Chapter 3
Integrated Sediment Habitat Mapping for Aquaculture Zoning

3.1 INTRODUCTION

In selecting AMAs within the coastal marine environment there is a need to be informed of relevant environmental parameters in order to provide the greatest opportunity for a genuinely sustainable aquaculture industry. Bivalve aquaculture has the potential to modify the benthic environment through the settling of live bivalves, broken shells, faeces, pseudo-faeces and farm debris. The relative influence of each is dependent upon factors such as culture methods, benthic habitat, sediment character, water depth, current regime, *etc*. While these inputs to the benthic environment are in many ways unavoidable, careful management with appropriate data collection and analysis at the planning stages can aid in mitigating potential impacts through intelligent placement of AMAs.

Previous research, detailing impacts on benthic environments of bivalve aquaculture has highlighted organic enrichment (Kaspar *et al.*, 1985; Hatcher *et al.*, 1994; Kaiser *et al.*, 1998; Cranford *et al.*, 2003; Hartstein and Rowden, 2004), enhanced nutrient regeneration through the remineralisation of organic material (Dahlback and Gunnarsson, 1981; Tenore *et al.*, 1982; Kaspar *et al.*, 1985; Gibbs *et al.*, 1992, Hatcher *et al.*, 1994; Grant *et al.*, 1995), development of anaerobic and acidic conditions (Dahlback and Gunnarsson, 1981; Tenore *et al.*, 1982; Kaspar *et al.*, 1985), and the physical effects of smothering, coverage and build-up of deposits on the seabed (Dahlback and Gunnarsson, 1981; Grant *et al.*, 1995; Mitchell, 2006). Changes in benthic community structure have also been observed, including changes in dominant organism and both increases and reductions in overall species biodiversity (Pearson and Rosenburg, 1978; Dahlback and Gunnarsson, 1981; Tenore *et al.*, 1982; Kaspar *et al.*, 1985; Chivlev and Ivanov, 1997; Grant *et al.*, 1995; Stenton-Dozey *et al.*, 1999; Crawford *et al.*, 2003).

Planning to mitigate these impacts requires a detailed and reliable understanding of the nature, extent, and characteristics of existing benthic environments.

3.2 MOTIVATION AND RELEVANCE TO THESIS OBJECTIVES

With a worldwide increase in shellfish aquaculture (FAO, 2002) and a growing awareness of its potential environmental impacts (Kaiser, 2001) there is a clear need to ensure that any possible effects are minimised and mitigated efficiently. Mapping and delineation of benthic habitats on the continental shelf are essential for coastal and marine managers who must ensure that activities carried out within this zone such as aquaculture, dredge tailing dumping, and sand mining do not adversely affect critical habitats. Thematic mapping of the benthic environment is therefore essential in protecting critical habitats and ensuring the sustainable use of marine resources.

The range of observed impacts of bivalve aquaculture on the benthic environment naturally leads to an analysis within the planning stages of finding the location best suited to minimise negative impacts on the benthos. A detailed, up-to-date and accurate assessment of the sedimentary and benthic habitats throughout the Bay of Plenty is vital to ensuring that any AMAs within the region are sited above non-unique, non-significant benthic habitats or sedimentary environments. In addition, areas of relative suitability (in terms of the benthic environment) need to be identified in order to best mitigate potential impacts of an aquaculture development. Until now, relatively little knowledge exists of shelf benthic environments within the Bay of Plenty and the only data available comprise either large scale charts interpolated from sparse datasets (*e.g.* McKnight, 1969; Doyle *et al.*, 1979) or disconnected local-scale detailed observations (*e.g.* Healy *et al.*, 1991; Hogan, 1992; Duffy, 1998; Hopkins and Robertson, 2001; Cole *et al.*, 2003).

3.2.1 CHAPTER AIMS

This chapter aims to:

- gather benthic habitat information for the purposes of aquaculture zoning within the Bay of Plenty;
- identify benthic habitats or communities which are of particular scientific or ecological significance (such as reef communities); and
- determine the suitability of the benthic habitats and environments to sustain the additional inputs resulting from bivalve aquaculture (specifically *Perna canaliculus*), thus allowing the preferential positioning of AMAs over areas of low conservation value and where impacts to the benthic environment are minimised.

The study intends to provide some of the essential information required to ensure that any open-coast suspended bivalve aquaculture undertaken within the Bay of Plenty is located with environmental sustainability in mind.

3.3 BACKGROUND: POTENTIAL EFFECTS OF AQUACULTURE ON THE BENTHIC ENVIRONMENT

3.3.1 ORGANIC ENRICHMENT OF SEDIMENTS

Mussel farms can modify the benthic environment. The filtering action of dense bivalve populations effectively diverts primary production energy from pelagic areas toward benthic food webs. In addition, it results in the packaging of fine suspended material into larger faeces and pseudo-faeces which rapidly settle to the seabed, especially under conditions of limited water flow (Cranford *et al.*, 2003). Though the specific dynamics of bivalve faeces/pseudo-faeces deposition (settling velocity, dispersal, resuspension) is relatively poorly understood, enhanced sedimentation and organic enrichment is well documented (Hatcher *et al.*, 1994; Cranford *et al.*, 2003; Hartstein and Rowden, 2004).

The fall out of the largely organic faeces and pseudo-faeces from cultured shellfish can create significant bio-deposition loadings on sediments, given the specific stocking densities of the site (Mitchell, 2006), along with other factors such as current speeds, depth, and food availability (Chamberlain *et al.*, 2001; Costa and Nalesso, 2006). The sedimentation of these bio-deposits can lead to organic enrichment of the sea floor (Kaspar *et al.*, 1985; Kaiser *et al.*, 1998; Inglis *et al.*, 2000), enhanced nutrient regeneration through the remineralisation of organic material (Dahlback and Gunnarsson, 1981; Tenore *et al.*, 1982; Kaspar *et al.*, 1985; Gibbs *et al.*, 1992; Hatcher *et al.*, 1994; Grant *et al.*, 1995; Ogilvie *et al.*, 2000), development of anaerobic and acidic conditions within the sediment profile (Dahlback and Gunnarsson, 1981; Tenore *et al.*, 1982; Kaspar *et al.*, 1985) and the physical effects of smothering, coverage and build up of deposits on the seabed (Dahlback and Gunnarsson, 1981; Grant *et al.*, 1995; Mitchell, 2006).

Deposition rates as high as 10 cm/yr of combined bio-deposits and shell litter have been measured from bivalve aquaculture sites in sheltered environments (Dahlback and Gunnarsson, 1981; Mattson and Linden, 1983). Reported ranges for the increase in organic material within sediments as a result of bivalve aquaculture vary from six fold (Feuillet-Girard *et al.*, 1994 in Mitchell, 2006), 2.3 - 3 times (Dahlback and Gunnarsson, 1981; Grant *et al.*, 1995; Chivilev and Ivanov, 1997), to no significant changes (Grant *et al.*, 1995; Chamberlain *et al.*, 2001; Crawford *et al.*, 2003; Costa and Nalesso, 2006; Mallet *et al.*, 2006). Increases in the organic content of sediments beneath bivalve aquaculture sites has been shown to be the cause of changes in benthic community structure (Levin and Gage, 1998). Sediment organic content, which is strongly linked to sediment particle size (Milliman, 1994), itself often a function of hydrodynamic regime (Dunbar and Barret, 2005), has also been shown to be negatively correlated with benthic in-faunal species richness (Levin and Gage, 1998).

3.3.2 ADJUSTMENTS IN BENTHIC COMMUNITY STRUCTURE

Changes in community structure within and on top of the seabed beneath bivalve aquaculture sites have been observed due to both organic enrichment of the sediments from falling bio-deposits (Pearson and Rosenburg, 1978; Dahlback and Gunnarsson, 1981; Tenore *et al.*, 1982; Kaspar *et al.*, 1985; Chivilev and Ivanov, 1997; Inglis *et al.*, 2000), and also due to the fallout of shell litter (Kaspar *et al.*, 1985; Grant *et al.*, 1995; Stenton-Dozey *et al.*, 1999; Crawford *et al.*, 2003). Where these changes in community structure have been attributed to organic enrichment, an increased abundance of opportunistic species such as deposit feeding polychaete species is often noted (Tenore *et al.*, 1982; Mattson and Linden, 1983; Kaspar *et al.*, 1985; Levin and Gage, 1998; Buschmann *et al.*, 1996; Chivlev and Ivanov, 1997; Stenton-Dozey *et al.*, 1999; Crawford, 2003; Hartstein and Rowden, 2004). The increased abundance of opportunistic deposit feeders is often at the expense of overall local benthic biodiversity (Pearson and Rosenburg, 1978; Kaspar *et al.*, 1985).

The fallout of shell litter from bivalve aquaculture sites can also induce changes in benthic macro-faunal species composition. Both Grant *et al.* (1995) and Stenton-Dozey *et al.* (1999) observed an increasing dominance of scavenging gastropods, feeding on fallen mussels. Kaspar *et al.* (1985) noted some differences between species composition beneath mussel farms and at reference sites which were attributed to fallen shell material in addition to changes resulting from organic enrichment. Crawford *et al.* (2003) determined that fallen shell material was the main influence at their sites rather than organic enrichment of the sediments.

3.3.3 INTERPRETING THE DISPARITY OF IMPACTS

Clearly the magnitude and specific details of observed impacts of bivalve aquaculture on the benthic environment varies greatly between sites. Relatively rapid water currents are generally cited as the main contributing influence minimising organic enrichment of sediments beneath the farms (Pearson and Rosenburg, 1978; Buschmann *et al.*, 1996; Kaiser *et al.*, 1998; Chamberlain *et al.*, 2001; Hartstein and Rowden, 2004; Costa and Nalesso, 2006; Mitchell, 2006). The currents act to enhance the dispersal of the falling bio-deposits and spread the fallout over a much greater area. Hartstein and Rowden (2004) observed a clear difference between sites with low relative hydrodynamism and accompanying fine sediments (9.1 ϕ, 0.002 mm) where organic enrichment, deposition of shell litter, and subsequent changes in species composition were recorded, and sites with relative energetic regimes and accompanying coarse sediments (4.4 ϕ, 0.047 mm), where no such changes occurred. In contrast, Kaspar *et al.* (1985) observed higher sediment organic contents, along with associated changes in species composition at a site with ‘strong tidal currents’. In addition to the hydrodynamic regime, specific stocking densities of the farm (Chamberlain *et al.*, 2001; Crawford *et al.*, 2003; Mallet *et al.*, 2006), water depth (Chamberlain *et al.*, 2001), and the food availability of the mussels (Chamberlain *et* *al.*, 2001; Mitchell, 2006) have also been cited as potential explanations for the range in observed impacts.

