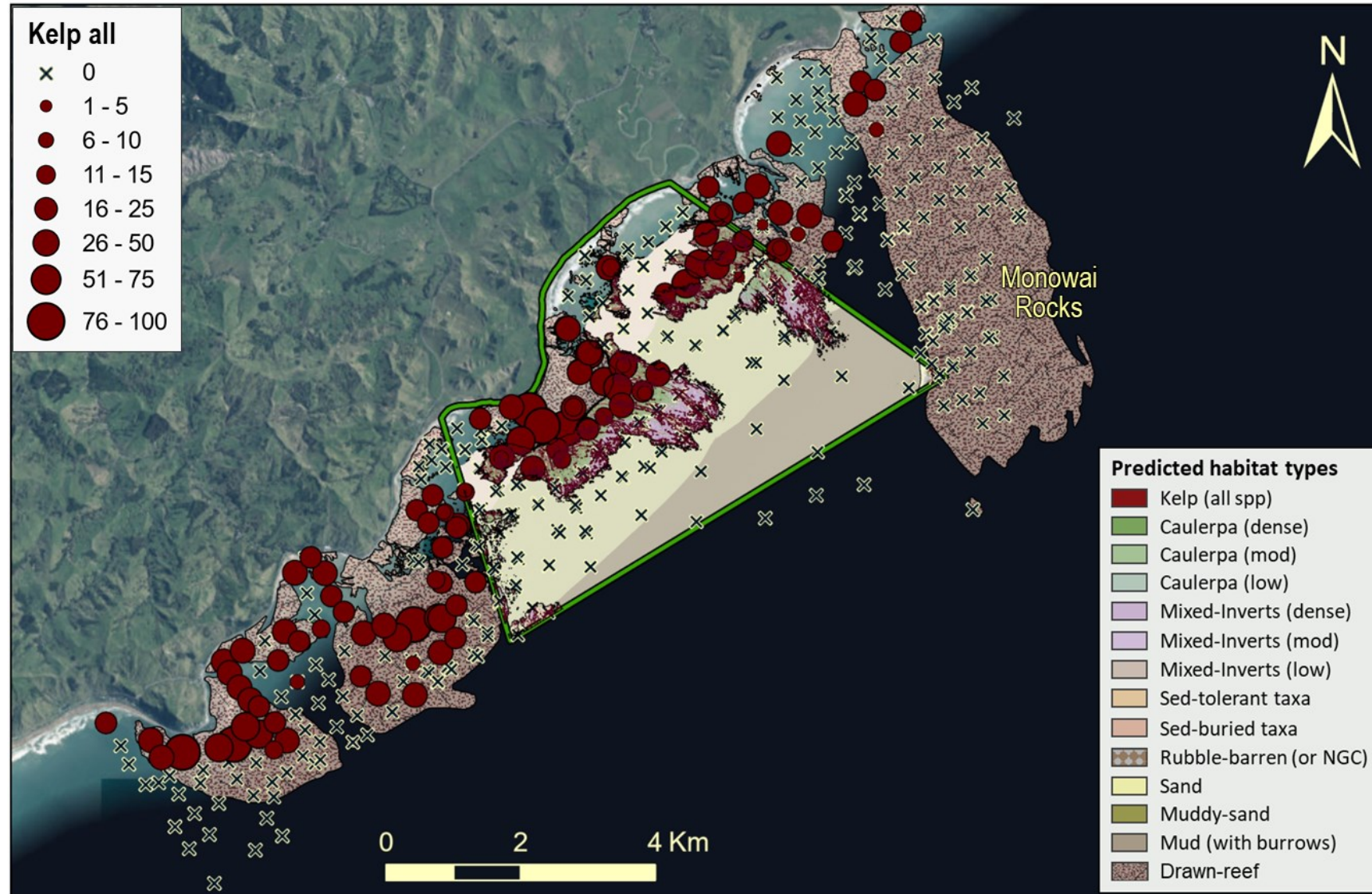


Figure 20. Distribution of observed kelp (% cover, from 2003 & 2024 video surveys) across the survey area. Transect-level video observations (circles) overlaid on the predicted habitat and community types (within MBES-zone) and drawn-reefs (outside MBES-zone); green boundary = TToR-MR.

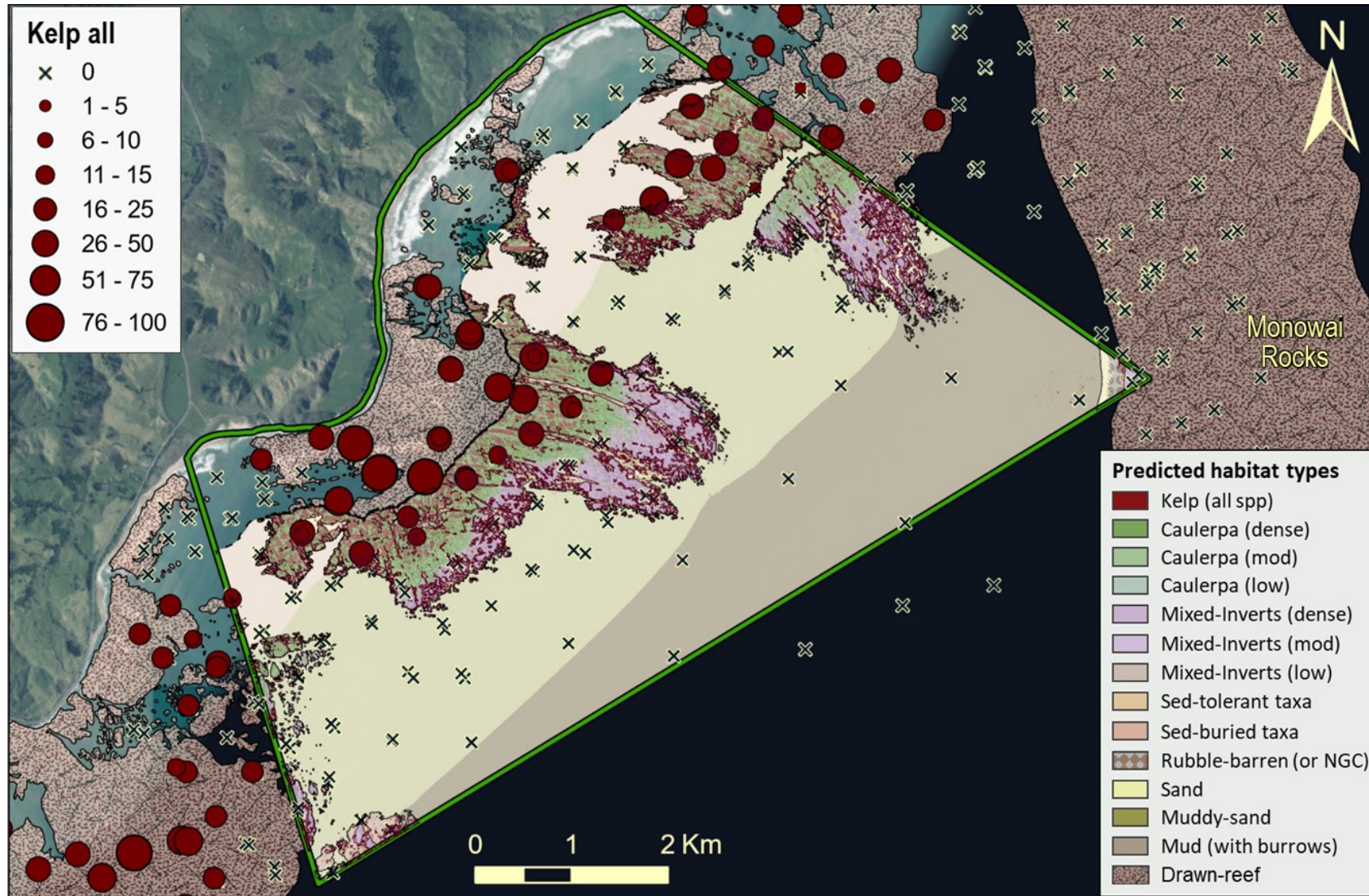


Figure 21. Distribution of observed mixed-kelp (% cover, from 2003 & 2024 video surveys) inside and adjacent to the TToR-MR. Transect-level video observations (circles) overlaid on the predicted habitat and community types (within the MBES-zone) and the drawn-reefs (outside of the MBES-zone); green boundary = TToR-MR.

3.4.2 *Caulerpa meadows (>Kelp zone and ≤ 20 m)*

On the steep flanks of the very same pinnacles (with Kelp at the tops) were *Caulerpa articulata* meadows -often in high densities of 50-85% cover (e.g., Figure 23a-f; Figure 24). '*Caulerpa* meadows' were located directly below the kelp zone and extended down to ~20 m (Figure 24, Figure 30, Figure 31 and Figure 32), although some sparse amounts of *Caulerpa* were found in deeper water often intermingled with the mixed invertebrates – indicating that the boundary between these two zone is transitional. Depth profiles across this mid-depth zone, identified the same series of pinnacle and rolling reefs, with each pinnacle raising up ~2 to 8 m high, traversing a new pinnacle every 30-50 m distance alongshore (e.g., Figure 22). In this depth-zone, "*Caulerpa*-meadows" occurred on most rocky slopes, and, in depths beyond Kelp distributions, *Caulerpa* also covered the tops of these deeper pinnacles (< 20 m depth) (e.g., Figure 23a-i).

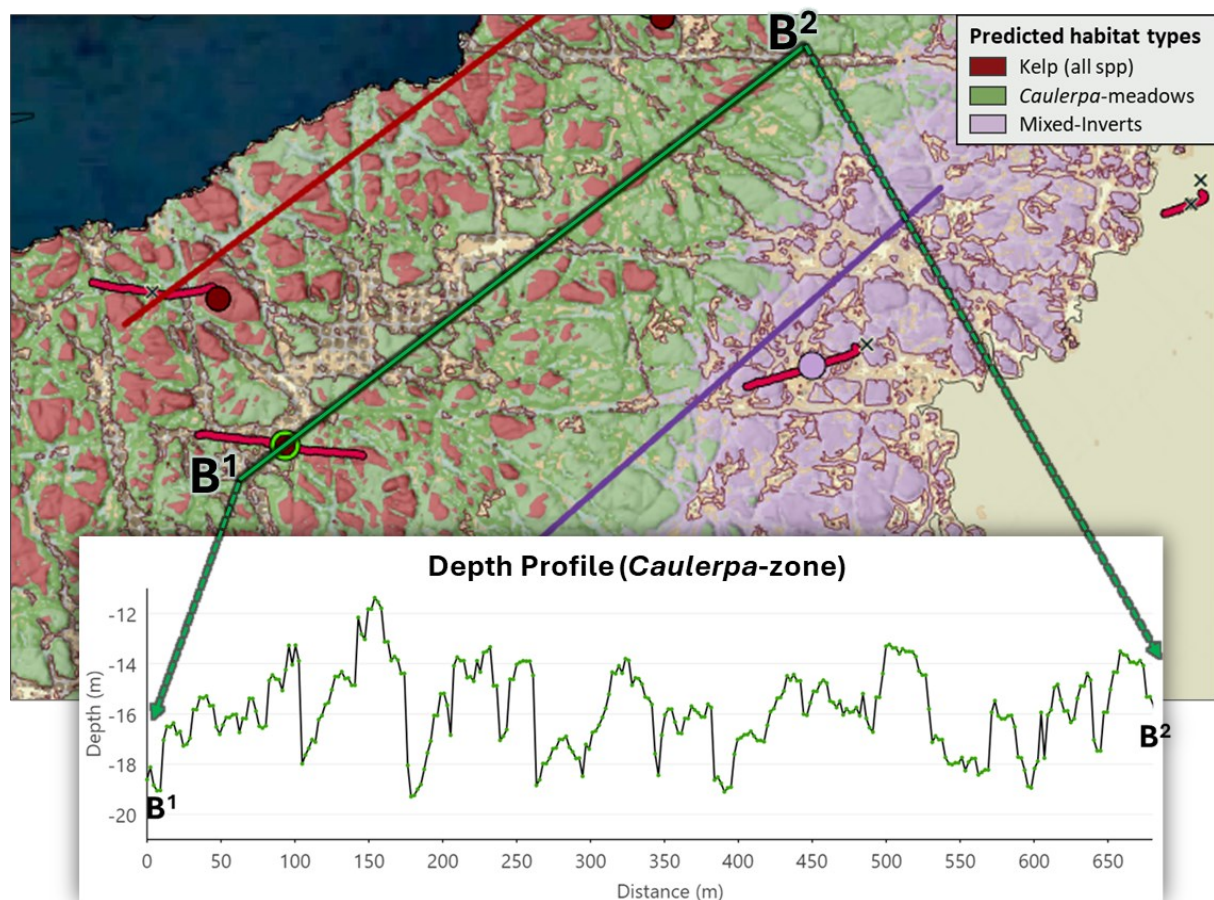


Figure 22. Bathymetry (depth) profiles depicting the pinnacle/rolling reef configuration (~2-8 m high) across the mid-reef (RR-01). "*Caulerpa*-meadows" occurred across the slopes and 'tops of deeper pinnacles' (photos in Figure 23). B1-B2 denote the start and end of the alongshore depth profile. See Figure 30, for full legend.

C. articulata also occurred in a wide range of densities and an assortment of rock features. For example, the densest meadows occurred on the higher sections of steep and rolling reefs, but *C. articulata* was also found, albeit in lower or sparse densities, on flat and low-lying reef reef-edges that were either partially, or sometimes fully, buried by sand (e.g., Site 126 in 2024, see Figure 23i), along with other sediment tolerant species (see section 0, below). *Caulerpa* are known to tolerate periods of sand burial and sediment deposition, and are therefore capable of tolerating the more sediment dynamic habitats along the interface between mobile

sediments and raised reefs. However, *C. articulata* was also found in low sparse and moderate densities on intermediate (or broad) slopes as well as lower-lying reef features down to 20 m (e.g., Figure 23g-h).

Caulerpa meadows were modelled based on their correlation with benthic terrain categories (most slope and raised-reef categories) in depth ≤ 20 m, excluded from the kelp zone (although sparse densities were occasional recorded). Higher densities meadows were conditional on higher slope angles, while moderate and low densities reflected a combination of Benthic Terrain classifications, slope and slope-std (Figure 30 and Figure 31, with summary statistic provided in Table 10). The final predicted *Caulerpa*-meadow zone comprised a 2.05 km² area within the MBES-zone of the TToR-MR (Table 8 and Figure 30, also see: Figure 31 and Figure 32).

