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Habitat mapping for the Waikato region coastal marine area: Bathymetry and substrate type

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Abstract

Effective management of coastal resources relies on an understanding of the state of, and the impact of pressures on, the coastal marine area. This includes an understanding of the extent and condition of seabed habitat. Waikato Regional Council (WRC) is responsible for managing the coastal marine area (CMA) that extends from Mean High Water Springs (MHWS) to 12 nautical miles offshore. Habitats range from sheltered shallow estuaries to dynamic open coast beaches, intertidal and subtidal rocky reefs, and deeper water offshore marine environments.

We have summarised the state of knowledge of the extent of seabed habitats within the Hauraki Gulf and the comparatively sparsely studied Waikato west coast, to provide a single habitat and bathymetry resource for the entire Waikato region CMA. This report also identifies data gaps, and is intended to be used to identify areas that may be ecologically significant, and prioritise future data collection.

1 Introduction

1.1 The Waikato region Coastal Marine Area

Waikato Regional Council is responsible for managing the coastal marine area (CMA) that extends from the shoreline (i.e., mean high water springs; MHWS) to 12 nautical miles offshore. This area includes the west coast from Mokau in the south to Karioitahi beach in the north, and on the east coast, the Firth of Thames and the Coromandel Peninsula. The Waikato CMA covers over 10,000 km^2 in area, includes about 1,150 km of shoreline and the water depth ranges from 0 to 500 m (Figure 1). Habitats and ecosystems in the CMA are diverse and highly valued for recreational, commercial, and cultural reasons (e.g., Ashraf and Phillips, 2012; Phillips, 2016; Waikato Regional Policy Statement 2016). The entire CMA on the east coast is part of the Hauraki Gulf Marine Park, and the entire CMA on the west coast is part of the West Coast North Island Marine Mammal Sanctuary. The CMA also includes Te Whanganui a Hei Marine Reserve on the Coromandel Peninsula and the Firth of Thames Ramsar site (a wetland of international importance). Habitats and ecosystems range from sheltered shallow estuaries to dynamic open coast beaches, intertidal and subtidal rocky reefs, and deeper water (about 50 to 500 m deep) offshore marine environments.

The CMA is under increasing pressure from numerous sources, such as coastal development, activities on land that lead to increased runoff of various contaminants, fishing, aquaculture, and climate change (e.g., Ministry for the Environment and Statistics New Zealand, 2015). Effective management of coastal resources relies on adequate understanding of the state of, and the impact of pressures on, the coastal marine area. This includes an understanding of the extent and condition of seabed habitat.

1.2 Seabed habitat mapping

Habitat maps of the seabed are needed to assist in many aspects of resource management, including the assessment of high value ecological areas, designation of areas that may require protection (e.g., coastal significant natural areas) and spatial planning of human activities.

Habitat mapping in the Waikato region CMA has previously been carried out in a piecemeal manner, by various agencies using various methods, and for various purposes (e.g., Morrison et al., 2003; Needham et al., 2013; Jones et al., 2016). Much of this information was collated for the Sea Change Tai Timu Tai Pari Hauraki Gulf Marine Spatial Plan (2017) to produce bathymetry and substrate maps for the entire Hauraki Gulf (MetOcean Solutions Ltd 2012 & 2013). In order to provide information for a review of the Waikato Regional Coastal Plan, and to guide future data collection and habitat mapping, there was a need to update this process and collate information for the west coast of the Waikato region to produce broad-scale habitat maps for the entire Waikato region CMA. This report documents the methods used to collate and analyse available bathymetry and substrate information, the limitations and information gaps that currently exist, presents the maps, and recommends areas for future data collection or research.

The maps summarise current knowledge on seabed habitats, at a broad-scale, for the entire Waikato region CMA. We have focused on two aspects of the seabed, bathymetry and substrate type, for which there is data available and which are also highly relevant to the ecological communities that may be present. Bathymetric data describes the topographic relief of the seafloor and overlying water depth. Substrate type describes whether the seabed is rocky, or composed of a soft sediment, such as sand or mud. Rocky reefs are often hotspots of biodiversity and productivity, supporting communities of marine plants, such as kelp forests, and provide habitat for many species of fish and invertebrates. Out of scope of this report is mapping of the habitat types based on the ecological communities present (i.e., whether there are seagrass or bivalve beds, mangrove or kelp forests, sponge gardens, rhodolith beds etc.). Information of this type is extremely patchy, so mapping at a regional scale would be very limited with the available data. Note that all available information of this type has recently been collated in a marine biodiversity stocktake for the Waikato region (Bouma, 2015).

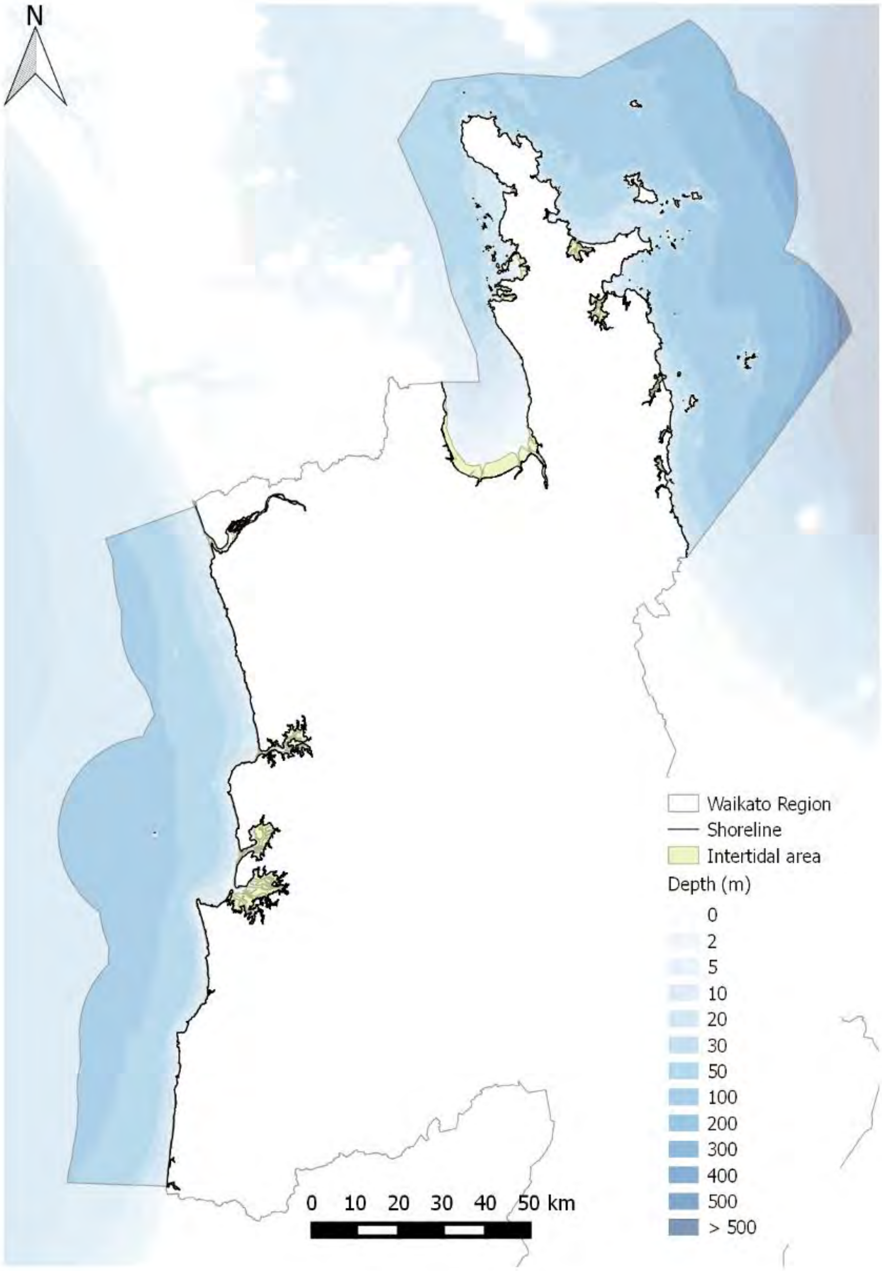


Figure 1: Waikato region CMA (Coastal Marine Area; i.e., the area from the shoreline to 12 nm offshore)

2 Methods

The following section is split into three different parts, pertaining to the data processing of bathymetry, rocky reefs and soft substrates respectively.

2.1 Bathymetry

2.1.1 Data

Bathymetry data was collected from multiple sources and in various formats as illustrated in Table 1 and Figure 2**.** These data sources include ENCs (Electronic Navigation Charts), sounding sheets, LIDAR (Light Detection and Ranging), single-beam and multi-beam data. It should be noted that soundings in parts of the west coast were sparsely distributed, with the data needing to be interpolated to fill in these gaps in the bathymetry maps produced here. This leads to a reduction in accuracy and potential to have missed out seabed features on the west coast of the Waikato region.

Table 1: Bathymetry datasets and sources

Data type	Source
Sounding sheet analysis	LINZ (digitised by MetOcean)
Electronic Navigation Charts (ENCs)	LINZ
LIDAR	WRC – 2017 WRC – 2007/08
Multibeam surveys	NIWA, University of Waikato, DML, WRC
Singlebeam surveys	NIWA, University of Waikato, WRC

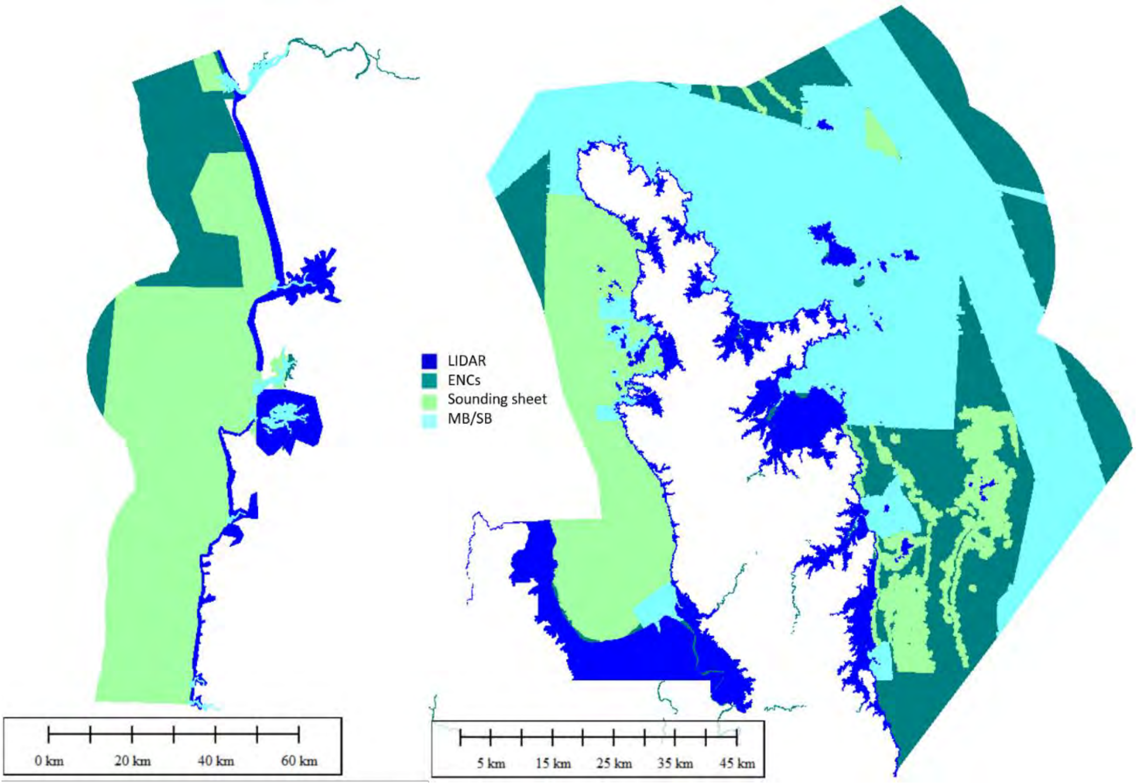


Figure 2: Area of coverage for various bathymetry data sources

2.1.2 Data structure

The terrain module of the open-source software GERRIS[1] (Popinet, 2011; 2012) was used to manage the multiple, sometimes large and overlapping datasets. GERRIS is an open-source fluid dynamic software package featuring dynamic grid generation and refinement.

For efficiency, each individual dataset was pre-processed and stored using a 2D kd-tree (KDT) hierarchical database system. This consists of recursively subdividing the working domain into homogeneous sub-domains (Figure 3). The smaller sub-domains at the bottom of the hierarchy (the leaves of the tree) contain the footprint of the data points themselves. For each of the non-leaf sub-domains, statistics on all the data points they include are gathered and stored.