The natural benthic environment at the site plays a key role in defining the magnitude of any potential impacts. Depositional impacts from an aquaculture site will depend in part on the existing habitat type, *e.g.* a rocky reef community will be more affected than a soft muddy sediment community. Soft sediment areas with a diverse benthic community will be able to break down sedimented material more efficiently and effectively than areas lacking a range of benthic organisms (Mitchell, 2006). Mallet *et al.* (2006) identify the natural concentration of organic matter in the sediment as an important factor in assessing the potential impacts of shellfish culture; sediments with little natural organic content are unlikely to be able to cope with additional inputs from an aquaculture development.

Given the reported variability in potential impacts and the various factors influencing them, we now undertake a detailed study of the Bay of Plenty benthic environment to identify its potential assimilative capacity for aquaculture waste materials.

3.4 METHODS OF SAMPLE COLLECTION AND ANALYSIS

3.4.1 SAMPLING REGIME

Sediment samples, underwater videography, and both in-faunal and epi-faunal organisms were collected from 13 shore normal transects extending from 10 m to 100 m depth for the purposes of identifying and classifying benthic environments and habitats (Figure 3.1).

Sediment samples, in-faunal and epi-faunal organisms, and underwater videography were obtained during two field exercises. Initially transects A and B were sampled from the University of Waikato research vessel *Tai Rangahau* on September 8/9, 2004 respectively. Subsequently, the vessel *MV Macy Gray* was used between December 6 and 9, 2004 to sample the remaining transects.

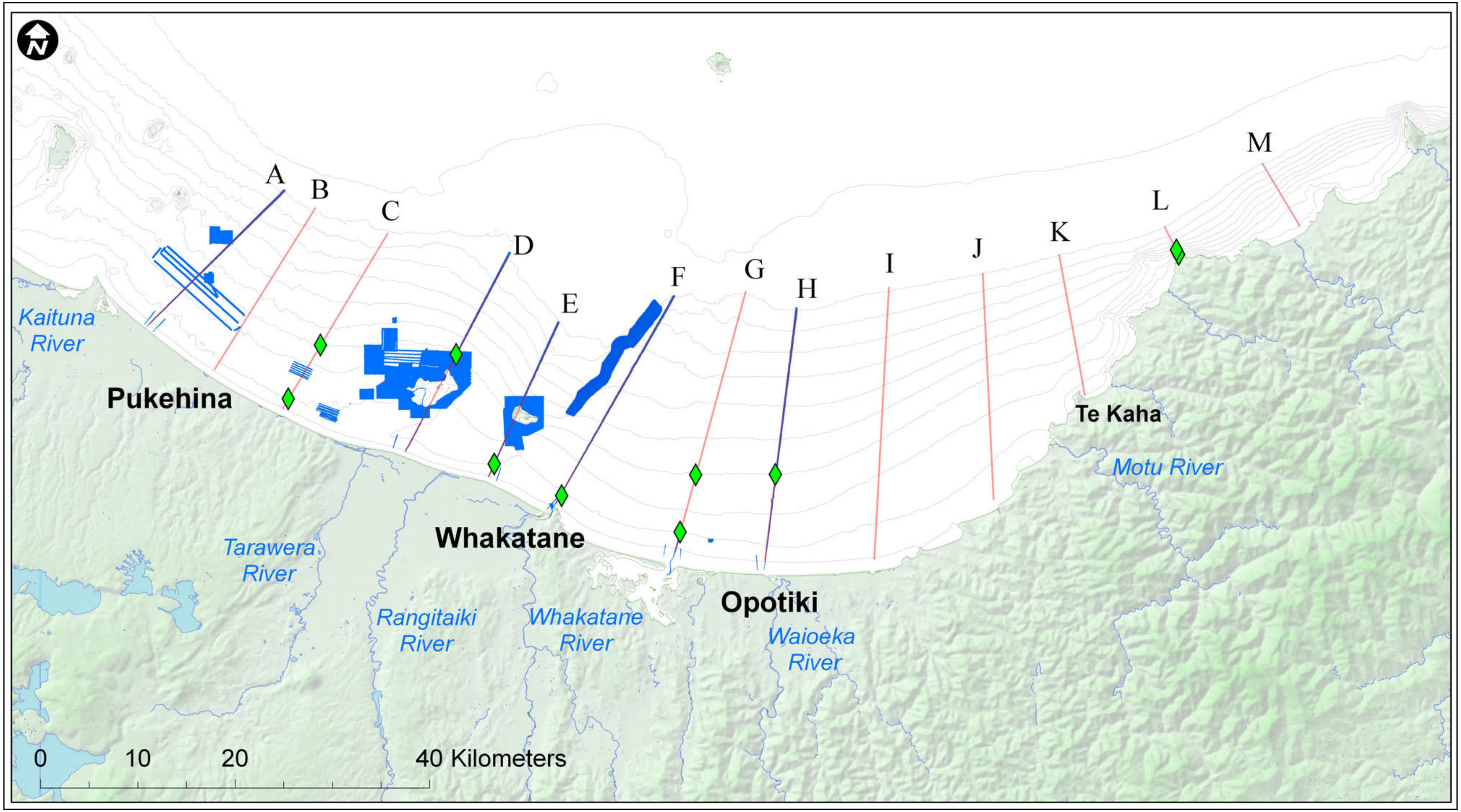

Figure 3.1 – Locality map of the Bay of Plenty transects (red, labelled A-M) used for sediment sampling, in-faunal organism sampling and underwater video. Sediment grab samples were obtained on each transect at 10 m depth contour intervals between 10 and 100 m. Underwater video was obtained on each transect at ~3 m depth contour intervals between 10 and 60 m, then at the 70 and 80 m depths also. Epi-faunal dredge tow locations are shown as green diamonds. The areas surveyed with the multi-beam echo-sounder are shown in blue. An accompanying CD-ROM contains details of specific sampling locations.

Sediment samples (n = 118) were obtained at each 10 m depth contour along the transect using a ‘SHIPEK’ grab sampler resulting in a mean sampling density over the shelf of one sample per 20 km^2. The shipek sampler is a center-pivot type sampler designed for use over a range of sediment substrates (*e.g.* McCave and Langhorne, 1982; Prior and Bornhold, 1989; Kimberly, 1990), and also to sample benthic epi-faunal and in-faunal organisms (*e.g.* Shackley and Collins, 1984; McCarthy *et al.*, 2004). Under optimal conditions the sampler obtains a sediment volume of 3000 mL from an area covering 0.04 m^2, with a bite depth of 102 mm (WILDCO, 2006). Some difficulty was experienced obtaining a full sample over hard packed sandy sediments. The sampler was not used when the video image indicated hard substrates. A sub-sample of the retrieved sediment, taken for grain size and organic content analysis, was placed in a labelled zip-lock bag on ice for subsequent analysis. The remaining sample was sieved through a 1 mm sieve, all organisms retained placed in a labelled sample jar and preserved in 5 % buffered formalin solution. Organisms were later classified to the lowest possible level at Leigh Marine Laboratory (University of Auckland) by graduate students (Mead *et al.*, 2005). Representative organisms were preserved and catalogued for future reference. Twelve successful dredge tows were conducted for epi-faunal organisms over distances ranging from 130 to 322 m at depths of between 20 and 40 m (Figure 3.1). The dredge tow has a mouth width of 760 mm, height of 115 mm, and 8 mm mesh. All organisms collected were preserved in 5 % buffered formalin solution and classified to the lowest possible level at Leigh Marine Laboratory.

A total of 200 video files were collected using a SplashCam® underwater camera unit connected to a Sony® digital video cassette recorder (GV-D800E) from the transects between 10 m and 80 m depth. Sixteen files were obtained on each transect between 10 m and 60 m depth, and then a file at each 10 m depth contour from 60 m to 80 m resulting in a mean sampling density over the shelf of one video per 12 km^2. The site identification code, depth, time, date, and Global Positioning System (GPS) co-ordinates were recorded on a whiteboard and videoed prior to each deployment. The camera was hand lowered with lights operating if necessary and the seabed recorded for a minimum of 60 seconds. It was originally proposed to use a sled to video the seabed along the transects from 10 to 50 m depths and the drop camera at deeper sites, however the abundance of patchy reefs encountered during the early surveys prevented the use of the sled, and a compromise was made with the densely spaced SplashCam® drops.

These methods recovered samples suitable for quantitative (sediment samples), semi-quantitative (in-faunal and epi-faunal ecology), and qualitative (videography) data on the seabed ecology and habitat types in the survey area. It is noted that due to the large area surveyed in comparison to the number and size of samples, these data have some limitations. However, these data provide base-line information over a large spatial scale, on the variety of organisms that inhabit the Bay of Plenty seabed, and also allow insights into the relative abundances and distributions of these organisms and their association with different physical seabed characteristics along the survey transects.

3.4.2 TECHNIQUES FOR DETERMINING GRAIN SIZE RELATIONS

Sediment grain size samples were initially treated with hydrogen peroxide (H_2O_2, 10%) to remove any organic material present (Day, 1965; Poppe *et al.*, 2000; Dane and Topp, 2002), prior to being analysed by either laser-sizer (n = 111) or mechanical dry sieving (n = 9) if particles larger than 1.0 mm were present. The use of two different methods to obtain grain size information is not optimal, though with the range of sediment sizes collected and available equipment was unavoidable. The strategy employed is detailed in Figure 3.2. While the laser-sizer is preferable due to its rapid and accurate analysis, the equipment available (Malvern Mastersizer-S 300RF) is limited to fractions between 1000 and 0.5 µm (Malvern, 1985). The less favourable method of mechanical dry sieving was used where particle sizes exceeded the range of the laser-sizer. This limitation is viewed as acceptable in these circumstances as it is the gross sediment parameters which are of interest, and only a limited number of samples (9) from a localised area of gravely sediments were analysed using sieving methods. Direct comparisons between population distributions determined by the differing methods should, however, be made with caution. Sieved distributions are weight based, in contrast to the volume based methods of the laser-sizer. The volume based distribution is equal to the weight based distribution only if the density of the particles is constant. Other key differences include the laser-sizer reporting the ‘equivalent sphere’ diameter (Rawle, 1995) as the output size for each individual grain, whilst the sieving method reports the minimum dimension of a particle (Sahu, 1965; Kennedy *et al.*, 1985). Thus, sieved distributions will be systematically finer than those analysed with the laser-sizer.

Samples analysed with the laser-sizer were subjected to ultrasonics for a minimum of 2 minutes prior to analysis to break up any clay aggregations. Sieved samples were dried in a convection oven for 12 hours at 90^{o}C prior to analysis. The large grain sizes and lack of clay sized particles in these samples prevented any agglomeration occurring during the drying process. The dried sediment (minimum 80 g) was then sieved through several banks of 200 mm diameter Endecotts® sieves conforming to ISO 3310. Sieve banks were arranged in 0.25 ϕ intervals (from -3.25 ϕ [9.52 mm] to 4.5 ϕ [0.044 mm]) and mechanically shaken with an Endecotts® Octagon 2000 digital shaker for a period of 10 minutes for each bank of sieves. Retained sediment on each sieve was weighed using a ‘Sartorius® Analytic AC2105’ electronic scale accurate to 0.001 g.