Species found in the '*Caulerpa*-meadow zone', include:

- Non-geniculate coralline algae (NGC, commonly up to 40-75% cover),
- Encrusting sponges (≤ 5 -20% cover, mostly orange coloured, and occasional yellow ones).
- Occasional grey massive sponge, *Ecionemia alata*
- Cream coloured turf-like material on the rocks, which appears to be present at most *Caulerpa* sites – and appears to be comprised of the denuded rhizome base of *Caulerpa*.
- Occasional occurrences of encrusting white ascidians; and white tubular sponges (≤ 2 -5% cover, possibly *Leucettusa tubulosa*).

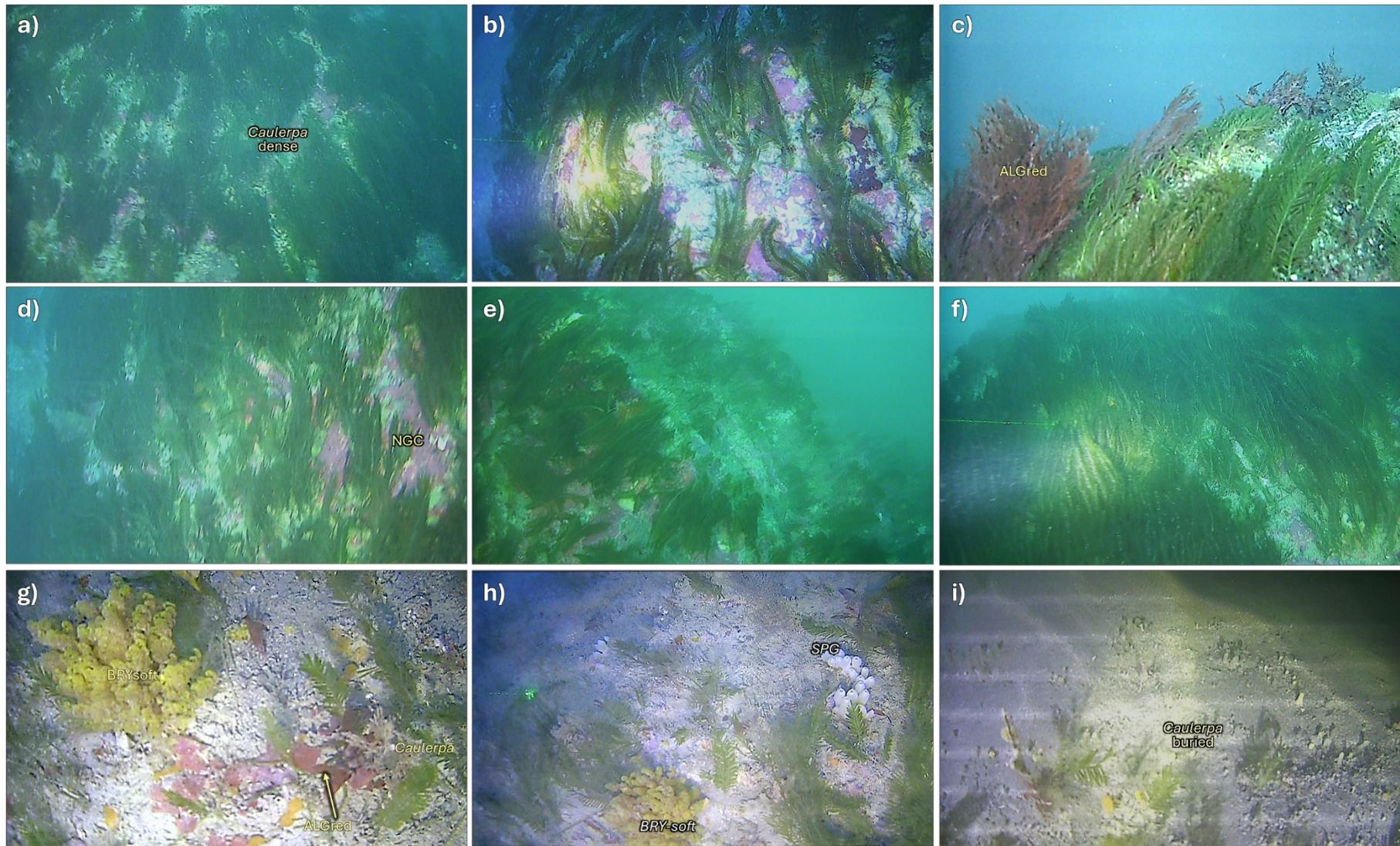


Figure 23. Examples of *Caulerpa* meadows in depths ≤ 20 m (a-f) as well as the variety of habitat *Caulerpa* can grow in (g-i).

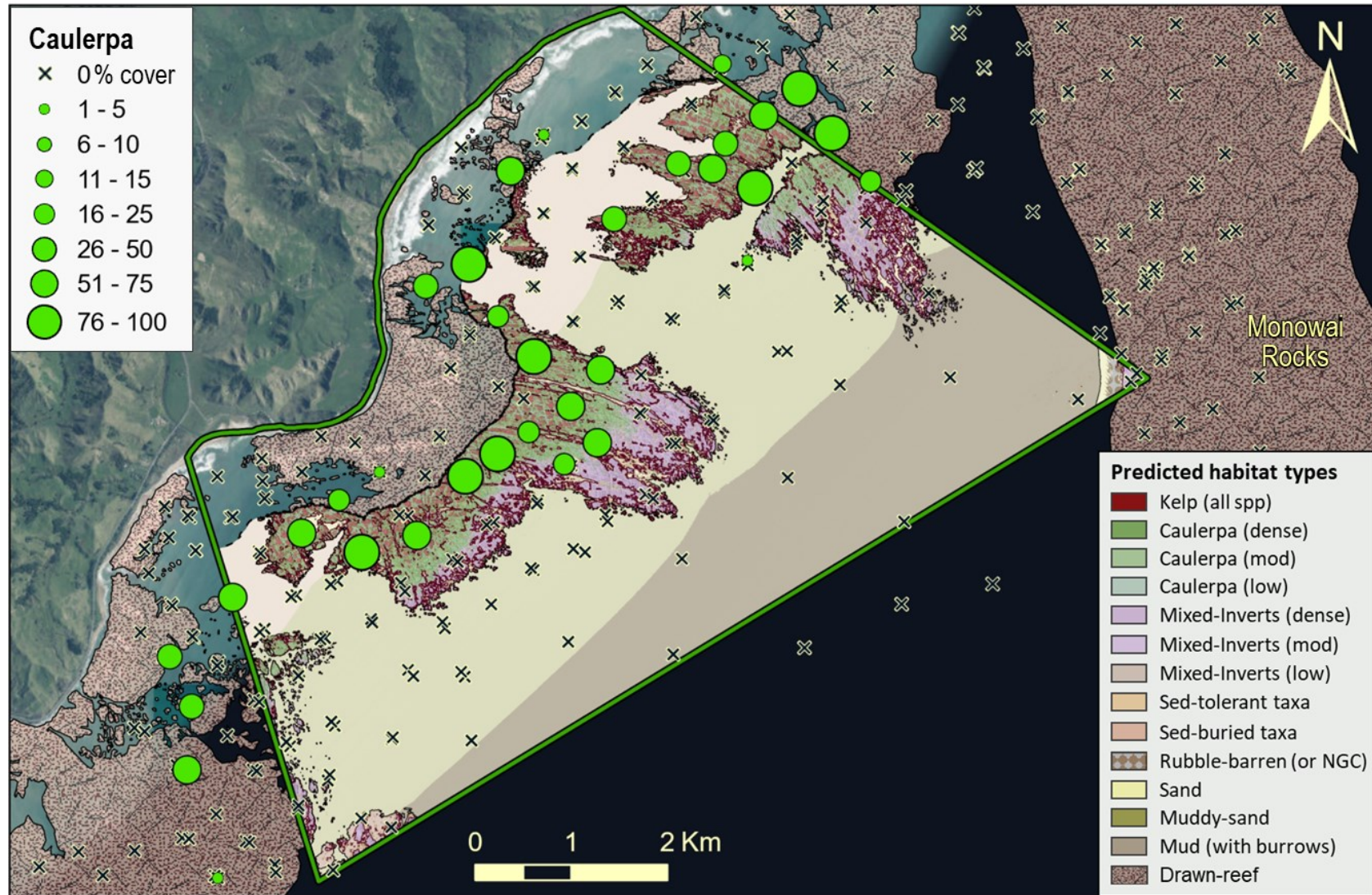


Figure 24. Distribution of observed *Caulerpa articulata* (% cover, from 2003 & 2024 video surveys) inside and adjacent to the TToR-MR. Transect-level video observations (circles), overlaid on the predicted habitat and community types (within the MBES-zone) and the drawn-reefs (outside of the MBES-zone); green boundary = TToR-MR.

3.4.3 Deep mixed-invertebrate assemblage (> 20 m)

In reef and patch-reefs located in depths > 20 m, *Caulerpa* became sparse, replaced by varying densities of 'mixed-invertebrates' (e.g., Figure 26 and Figure 27) comprised of various combinations of sessile sponges, bryozoans, hydroids (see example photos in Figure 26). The bathymetry of these deeper reefs was slightly lower, on average, than those closer to shore, however, the rolling reef configuration (~2-6 m high) was still present in these deeper-reef sections (e.g., Figure 25 and Figure 28, for the southern end of Rocky Reef 01 [RR-01]), but here, supported a "Mixed-invertebrate" assemblage. In this section of the reef, higher densities of mixed invertebrate species were located on the upper sections of raised reefs, especially the tops of ridge lines, while only low densities of mostly sediment-tolerant taxa were found growing on the lower sections of these reefs, which were mostly covered in a veneer of fine silty sediment (see Section 3.4.4, below).

Species found in the 'Mixed-invertebrate zone', include:

- 1) Erect sponges (particularly, the bright orange or yellow shrubby tree-like sponge, *Pararhaphoxya sinclairi* (e.g., Sites 161, 191, 194), grey massive sponge, *Ecionemia alata* (e.g., Site 163); and the bowl-shaped sponges incl. the maroon coloured, *Stelletta maori* (e.g., Sites 191 and 316) and the cream-coloured *Psammocinia hawere*);
- 2) Soft bryozoans (e.g., erect, flexible and bushy colonies, mostly Catenicellidae) are a very characteristic taxa in this habitat zone, with % cover generally varying from 6-40% cover, across much of the these transects. This family of bryozoa is also known to be tolerant of sediment environments;
- 3) Turfing species, such as large bushy hydroids (e.g., Site 143) and delicate fern-like hydroids (e.g., Sites 143, 310)
- 4) Non-frame building bryozoans, such as *Menipea* sp. [e.g., Site 308] and *Margaretta barbata*¹¹ [e.g., Sites 316 and 132]);
- 5) Smaller growth forms, such as the occasional globular sponges (likely *Aaptos globosum*); and patches of white tubular sponges (possibly *Leucettusa tubulosa*).
- 6) Non-geniculate coralline algae (NGC, low % cover ≤ 5-35% cover),
- 7) Red bladed algae (≤4-8%, although rare occasions of 12-16% cover e.g., Site 191).
- 8) Crayfish (Site 194)

Bathymetry, slope-std, ruggedness, and the Benthic Terrain classifications were used to distinguish the 'mixed-invertebrate' and the 'sediment-tolerant taxa' from each other and other habitat zones (Table 11; Figure 30). Mixed invertebrates were modelled based on their correlation with deeper reefs (> 20 m) conditional on slope-std > 3.0 (compared to sediment-tolerant taxa which were correlated with lower slope-std ≤ 3) and Benthic Terrain categories representative of raised features with high ruggedness. Initial models examined ruggedness directly, but a bimodal relationship with ruggedness was not well modelled. This was due to the low data density within the MBES-zone. For example, although there were 51 deep 'mixed-invertebrate' sites that were sampled, only 9 were located within the TToR-MR in the MBES-zone, so modelling parameters were somewhat limited (but see summary statistic provided in Table 11). However, % cover of the mixed invertebrate community increased

¹¹ Note these identifications are based on drop camera observations and would need to be verified by specimen collections.

linearly with slope-std (an indicator/surrogate of reef complexity) - and was a good predictor of their spatial distribution (see: Figure 25, Figure 30, Figure 31 and Figure 32). The final predicted 'Mixed-invertebrate zone' comprised a 0.1.68 km² area within the MBES-zone of the TToR-MR (Table 8 and Figure 30, also see: Figure 31 and Figure 32).

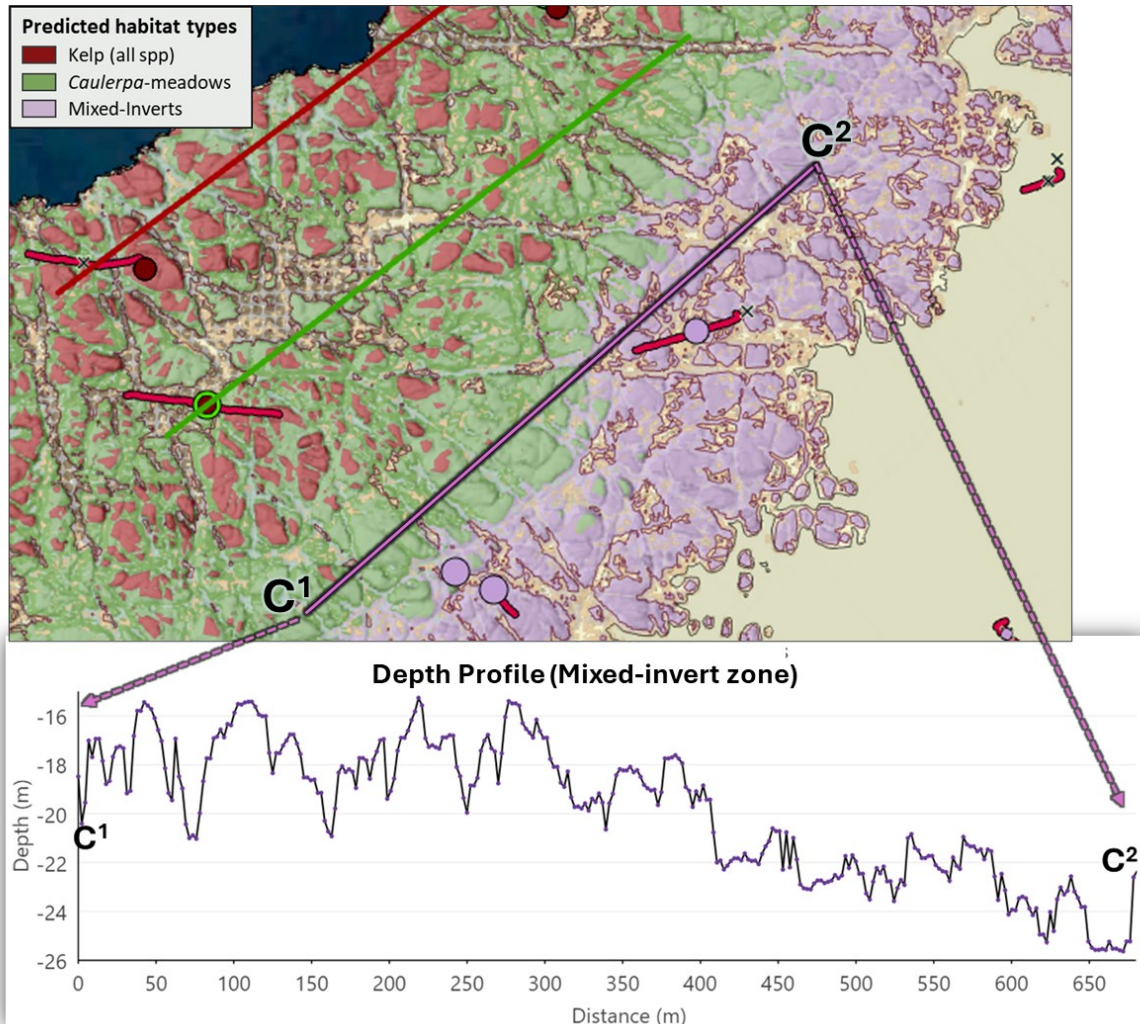


Figure 25. Bathymetry (depth) profiles depicting the pinnacle/rolling reef configuration (~1-6 m high) across the deeper-reef (RR-01). The “Mixed-invertebrates” zone was dominated by sponges, bryozoans and hydroids (see photos in Figure 26), with higher densities on the upper sections of raised reefs, than lower, sediment-veneered reef. C1-C2 denote the start and end of the depth profile.