Such a data structure can be very large but is very efficient to query. The cost of finding a specific point in the dataset scales with log(N) where N is the number of points in the dataset (Cormen et al., 1990). The cost of gathering statistics for all the points included in a query domain is generally much lower than log(N) because, when querying the kd-tree, if a sub-domain is fully included in the query domain the statistics for the whole sub-domain can be loaded straight away and consequently the data points do not need to be individually retrieved.

Choosing to use such a structure has accompanying limitations in terms of the type of bathymetry reconstruction that can be achieved using the stored statistics. It also involves a large cost in terms of disk space, but this provides huge savings in term of RAM and CPU usage which can prove critical when huge (multiple gigabyte) datasets are used.

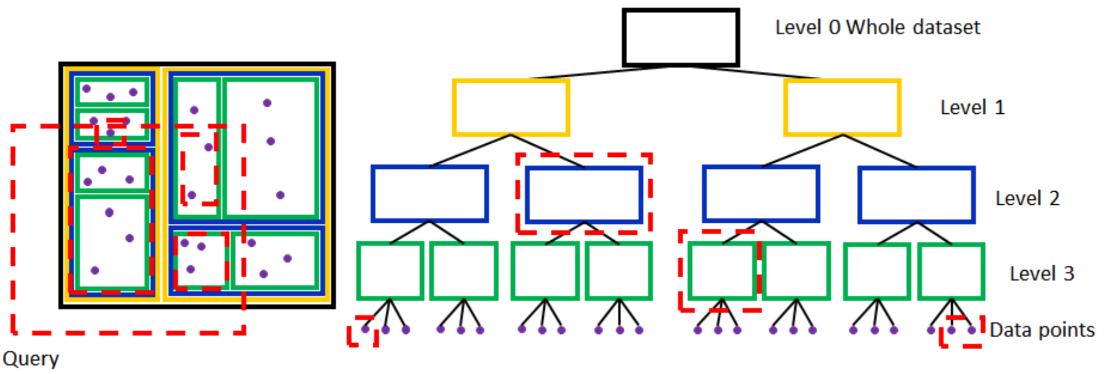


Figure 3: Illustration of the concept of KDT database systems as used by GERRIS. The subdivided domain with the data points in purple is shown on the left and its tree representation on the right.

2.1.3 Mesh generation

GERRIS includes numerical algorithms designed to manage bathymetry datasets which, for this project, were used to generate depth values at specific locations, e.g. at regular grid nodes on a Cartesian grid. GERRIS is natively based around a quad-tree structure (Popinet, 2004) which enables a square domain to be turned into a highly complex mesh according to well defined criteria. If the criteria are satisfied for the initial domain cell it gets split into four equal sub-domains and so on in a recursive way (Figure 3). For example, a condition such as “if a land point and a sea point are contained within the cell and the size of the cell is larger than x” will allow the generation of a mesh with controlled resolution near the coastline. There is no limitation on the complexity of the mesh refinement criteria.

Ideally the criteria used to create the mesh should be based on the physical properties of the desired bathymetry, the density of the data points available and the scale at which the bathymetry needs outputting. For the present work, the maximum resolution of the GERRIS mesh was limited by the dataset resolution. Bathymetry data were irregularly distributed inside the domain of interest, and there were both regions of higher data density and regions of very sparse point density. To solve this, we constructed several domains with different resolutions,

[1] www.gfs.sf.net

according to the data distribution. The minimum size of each mesh was controlled by a guide dataset created from a lower resolution reconstruction of the bathymetry. The details of the mesh were controlled by a criterion based on the standard deviation in depth over a cell of the mesh.

For each domain, GERRIS is used to automatically create a bathymetry grid of local resolution dictated by predefined criteria based on the local data density, the resolution of the desired output or any scale of interest. Once the grid is created, GERRIS gathers the statistics of all the points of all the datasets in each cell of the grid and reconstructs the bathymetry using a least-square bilinear approximation technique.

2.1.4 Datums

Data was supplied in various horizontal projections and different formats, including WGS84; decimal degrees, degrees and minutes, degrees minutes and seconds, NZTM and NZGD 1949. The vertical datums included lowest astronomical tide (LAT), local mean sea level datums (LVD) and NZVD2016. Each dataset was converted to a common horizontal projection/datum and vertical datum; New Zealand Transverse Mercator/New Zealand Geodetic Datum 2000 (NZTM/NZGD2000) and both local vertical datums (LVD) and NZVD2016. Local vertical datums included Moturiki 1953 for the west coast data and Auckland 1946 for the east coast data, (Figure 4). The conversion between local vertical datums and NZVD2016 was performed using the conversion layers supplied by LINZ through the LINZ data portal and is illustrated in Figure 5, and according to the equation supplied by LINZ: $H_{NZVD} = H_A$ (LVD) – O_A (offset)

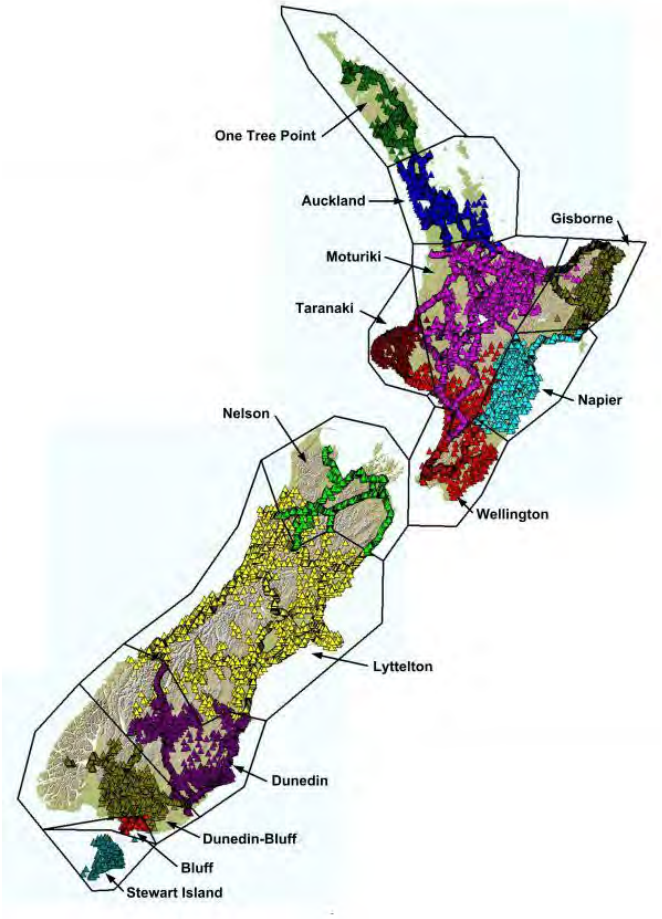


Figure 4: Local Mean Sea Level Datums (Source: LINZ; https://www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/local-mean-sea-level-datums)

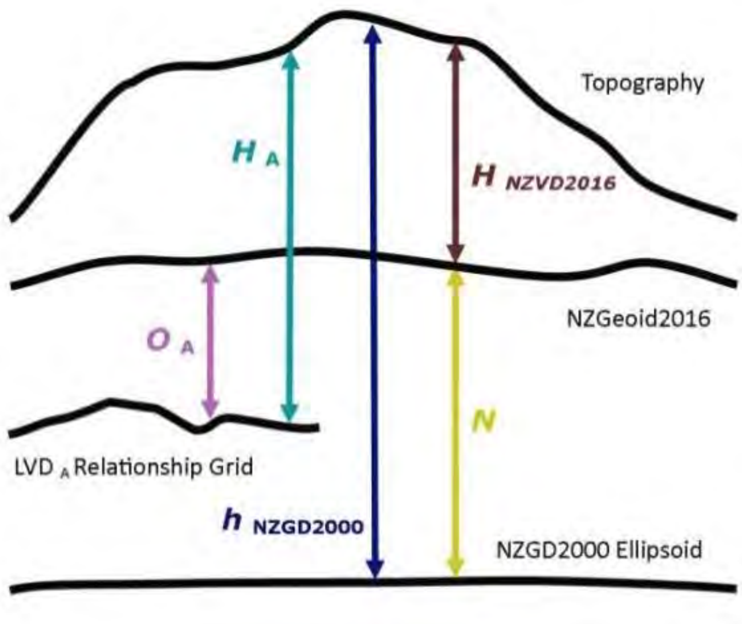


Figure 5: Relationship between local vertical datums (LVD) and NZVD 2016 geoid (Source: LINZ; https://www.linz.govt.nz/data/geodetic-services/coordinate-conversion/converting-between-nzvd2016-nzgd2000-and-local-vertical-datums)

2.2 Rocky reefs

Rocky reefs, both shallow and deep, represent important physical habitats for many marine species including fish, crustaceans, and provide a suitable substratum for the growth of macroalgae such as kelp species (Smith, 2004). Rocky reefs also provide a habitat for significant numbers of indigenous and endemic marine flora and fauna in New Zealand (Nelson and Gordon, 1997). Many previous studies on rocky reefs have focused on local scale and community structure, with little information available on regional scale locations of rocky reef communities. The location and composition of benthic reef communities are distributed with relation to physical habitat variables, including depth, wave exposure, water clarity/sedimentation and nutrient availability (Shears and Babcock, 2000).

Where possible, high resolution bathymetry, including multibeam surveys, was used to map deep and shallow rocky reefs using a slope analysis method within a geographical information system (GIS). Where high resolution data was not available, sounding sheets were used in combination with existing habitat maps and local interviews to identify areas of potential rocky reef, with a view of using this as a guide for potential future surveys.

2.2.1 Data

Several datasets showing the spatial locations of rocky reefs within the Waikato region have been previously developed (Figure 6), and where possible existing datasets were combined and utilised for this project. Existing datasets were often limited in geographical extent, either covering the east coast or the west coast. However, where new datasets were created, effort was made to be consistent across the entire Waikato region. Each dataset is briefly outlined below.

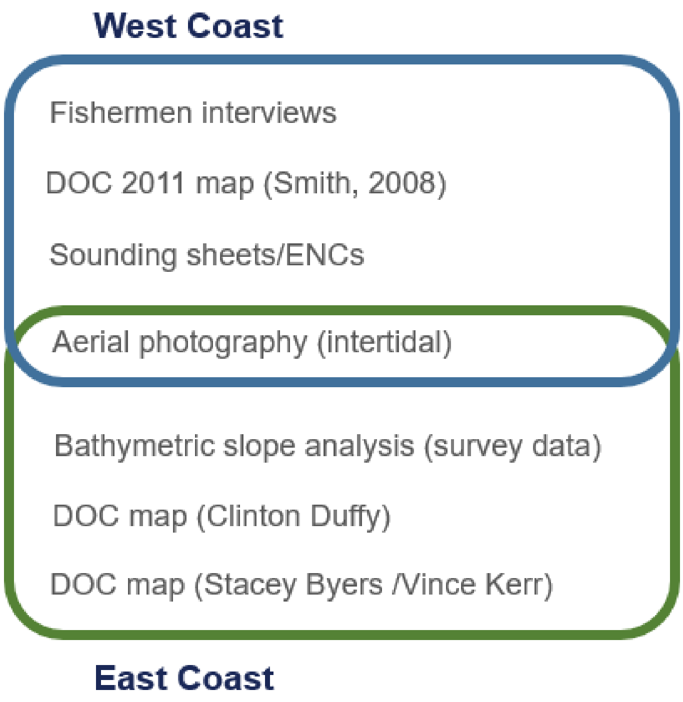


Figure 6: **Available rocky reef data for the Waikato region.**

Fisherman interviews

For the west coast, where limited data existed, a local fisherman who had information regarding potential areas of interest was interviewed and these locations were digitised in GIS (Figure 7).