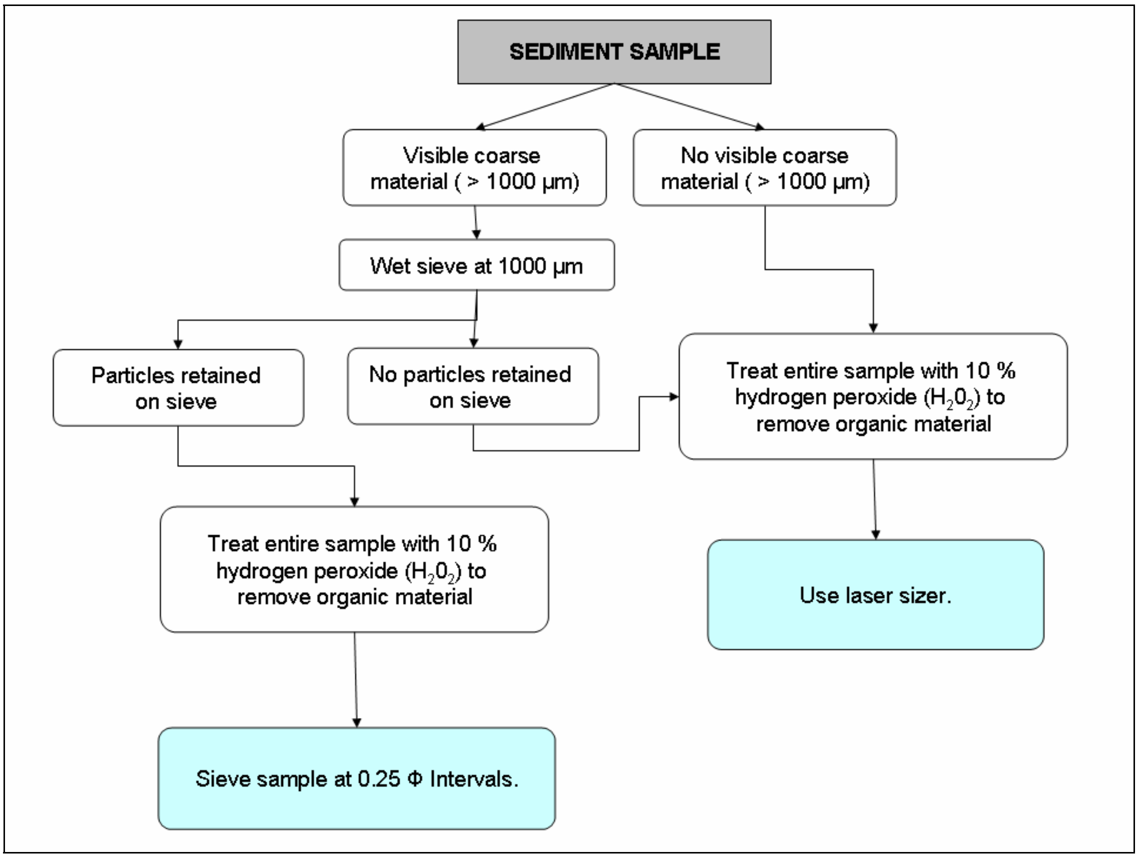

Figure 3.2 Flow chart of sediment grain size analysis methodology. Due to the variety of sediments collected two main analysis methods were required – laser sizing and mechanical sieving.

Moment based means, sorting, skewness and kurtosis were determined using custom written MATLAB® routines. Sediment characteristics were gridded within the rectangular co-ordinate system of the New Zealand Map Grid (NZMG1949) using Golden Software's SURFER® (v 7.0). A kriging algorithm was used to interpolate datasets over a grid resolution of 2000 m (East-West direction) and 1000 m (North-South direction). Areas of known rocky reef or boulder reef were excluded from these interpolations. While it is acknowledged that the interpolation of data across such distances will have inaccuracies over small scales, the method provides valuable information over larger scales and provided this is kept in mind is justifiable given the scale of the environment under study.

3.4.3 MEASUREMENT OF SEDIMENT ORGANIC CONTENT

Sediment organic contents, as Ash Free Dry Weights (AFDW) were determined by Loss On Ignition (LOI) methods at 500°C for a period of not less than 4 hours (Konrad *et al.*, 1970; Dean 1974; Heiri *et al.*, 2001). Initial dry weight determinations were made after drying sediments at 105°C for 24 hours and cooling in a dessicator (*e.g.* Hartstein and Rowden, 2004; Mallet *et al.*, 2006). Table 3.1 details the methodology used, which is similar to standard methods described by Dean (1974), Heiri *et al.* (2001) and Ballinger (2003).

Table 3.1 Methodology used to determine sediment organic content.

1	A ceramic or nickel crucible is cleaned, dried in an oven and left to cool in a desiccator
2	The crucible is weighed and the weight recorded
3	The sample (~8-10 g) is placed in the crucible and dried in an oven at 105°C overnight
4	The crucible (and sample) is removed from the oven and allowed to cool in a dessicator
5	The crucible (and sample) is weighed and the weight recorded
6	The crucible (and sample) is placed in a furnace at 500°C for a period not less than 4 hours
7	The crucible (and sample) is removed from the furnace and allowed to cool in a dessicator
8	The crucible (and sample) is weighed and the weight recorded

The difference between the post combustion (500°C) and pre-combustion dry weights is the amount of organic carbon ignited:

$$\mathrm{LOI}_{\mathrm{organic}}(\%) = \frac{\mathrm{DW}_{105} - \mathrm{DW}_{500}}{\mathrm{DW}_{105}} \times 100 \qquad \textbf{Equation 3.1}$$

where $\mathrm{LOI}_{\mathrm{organic}}$ is the Loss on Ignition at 500°C (as a percentage), DW_{105} represents the dry weight of the sample before combustion and DW_{500} is the dry weight of the sample after combustion. All crucibles and samples were weighed on a set of 'Sartorius® Analytic AC2105' electronic scales accurate to 0.001 g. This technique has been assessed to have a likely maximum error of 2% provided sample volumes, temperatures and exposure times are constant between the samples (Heiri *et al.*, 2001).

3.4.4 MEASUREMENT OF SEDIMENT CARBONATE CONTENT

The carbonate content of the sediment samples was determined by acid digestion (*e.g.* Morrisey *et al.*, 1998; Briere *et al.*, 1999; Poppe *et al.*, 2000). Whilst LOI at 950°C can also be used to determine carbonate content (Dean, 1974; Heiri *et al.*, 2001), the limitations of the available furnace prevented the application of this method. The method used (Table 3.2) followed that of Morrisey *et al.* (1998), Briere *et al.* (1999) and Poppe *et al.* (2000).

Table 3.2 Methodology used to determine sediment carbonate content.

1	Wash containers, dry in a dessicator and weigh
2	Place a subsample of the sediment (~5 g) in the container and oven dry at 105°C overnight
3	Remove sediment from the oven and allow to cool to room temperature in a dessicator, weigh the dry sediment
4	Manually remove any large shell material with tweezers
5	Cover sample with 25% acetic acid until no further effervescence occurs
6	Dry sediment in oven at 105°C overnight
7	Remove sediment from oven and allow to cool to room temperature in a dessicator
8	Weigh the dry sediment

The difference between the sediment dry weight post-acid digestion and the dry weight prior to acidification represents the amount of shell material:

$$\text{Carbonate } (\%) = \frac{\mathrm{DW}_{\mathrm{initial}} - \mathrm{DW}_{\text{post digestion}}}{\mathrm{DW}_{\mathrm{initial}}} \times 100 \qquad \textbf{Equation 3.2}$$

where ‘Carbonate (%)’ is the percentage of carbonate in the sample, $\mathrm{DW}_{\mathrm{intial}}$ is the initial dry weight of the sediment and $\mathrm{DW}_{\text{post digestion}}$ is the weight of the sediment after acid digestion.

3.4.5 INTERPRETATION TECHNIQUES FOR UNDERWATER VIDEOGRAPHY

Underwater videography was evaluated for habitat type/complexity (Table 3.3), with additional biogenic characteristics and any epi-faunal organisms observed being recorded. Representative clips (15 – 20 s) of each site (n = 200) were saved with positional information attached, for incorporation to a hyperlinked GIS viewer (see attached CD-ROM). The files were also used to ground truth the mutlibeam data surrounding reef areas and to classify reef and soft sediment habitats.

Table 3.3 Complexity scale and predominant habitat types used to classify the seabed within subtidal AMAs from underwater video (Mead *et al.*, 2003)

Complexity scale	Habitat type
0	Very fine muds and silts ,worm holes, disturbed sediment remains in suspension
0.25	Mainly mud/silt, some worm holes
0.5	Mixture mud/silt and fine sands
0.75	Very fine sand, may have ripples, small amounts of mud/silt
1	Sand
1.25	Sand with visible cobbles or rocks
1.5	Mainly sand with areas of rock
1.75	Rocks and cobbles inundated with sand
2	Bare rock and cobble reef
2.25	Rock and cobble reef with turf cover, sponges, small plant life
2.5	Rocky reef with some boulders and turf cover
2.75	Rock and boulder reef with turf cover, sponges and some plant life
3	Small boulder reef with turf cover, sponge and plant cover
3.25	Mixed boulder reef, turf and plant cover
3.5	Mixed boulder reef, dense plant cover
3.75	Mixed boulder reef, large rock outcrops, dense plant cover
4	Complex boulders, large wall, rocky overhangs, dense plant cover

3.4.6 COLLECTION AND ASSIMILATION OF MULTI-BEAM SONAR DATA

Multi-beam bathymetric data were collected by the University of Waikato at targeted sites within the study area during August 2005 aboard the *MV Macy Gray*, equipped with a Triton Imaging®/Simrad® EM3000 multi-beam bathymetric system. This system produces up to 127 beams arrayed over an arc of 130° and operates by ensonifying a strip of sea floor across track, and detecting the bottom echo with narrow across track listening beams (Kongsberg, 2006). The swath of sea floor imaged on each survey line was 5 to 6 times the water depth. Regular profiles of the speed of sound were obtained and the multi-beam unit adjusted accordingly, providing accuracy in the vertical plane of ±0.5 m. A Real Time Kinematics (RTK) GPS was used when available for navigation and incorporated into the multi-beam files, when the RTK system was offline Differential GPS (DGPS) was used, providing positional accuracy of ±2 m. Soundings were binned into 0.5, 1.0, and 1.5 m cells for depth ranges of 0-30 m, 30-60 m, and 60 m+ respectively to maintain manageable file sizes. Raster grids were created within the ArcGIS® platform.