Some differences in species distributions within this group were observed. For example, higher densities and more bryozoan species were found on deep raised reefs in the offshore southern corner of the TToR-MR (i.e., RR-09); while higher % cover of *E. alata* were found on the raised reefs in the northern offshore corner of the TToR-MR (i.e., RR-10a = Monowai Rock). However, the limited data density did not warrant any assessment of density changes. However, it would be likely that slope-std and height above the seafloor (if available in the future) would be expected to provide valuable prediction of higher densities of this community type.

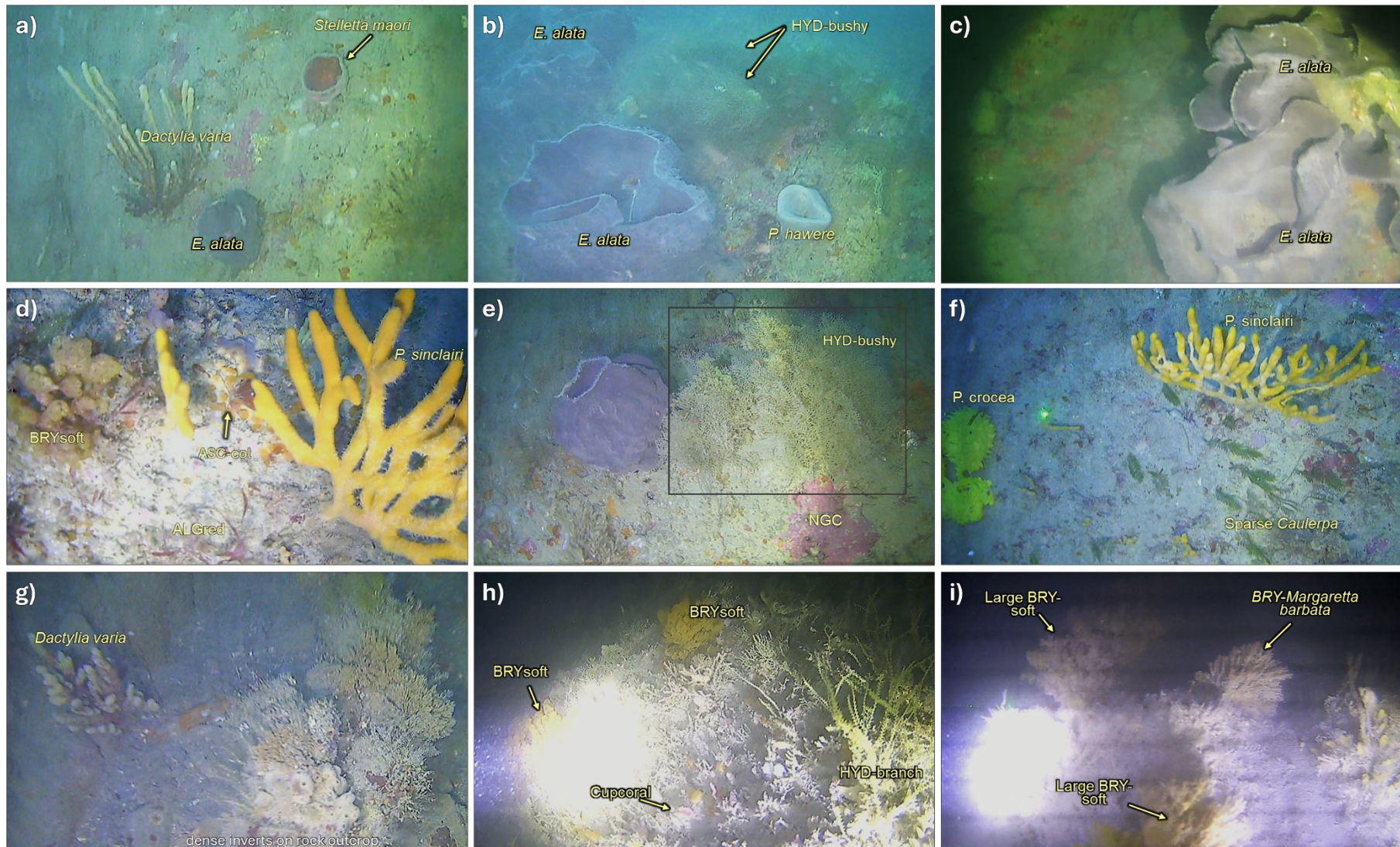


Figure 26. Examples of the 'Deep mixed-invertebrate' assemblage in depths > 20 m.

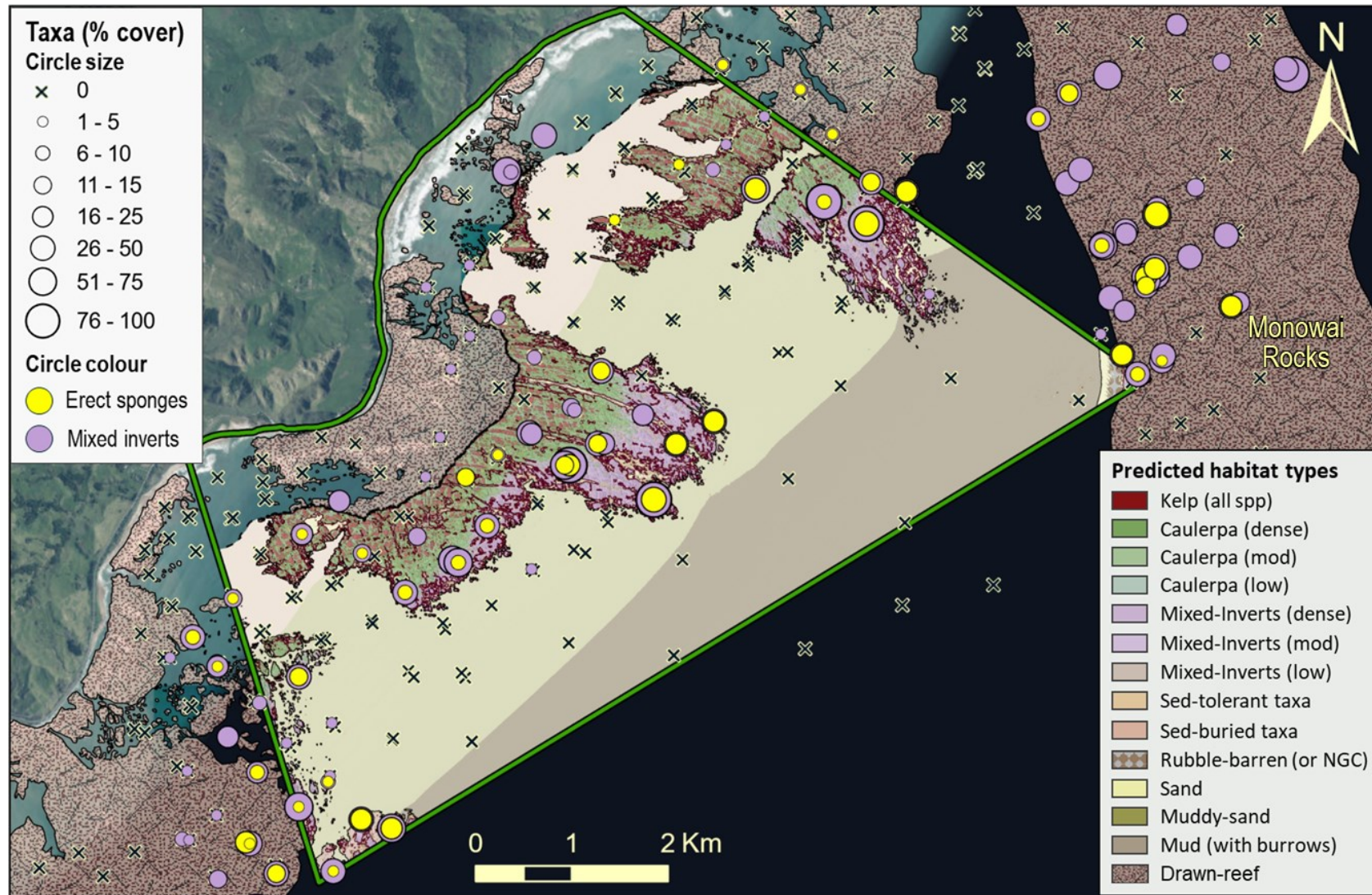


Figure 27. Distribution of observed mixed invertebrates, including erect sponges (% cover, from 2003 & 2024 video surveys) inside and adjacent to the TToR-MR. Transect-level video observations (circles), overlaid on the predicted habitat and community types (within the MBES-zone) and the drawn-reefs (outside of the MBES-zone); green boundary = TToR-MR.

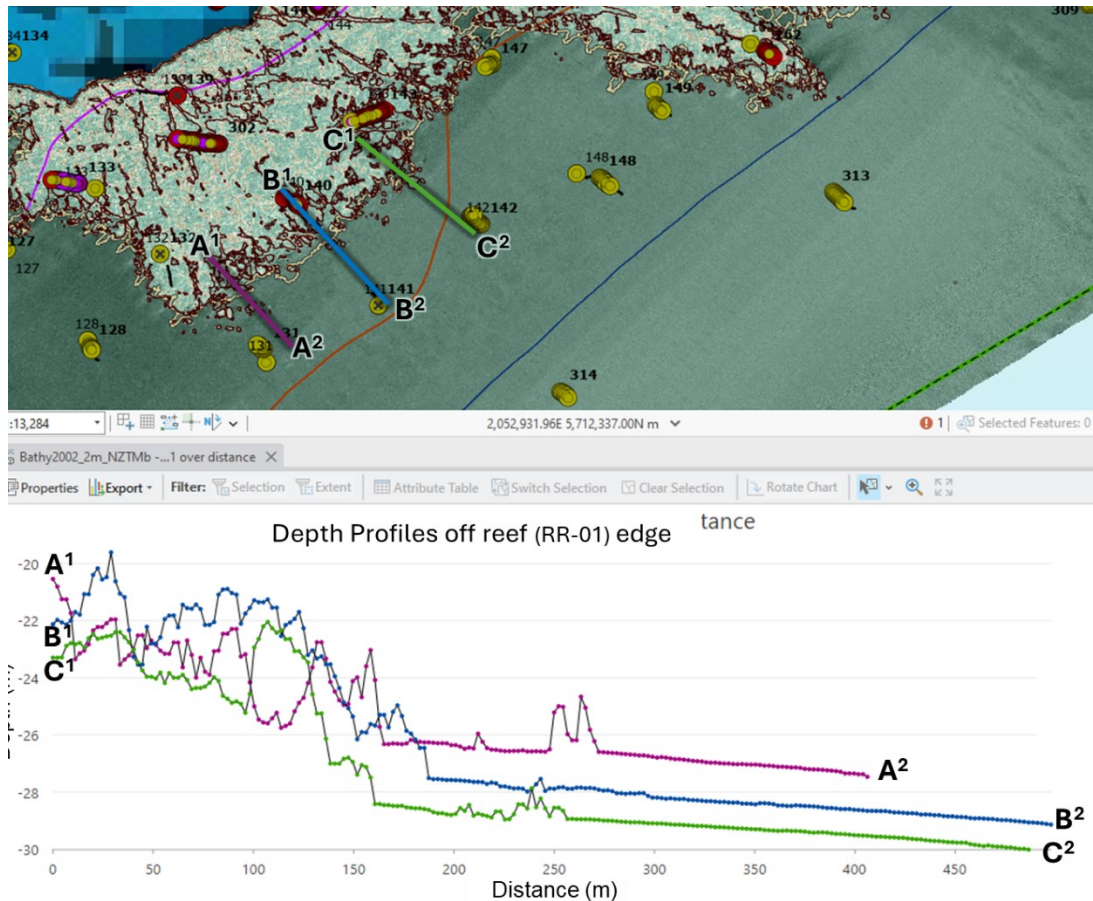


Figure 28. Three bathymetry profiles depicting the pinnacle/rolling reef configuration (~2-6 m high) across the deeper reef (RR-01). The deeper reef supports “mixed-invertebrates”, while the adjacent gently sloping muddy-sand zone, was barren of visible epifauna.

For example, densities of this assemblage were higher on raised reefs in depths > 20 m, with larger and more diverse assemblages present on the tops of reef ridges etc. For example, raised ridge features in deep areas comprised 100% cover dominated by large *E. alata* sponges covering up to 40% of the ridge, along with soft-corals (commonly up to 40% cover), bush hydroids (up to 18-40% cover) and a variety of other mixed sessile species. Here, the height of the reef above the sediment veneer seemed to be a factor in increased densities and diversity-likely due to smothering by sediment in lower sections of these sediment-veneered reefs. To capture this variation in density, in the models, height above seafloor base would be expected to be a useful predictor. This layer wasn't available during this project, but we would recommend this be included in any further modelling of this community type.

3.4.4 Sediment tolerant taxa on low-lying reefs:

Many deep reef, particularly those with low-relief, were draped in a veneer of fine sediment. In these locations, invertebrate %cover was generally sparse or low, and characterised by a suite of sediment tolerant species.