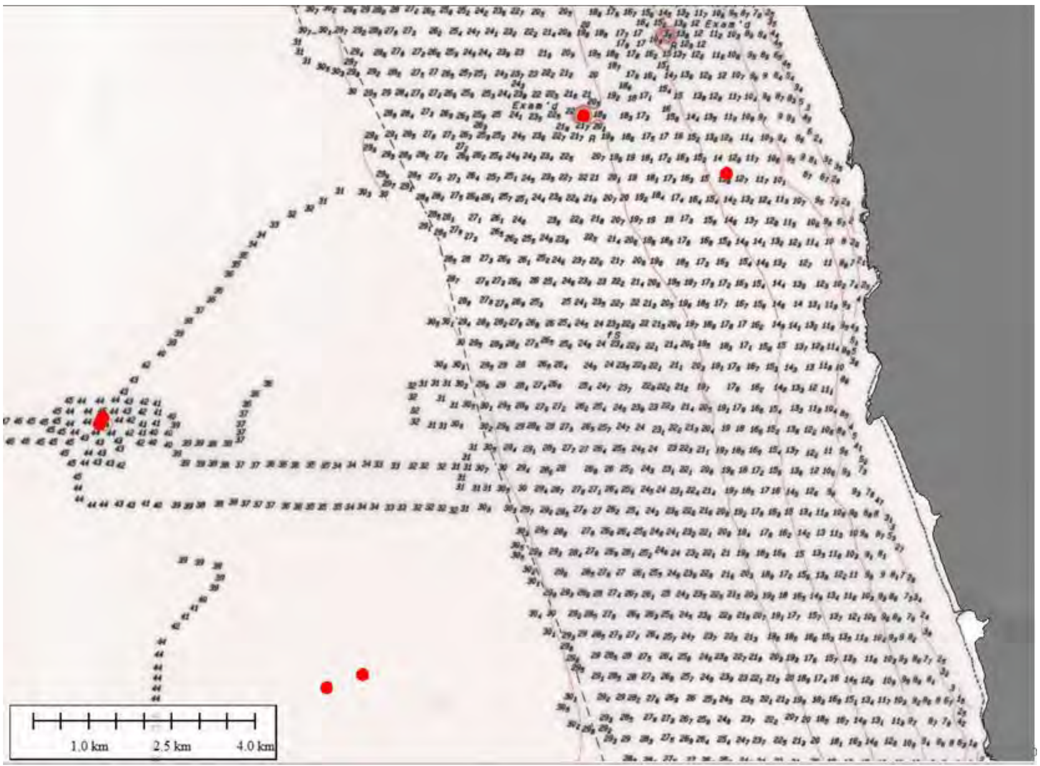


Figure 7: **Selected locations of potential rocky reefs, resulting from an interview with a local fisherman, overlaid on sounding sheets.**

DOC and MFish 2011 reef layer

The main dataset showing the spatial locations of rocky reefs within the Waikato west coast regional boundaries was developed in 2011 by the Department of Conservation and Ministry of

Fisheries (now Fisheries New Zealand Ministry for Primary Industries). This study mapped the coastal marine habitats in the New Zealand territorial sea at a broad-scale.

Figure 8: DOC and MFish 2011 reef shapefile layer (red) on the West Coast of the Waikato region

Sounding sheets/ENCs

On the west coast, sounding sheets were acquired from LINZ and digitised in order to identify likely areas of rocky reef in a similar manner to the work previously done by Stacey Byers and Vince Kerr on the east coast and Hauraki Gulf (Kerr, 2011). Both contours and hazard features were identified, including those shown in Figure 9.

Soundings on some of the sheets for the west coast were sparsely distributed with the potential for seabed features to be missed or entirely unmapped. Figure 7 illustrates this, where some sites identified through fisherman interviews are not covered by the soundings.

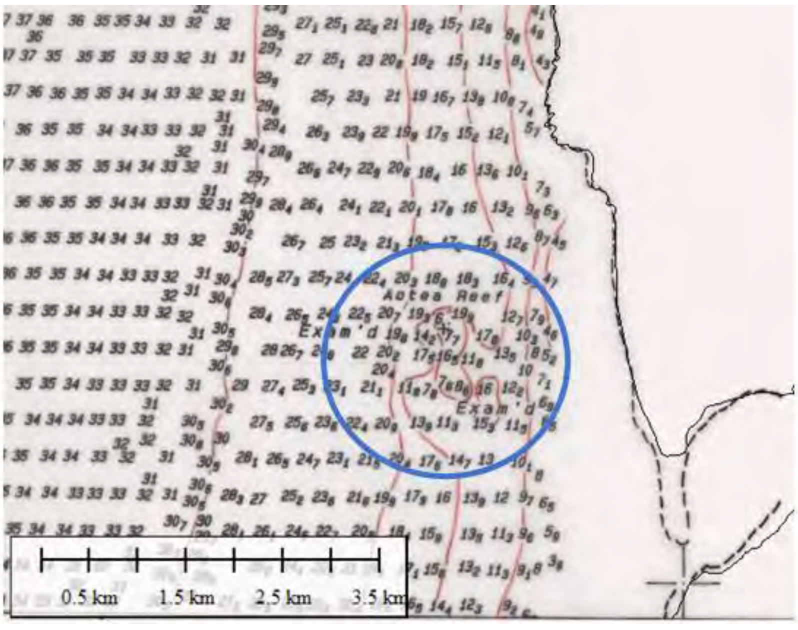
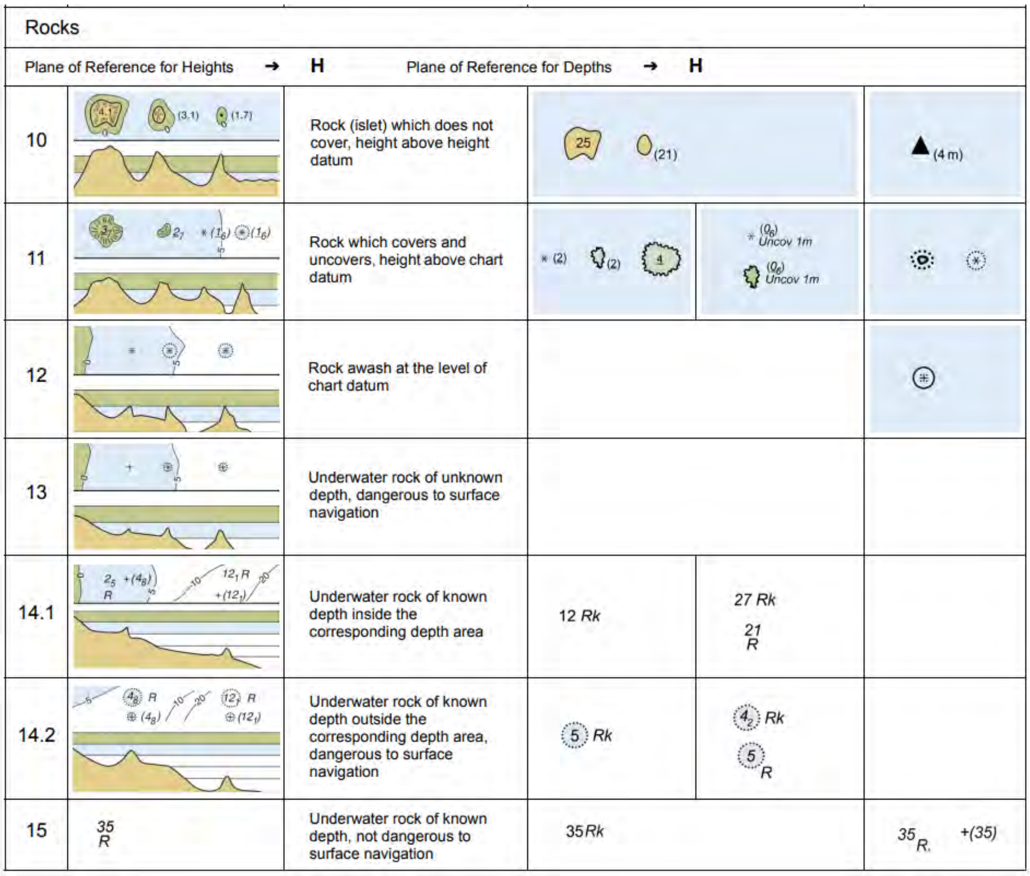


Figure 9: Example of reef system identification from sounding sheet depths and contours.



Rocks					
Plane of Reference for Heights → H		Plane of Reference for Depths → H			
10	4.1 (3.1) (1.7)	Rock (islet) which does not cover, height above height datum	25 (21)		(4 m)
11	3₇ 2₇ (1₆) (1₆)	Rock which covers and uncovers, height above chart datum	(2) (2) 4	(0₆) Uncov 1m (0₆) Uncov 1m	
12		Rock awash at the level of chart datum			
13		Underwater rock of unknown depth, dangerous to surface navigation			
14.1	2₅ R +(4₈) 12₁ R +(12₁)	Underwater rock of known depth inside the corresponding depth area	12 Rk	27 Rk 21 R	
14.2	4₈ R (4₈) 12₁ R (12₁)	Underwater rock of known depth outside the corresponding depth area, dangerous to surface navigation	5 Rk	4₂ Rk 5 R	
15	35 R	Underwater rock of known depth, not dangerous to surface navigation	35 Rk		35 R. +(35)

Figure 10: **A guide to the identification of rock structures on Nautical Charts (Source: Chart 5011 (INT 1) Symbols and Abbreviations used on Admiralty Charts, 7th Edition 2018).**

Aerial photography

Aerial photography has been used to map intertidal rocky reef structures, both on the east and west coasts (Bronwen Gibberd pers. comm.); this was then integrated with the subtidal layers. Aerial photography was also used to observe subtidal reefs where water clarity allowed (east coast) or where wave breaking patterns indicated a subtidal structure (west coast) as illustrated in Figure 11.

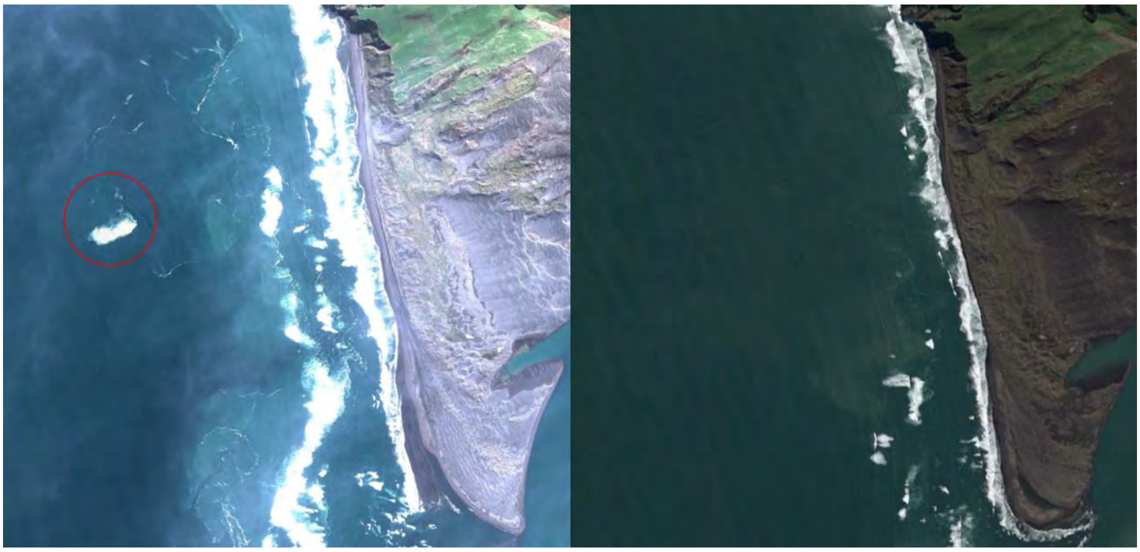


Figure 11: **Visual identification of rocky reefs using aerial photography during large wave events (shown here is Aotea Reef on the west coast of the Waikato region).**

Bathymetric slope analysis

A bathymetric slope analysis was limited to areas where high resolution bathymetry data was available (i.e., the east coast Hauraki Gulf region, Figure 12). This data was used in the form of a floating raster dataset, with a cell resolution of 10 m. A slope analysis on this data was performed in ArcGIS, whereby the maximum rate of change between each cell and its neighbour is calculated. The raster dataset was then categorised by slope and converted to polygons to denote areas where the slope varies by more than 5%, following recommendations by Stacey Byers and Vince Kerr (pers. comm.) in their study of rocky reefs from Navy fare sheets. At this stage some smoothing of the data was needed, using ArcGIS to group multiple small polygons into larger ones. A full description of the methods used is described in MetOcean Solutions Ltd (2013).