Multi-beam data were collected from numerous locations throughout the region to delineate reef habitats, determine their morphologic structure and to increase the knowledge of the detailed bathymetry surrounding significant features within the Bay of Plenty. Due to the size of the study area, not all reef habitats within the Bay could be surveyed, the multi-beam investigation focused on offshore reef habitats in areas which are more likely to be proposed as aquaculture zones *i.e*. those in the middle of the bay, rather than the relatively inaccessible (for an aquaculture project) regions near Cape Runaway in the far east of the study area. Boundaries for these reefs have been digitised from 1:100,000 and 1:300,000 hydrographical charts (Linz, 1997 & 2002). Underwater videography was used to ground truth and classify the reef habitats depending on their degree of complexity. Bathymetric grids of each reef surveyed were created and incorporated into the GIS data viewer of benthic habitats within the Bay of Plenty (see accompanying CD-ROM). Snapshots are also provided in Figures 3.3-3.11.

3.5 RESULTS

3.5.1 PARTITIONING REEF HABITAT TYPES

Multi-beam bathymetric surveying of targeted areas within the study region clearly delineated the boundaries (Figure 3.3) and determined the detailed morphology of specific reef habitats which are of high preservation value (*e.g.* Figure 3.4). Reef habitats identified from the underwater videography (Table 3.3) included boulder reef with tall plants (*e.g. Ecklonia* spp.), patchy reef with small plants (*e.g. Carpophyllum* spp., *Xiphophoa* spp.), cobble and patchy reef unknown hard substrates (no underwater videography coverage), and reef areas digitised from charts (no multi-beam or videography coverage, Figure 3.3).

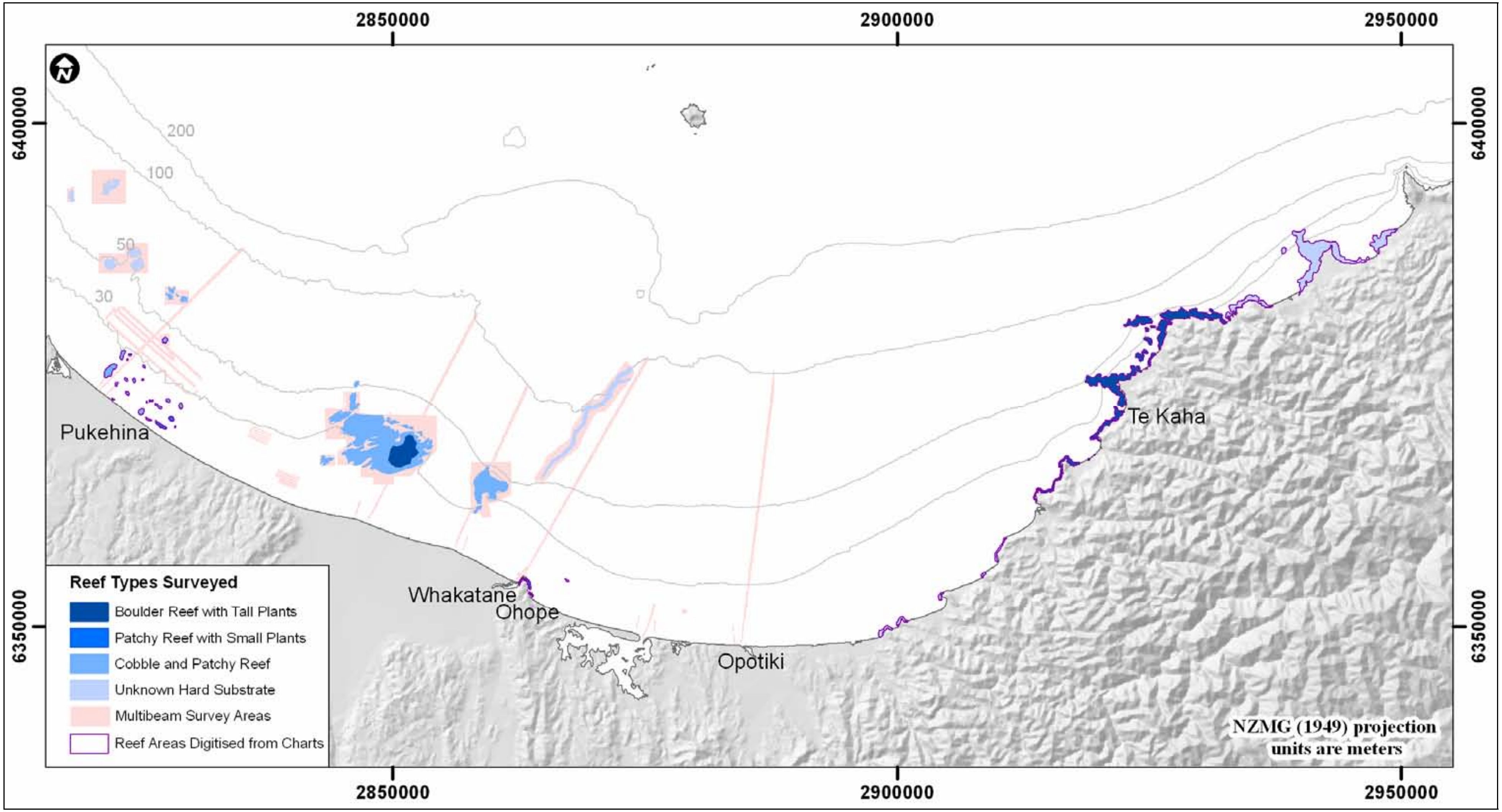

Figure 3.3 Reef areas within the Bay of Plenty. All areas surveyed with the multibeam sounder are shown in light red. Areas with purple boundaries indicate reef identified from digitising boundaries from hydrographic charts. Reef type determined from underwater video files.

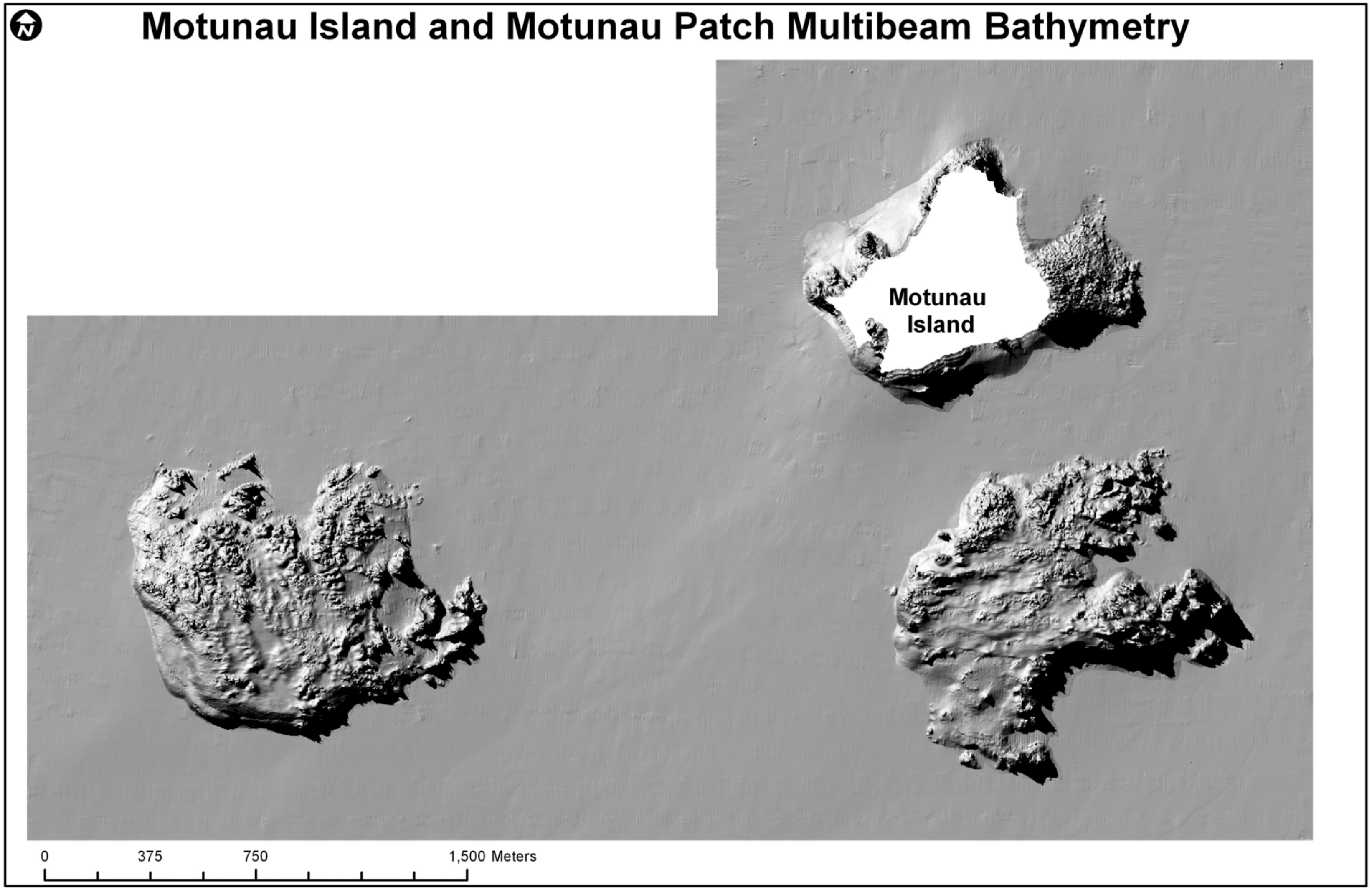

Figure 3.4 Multibeam bathymetry of Motunau Island and Motunau Patch. Vertical exaggeration of 5 times, illumination from 315^{o} and an angle of 45^{o} above the horizontal. These data were used to delineate specific extents of reef habitats and clearly define the morphology of the reef structures.

3.5.2 UNDERWATER VIDEOGRAPHY

Main trends observed from the underwater videography and multi-beam data included:

- rippled gravel and shell lag in depths of 10-40 m in western areas;
- fine sands and silts extending to shallow (~10 m) nearshore areas east of Whakatane;
- shallow (< 30 m) boulder type reefs typically have tall plant growth (*e.g.* Ecklonia radiate), characteristic of the entire east coast of the North Island (Shears and Babcock, 2003);
- deeper reef along transect L was covered with encrusting red algae and sponge (*e.g. Acorina alata* and *Cliona celata*), which are more typical of offshore island reef communities than mainland locations (Shears and Babcock, 2003).