“Sediment-tolerant taxa’ included:

In shallow depths < 20 m:

- 1) Sparse densities of *Caulerpa articulata* were often present both around reef-edges, and on partially buried reefs within the patch-reef zone – located at the southern edge of

the TToR-MR. These shallower depths also supported the characteristic presence of low numbers of the bright yellow (loaf-shaped) sponges, *Polymastia crocea* (i.e., 1-3 indiv.).

In depths \geq 20 m:

- 2) Tall erect tree-like sponges (\leq 1 m tall), such as *Callyspongia ramosa* (a tall yellow sponge with white-tips, e.g., Sites 162, 163, 175, 191), *Dactylia varia* (erect purple/tan coloured sponge, e.g., Sites 143, 162, 316), *Iophon minor* (tall yellow strappy sponge, e.g., Site 310),
- 3) The common occurrence of bright yellow loaf-shaped sponges, *Polymastia crocea* (e.g., Sites 140, 143, 150, 161, 162, 163, 191, 194; photo in Figure 26f) and the occasional *Ciocalypta penicillus* found partially or mostly buried under sediment (e.g., Site 126).
- 4) Soft bryozoans (e.g., erect, flexible and bushy colonies, mostly Catenicellidae), generally low % cover \leq 5-12% cover (e.g., photo in Figure 26h). This family of bryozoa is also known to be tolerant of sediment environments;
- 5) Solitary cup corals, including mostly *M. rubrum* (e.g., photo in Figure 26h) and rare occurrences of the wider corallum (or wider cup shape) *F. knoxi* (e.g., Sites 162, 163, 305).
- 6) Along with occasional occurrences the globular sponges (likely *Aaptos globosum*) (e.g., Site 163).

This community was often associated with the edges and gulleys of large reefs and in and around patch-reef zones. In some situations, these taxa were seen buried in sediment with the reef they were attached to fully buried beneath a thick layer of sediment. Of the 43 sites where this community was recorded, 17 sites had associated MBES data (see summary statistic provided in Table 12). Sediment-tolerant taxa were modelled using their correlation with hard-bottom habitats, conditional on slope-std being \geq 1 and \leq 3.0 (compared to Mixed-invertebrates which were correlated with lower Slope-std $>$ 3) and ruggedness \leq 2.1. Here backscatter was also examined, to supervise/guide model parameters, but wasn't included directly due to the high levels of noise associated with the backscatter layer. However, visually this layer was extremely informative when used with the other MBES layers. Areas with high reflectivity but little to no raised features were distinct features of this habitat zone. However, low slope-std (1-3) and low ruggedness (\leq 2.1) together were a good surrogate of this habitat zone, and provided a useful means to delineating this habitat (Figure 30, e.g., Figure 31). The final predicted 'Sediment-tolerant taxa zone' comprised a 0.76 km² area (here combining the sed-tolerant and the sed-buried zones) within the MBES-zone of the TToR-MR (Table 8 and Figure 30, also see: Figure 31 and Figure 32).

3.4.5 Rubble and sand-gap habitats

Rubble habitats were generally free of sediment veneer, but had little to no biotic cover. The exception was sparse cover of NG coralline algae (characteristically \leq 10-15% cover) and occasional occurrence of low % cover of encrusting sponges (characteristically \leq 5% cover). Rubble-habitat was modelled using its correlation with low-lying habitats (the zone outside raised features, but inside hard habitats), conditional on ruggedness $>$ 2.1 (Figure 29, also see e.g., Figure 32 and Table 13). Conversely, Sediment-gaps (soft-sediment within the reef matrix) were modelled as ruggedness $<$ 2.1 and slope-std $<$ 1, guided by examining the low reflectivity backscatter areas ($>$ 42) within the reef. Predicted 'Rubble habitat' and 'sand-gaps' comprised an area of 0.30 and 0.31 km², respectively - within the MBES-zone of the TToR-MR (Table 8 and Figure 30, also see: Figure 31 and Figure 32).

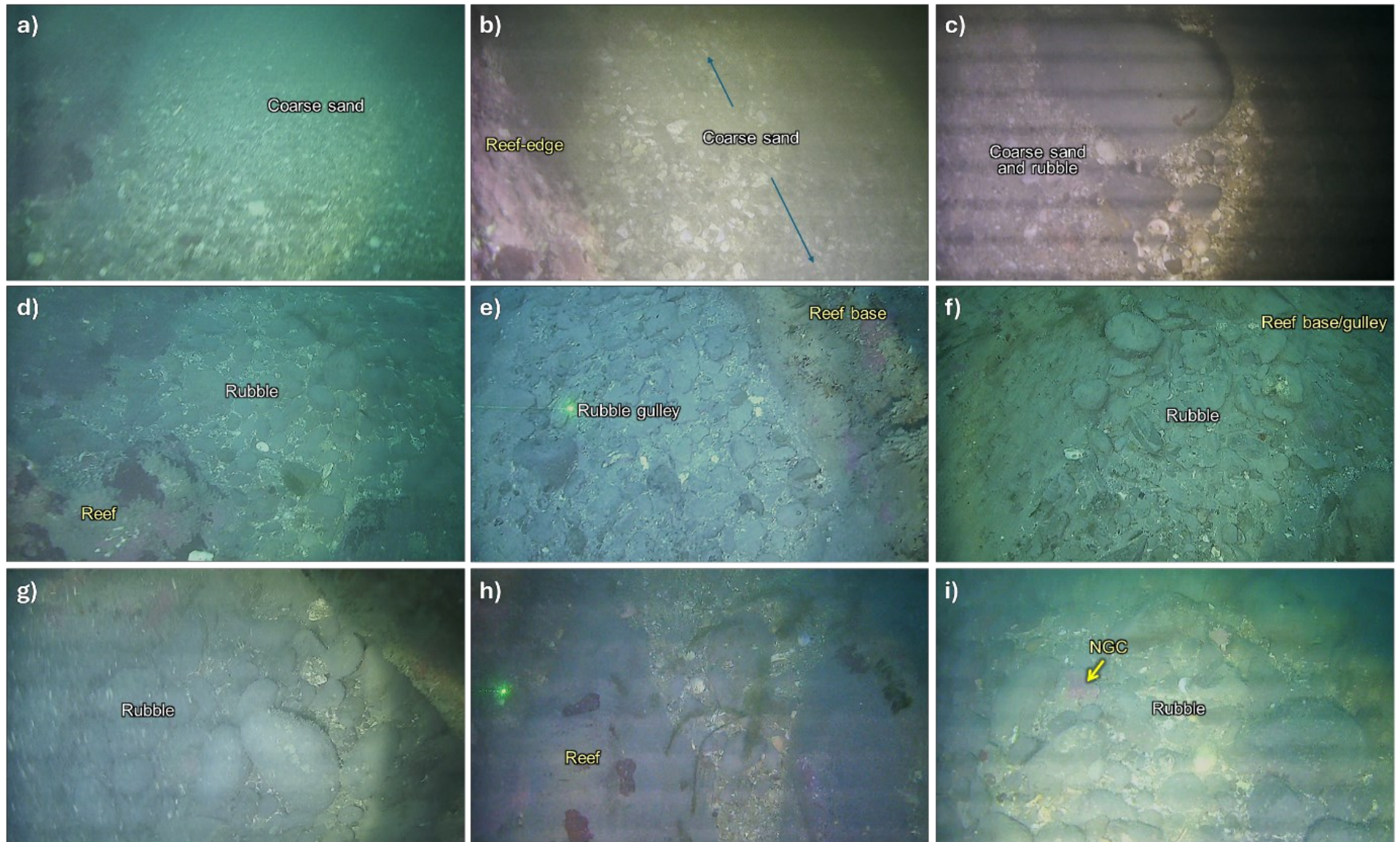


Figure 29. Examples of “Barren (or NGC)” habitats, dominated by sand gulley in shallow reef zones $\sim <20$ m (a-c); and rubble habitats in mid to offshore zones (d-i).

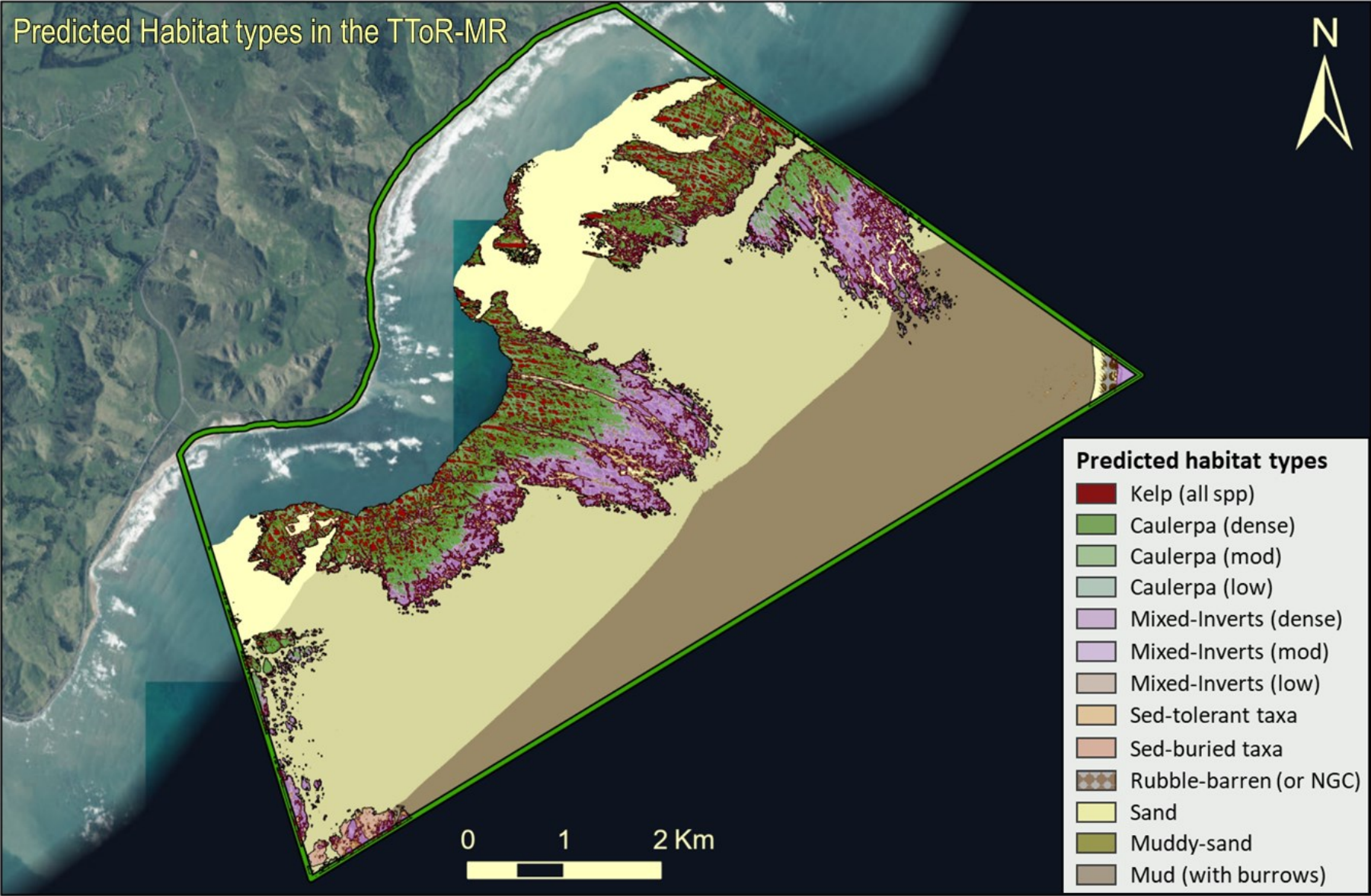


Figure 30. Predicted habitat and community types within the MBES-zone of the TToR-MR. Green boundary = TToR-MR.

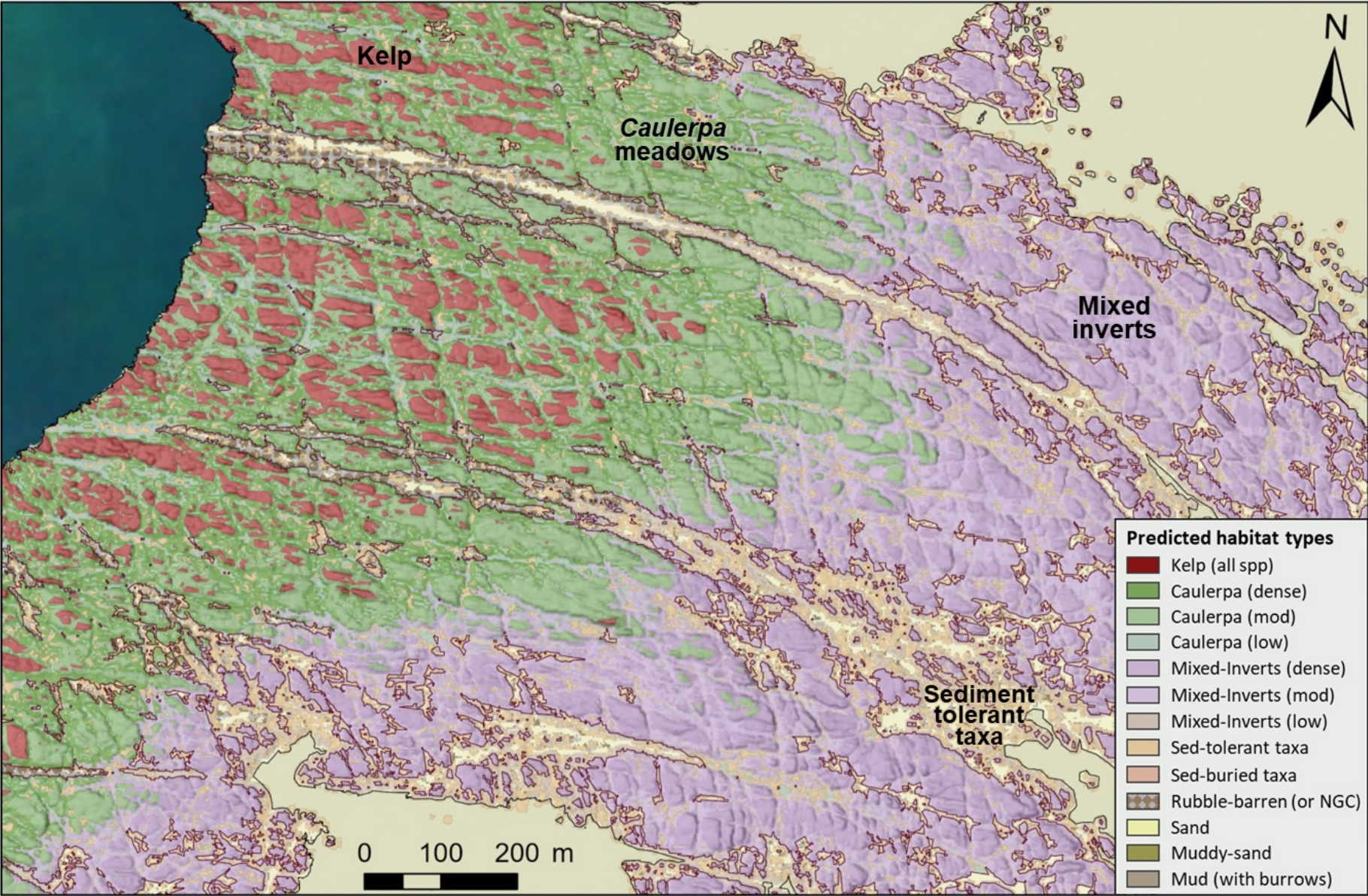


Figure 31. Zoomed-in example of the predicted habitat and community types across the central reef (RR-01) within the MBES-zone of the TToR-MR.