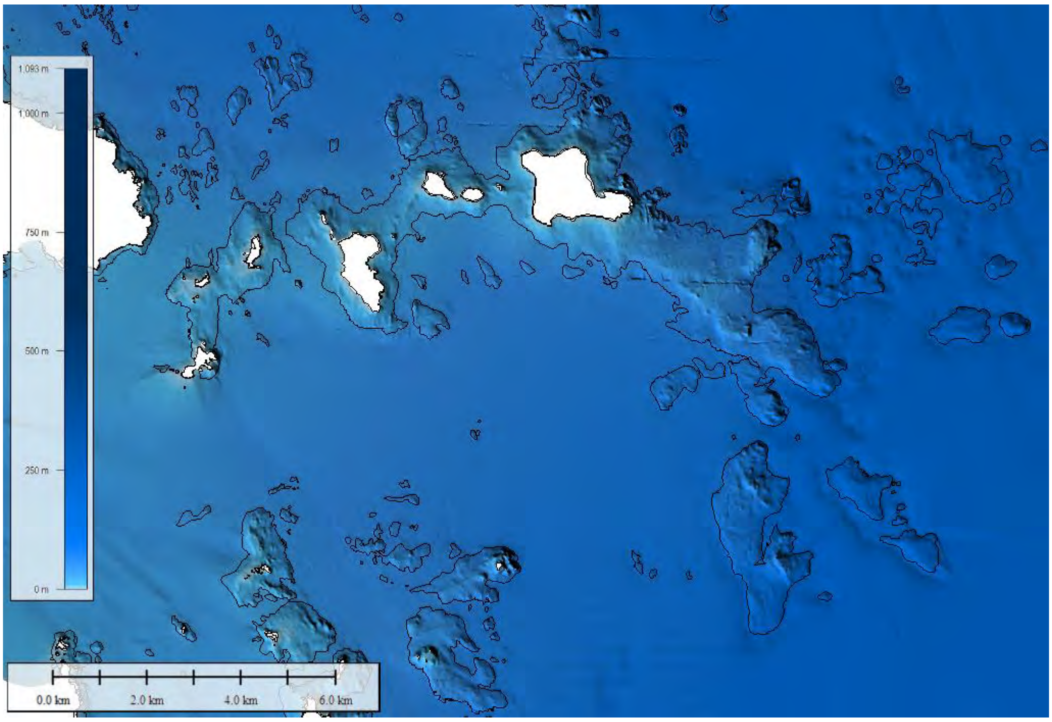


Figure 12: **Rocky reefs delineated using a bathymetric slope analysis**

DOC (Clinton Duffy)

A dataset used for the east coast of Waikato was produced by Clinton Duffy at the Department of Conservation (pers. comm.) and consists of polygons created from extensive dive logs and relevant charts and maps (Figure 13). Locations of reefs described in several DOC reports were also used as a guide; including those mentioned in Smith (2004).

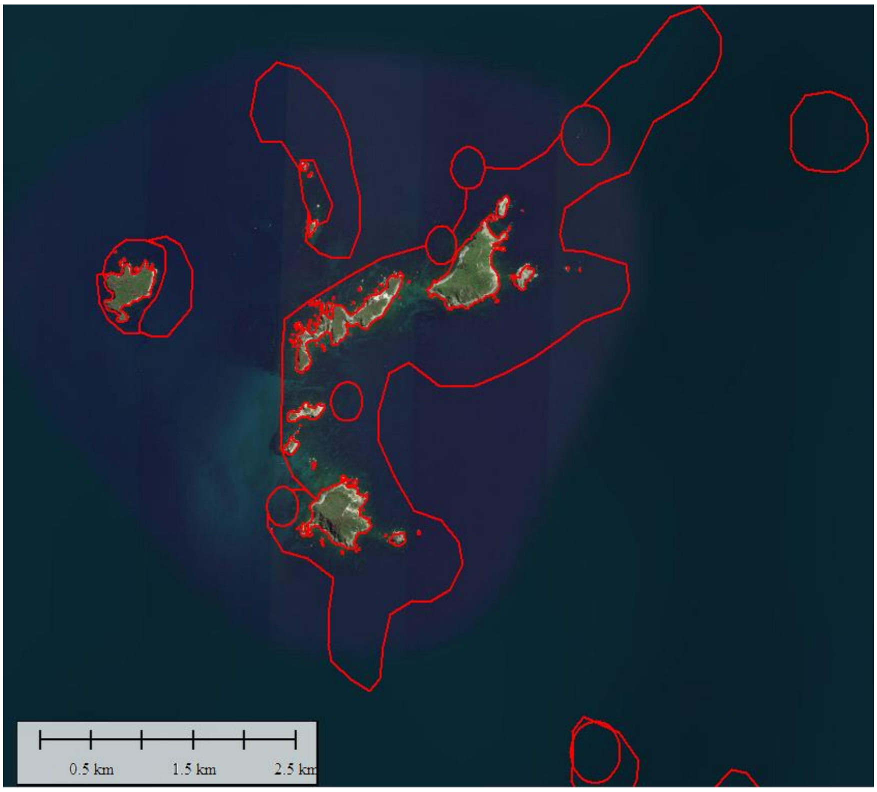


Figure 13: **Example of rocky reefs mapped by Clinton Duffy (DOC)**

DOC (Vince Kerr and Stacey Byers)

This dataset is limited to the east coast only and was created by Stacey Byers and Vince Kerr in 2009, for the Auckland Conservancy and the Department of Conservation (Kerr, 2011). The study used numerous methods to define intertidal, subtidal and offshore environments, including rocky reefs. These were classified through a combination of aerial photographic interpretation and where aerial photographs were not available, slope analysis of sounding sheets. The sounding sheet analysis consisted of investigating regions on the paper sheets where depth varied by greater than 2 m between consecutive contours. A GIS analyst then drew up a 'best estimate' polygon to denote the edge of the topographic feature. These were then categorised into areas of low (<2.5% slope), medium (2.5-5% slope), and high slopes (>5% slope).

2.2.2 Integration of all available data

Rocky reef locations were examined using the available datasets, and a confidence level attributed to each polygon within the metadata (Figure 14). This was performed slightly differently for the west and east coasts, depending on the data available. On the east coast this was done by firstly using the bathymetric slope analysis as the baseline layer, with a value of 2 given in the metadata (Verif_BSA). This was then directly compared to DOC (Vince Kerr and Stacey Byers) data, and where the two datasets overlapped a value of 2 was given within the metadata (Verif_VK). The resulting dataset was compared to the indicative reef maps produced by DOC (Clinton Duffy). Where these datasets directly overlapped a value of 2 was given in the metadata (Verif_DOC), however as this data is indicative and does not necessarily show the exact location a score of 1 was given if the final dataset was within 20 m of the indicative layer. Where no bathymetric slope analysis was available due to a lack of data, the rocky reef shapefiles from the DOC (Vince Kerr and Stacey Byers) dataset was used as the baseline and verified against the DOC (Clinton Duffy) data. These scores were then tallied as a confidence level within the metadata (called "Confidence"); where reefs are shown in all three datasets a maximum confidence level of 6 is given, and where reefs are only shown in one of the three original datasets a confidence level of 2 is given.

On the west coast, verification was undertaken by using the sounding sheet and ENC analysis as the baseline layer, with a value of 2 given in the metadata (Verif_SS&ENCs). This was then compared to the DOC and MFish (2011) layer and where the 2 layers overlapped at all a value of 2 was given in the metadata (Verif_DOC). Thirdly, the layers were compared to the sites given from the fisherman interview, these were given a confidence score of 1 and recorded in the metadata (Verif_FM), leading to a maximum confidence score of 5 for the west coast, given the limited data available. This allows an assessment of confidence of the location and extent of reefs mapped. Where confidence levels are low, further work, either through the collection of more detailed bathymetry data or field work, could be completed to verify the reefs mapped.

This dataset was then further combined with intertidal reef maps produced through digitising aerial photography (Needham et al., 2013; Bronwen Gibberd pers. comm.), and polygons derived from this data were given a confidence score of 2 in the metadata (Verif_Aeri).

For each reef polygon in the final data layer, a minimum depth (Depth_min) and maximum depth (Depth_max), was extracted from the bathymetry and the values recorded within the metadata. This enables the layers to be classified as deep or shallow rocky reefs depending on the criteria required.

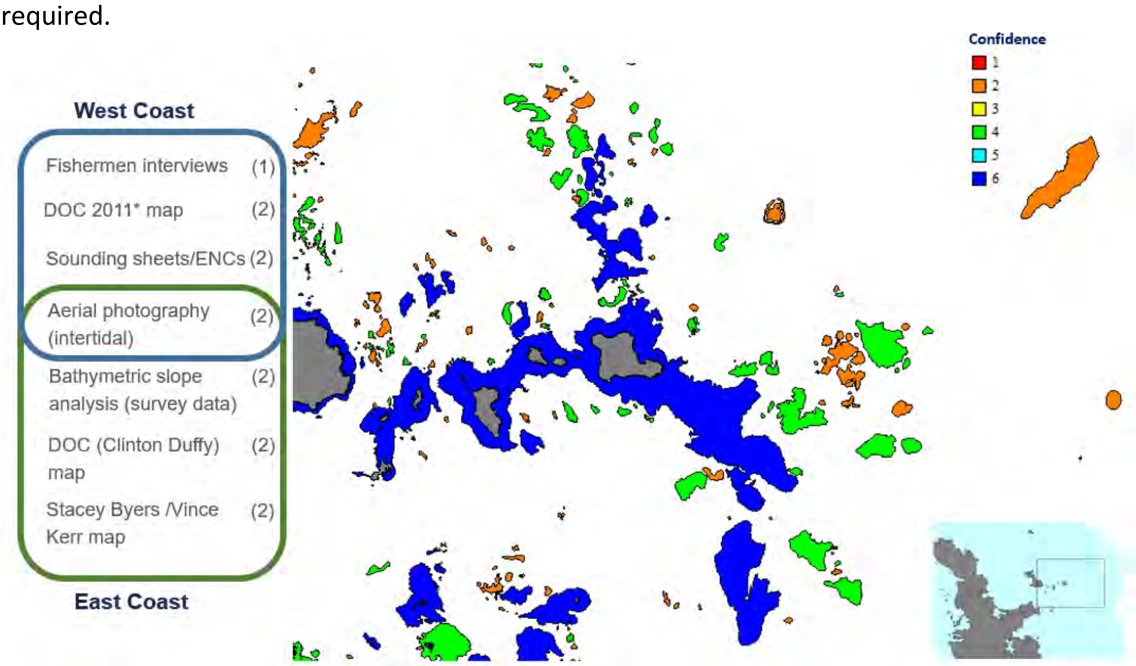


Figure 14: **Example of confidence scores for an area of rocky reef data. Scores range from 1 in red (lowest confidence) to 6 in blue (highest confidence)**

2.3 Soft substrates

2.3.1 Data

Very limited data exists for a detailed classification of soft subtidal sediments within the Waikato west coast CMA. From the point sample data that does exist, the interpolation method of MetOcean Solutions (2013) was applied to the east coast.

Three data sources containing quantitative sediment information were identified in this study for the west coast. The main dataset was the NZOI sediment charts (see Bardsley (2008) for details). These included NZOI Coastal Series Sediment Charts (Doyle and Arron, 1982; Arron and Doyle, 1983) and New Zealand Regional Sediments (Mitchell et al., 1989). A local study conducted by NIWA (Thrush et al., 2003) provided limited data points inside the intertidal area of Kawhia Harbour. Furthermore, the WRC Regional Estuary Monitoring Programme (REMP) provided sediment information for five intertidal locations within Whaingaroa (Raglan) Harbour (with data collected from 2001 to present).

Additional information on soft substrate was obtained from the digitisation of raster navigation charts (RNCs), from which the location and sediment classification presented in the available charts were compiled. The spatial distribution of all quantitative sediment points is represented in Figure 15.