Soft sediment habitat classifications from the underwater videography are in agreement with the six sites located within the Bay of Plenty from McKnight’s (1969) historical study of soft sediment communities surrounding New Zealand. McKnight (1969) observed sandy sediments in 22 m depth just east of Ohope (between transects F and G, Figure 3.5) while the other 5, between 26 and 99 m depths, were found to have muddy or mud-sand substrates. Hogan (1992) and Duffy (1998) conducted qualitative nearshore (< 20 m) surveys of benthic habitats in the areas of Te Kaha (between transects K and L) and between Opape and Matakaoa Point (transects H, I, J, K and L) respectively. Similar habitat types to the present underwater camera survey were found, with *Ecklonia radiata* covered boulder reef near the shoreline (compare to Figure 3.3) and silty sands present at depths greater than 10-15 m depths (Hogan, 1992; Duffy, 1998).

3.5.3 INTERPRETING SEDIMENTARY HABITATS AND ENVIRONMENTS

Soft sediment grain sizes, characterised by the 50th percentile grain size (D50), vary greatly throughout the region (0.5 – 7 ϕ or 0.71 – 0.008 mm). Coarsest (D50 > 0.02 mm) sediments are found in the nearshore regions off Pukehina (Figure 3.5), where they are interspersed with patchy cobble reef. Fine sands dominate other nearshore regions. Silty and muddy sediments are found in depths beyond 50 m with the exception of sandy sediments in deep water (> 80 m) offshore from Whakatane (transects F and G, Figure 3.5). Doyle *et al.* (1979), (Figure 3.6) inferred that the sandy sediments in deep water extended farther inshore than the interpolation scheme used in the present study determined. It should be noted, however, that on transect F at 60 m depth, the data indicate coarser sediments than the interpolated value, and equally at 70 m, the data indicate finer sediments than the interpolated value (Figure 3.5). It is apparent that surrounding this feature both the present study and that of Doyle *et al.* (1979) lack enough sample points to accurately describe the specifics of the sediment distributions. Additionally, Doyle *et al.* (1979) missed the large mud bank NE of Whakatane, most likely due to their minimal sampling in that area. The delineation of areas of reef and hard substrate within the present study has improved greatly from that of Doyle *et al.* (1979)

Sediment mud contents, characterised by the percentage of total material finer than 63 µm, follow a similar pattern to that of the D50 grain size. Sediments composed entirely of muddy sized sediments exist in areas deeper than 50 m in the central and eastern regions of the Bay of Plenty (Figure 3.7). The general pattern of increasing mud contents in an offshore direction is consistent with that found by Hopkins and Robertson (2001) from a detailed local scale survey along transect H between 28 and 46 m depth. While the patterns and magnitudes of the mud fraction are very similar between the two surveys, the simplistic grain size classification scheme employed by Hopkins and Robertson (2001) prevents any further comparisons. Sediments in the deeper regions of the western areas, nearer Pukehina, and from transects A to D, consist of fewer mud sized particles (Figure 3.7). Comparison with the chart of Doyle *et al.* (1979) show a strong similarity in the distributions of sediments with high mud contents (> 90 %) (Figure 3.7), and both areas described as silts and muds by Doyle *et al.* (1979) (Figure 3.6). The definition criterion employed by Doyle *et al.* (1979) results in both ‘silts’ and ‘muds’ containing greater than 90 % of particles finer than 63 µm.

Many samples displayed bimodal sediment distributions. To quantitatively describe the ‘degree’ of bimodality a ‘bimodality index’ was developed and applied to the data. This index determines the size difference (in phi units) between local maxima which are above a threshold value (1 % of the total volume) within the grain size distribution curve. The index reports a phi size measure which is indicative of the degree of separation between the two modes. Display of this index (Figure 3.8) shows that sediments to the east of Whakatane (transect F) are unimodal. Sediments to the west of Whakatane increase in their bimodality (the size separation between the two modes making up the population) in both westerly and offshore directions.

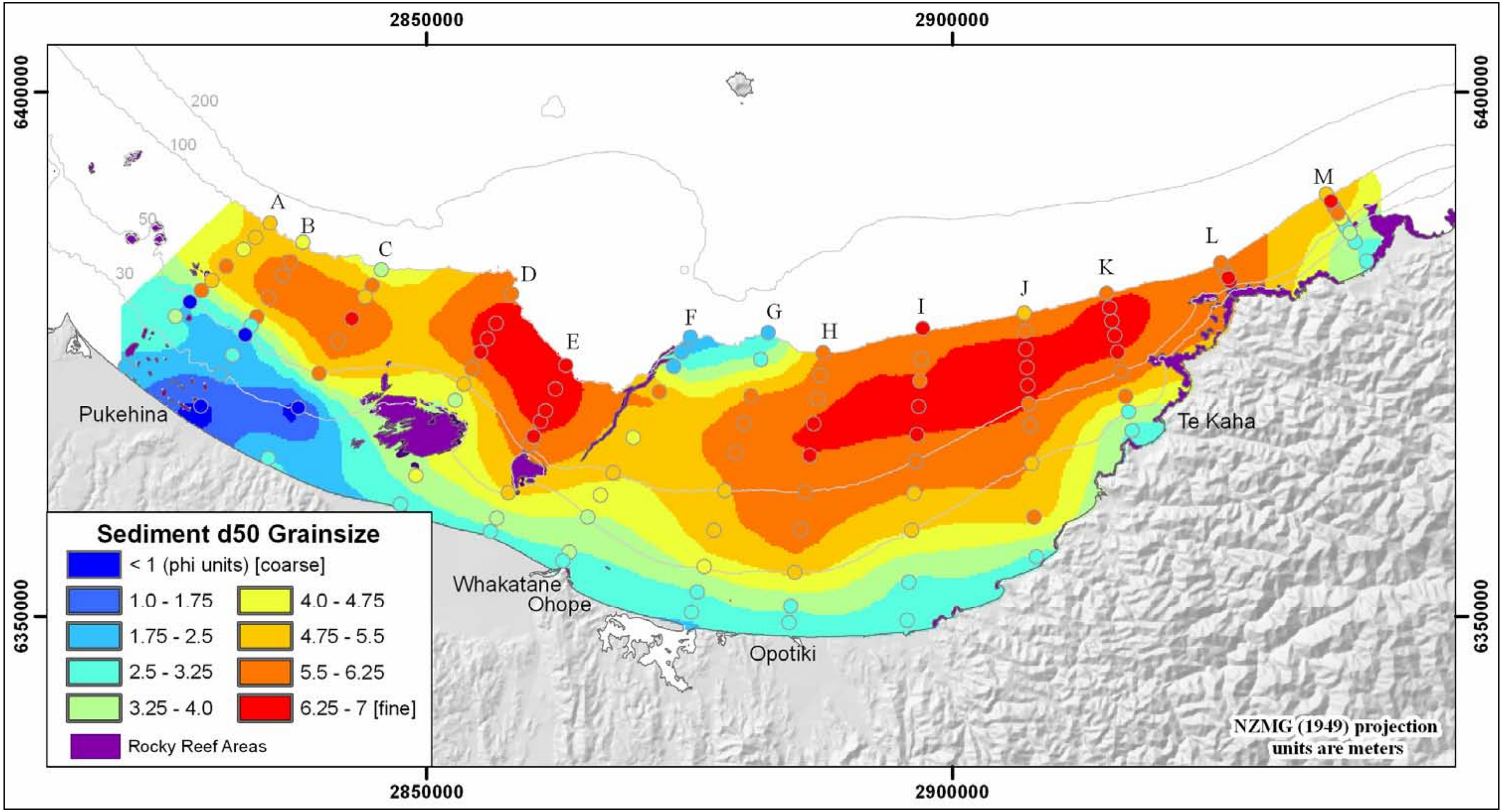

Figure 3.5 Sediment 50th percentile grain sizes (D50) within the Bay of Plenty, from analysis of 118 sediment grab samples (coloured circles indicate measured data). Rocky reef areas delineated from multi-beam bathymetry and hydrographic chart digitising. Convert phi sizes to mm by mm = 2^{-phi}.

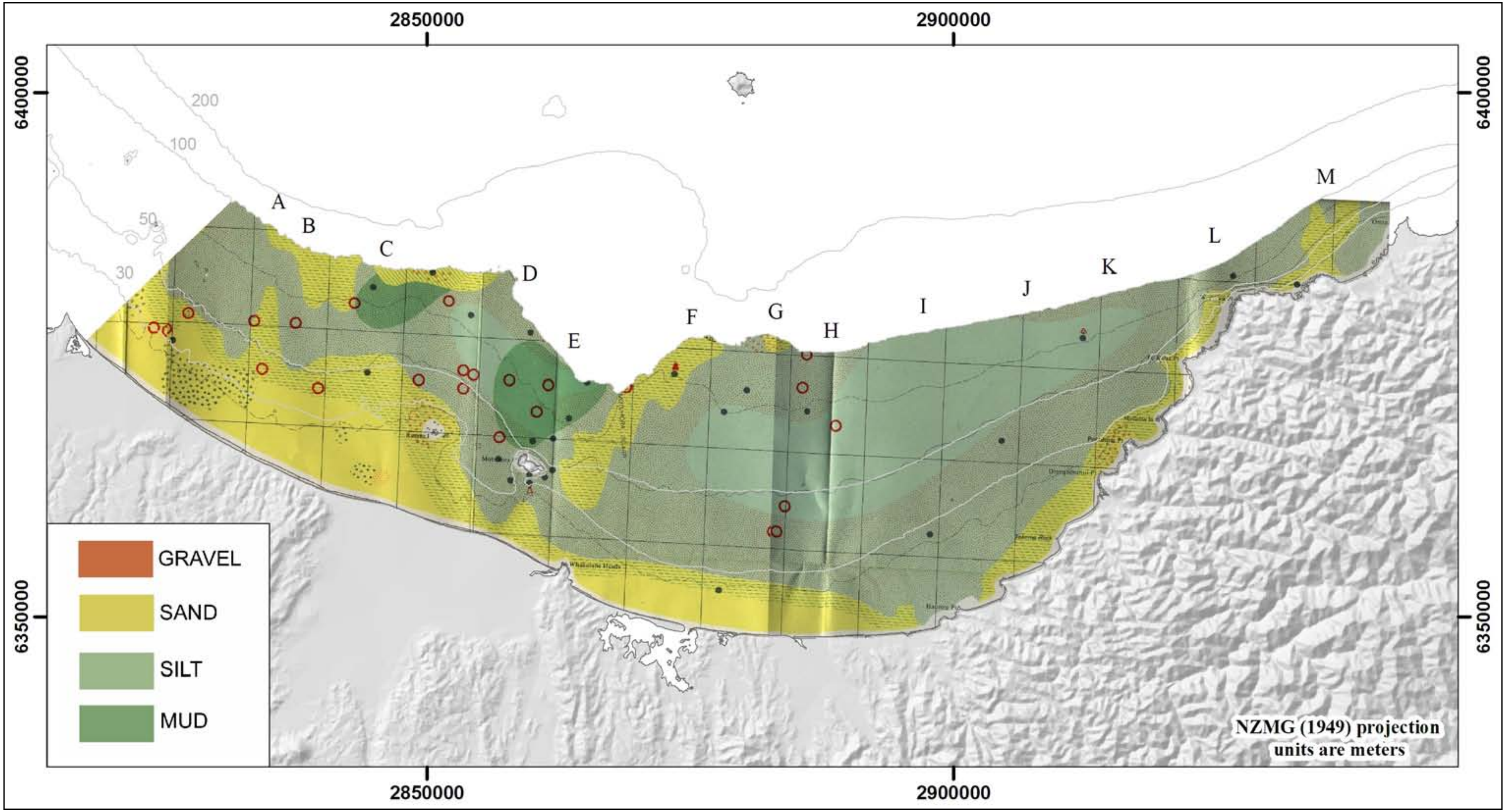

Figure 3.6 Sediment description from Doyle *et al.* (1979). Sample sites are shown as grey dots. Doyle *et al.* (1979) define both silts and muds as having < 90% of particles finer than 63 µm. Locations of transects from the present survey displayed to aid comparisons.