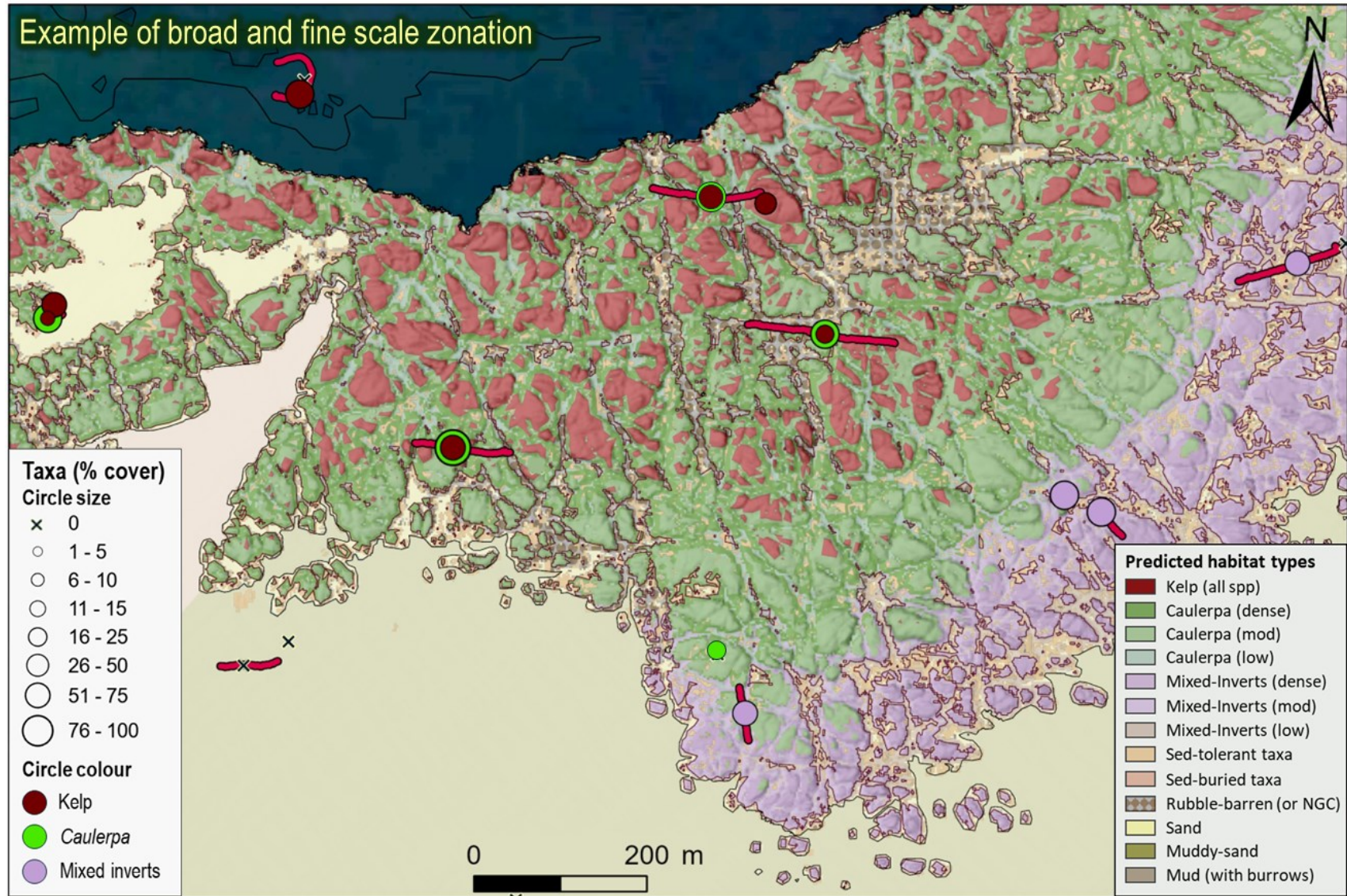


Figure 32. Example of broad scale (distance offshore) and fine-scale (within a transect) community zonation, across a section of reef (south-side of RR-01), in the MBES-zone of the TToR-MR. Transect-level video observations (circles) overlaid on the predicted habitat and community types; Red lines depict the track-line of each video-site.

Table 8. Benthic habitat types - as mapped in Figure 30. Mod= moderate density; low = low density. Area was calculated in ArcGIS for each habitat type polygon.

Benthic habitat types (as modelled in Figure 30)	Area km ²
Kelp (mixed spp)	0.6193
Caulerpa meadows (dense)	0.8319
Caulerpa meadows (mod)	0.8619
Caulerpa meadows (low)	0.3591
Mixed invertebrates (dense)	0.5650
Mixed invertebrates (mod)	0.7909
Mixed invertebrates (low)	0.3219
Sediment tolerant taxa	0.6808
Sediment buried taxa	0.0815
Rubble (cobble, pebbles and gravel)	0.2955
Soft-sediment (gaps within the reef)	0.3108
Sand (depths < 17 m)	1.7682
Muddy-sand (depth 17-35)	7.2255
Deep mud (depth > 35 m)	5.4135

3.4.6 Assessment of previous survey maps

A comparison with ASR's 2003 habitat maps, identified that the semi-formal gridded sampling pattern employed in 2003, provided a very good general depiction of where the main reefs were, and the types of habitats that were present at broad-spatial scales, both within and outside of the TToR-MR. However, compared to the accurate fine-scale resolution of the MBES data and the MBES-derived habitat maps, the 2003 historic maps were very coarse with their boundaries inaccurate at fine spatial-scales. Comparison with Pinkerton et al. (2009) found the same mismatch of reef boundary (as would be expected without having MBES maps), but also had less accordance than ASR at the broad-scale. Neither study identified or mapped *Caulerpa*, yet this is one of the most prominent biological habitats within the marine reserve.

It is unclear from the 2003 ASR drop camera imagery whether *Caulerpa* is present or not. This is mostly due to the lack of lighting. High lumen underwater lighting positioned correctly so as to not burn out the seafloor or cancel out shadows – is one of the most critical aspects of underwater video surveys, and is often overlooked and under invested in. However, compared to the cost to collect, process and analyses these types of data the cost of good lighting is much less, but can be the difference between a great study and one that can't distinguish much. The fact that the ASR's survey was unable to even identify whether *Caulerpa* was present is a good example of this. While the lighting of the Splashcam was by no means great, it was able to adequate light up the green of the *Caulerpa* meadows (as nicely seen in Figure 23).

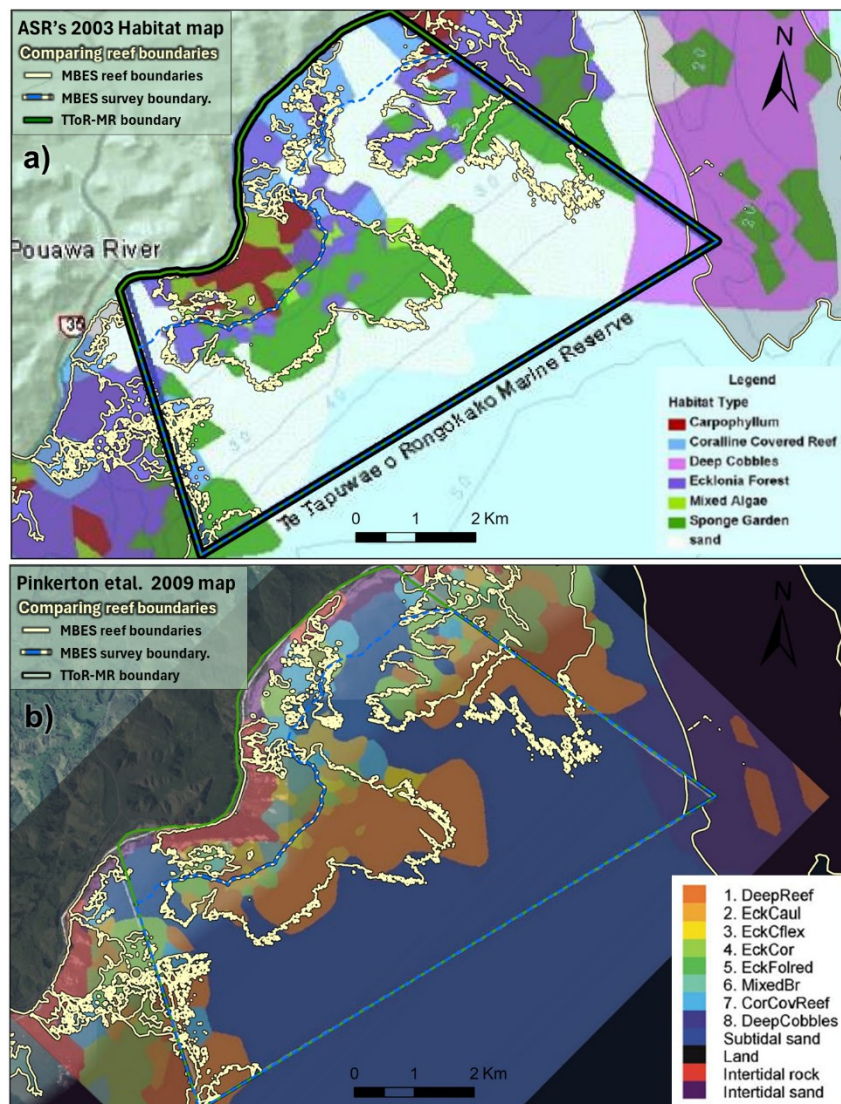


Figure 33. Reef boundaries derived from this study compared to previous survey maps. a) ASR's 2003 unpublished habitat map; and b) Pinkerton et al.'s 2009 map.

Neither of the habitat maps produced by these two previous studies, described or mapped the occurrence of several habitats at the one site. The present study identified that different community types occurred at the same sites, on different aspects of the same pinnacle. For example, the shallow tops of tall pinnacles composed kelp, while dense *Caulerpa* meadows grew across the rocky slopes of the same pinnacles. Similarly, further offshore mixed invertebrates were characteristic on deeper sections of the reef, while *Caulerpa* grew on shallower sections of the same reefs where depth zones overlapped on the same rocky features; conversely sediment tolerant taxa were present where ever there was low-lying reef with a veneer of sediment or semi-buried in sediment, which were often found at the base of these pinnacle or along the edges of the reef. Consequently, a single video transect that traversed the reef-sand interface, and up, over and down the ≤ 12 m high pinnacles¹², could include a range of habitat types within a single site. This fine-scale vertical zonation was not captured or described in the previous projects. Rather their maps were limited to changes in habitat zones alongshore and/or offshore, but not vertically within the same location. In this study, the integrated habitat map predicted the alongshore and offshore zonal changes between these habitat types well (Figure 30) it also accurately predicted the fine-scale vertical

¹² Various combinations of this were very common in sites across the entire TToR-MR.

zonation between these habitats – i.e., this combination of zonal patterns– where each community type is present where their environmental and depth conditions are met (e.g., Figure 31 and Figure 32). ASR was unable to capture this in part due to the inability to identify the presence of *Caulerpa*. Yet, this makes a major difference when calculating the areal amount of each community type within the TToR-MR, and relative to similar habitats along the adjacent coastline. The ability to use the MBES data to capture this fine-scale habitat and relief complexity relative to key community groups (see Figure 30 to Figure 32) is a great achievement, even with the many data issues and limitations.

3.5 Temporal changes in benthic communities

3.5.1 Observed differences

One of the main qualitative changes that seems to have occurred is a noticeable loss or reduction of *Ecklonia* at sites within the TToR-MR. *Ecklonia* was very common on reef top sites in the 2003 survey, with densities ranging from low to moderately high. Sites where *Ecklonia* would have been expected to be seen, often had very few *Ecklonia* plants, where denser beds had been present in 2003. Given that the video footage in 2003 was limited to < 2min in one drop-camera spot, compared to the 2024 survey which traversed the seafloor for 5-10 min – one would expect that the 2024 survey was much more likely to encounter *Ecklonia* beds at these sites, yet this was not the case. Given the grid like spacing of the drop-camera sites, it seems unlikely that sampling targeted kelp sites (although this is not known). As discussed above, differences might simply reflect a difference in habitat-zone (i.e., missing the kelp zone). However, this seems unlikely too as, many of these sites had other kelp species (i.e., *C. maschalocarpum* and/or *C. flexuosum*) present, with the two *Carpophyllum* kelp species seemingly unchanged between the two survey times. It therefore seems that a reduction in *Ecklonia* across the marine reserve might have occurred, and may be worth examining further. There did not appear to be any obvious change to the benthos in areas where *Ecklonia* generally occurs, however the lack of adequate lighting in the 2003 survey means that understorey species were not able to be determined. Changes in other taxa were not possible to determine¹³.

As mentioned above, rippled muddy-sand areas offshore do seem to have changed, with more silt covering them in 2024 than in 2003. This would be expected give the high runoff due to intensive and extensive impacts from the cyclone Gabrielle and subsequent storms. However, it is also unclear how seasonally (and inter-seasonally) changeable these sediment bedforms are. Given that the sediment processes are affecting many benthic habitats within the TToR-MR, understanding the intensity and dynamics of these processes will be important in predicting the impacts they may have on these communities through time, and the relative role terrestrial input may have on exacerbating these effects.

4 Acknowledgements

We would like to thank the skipper of the vessel, Jaime Quirk, and Zachary Penman and Kauri Waitoa for their help during the 2024 field survey. We also thank LINZ for collecting and sharing the multibeam bathymetry and backscatter data, and Brad Cooper for his assistance in providing those data.

¹³ Due to differences in between-year video quality.