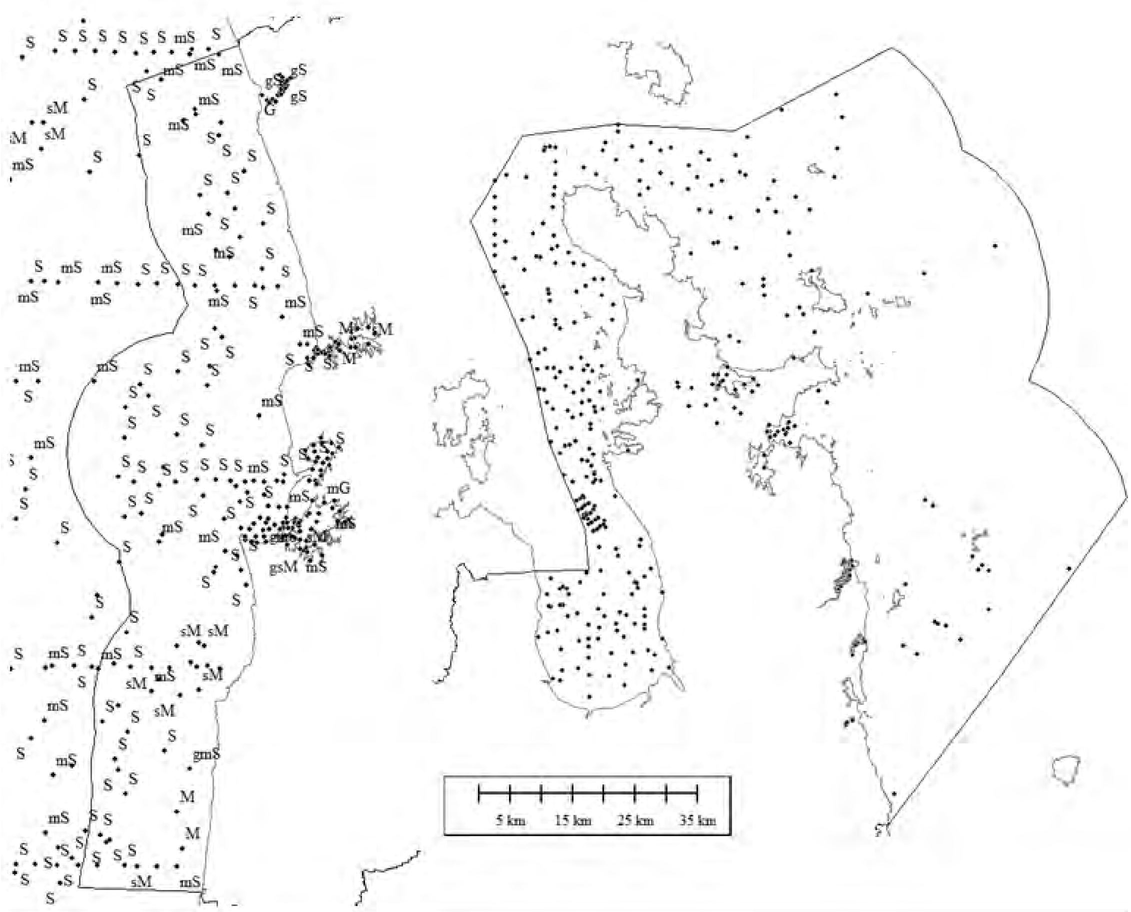


Figure 15: Quantitative sediment samples

2.3.2 Classification

To combine sediment data from different surveys a consistent substrate classification scheme was adapted, based on the Folk scale (Figure 16) (Folk, 1954), with particle size definitions based on the Wentworth scale (Wentworth, 1922). Sediments grouped under the Folk scale are classified into textural groups based upon the relative proportions of gravel (>2 mm), and the ratio of sand (2–0.0625 mm) to mud (<0.0625 mm). A broad scale classification adapted from Long (2006) was also used. Both the original Folk class (Folk_scale) and broad class (Folk_broad) are recorded in the metadata of the final sediment distribution dataset.

Data, with the original sediment fractions accessible, were converted to the Folk classification. However, many data points, including all from the NZOI data, had previously been classified under the Folk scale but had no raw data easily accessible. For these locations estimates of gravel, sand and mud fractions were created by taking the midpoint of the appropriate Folk classification.

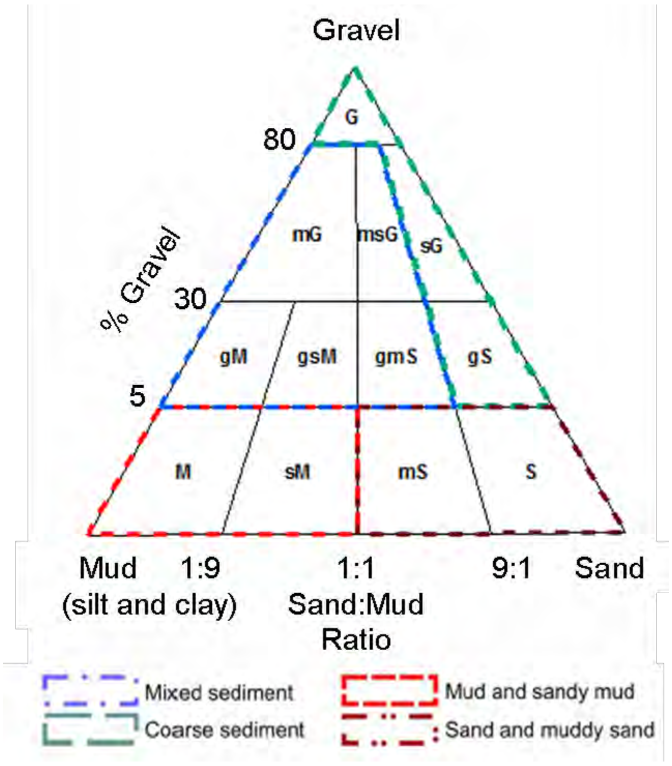


Figure 16: **Surficial sediment classification based on Folk (1954) and broad scale classification modified from Long (2006). Uppercase letters indicate largest proportion; lowercase letters indicate qualifiers.**

2.3.3 Interpolation

Once all data had been allocated a percentage fraction for mud, sand and gravel, these values were interpolated within a GIS environment to create a continuous sediment dataset. All interpolation methods essentially estimate the value at a given location as a weighted sum of the data values at the surrounding locations. Almost all interpolation methods assign weights according to functions that give a decreasing weight with increased separation distance. Numerous methods of interpolation exist and the choice of different algorithms depends on the quantity, quality and spread of the data available. As discussed in many papers (e.g. Jerosch, 2013; Ren et al., 2012; Verfaille et al., 2006; Taylor and Morrison, 2008), one of the most commonly used methods for interpolation of this type of data is kriging. This method often helps to compensate for the effects of data clustering, treating clusters more like single points and reducing the weighting, this method also gives estimates of estimation error (kriging variance). However, one issue with using kriging is that although it is one of the most powerful interpolators it is also complex, using sophisticated statistical methods that consider the unique characteristics of the data, which can be difficult to apply if the data is sparse and disjointed. Also, within this method the interpolated value is allowed to exceed maximum and minimum values from the original data, which in this instance would be less than 0% or greater than 100%. Often it is also useful to use co-kriging, (Jerosch, 2013; Verfaille et al,. 2006), in order to investigate the spatial variability of sediments with other environmental factors, such as depth or slope, unfortunately within the scope of this work and the data available this was not possible.

Other methods of interpolation can also be used depending on the data, including spline and inverse distance weighting. Inverse distance weighting (IDW) simply assumes that the nearer a sample point is to the cell whose value is to be estimated, the more closely the cell's value will resemble the sample point. Due to this, IDW averages out any trends that may spatially occur in the dataset, however, it also cannot make estimates above or below the maximum and minimum sample points present. Cummings et al. (2002) used this method due to the spatially disjunctive nature of the data they were processing.

Due to the broad and uneven spread of data with limited spatial availability in many areas, regardless of the interpolation method, there will be regions of unreliable estimates. Hence, a simple IDW interpolation was performed, allowing the general trends of sub-tidal sediments to be determined. However, in order to gain more detailed sub-tidal sediment maps more data is required.

In order that the sediment fractions added up to 100%, firstly the gravel fraction was interpolated, as sand and mud then make up a ratio of the remaining fraction, ensuring the total sediment component was 100%. Three raster layers, one for each of the gravel, sand and mud fraction of the surficial sediment, were interpolated, allowing the spatial distribution of the surficial sediment to be classified according to Folk scale. Shapefiles of the spatial distribution of the percentage gravel, sand and mud fractions and the Folk classification have been produced.

3 Results and Discussion

3.1 Bathymetry

Examples of the high resolution multibeam that was provided by LINZ for the east coast are illustrated in Figure 17; these clearly illustrate the extent of rocky reefs as well as interesting bed forms.

Bathymetry grids produced at the regional scale are at a 0.0005 decimal degree resolution (approximately 50m) in both local vertical datum and NZVD2016. The coverage of these datasets is shown in Figure 18. These datasets were also used to produce contours in a shapefile format for both the east and west coasts (Figure 19 and Figure 20).

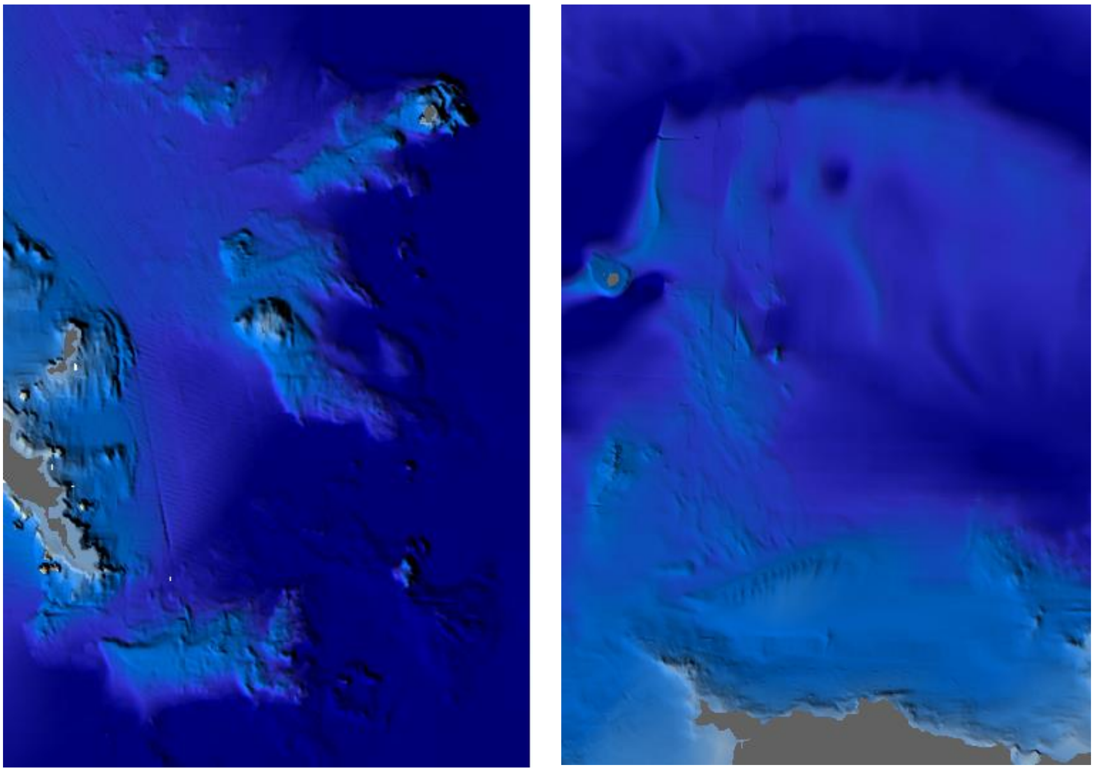


Figure 17: Examples of LINZ high resolution multibeam survey data collated for the east coast