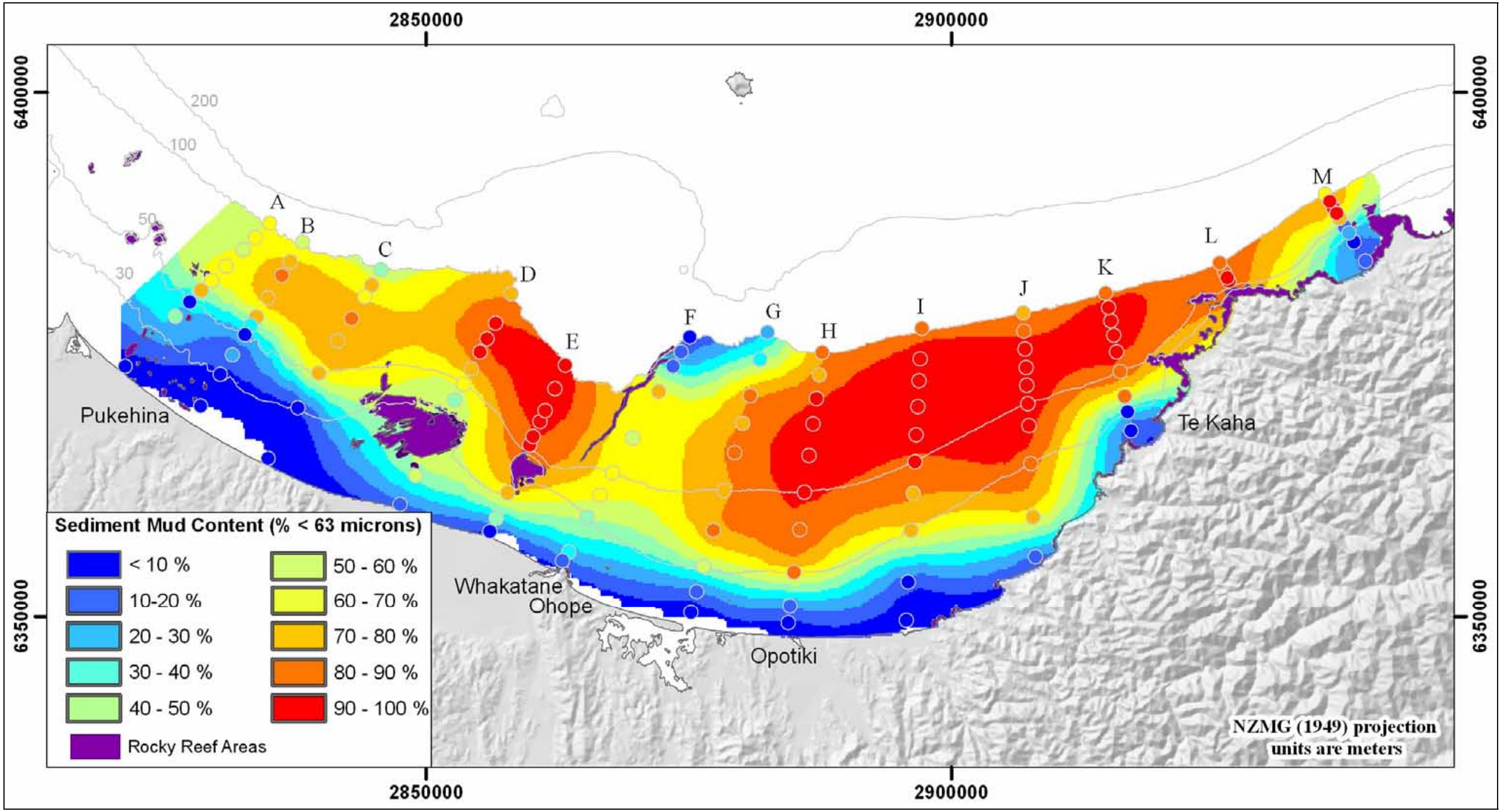

Figure 3.7 Sediment mud content (fraction of the total sample finer than 63 μm) within the Bay of Plenty from analysis of 118 sediment grab samples (coloured circles indicate measured data). Rocky reef areas delineated from multi-beam bathymetry and hydrographic chart digitising.

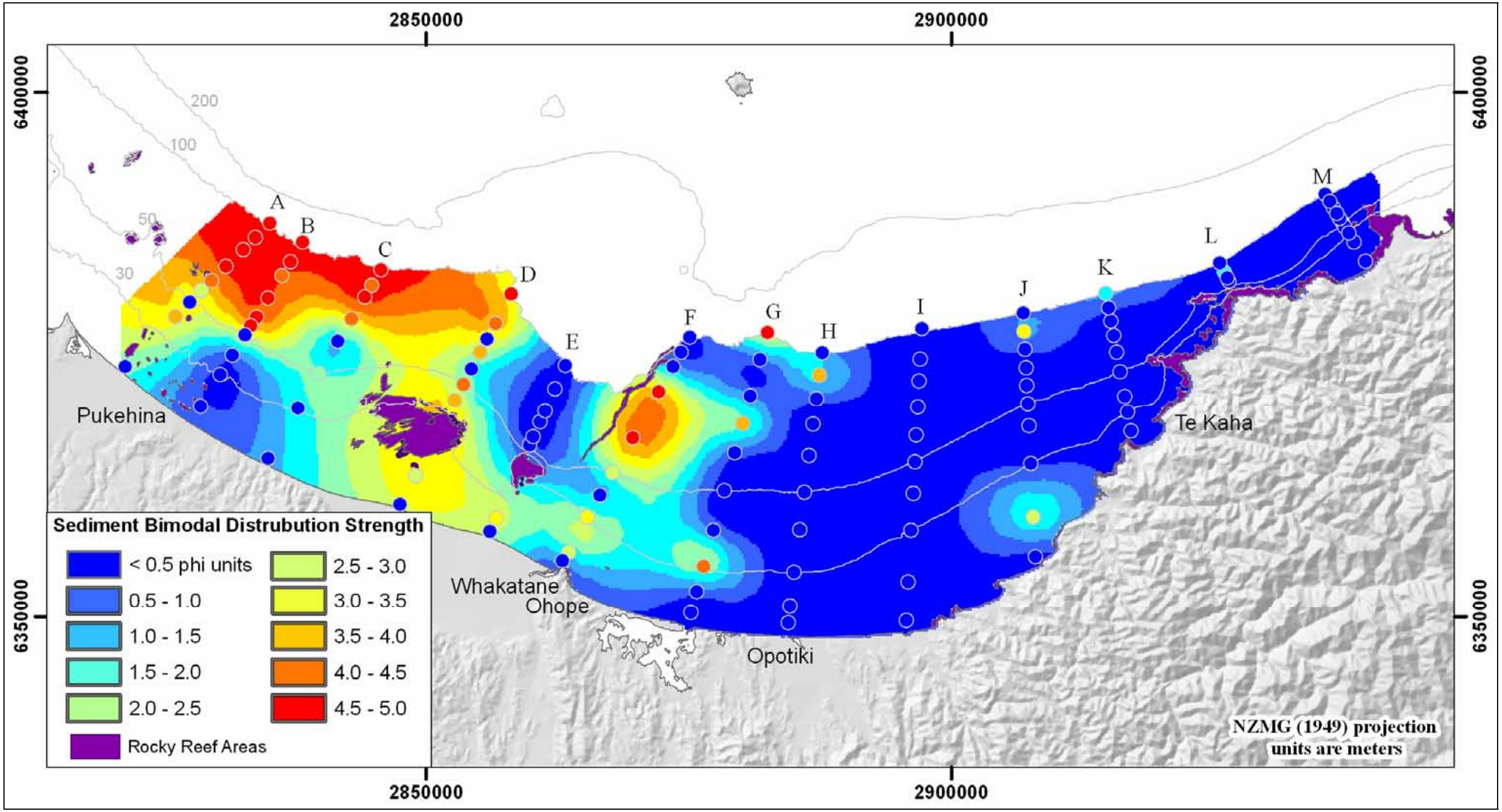

Figure 3.8 Sediment 'bimodality', defined as the difference (in phi units) between local maxima in the grain size distributions, within the Bay of Plenty, based on analysis of 118 sediment grab samples (coloured circles indicate analysed data). Only peaks greater than 1% of the total volume were considered in the bimodal analysis, unimodal sediments have a value of 0, populations determined through sieving methods have been disregarded. Rocky reef areas delineated from multi-beam bathymetry and hydrographic chart digitising.

Bimodality can occur if fine grained sediments are deposited immediately above coarser sediments. The finer grains may infiltrate the coarser ones by settling downward through the large pore spaces among the coarser grains. For this process to be effective, the diameter of the smaller grains must be less than about one-tenth the diameter of the larger (Blatt, 1982). The bimodal sediments observed within the Bay of Plenty fit this critetion. Burrowing organisms are also capable of creating bimodal distributions if the sediment profile is made up of distinct well sorted laminae. The in-faunal grab sample data did not indicate any major spatial variation in burrowing organisms across the study region. It is likely that the bimodal distributions have been developed from the preferential transport of finer silty and muddy sediments, and their deposition on top of coarser sandy sediments. There is no evidence of bimodal distributions being found by Doyle *et al.* (1979) in the same area. This could be due either to their samples being uni-modal, or more probably limitations in their grain size analysis and display scheme not allowing the representation of bimodal distributions.

Sediment organic contents ranged from 0.0 to 6.0 % of the dry weight of sediment (Figure 3.9). Relatively (for the Bay of Plenty) high organic contents (> 4.5 %) were found in deeper areas (60 – 80 m) with higher mud contents, and finer d50 grain sizes. Sediment organic content is observed to be lower in the sandy sediments nearer the shore (Figure 3.9). Linear regression of the sediment organic content and d50 grain size (in phi units) indicate a negative correlation (Figure 3.10), *i.e.* the finer the d50 grain size, the higher the organic content is likely to be, consistent with other continental shelf sediments (Milliman, 1994). The detailed local scale survey of Hopkins and Robertson (2001) between 28 and 46 m along transect H revealed sediment organic contents in the range of 2.1 to 5.4 % d.w. (n = 34), again consistent with samples from the current study in the same region (1.8 to 3.7 % d.w., n = 4).