5 References

- Anderson, T.J. (2022). Review of Pelorus Sounds multibeam seafloor mapping (HS66): The next steps to identify and map important sites of marine biodiversity (2022). *Marine Bioservices Client Report No. MBS2201*. Prepared for Marlborough District Council, August 2022. 122p. [Download PDF](#)
- Anderson, T.J., Cochrane, G.R., Roberts, D.A., Chezar, H., and Hatcher, G., (2008). A rapid method to characterize seabed habitats and associated macro-organisms, *In* Todd, B.J., and Greene, H.G., eds., *Mapping the Seafloor for Habitat Characterization*: Geological Association of Canada, Special Paper 47: 71-79.
- ASR. 2003. Gisborne marine survey: *Unpublished maps and compact discs (including remote video footage)* held by Department of Conservation, Bay of Plenty East Coast Conservancy. 9 p.
- Booth, J.D. (2003). Research sampling design for rock lobsters in Te Tapuwae o Rongokako Marine Reserve. DOC Science Internal Series 128. 25pp.
- Freeman, D. J. 2001. Te Tapuwae o Rongokako Marine Reserve: Baseline survey report. East Coast Hawke's Bay Conservancy Technical Support Series 10, Department of Conservation, Gisborne, New Zealand.
- Freeman, D.J. & MacDiarmid, A.B. (2009) Healthier lobsters in a marine reserve: effects of fishing on disease incidence in the spiny lobster, *Jasus edwardsii*. *Marine and Freshwater Research* **60**: 140–145.
- Freeman DJ (2005) Reef fish monitoring: Te Tapuwae o Rongokako Marine Reserve. Unpublished report held by East Coast/Hawke's Bay Conservancy, Department of Conservation, Gisborne, New Zealand. 26 p.
- Freeman DJ, Duffy CAJ (2003) Te Angiangi Marine Reserve reef fish monitoring 1995–2003. East Coast/Hawke's Bay Conservancy Technical Support Series No. 14. East Coast/Hawke's Bay Conservancy, Department of Conservation, Gisborne, New Zealand. Shears and Babcock 2007;
- Nichol, S.L; Anderson, T.J; McArthur, M; Barrett, N; Heap, A.D; Siwabessy, P.J.W; Brooke, B; and Shipboard Party. (2009). *Southeast Tasmania Temperate Reef Survey, Post Survey Report*. Geoscience Australia Report, Record 2009/43, 73p. [Download PDF](#)
- Ross PM. 2021. The coastal habitats of Tairāwhiti: A review of the scientific, local, and customary knowledge *Environmental Research Institute Report No. 152*. Client report prepared for Gisborne District Council. Environmental Research Institute, The University of Waikato, Hamilton. 81pp.
- Walbridge, S.; Slocum, N.; Pobuda, M. and Wright, D.J. (2018) Benthic Terrain Modeler (BTM) 3.0, tools for understanding and classifying the benthic environment. [Software]. Redlands, CA, Esri. [Full details and description :Geosciences 8: 94, 24pp.
- Wilson, C.; Freeman, D.; Hogan, K.; Thompson, K. 2007: Maori methods and indicators for marine protection: summary of research findings. Ngati Kere, Ngati Konohi, Ministry for the Environment and Department of Conservation, New Zealand. 59 p.
- Wright, D., Pendleton, M., Boulware, J., Walbridge, S., Gerlt, B., Eslinger, D., Sampson, D. and Huntley, E. (2012) 'ArcGIS Benthic Terrain Modeler (BTM), v. 3.0, Environmental Systems Research Institute, NOAA Coastal Services Center, Massachusetts Office of Coastal Zone Management', Available online at <http://esriurl.com/5754>.] [Preprint].

Appendix A. HS76 MBES maps

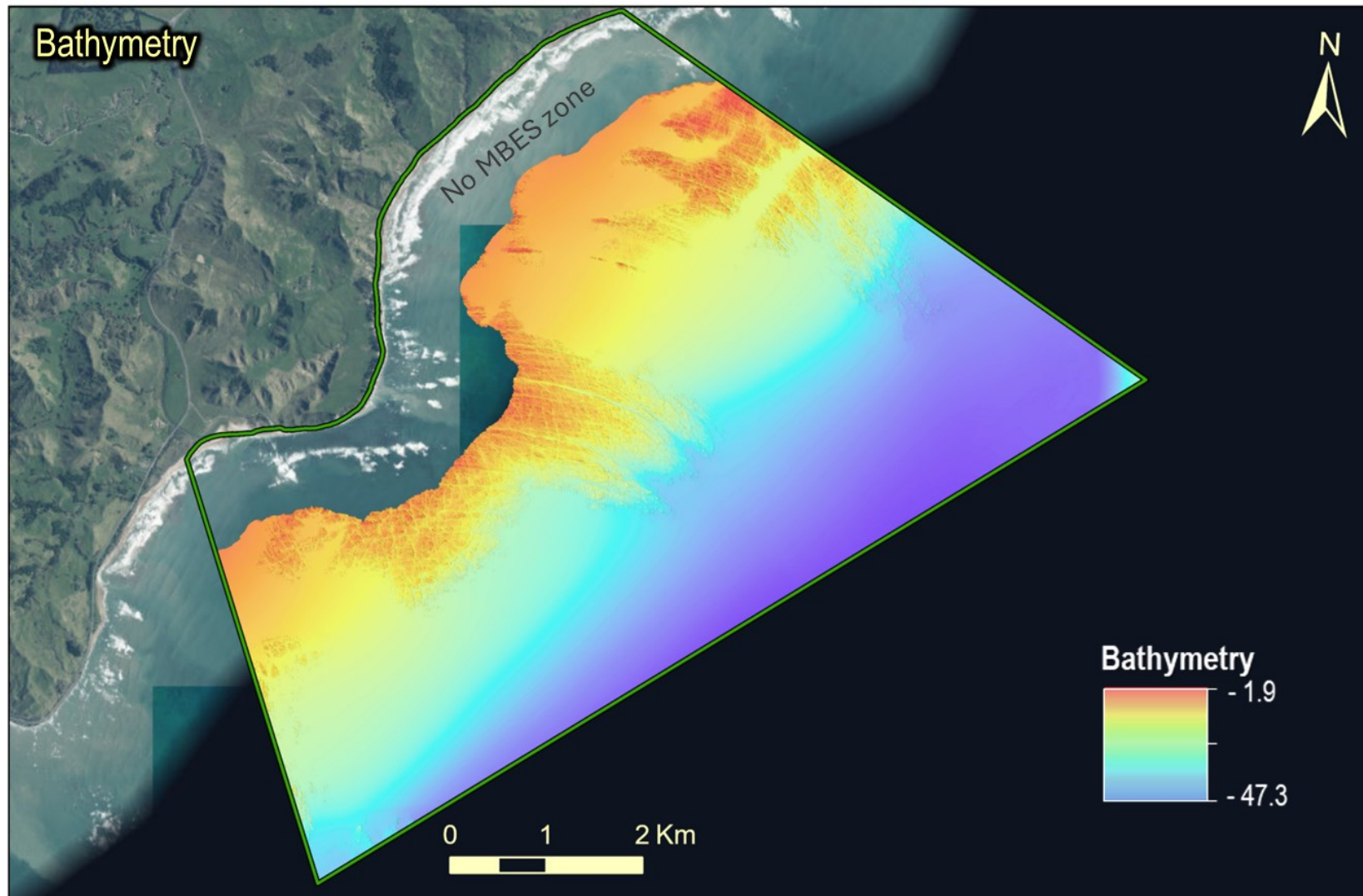


Figure 34. MBES bathymetry (2 m resolution) collected from LINZ hydrographic survey HS76, within the TToR-MR. Draped over hillshade.

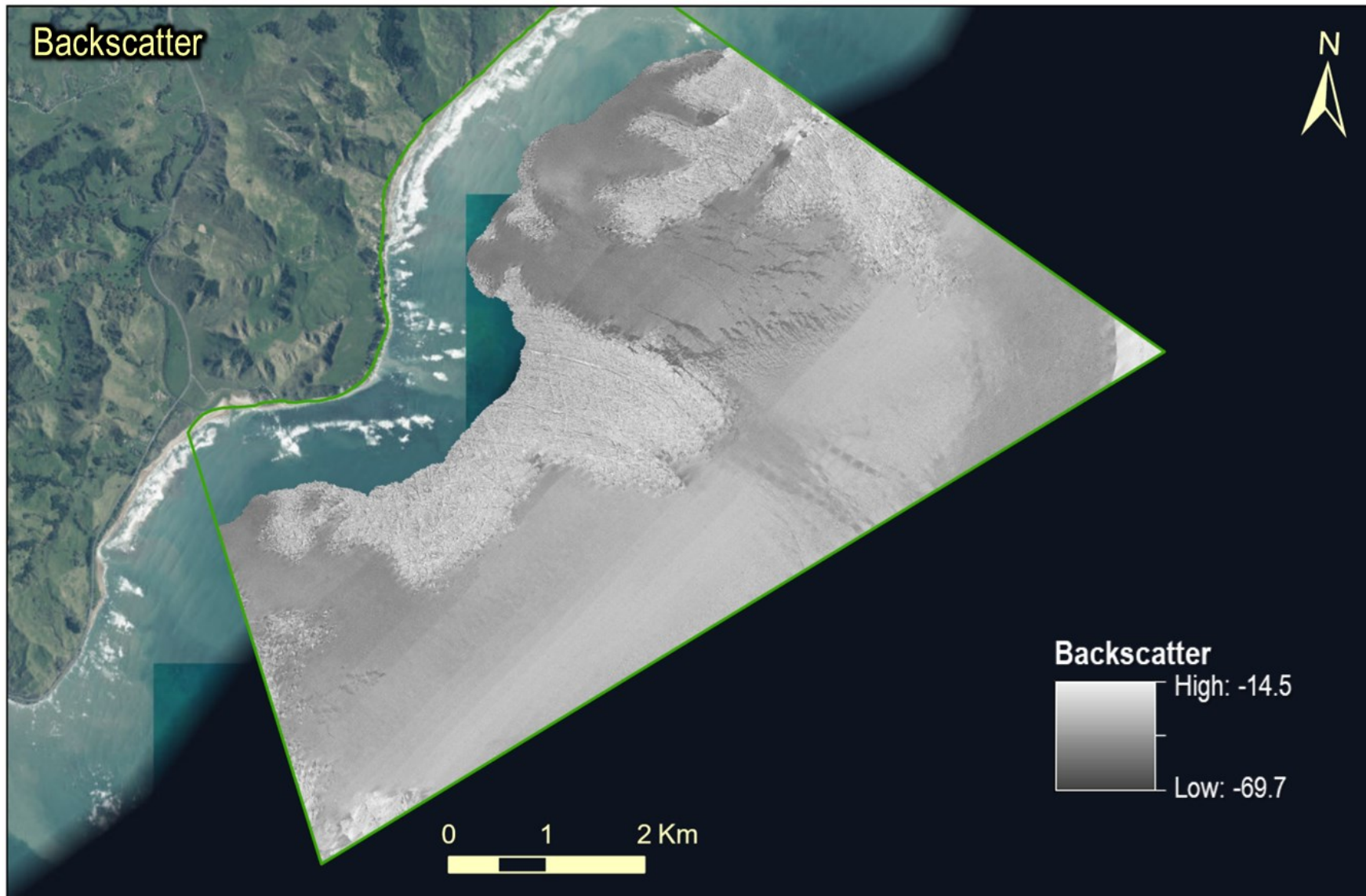


Figure 35. MBES backscatter (1 m resolution) collected from LINZ hydrographic survey HS76, within the TToR-MR. Draped over hillshade.

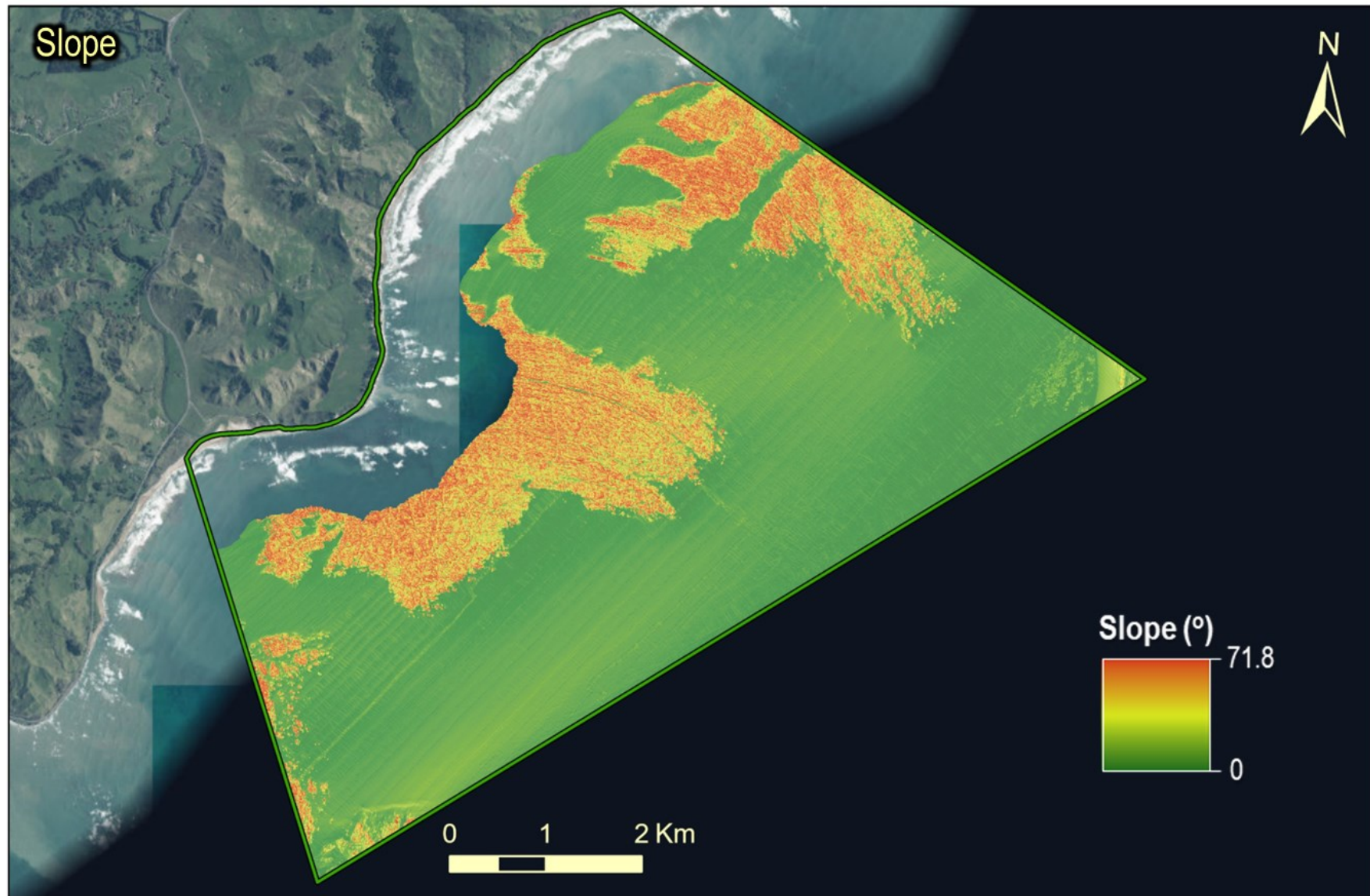


Figure 36. Slope (3 x 3 cell resolution derived from the HS76 bathymetry), within the TToR-MR. Draped over hillshade.