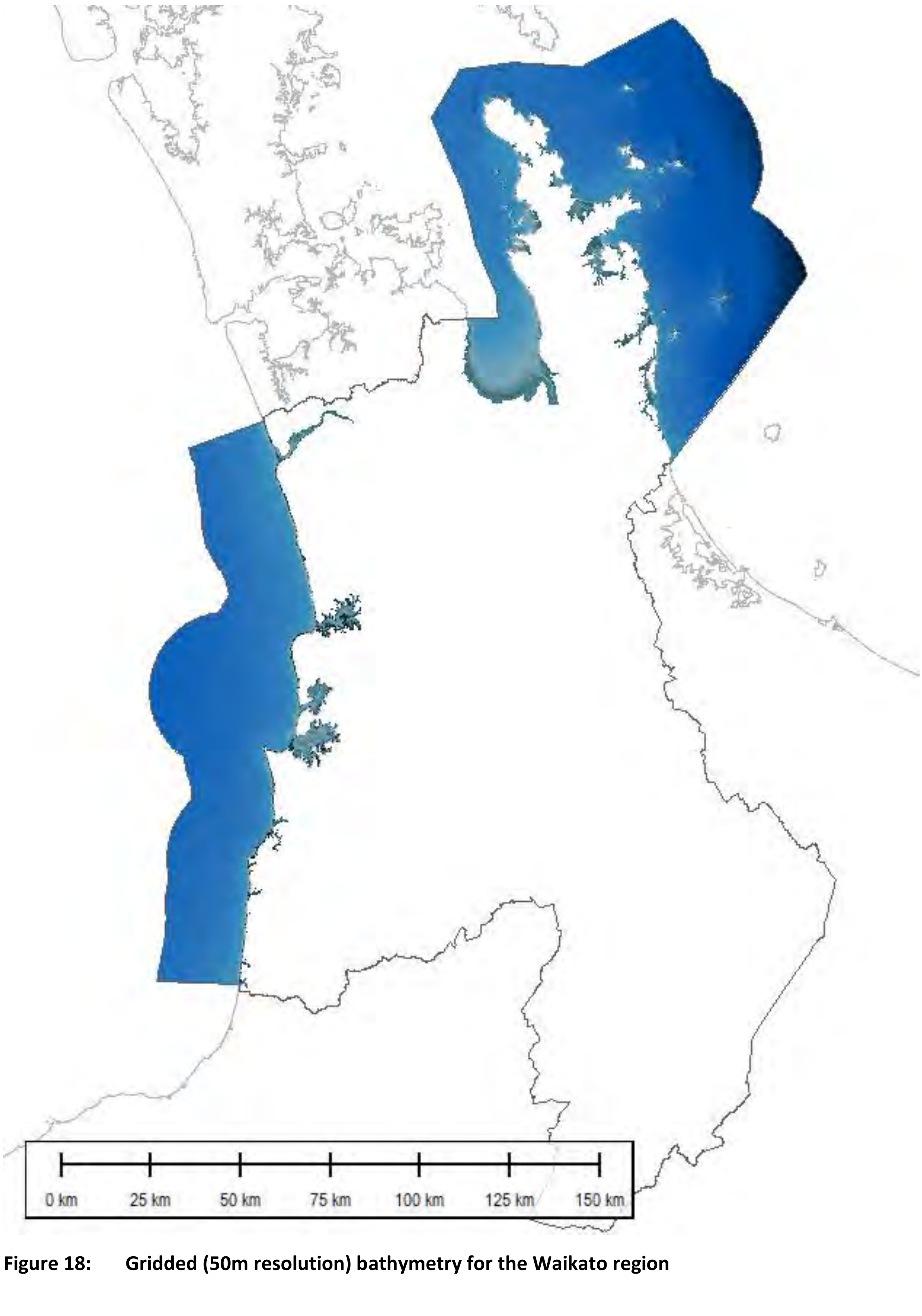


Figure 18: **Gridded (50m resolution) bathymetry for the Waikato region**

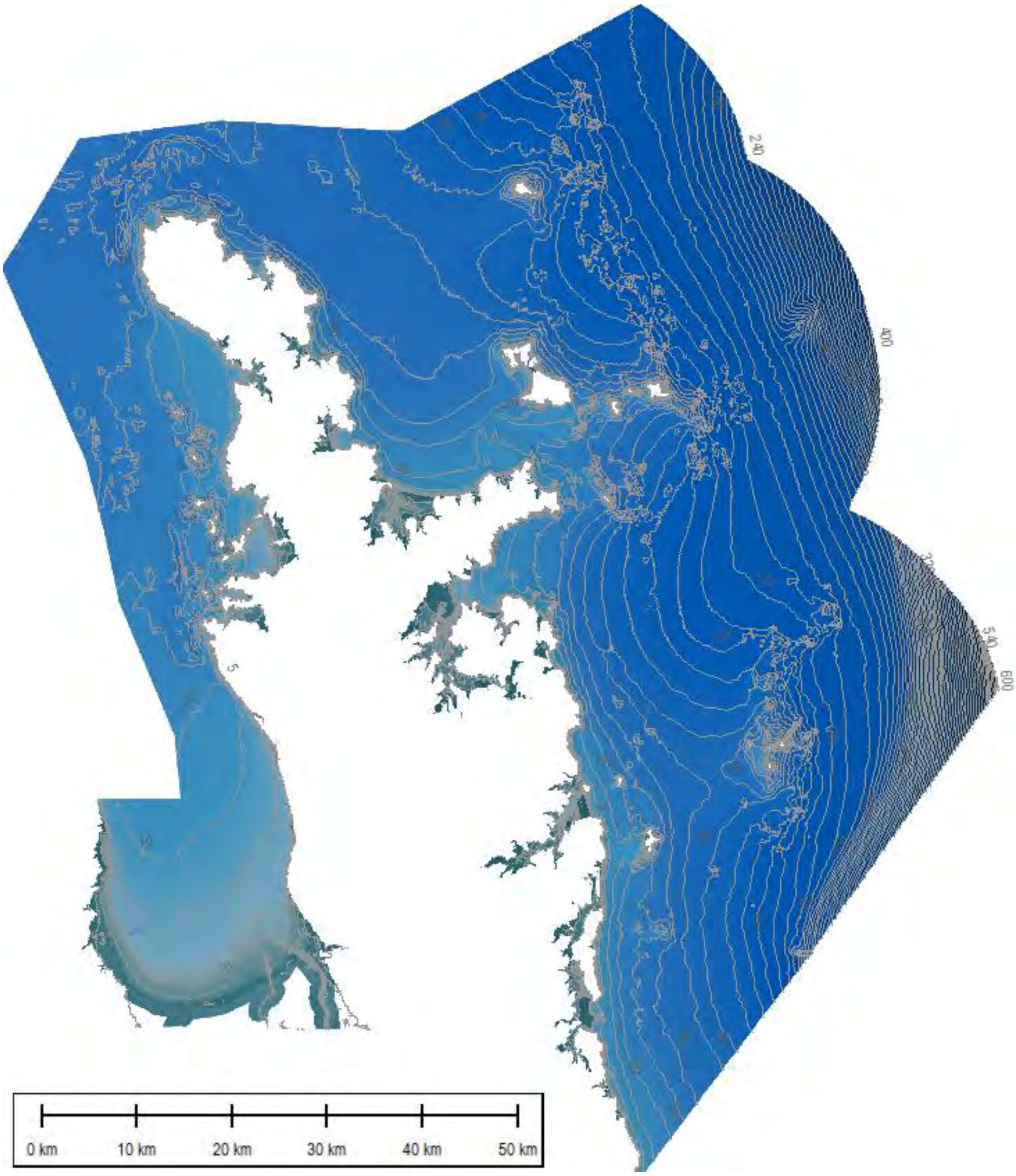


Figure 19: **Contours produced from gridded (50m resolution) bathymetry for the east coast Waikato region**

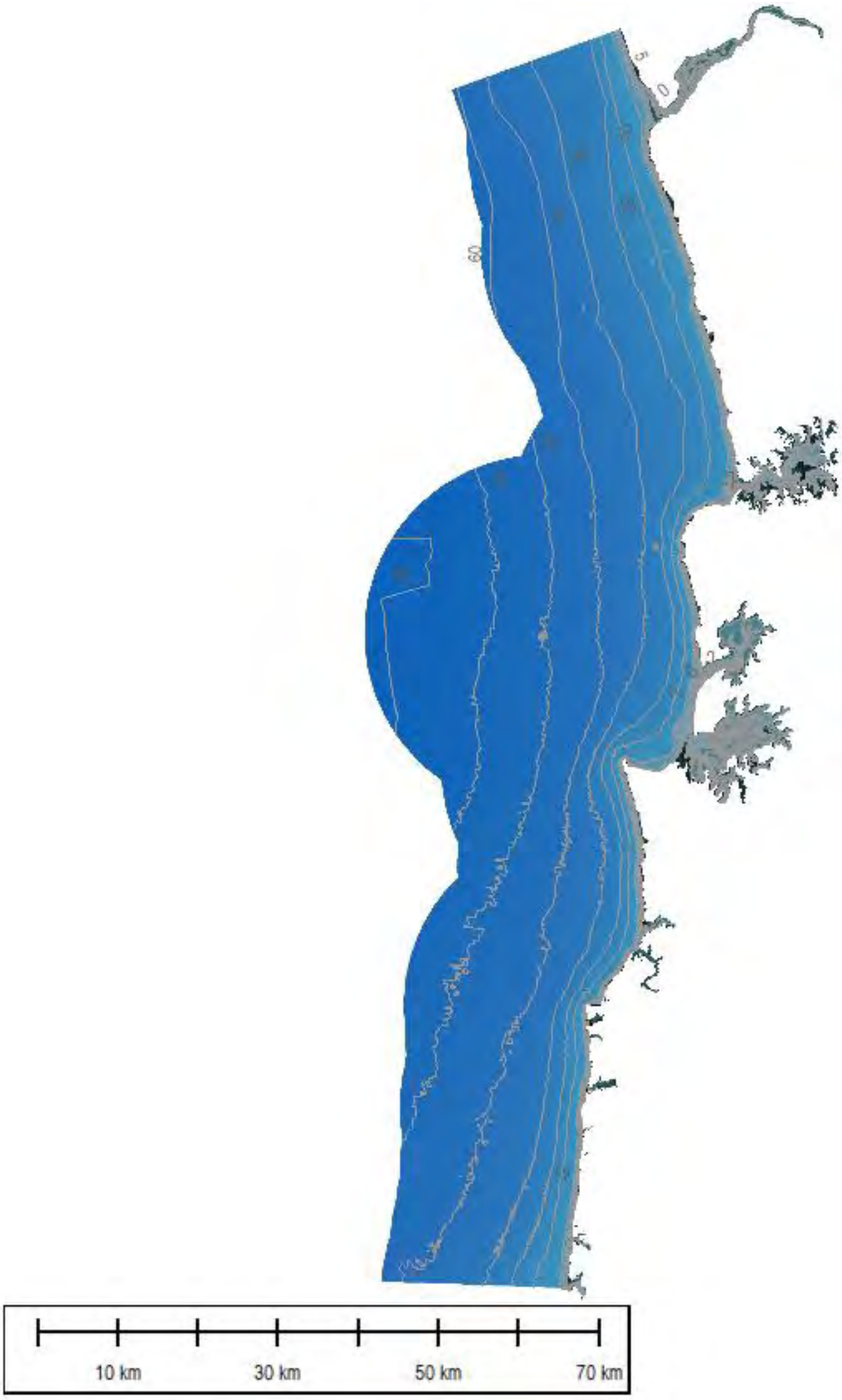


Figure 20: Contours produced from gridded (50m resolution) bathymetry for the west coast Waikato region

The difference in both the quantity and quality of data available for the east and west coasts will significantly affect the accuracy of the resulting bathymetric datasets. One area particularly offshore of the west coast (Figure 2), for which some areas do not even have soundings available.

Future data collection could be targeted using the rocky reef layer to identify areas of interest, either in terms of biodiversity or bathymetry.

3.2 Rocky reefs

Shapefile datasets were produced to show the extent and confidence of the rocky reef locations for both the east and west coat of the Waikato Region (Figure 21 and Figure 22).

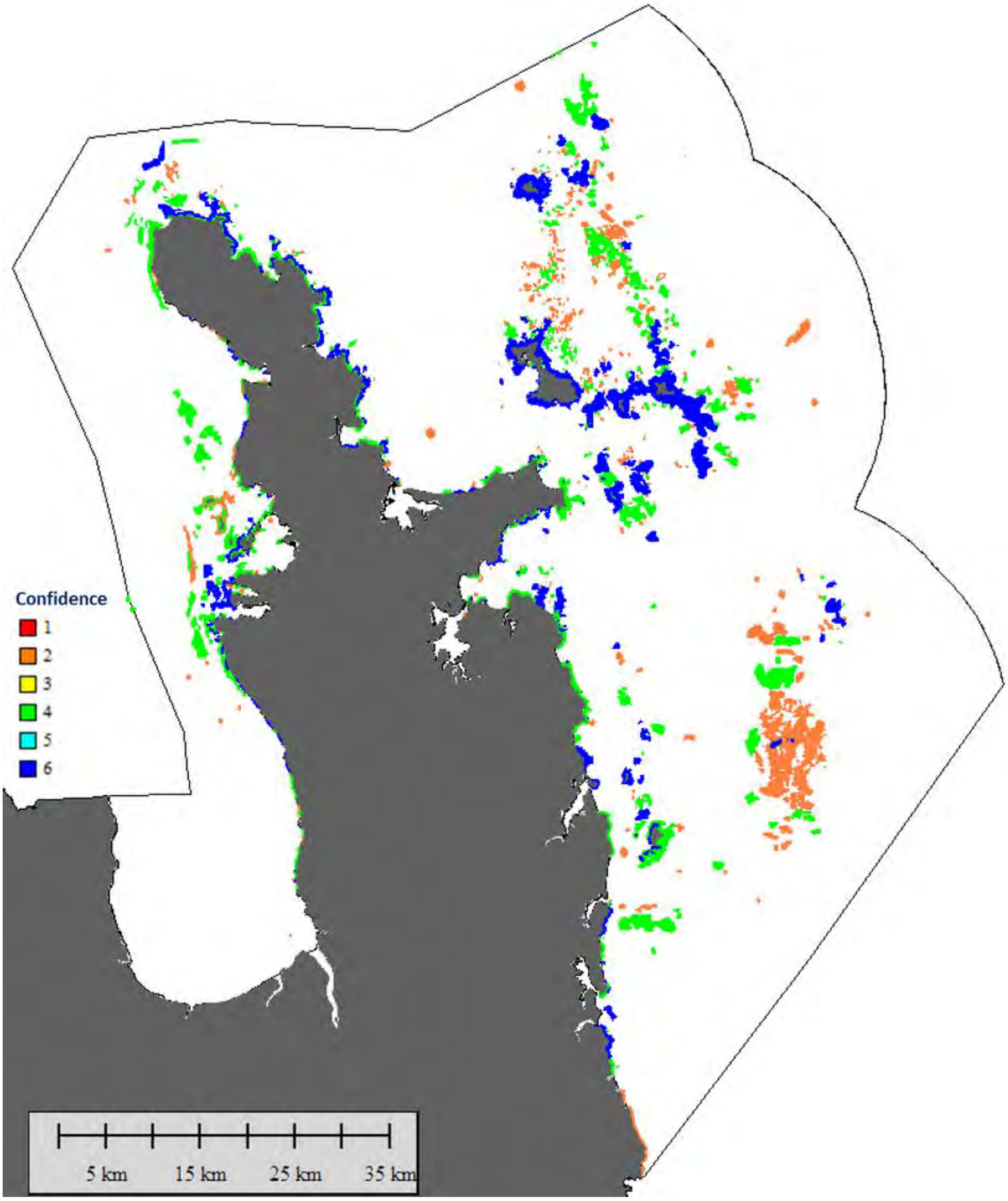


Figure 21: Rocky reef extent and confidence level for the Waikato region east coast