Large variation was found in the sediment carbonate content across the Bay of Plenty with little obvious trends (Figure 3.11). Transect average carbonate contents do, however, decrease in a west to east direction (Figure 3.11), from an average of 3.1 % over transect A, to an average of 0.6 % over transect M.

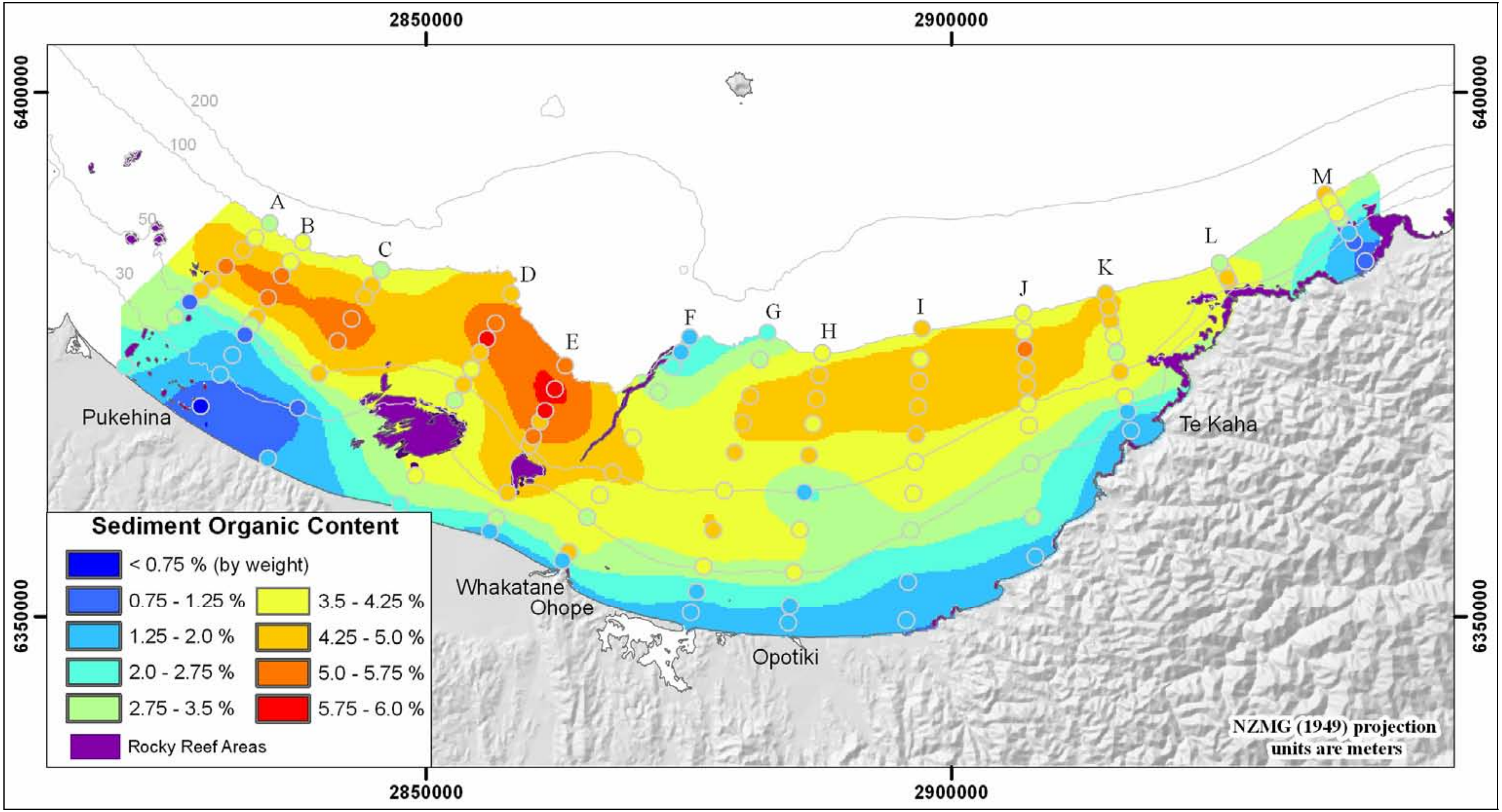

Figure 3.9 Sediment organic content (percent by dry weight), determined by loss on ignition at 500°C, within the Bay of Plenty, based on analysis of 118 sediment grab samples (coloured circles indicate analysed data). Rocky reef areas delineated from multi-beam bathymetry and hydrographic chart digitising.

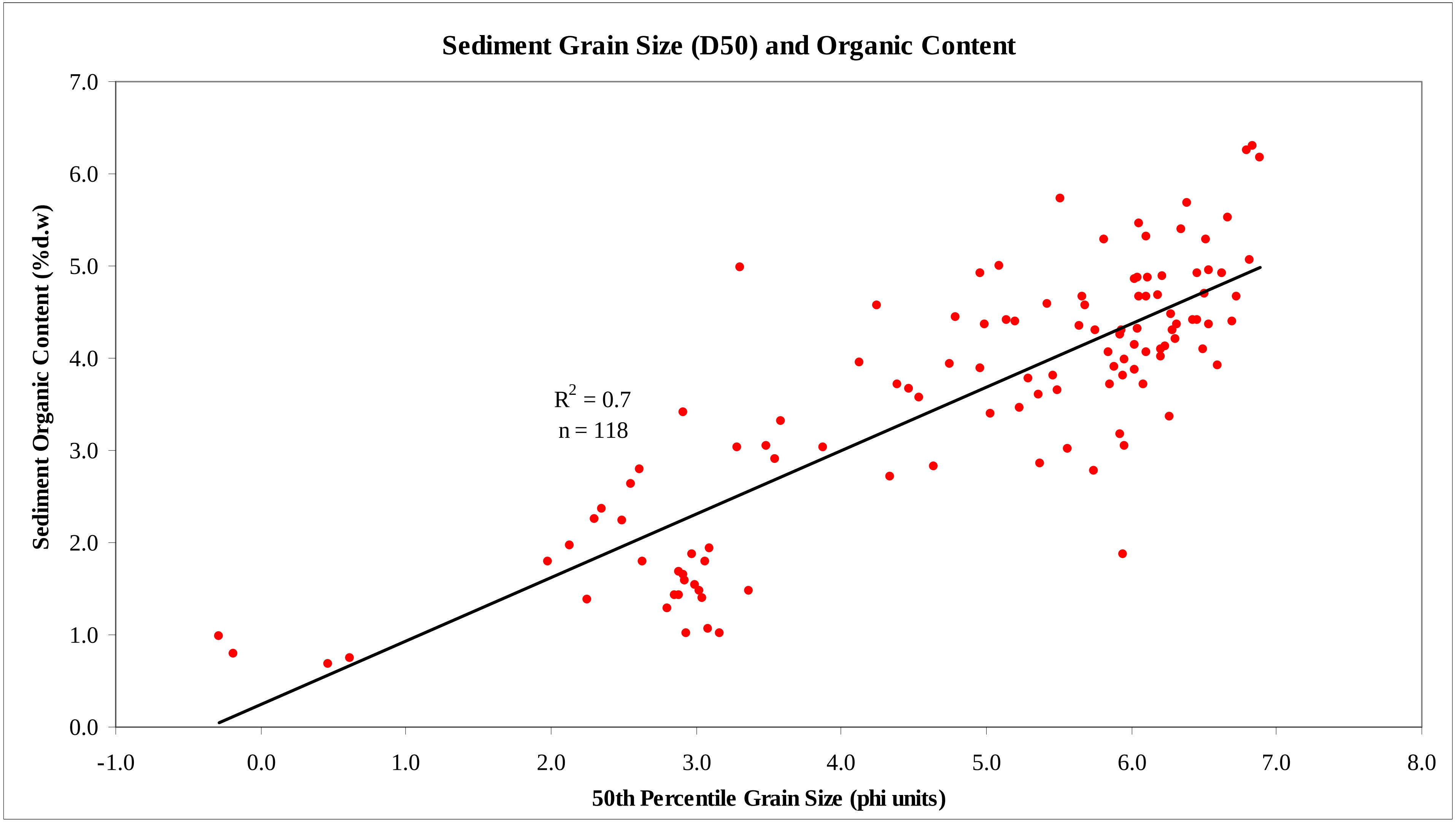

Figure 3.10 Relationship between sediment d50 grain size and sediment organic content within the Bay of Plenty. The relationship indicates that finer sediments have higher organic contents.