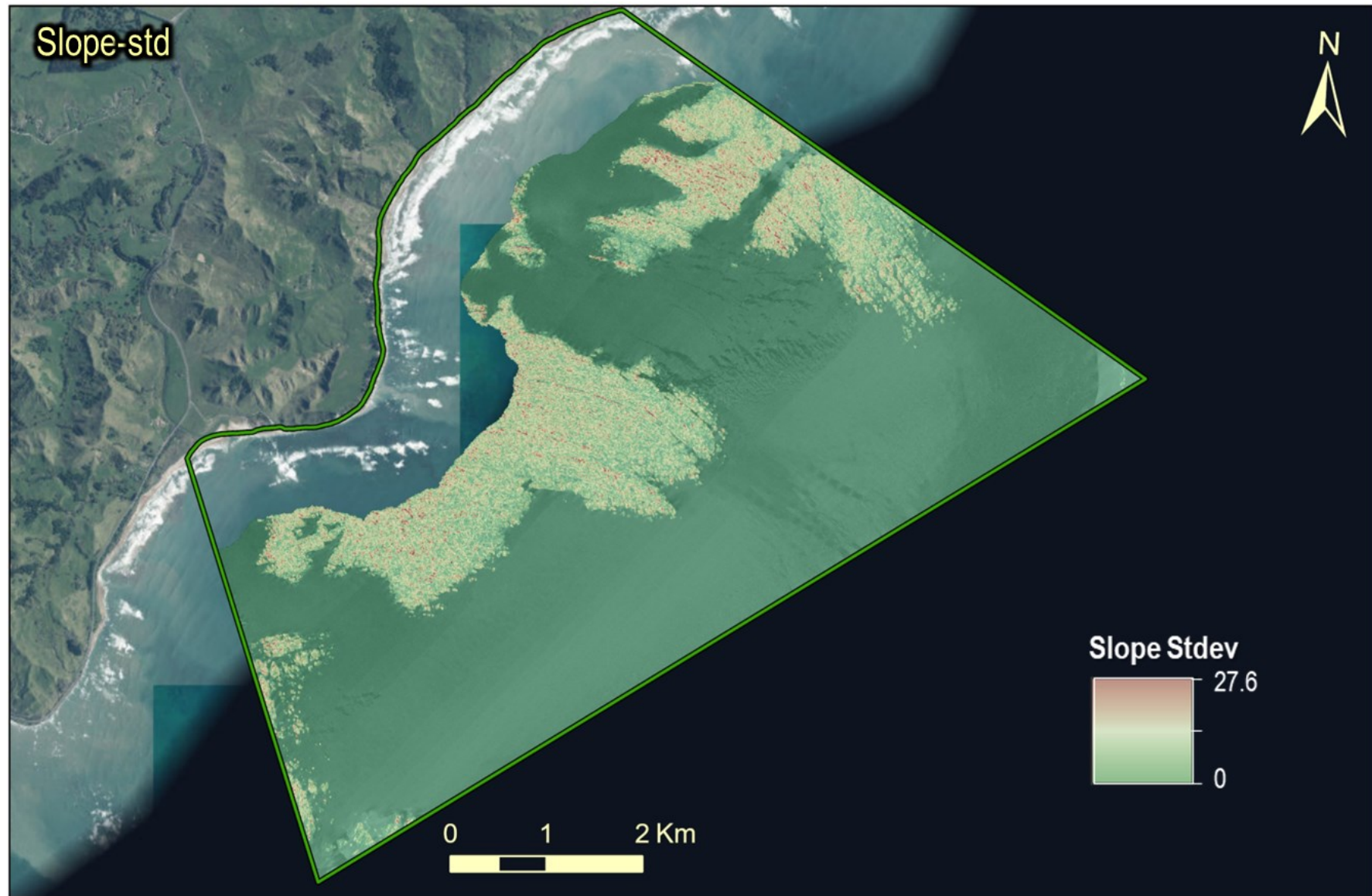


Figure 37. Standard deviation of the slope (Slope-std; derived from the HS76 bathymetry, 3 x 3 cell resolution) within the TToR-MR. Draped over hillshade.

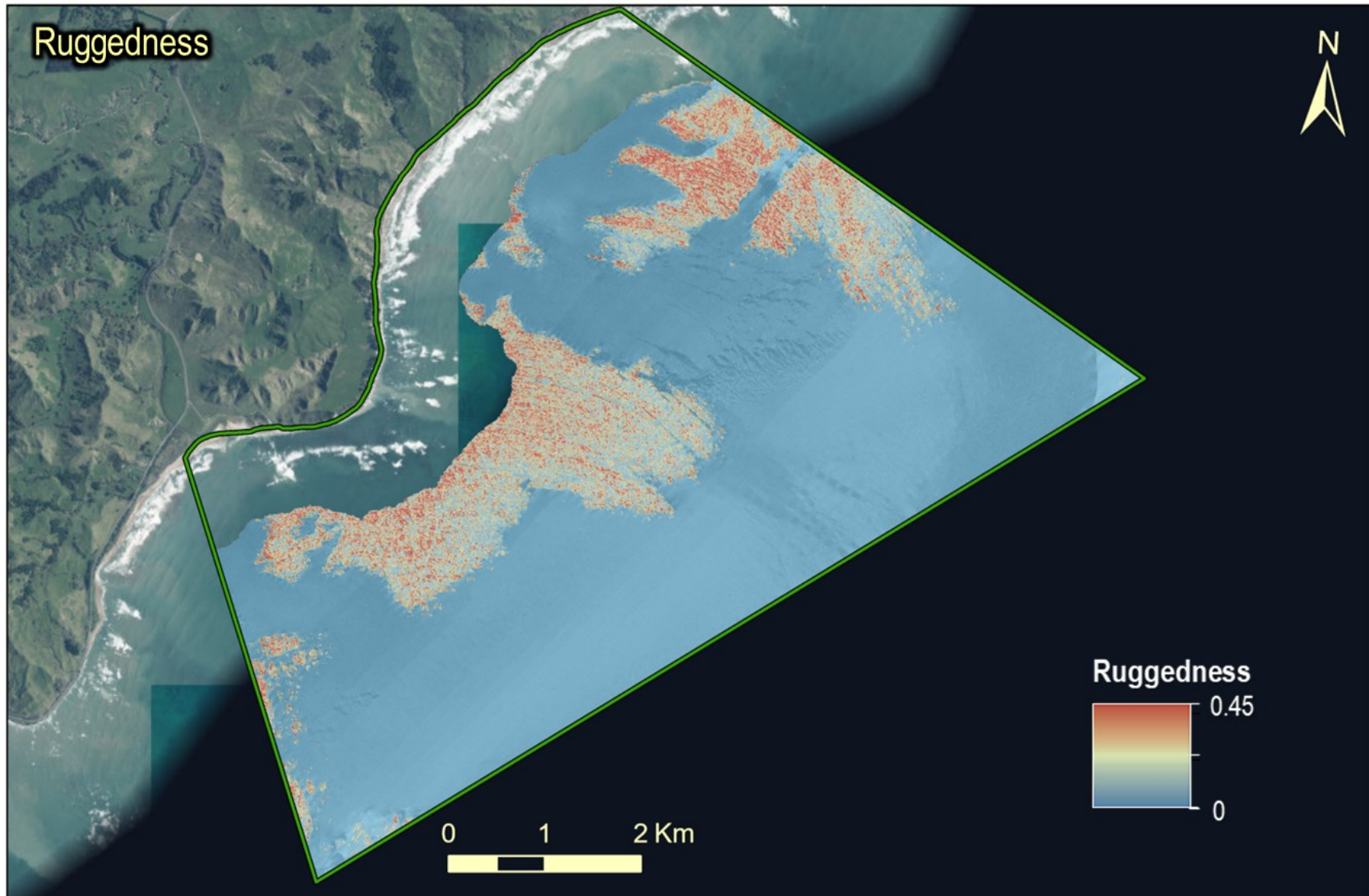


Figure 38. Ruggedness (derived from the HS76 bathymetry, 3 x 3 cell resolution) within the TToR-MR. Draped over hillshade.

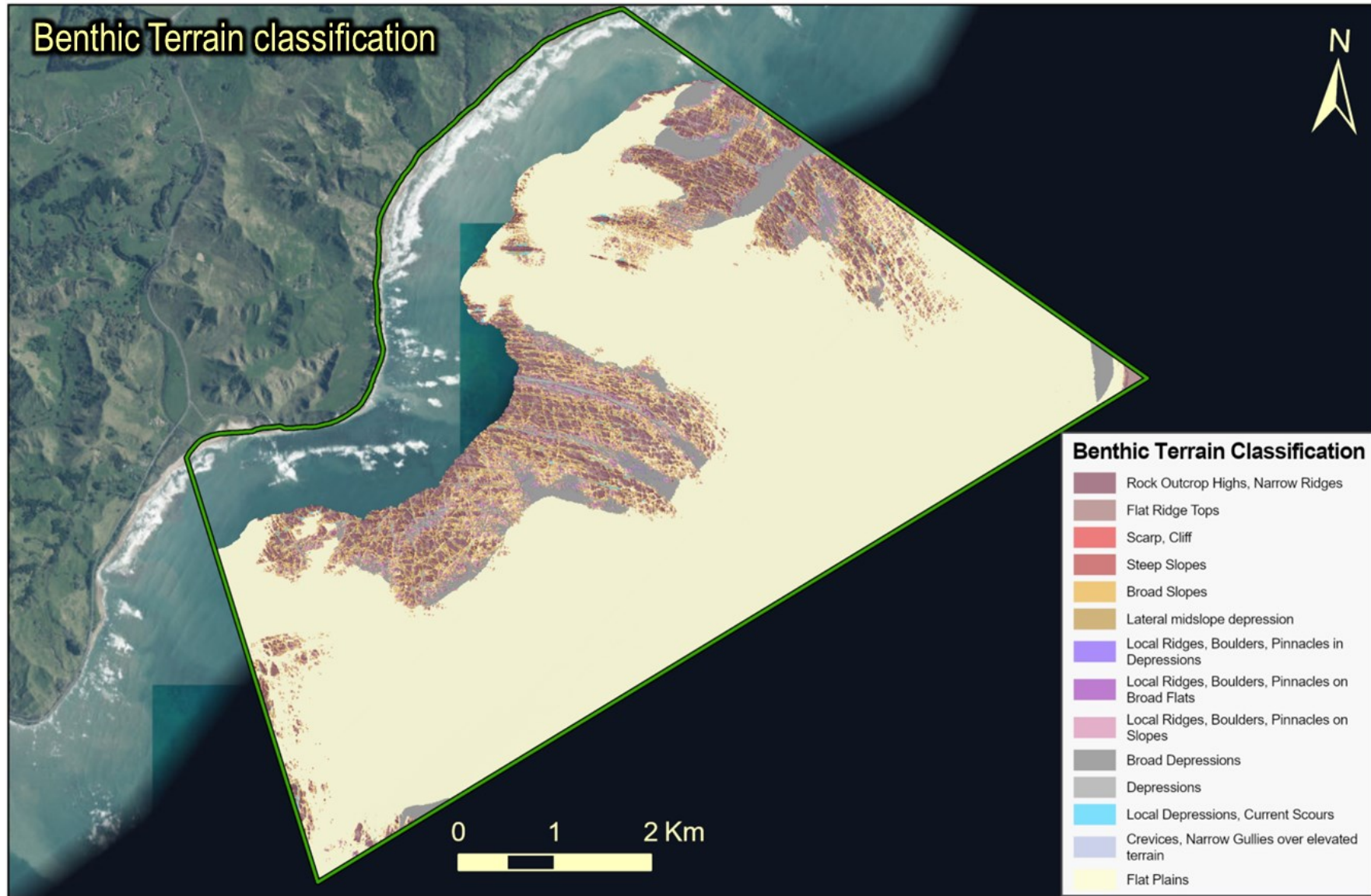


Figure 39. Benthic Terrain Model classifications (derived from the HS76 bathymetry, 3 x 3 cell resolution), within the TToR-MR. Draped over hillshade.

Appendix B. MBES Summary statistics for each habitat/community type.**Table 9. MBES summary statistics for “Kelp forest” sites within the TToR-MR.**

Rubble zones occurred in 113 sites (23 in the MBES-zone of the TToR-MR , and 26 within the MBES boundary).

MBES variables	n	Mean	StdDev	StdErr	Min	Max
BS Max	26	-25.6583	2.8798	0.5648	-20.8701	-34.1005
BS Range	26	-54.1857	5.6962	1.1171	-46.0710	-64.9706
BS 90% CI	26	-33.7227	2.8229	0.5536	-31.2610	-41.6605
BS Range	26	28.5274	6.7457	1.3229	40.6299	20.4706
Bathy Max	26	-16.7005	2.1404	0.4198	-13.0615	-21.2689
Bathy Range	26	-9.7381	2.6892	0.5274	-4.6865	-17.1074
Bathy 90% CI	26	-11.9291	2.4606	0.4826	-6.9798	-18.2105
Bathy Range	26	6.9624	2.6059	0.5111	0.8818	10.6192
Ruggedness Max	26	0.1125	0.0649	0.0127	0.0002	0.2442
Ruggedness Range	26	0.0002	0.0003	0.0001	0.0000	0.0009
Ruggedness 90% CI	26	0.0296	0.0179	0.0035	0.0000	0.0673
Ruggedness Range	26	0.1122	0.0647	0.0127	0.0002	0.2432
Slope-std Max	26	14.9073	4.9365	0.9681	0.9892	23.4881
Slope-std Range	26	0.5204	0.4460	0.0875	0.0000	1.4290
Slope-std 90% CI	26	7.8765	2.9040	0.5695	0.2189	12.5075
Slope-std Range	26	14.3869	4.6800	0.9178	0.9703	22.8948
Slope Max	26	41.3803	13.0350	2.5564	2.6925	60.3762
Slope Range	26	0.2365	0.2317	0.0454	0.0204	0.9758
Slope 90% CI	26	20.5831	8.0815	1.5849	1.2760	33.2900
Slope Range	26	41.1439	12.9462	2.5390	2.5928	60.2371

Table 10. MBES summary statistics for “*Caulerpa articulata* meadows” sites, within the TToR-MR. Native *Caulerpa* meadows occurred in 37 sites (22 in the MBES-zone of the TToR-MR , and MBES boundary).