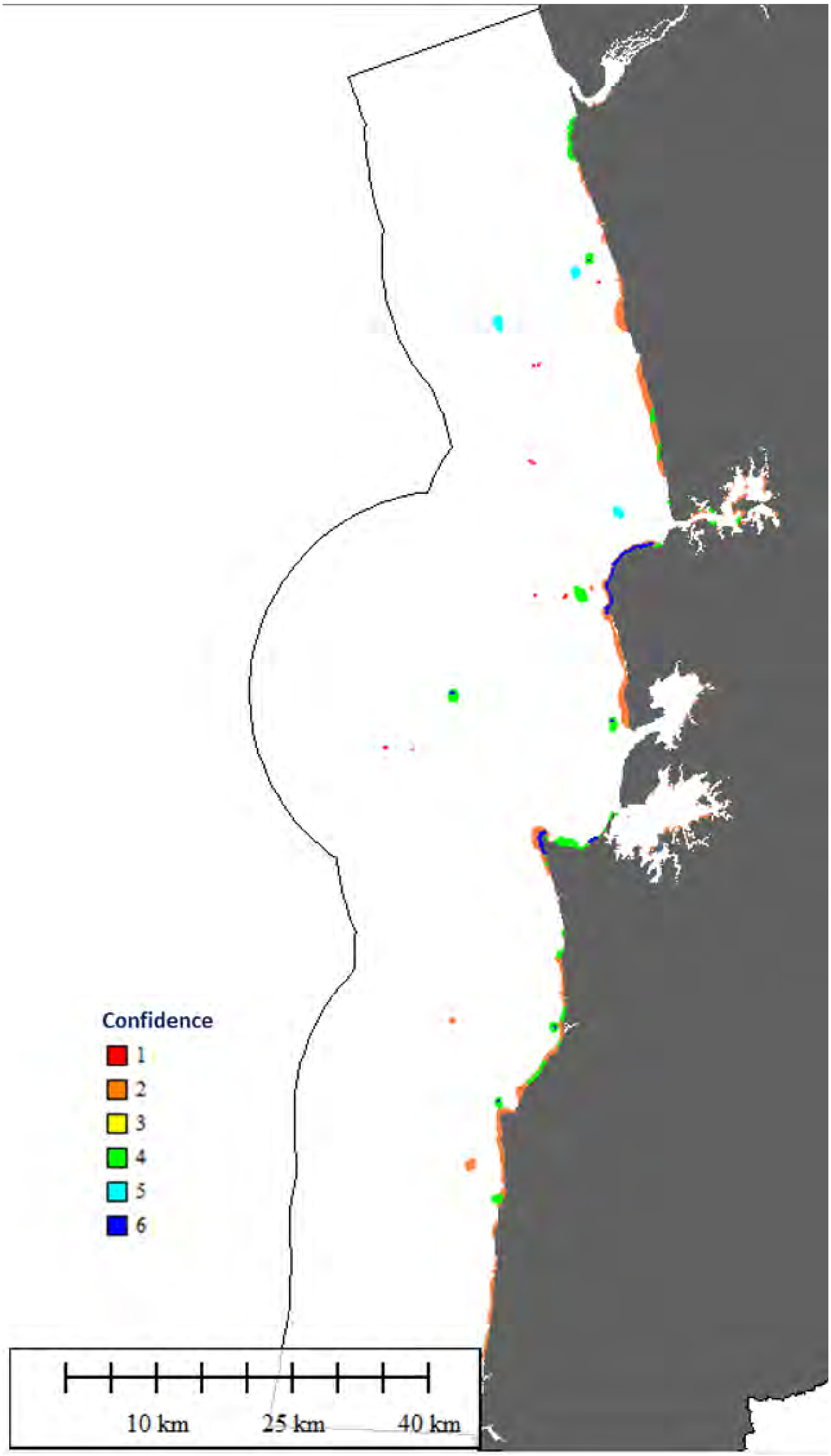


Figure 22: **Rocky reef extent and confidence level for the Waikato region west coast**

Large areas of rocky reef can be seen on the east coast, with a fairly high level of confidence of their extent and location. Some areas were missing from the high quality multibeam data available and could be a good candidate for further multibeam surveys to increase confidence, particularly around the Alderman Islands.

On the west coast limited high-quality data exists and hence the reefs mapped are subjected to a lower confidence level. In this region the locations identified through the fisherman interview would be useful to be mapped; in many cases these areas have never been identified as rocky reefs in any previous studies and are not even included in the sounding sheets. Anywhere potentially identified as a rocky reef but with a low confidence score would be worth further investigation as these areas are potentially of high ecological value for the west coast.

3.3 Soft substrates

Final data layers include an interpolated Folk scale sediment layer, shown in Figure 23 and Figure 24 for east and west coasts, and a more general broad scale sediment dataset, Figure 25 and Figure 26 (Folk_Broad).

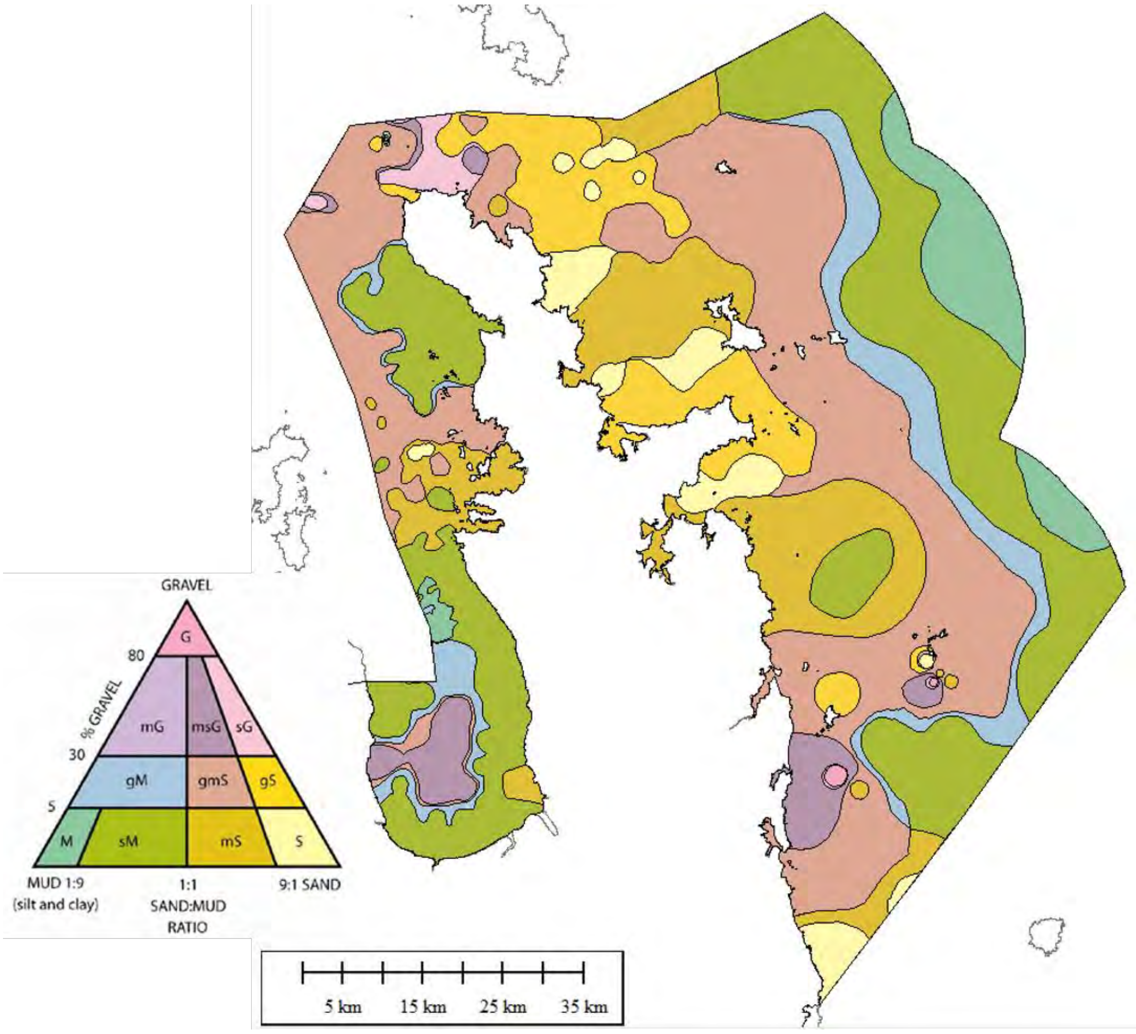


Figure 23: Surficial sediment map for the Waikato region east coast

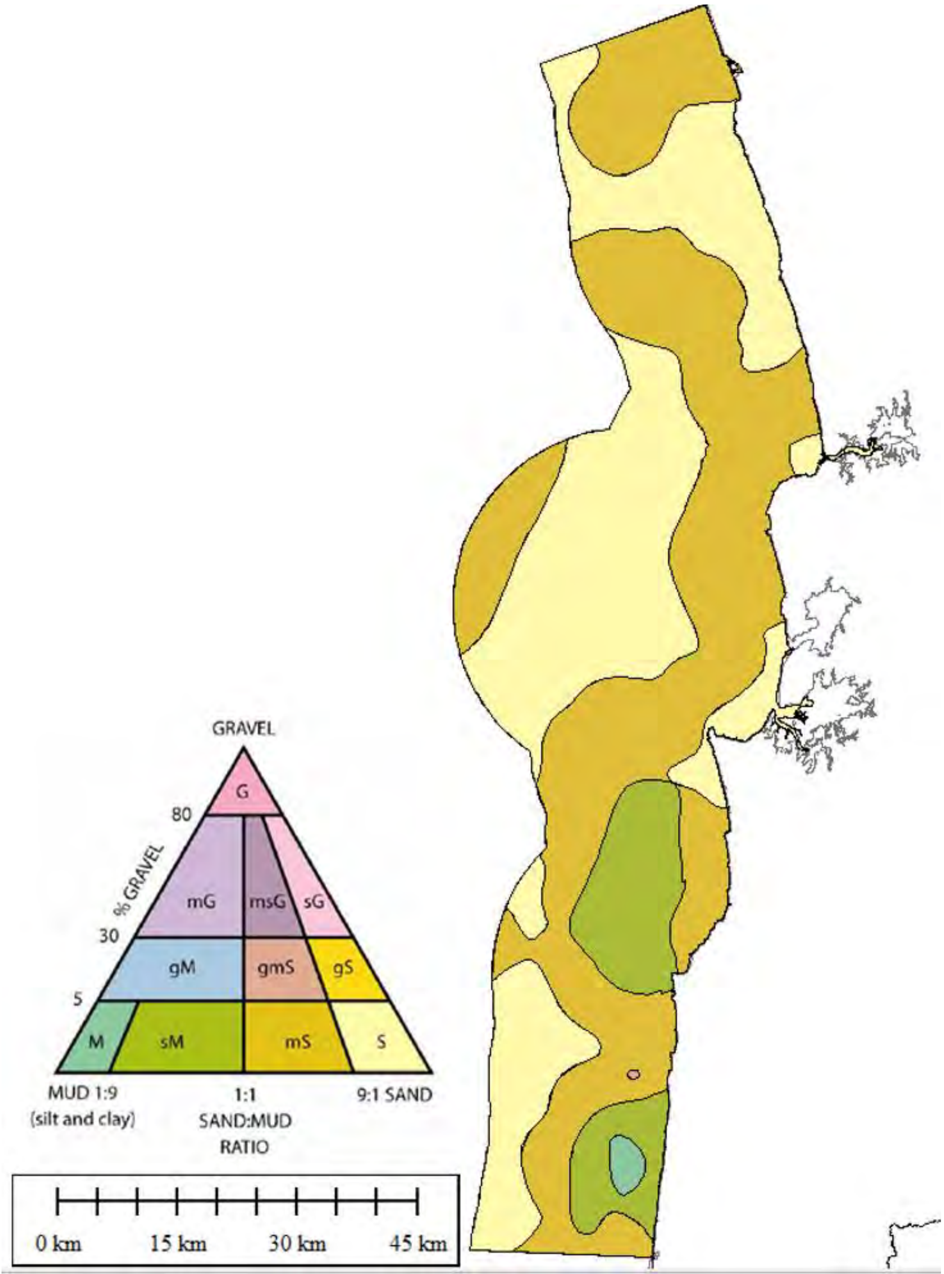


Figure 24: Surficial sediment map for the Waikato region west coast

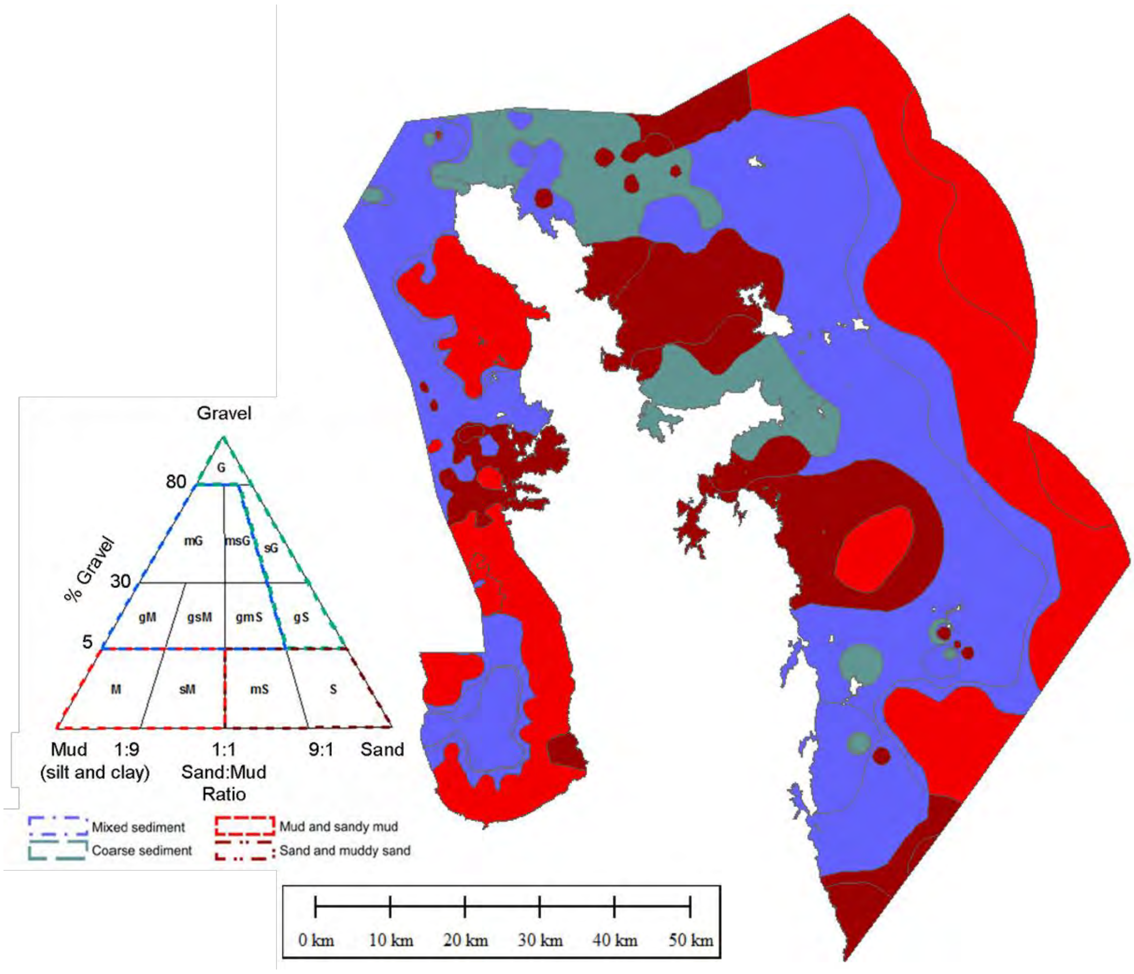


Figure 25: **Broad scale surficial sediment classification for the Waikato region east coast. Surficial sediment classification based on Folk (1954) and broad scale classification modified from Long (2006). Uppercase letters indicate largest proportion; lowercase letters indicate qualifiers.**

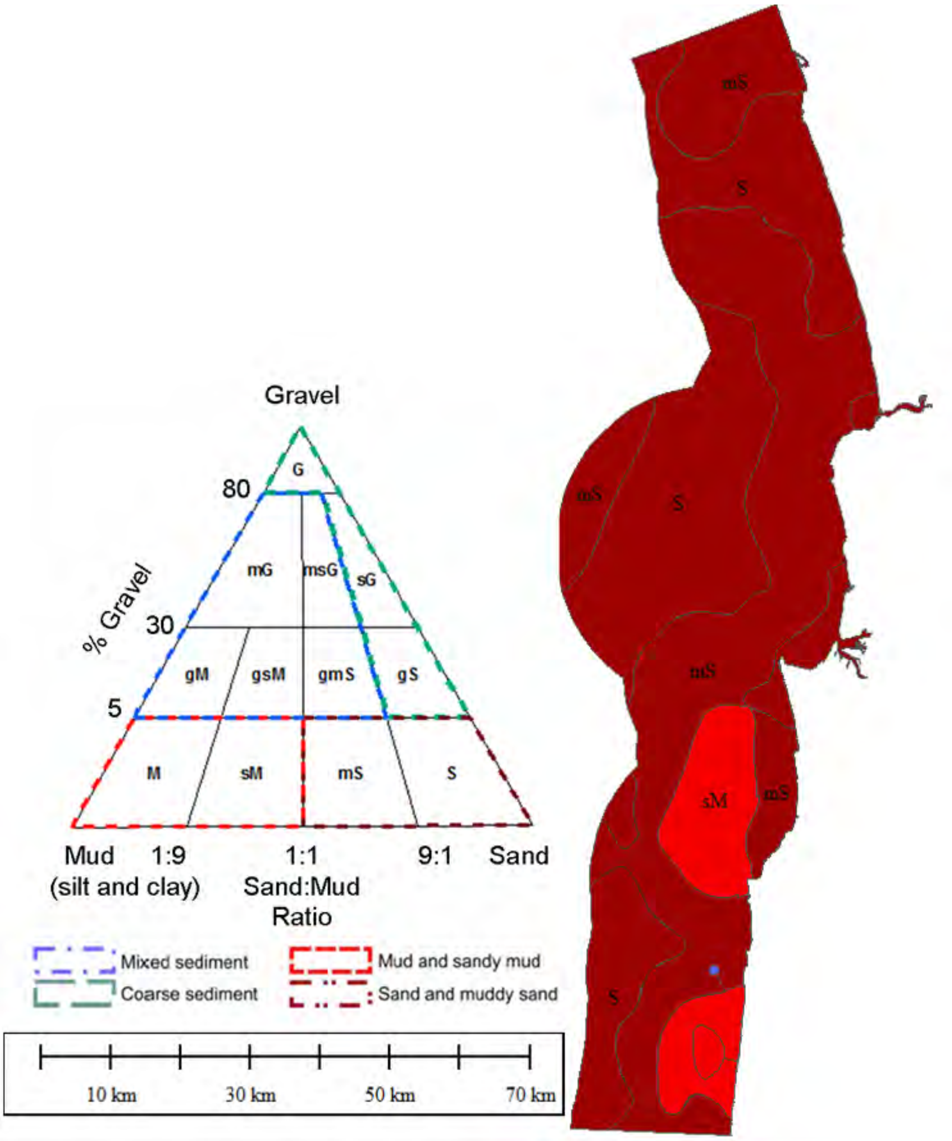


Figure 26: **Broad scale surficial sediment classification for the Waikato region west coast. Surficial sediment classification based on Folk (1954) and broad scale classification modified from Long (2006). Uppercase letters indicate largest proportion; lowercase letters indicate qualifiers.**

The spatial layers presented in this report are highly susceptible to errors due to the sparse spread of available data; however, they do provide a baseline of current knowledge, highlight potentially ecologically valuable areas, and high priority areas for further data collection, with the long-term view of improving our knowledge of the Waikato Region CMA.

Although it was hoped to include intertidal data, the limited datasets available made this unfeasible. The spatial variability of sediments in shallow and intertidal regions is dependent on many environmental factors, including depth, slope, current speed, tidal asymmetry etc. Where large numbers of sediment samples exist along with maps of these environmental factors a co-kriging method can be used (Jerosch, 2013; Verfaille et al., 2006). However, in this region the data simply did not exist to perform the analysis. Therefore, further sediment sampling in the intertidal areas (such as in estuaries) may make this kind of analysis feasible in the future.

The subtidal environment of the west coast appears to be dominated by sands and muds in varying ratios, whereas the east coast is a much more complex patchwork of sands, muds and gravels. The offshore region of the west coast has a reasonable spread of sediment samples (Figure 15) as does the Firth of Thames, however the sample points in the offshore region of the east coast is much sparser, potentially due to the deeper waters off this coast restricting data collection.

Quality of available data was also an issue; the metadata was sometimes missing making the dataset unusable, or the method used to classify the data was incompatible with a quantitative method using sediment grain size and ratio percentages. These datasets were usually a result of quick intertidal surveys were the sediment was simply described and were suitable in the context of the original study, but in the long-term made the data less useful for other purposes. This highlights the need for collection and storage of data and metadata by standard protocols, which can ideally be used for multiple purposes.

3.4 GIS layers

The GIS data layers produced for this project and described in sections 3.1 to 3.3 above, are summarised in Table 2.

Table 2: Summary of bathymetry and substrate GIS layers produced for this project

Layer	Data type	File name
Bathymetry grid	Raster	Waikato_0.0005_NZVD2016_NZTM.grd
Bathymetry contours	Shapefile	All_Contours_0.0005_LocalVD_NZTM.shp
Bathymetry sources	Shapefile	BathySource_guide.shp
Rocky reefs (extent and confidence score)	Shapefile	East and West Rockyreefs.shp
Soft substrate (Folk scale and broad-scale classifications)	Shapefile	All_subtidal_sediment_polygon.shp (N.B. This includes intertidal areas for the east coast, but not the west coast)

4 Recommendations

This report summarises the state of knowledge of seabed habitats (bathymetry and substrate type) within the entire Waikato region CMA. Unfortunately, due to limited data availability intertidal sediments on the west coast could not be included. Several recommendations have arisen from this project and are outlined below.

Broadly, as a general comment on data management, data sources were spread across many different organisations, stored in many different formats and in some instances metadata had been lost, rendering the data much less useful. A concerted effort is needed (across New Zealand) to catalogue what exists and to collate and store this data appropriately.

More specific recommendations that can improve our knowledge of the seabed habitats in the Waikato region CMA include:

- The waters around the Alderman Islands on the east coast have not been comprehensively surveyed and so the extent of the reefs there have a low confidence score. These would require singlebeam in the shallow regions and potentially multibeam in deeper areas.

- In terms of bathymetry one of the key areas that had limited data was Aotea Harbour on the west coast; this harbour is considered of high ecological and cultural importance and the vast intertidal areas are important for seagrass, shellfish and shorebirds (Hillock and Rohan, 2011). Some singlebeam exists for the main channels but there is limited data around the mouth of the harbour.

- There were large areas offshore of the west coast without survey or sounding data, and so there is scope for further investigation of areas identified here as likely rocky reefs. This could initially involve drop camera surveys followed by single beam or multibeam to map the exact location and extent. Focus should be given firstly to the sites identified through the fisherman interviews, as well as any other low confidence sites. Following this, areas of known rocky reef could be surveyed to assess the quality and nature of the habitat and determine if they are high value habitats.

- Collection of data on intertidal sediments on the west coast would address the current data gap.

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