MBES variables	n	Mean	StdDev	StdErr	Min	Max
BS Max	22	-11.3100	4.7449	1.0116	-4.6865	-23.3144
BS Range	22	-18.4862	3.9534	0.8429	-11.8519	-25.2144
BS 90% CI	22	-13.6201	4.3608	0.9297	-6.9798	-23.4308
BS Range	22	7.1761	2.4928	0.5315	0.7576	10.7365
Bathy Max	22	-24.1651	3.9207	0.8359	-17.0907	-37.5600
Bathy Range	22	-56.3342	5.5836	1.1904	-47.3309	-69.6912
Bathy 90% CI	22	-33.3244	2.7641	0.5893	-30.0000	-42.6005
Bathy Range	22	32.1691	7.5243	1.6042	15.1201	47.5600
Ruggedness Max	22	0.1126	0.0661	0.0141	0.0011	0.2442
Ruggedness Range	22	0.0002	0.0003	0.0001	0.0000	0.0009
Ruggedness 90% CI	22	0.0303	0.0169	0.0036	0.0000	0.0673
Ruggedness Range	22	0.1124	0.0659	0.0140	0.0011	0.2432
Slope-std Max	22	15.0804	4.6288	0.9869	2.3522	23.4881
Slope-std Range	22	0.4349	0.4098	0.0874	0.0000	1.4290
Slope-std 90% CI	22	8.0473	2.7159	0.5790	0.1651	12.5075
Slope-std Range	22	14.6455	4.4112	0.9405	2.3366	22.8948
Slope Max	22	42.0344	12.5732	2.6806	1.3094	60.3762
Slope Range	22	0.1482	0.0868	0.0185	0.0204	0.3024
Slope 90% CI	22	21.1124	7.4019	1.5781	0.7233	33.2900
Slope Range	22	41.8863	12.5506	2.6758	1.2715	60.2371

Table 11. MBES summary statistics for “Mixed-invertebrate” sites within the TToR-MR. Mixed-invertebrates occurred in 67 sites (16 in the MBES-zone of the TToR-MR , and 18 within the MBES boundary).

MBES variables	n	Mean	StdDev	StdErr	Min	Max
BS Max	18	-23.4629	2.8077	0.6618	-19.9301	-30.3211
BS Range	18	-46.7517	3.6352	0.8568	-41.0306	-55.2010
BS 90% CI	18	-31.2107	2.6789	0.6314	-28.4301	-40.7108
BS Range	18	23.2889	4.4235	1.0426	17.6397	33.0711
Bathy Max	18	-27.7283	3.6705	0.8651	-22.5265	-36.9982
Bathy Range	18	-23.0108	4.4014	1.0374	-17.0930	-32.9537
Bathy 90% CI	18	-24.7468	3.9739	0.9367	-19.6533	-34.3195
Bathy Range	18	4.7175	1.9245	0.4536	1.4104	6.9190
Ruggedness Max	18	0.0388	0.0426	0.0100	0.0008	0.1382
Ruggedness Range	18	0.0001	0.0002	0.0000	0.0000	0.0006
Ruggedness 90% CI	18	0.0103	0.0104	0.0024	0.0002	0.0322
Ruggedness Range	18	0.0387	0.0425	0.0100	0.0008	0.1375
Slope-std Max	18	8.4683	4.8320	1.1389	1.1023	18.7318
Slope-std Range	18	0.1576	0.2295	0.0541	0.0000	0.8353
Slope-std 90% CI	18	4.2970	2.5939	0.6114	0.7542	8.8084
Slope-std Range	18	8.3108	4.6664	1.0999	1.0490	17.8965
Slope Max	18	24.9260	12.7625	3.0081	4.1368	52.5330
Slope Range	18	0.2454	0.2746	0.0647	0.0715	1.2170
Slope 90% CI	18	12.0937	6.0931	1.4362	2.5492	22.1582
Slope Range	18	24.6806	12.6800	2.9887	3.9641	51.9648

Table 12. MBES summary statistics for “Sediment-tolerant-taxa” within the TToR-MR. Sediment-tolerant-taxa occurred in 49 sites (18 in the MBES-zone of the TToR-MR , and 21 within the MBES boundary).

MBES variables	n	Mean	StdDev	StdErr	Min	Max
BS Max	21	-25.1773	5.4427	1.1877	-43.8603	-17.0907
BS Range	21	-50.9730	6.1063	1.3325	-59.9301	-36.6201
BS 90% CI	21	-33.2294	4.4659	0.9745	-47.9608	-29.3811
BS Range	21	25.7956	8.4159	1.8365	10.0797	42.8394
Bathy Max	21	-27.3133	6.7405	1.4709	-36.0008	-10.2003
Bathy Range	21	-21.8077	7.0811	1.5452	-31.6568	-9.4918
Bathy 90% CI	21	-23.7253	6.8308	1.4906	-32.6592	-9.6280
Bathy Range	21	5.5056	2.4900	0.5434	0.7086	10.7365
Ruggedness Max	21	0.0555	0.0395	0.0086	0.0000	0.1625
Ruggedness Range	21	0.0001	0.0001	0.0000	0.0000	0.0005
Ruggedness 90% CI	21	0.0151	0.0111	0.0024	0.0000	0.0377
Ruggedness Range	21	0.0554	0.0394	0.0086	0.0000	0.1624
Slope-std Max	21	10.9155	4.8104	1.0497	0.1769	19.2690
Slope-std Range	21	0.2012	0.2660	0.0580	0.0000	0.7880
Slope-std 90% CI	21	5.6016	2.8542	0.6228	0.1052	9.7738
Slope-std Range	21	10.7143	4.7640	1.0396	0.1769	19.2545
Slope Max	21	30.7417	13.1102	2.8609	0.8685	51.8022
Slope Range	21	0.1498	0.1089	0.0238	0.0307	0.4191
Slope 90% CI	21	14.4588	7.8059	1.7034	0.6632	26.0801
Slope Range	21	30.5920	13.1563	2.8709	0.6290	51.7689

Table 13. MBES summary statistics for “rubble” (substrata) within the TToR-MR. Rubble occurred in gully's; in amongst patch-reefs; and on the scree-slope flanking the Monowai Rocks. As a consequence, MBES variables were distributed in three peaks for each habitat. Consequently, ranges for these MBES variables, span all three habitat types, and are therefore broader than would be expected if there was just a single rubble-type habitat. Rubble zones occurred in 97 sites (23 in the MBES zone of the TToR-MR , and 39 within the MBES boundary).

MBES variables	n	Mean	StdDev	StdErr	Min	Max
BS Max	39	-24.2478	4.3872	0.7025	-17.0907	-36.9301
BS Range	39	-50.0255	5.9155	0.9472	-41.0306	-62.1311
BS 90% CI	39	-32.3056	3.4868	0.5583	-28.4301	-41.6605
BS Range	39	25.7777	7.9513	1.2732	8.8199	42.8394
Bathy Max	39	-26.8339	7.4666	1.1956	-12.4180	-44.9621
Bathy Range	39	-21.4211	8.6060	1.3781	-6.7878	-39.8841
Bathy 90% CI	39	-23.3067	8.0403	1.2875	-10.0163	-41.3761
Bathy Range	39	5.4128	2.7352	0.4380	0.8448	10.7365
Ruggedness Max	39	0.0570	0.0552	0.0088	0.0001	0.2382
Ruggedness Range	39	0.0001	0.0001	0.0000	0.0000	0.0006
Ruggedness 90% CI	39	0.0134	0.0124	0.0020	0.0000	0.0392
Ruggedness Range	39	0.0569	0.0551	0.0088	0.0001	0.2379
Slope-std Max	39	9.8472	5.9793	0.9574	0.5048	23.4881
Slope-std Range	39	0.1639	0.2455	0.0393	0.0000	0.9755
Slope-std 90% CI	39	4.8903	3.2424	0.5192	0.1166	10.8984
Slope-std Range	39	9.6834	5.8555	0.9376	0.4918	22.8948
Slope Max	39	27.7901	16.1927	2.5929	1.0349	60.3762
Slope Range	39	0.1298	0.1035	0.0166	0.0065	0.4191
Slope 90% CI	39	13.2498	8.2754	1.3251	0.6971	27.3274
Slope Range	39	27.6603	16.1832	2.5914	0.8205	60.2371

Table 14. MBES variables summary statistics for sand (substrata) sites within the TToR-MR.. Sands were of coarse grains, with waved or rippled bedforms characteristic of a mobile and dynamic sand zone. Muddy sand occurred in 76 sites (29 in the MBES zone of the TToR-MR, and 33 within the MBES boundary).

MBES variables	n	Mean	StdDev	StdErr	Min	Max
BS Max	33	-28.7936	7.3636	1.2818	-42.6005	-18.0404
BS Range	33	-53.3510	6.3356	1.1029	-69.6912	-40.7108
BS 90% CI	33	-36.3892	5.6213	0.9785	-46.7010	-28.7512
BS Range	33	24.5573	10.5240	1.8320	7.2402	47.5600
Bathy Max	33	-20.4988	6.7257	1.1708	-37.7355	-11.3320
Bathy Range	33	-16.3820	7.2620	1.2642	-35.9978	-4.6865
Bathy 90% CI	33	-17.7824	6.9302	1.2064	-36.2591	-6.9798
Bathy Range	33	4.1168	3.0737	0.5351	0.5648	9.8473
Ruggedness Max	33	0.0547	0.0636	0.0111	0.0000	0.2442
Ruggedness Range	33	0.0001	0.0002	0.0000	0.0000	0.0009
Ruggedness 90% CI	33	0.0142	0.0165	0.0029	0.0000	0.0662
Ruggedness Range	33	0.0546	0.0634	0.0110	0.0000	0.2432
Slope-std Max	33	9.0299	7.2922	1.2694	0.1840	23.4881
Slope-std Range	33	0.1537	0.2447	0.0426	0.0000	1.0480
Slope-std 90% CI	33	4.5397	4.0334	0.7021	0.0881	11.9628
Slope-std Range	33	8.8762	7.1431	1.2435	0.1771	22.8948
Slope Max	33	24.5954	19.7755	3.4425	0.8118	60.3762
Slope Range	33	0.1306	0.1023	0.0178	0.0144	0.4166
Slope 90% CI	33	11.8374	10.5209	1.8314	0.5738	33.2449
Slope Range	33	24.4648	19.7706	3.4416	0.7316	60.2371

Table 15. MBES summary statistics for rippled muddy-sand in the midshore zone of the TToR-MR.. Muddy sand occurred in 190 sites (93 in the MBES zone of the TToR-MR; and 101 within the MBES boundary).

MBES variables	n	Mean	StdDev	StdErr	Min	Max
BS Max	101	-32.6650	7.1987	0.7163	-17.0907	-43.8603
BS Range	101	-50.5592	4.9441	0.4920	-40.7108	-64.9706
BS 90% CI	101	-38.7152	4.9871	0.4962	-29.3811	-47.9608
BS Range	101	17.8941	9.7266	0.9678	6.6103	42.8394
Bathy Max	101	-25.6436	9.0982	0.9053	-10.2003	-47.0510
Bathy Range	101	-23.4022	9.3761	0.9330	-6.7878	-46.7193
Bathy 90% CI	101	-24.1504	9.1786	0.9133	-7.9830	-46.7964
Bathy Range	101	2.2414	2.3967	0.2385	0.3129	10.7365
Ruggedness Max	101	0.0221	0.0390	0.0039	0.0000	0.1625
Ruggedness Range	101	0.0001	0.0008	0.0001	0.0000	0.0081
Ruggedness 90% CI	101	0.0053	0.0107	0.0011	0.0000	0.0567
Ruggedness Range	101	0.0220	0.0389	0.0039	0.0000	0.1624
Slope-std Max	101	4.3381	5.7021	0.5674	0.1418	19.2690
Slope-std Range	101	0.0712	0.2015	0.0201	0.0000	1.1627
Slope-std 90% CI	101	2.0913	3.1281	0.3113	0.0751	11.8413
Slope-std Range	101	4.2669	5.5921	0.5564	0.1241	19.2545
Slope Max	101	12.1284	15.9630	1.5884	0.5781	53.4324
Slope Range	101	0.1327	0.1574	0.0157	0.0041	1.0910
Slope 90% CI	101	5.3210	7.7859	0.7747	0.4595	31.8312
Slope Range	101	11.9957	15.9401	1.5861	0.4419	53.1628

Table 16. MBES summary statistics for deep mud sites within the TToR-MR. Deep mud sites were characterised by flat sediments with burrows. Although burrows were sparse, this characteristic was only found in this deepest habitat. Muddy sand occurred in 17 sites (11 in the MBES zone of the TToR-MR and MBES boundary).

MBES variables	n	Mean	StdDev	StdErr	Min	Max
BS Max	11	-30.2914	5.7063	1.7205	-20.8701	-36.6201
BS Range	11	-47.5006	6.0327	1.8189	-41.0306	-62.7610
BS 90% CI	11	-35.6160	3.6049	1.0869	-28.4301	-41.0306
BS Range	11	17.2092	9.0160	2.7184	8.1899	37.1606
Bathy Max	11	-38.1359	7.1241	2.1480	-25.7499	-46.1059
Bathy Range	11	-36.2527	8.1768	2.4654	-19.5907	-45.0936
Bathy 90% CI	11	-36.8376	7.7718	2.3433	-21.8261	-45.2183
Bathy Range	11	1.8832	1.7146	0.5170	0.4891	6.1592
Ruggedness Max	11	0.0180	0.0452	0.0136	0.0000	0.1487
Ruggedness Range	11	0.0000	0.0000	0.0000	0.0000	0.0000
Ruggedness 90% CI	11	0.0042	0.0104	0.0031	0.0000	0.0338
Ruggedness Range	11	0.0180	0.0452	0.0136	0.0000	0.1487
Slope-std Max	11	3.0723	5.1508	1.5530	0.2700	16.7480
Slope-std Range	11	0.0156	0.0081	0.0024	0.0000	0.0269
Slope-std 90% CI	11	1.6895	3.1607	0.9530	0.1207	10.0083
Slope-std Range	11	3.0567	5.1474	1.5520	0.2578	16.7255
Slope Max	11	8.8275	14.0126	4.2249	0.9203	44.5904
Slope Range	11	0.0571	0.0349	0.0105	0.0041	0.0966
Slope 90% CI	11	4.4439	7.2745	2.1933	0.4595	23.1475
Slope Range	11	8.7704	14.0060	4.2230	0.8834	44.4960