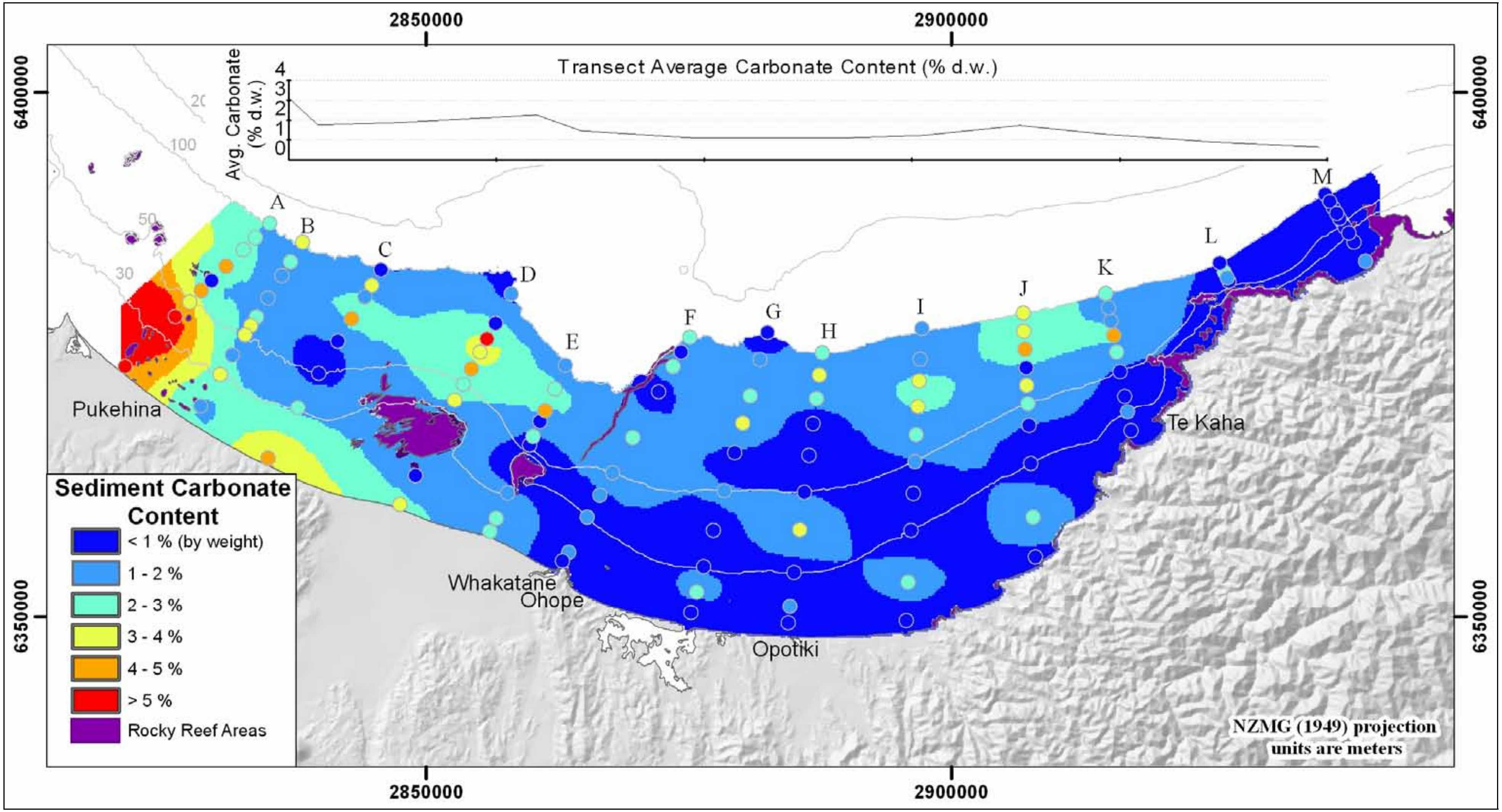

Figure 3.11 Sediment carbonate content (percent dry weight, determined by acid digestion) within the Bay of Plenty based on analysis of 118 sediment grab samples (coloured circles indicate analysed data). Rocky reef areas delineated from multi-beam bathymetry and hydrographic chart digitising. Graph within the chart indicates transect average carbonate contents increasing from east to west.

3.5.4 BENTHIC BIOTA: SEDIMENT IN-FAUNA

Quantitative biotic integrity indices (measuring the balance, diversity, and functional organisation of species assemblages, *e.g.* Karr, 1981; Weisburg *et al.*, 1997) cannot be applied to the benthic in-faunal data as a result of the inability of the SHIPEK sampler to obtain a consistent volume of sediment at each site, the large area surveyed relative to the number of samples and the lack of replicate samples at each site. However, the data gathered are indicative of the range of organisms present at each site sampled and can be used in a qualitative sense.

A total of 2270 individuals, representing 101 different species from 12 groups were identified from the 118 grab samples (Figures 3.12 and 3.13, Mead *et al*., 2005). No known rare or endangered species were found within the samples. Large variations in species and abundances were found in the grab sample data, demonstrating the patchy distribution of benthic organisms.

Polychaetes and isopods tend to be the dominant species in the sub-tidal soft sediments between 10 and 100 m depths, with bivalves also present in large numbers (Figures 3.12 and 3.13, Mead *et al*., 2005). All three groups were found throughout the range of depths surveyed (10 – 100 m) within the study area, though some trends were apparent in their distribution. Amphipods were found in higher numbers in the shallower (< 50 m) fine silty areas whilst polychaetes were dominant in the slightly coarser sediments with higher organic contents found in the offshore areas of transects A, B, and C (Figures 3.4 and 3.9). A wide variety of bivalves were found spread throughout the region. Echinoderms (brittle stars and sea cucumbers) and foraminifera were also common within the samples (Figure 3.13, Mead *et al*., 2005). Whilst the echinoderms were relatively widely spread, foraminifera were restricted to sites deeper than 60 m.

McKnight (1969) classified the community type in muddy areas of the Bay of Plenty as *Nemocardium* community, specifically the *Nemocardium pulchellum* (bivalve) – *Pleuromeris zelandica* (bivalve) community, which is dominated by deposit-feeding bivalves and worms. In contrast, the sandy infaunal community was identified as a *Venus* community, specifically the *Scalpomactra scalpellum – Maorimactra ordinaria* community, which is characterised by suspension-feeding bivalves, probably due to the low organic content of the substrate in comparison to the muddy sands of other areas.

While there is good agreement between the current survey and that of McKnight (1969), there are several noteworthy differences. Bivalves were not found to be the dominant fauna of the sub-tidal areas (as found by McKnight, 1969), but rather polychaetes and iso/amphi-pods dominate. This is potentially an artefact of the methodology, equipment, and sample preservation techniques used, with McKnight's (1969) survey under-representing soft bodied organisms (Table 3.4). McKnight's (1969) investigation utilised samples collected by a range of differing methods including grabs of various types, dredges and trawls. Combining these different types of sampling methodologies to classify benthic communities can lead to differences of interpretation with respect to dominant organisms. The present data supports this hypothesis through the differences in species collected with the grab sampler and dredge tow, especially for soft bodied species (Figures 3.13 and 3.15, Mead *et al*., 2005). An example of this can be observed from the collected data with reference to the deposit feeding nutshells, *Nucula* spp. In the grab samples, *Nucula* spp. follows the sediment type well, with very few being found in sandy and coarse sediment regions, and larger numbers in muddy areas. (*Nucula* spp., feature in McKnight's (1969) deposit-feeding dominated *Nemocardium pulchellum – Pleuromeris zelandica* community, with more than 50% occurrence). A total of 131 *Nucula* spp. were identified from the grab samples, the 5th most common species. However, no *Nucula* spp. were found in any of the dredge-tows, most likely because these species are small (dredge mesh size was 8 mm) and very fragile, and so were not collected by the dredge.

Hopkins and Robertson (2001) undertook a detailed survey of a limited area in 28 – 46 m depths along transect H, and found similar species and abundances to the present study, with deposit feeders dominating. The differences between their work and that of McKnight (1969) can also be attributed to sampling and preservation techniques (Table 3.4).

Table 3.4 Comparison between benthic fauna studies of McKnight (1969), Hopkins and Robertson (2001), and this study.

Study	Target species	Area covered	Notes / Implications
McKnight (1969)	In-fauna and epi-fauna	Bay of Plenty wide with lower sampling resolution (~1/2) than this study	Sampling techniques under-represent soft bodied organisms. Wide range of techniques used within the one survey, resulting in some differences compared to Hopkins and Robertson (2001) and this study.
Hopkins and Robertson (2001)	In-faunal species	Targeted survey over a small area offshore from Opotiki (28-40 m depth)	Results consistent with this study over the area covered
This study (sediment grabs)	In-faunal species	Bay of Plenty shelf, Pukehina- East Cape	Transect-line sampling methodology
This study (dredge tows)	Epi-faunal species	Bay of Plenty shelf, Pukehina- East Cape	Lack of resolution due to initial problems with dredge

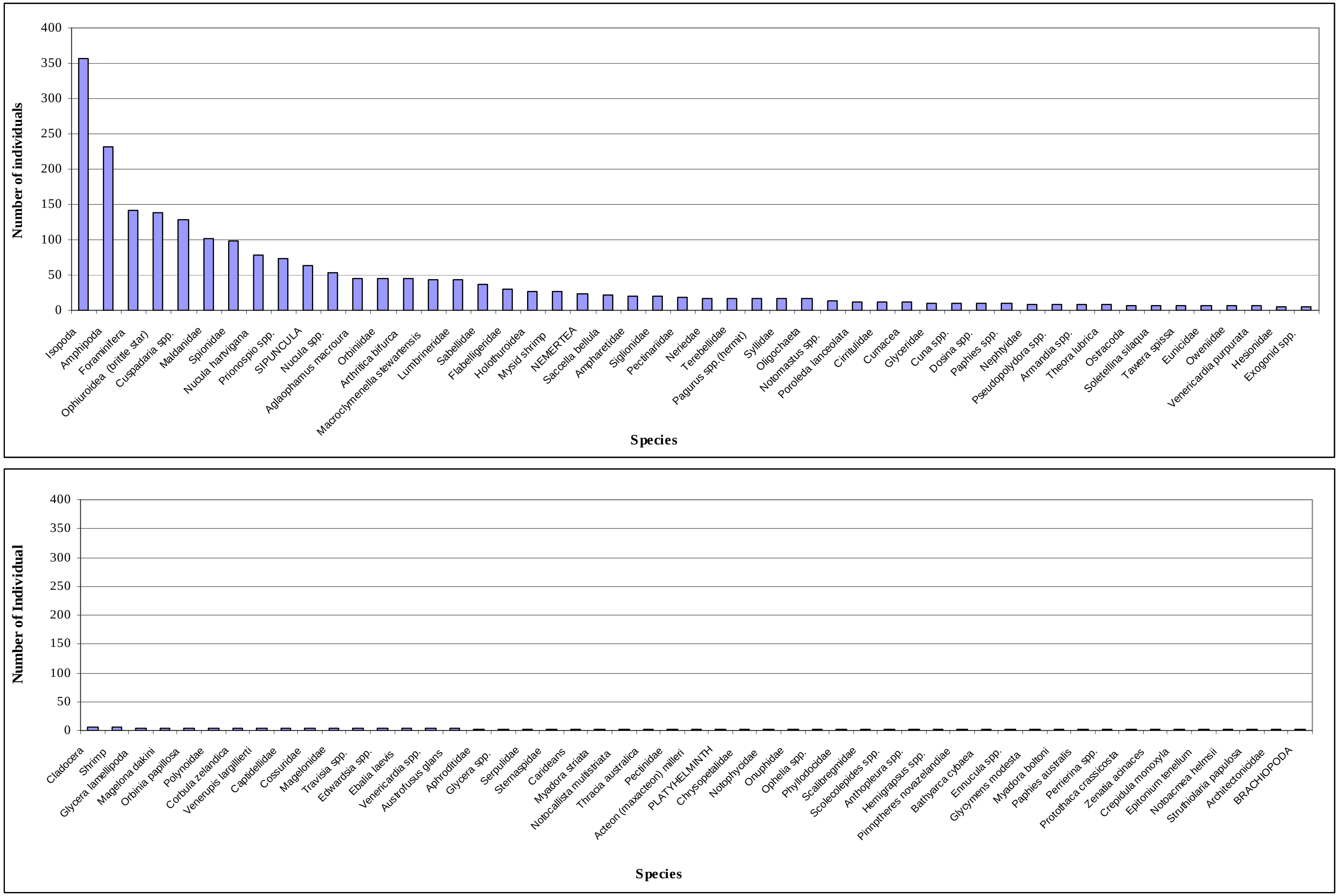

Figure 3.12 Species rank sum of all identified fauna from 118 sediment grab samples between 10 and 100 m depth within the Bay of Plenty survey (Mead *et al*., 2005). Samples classified at Leigh marine laboratory by graduate students.

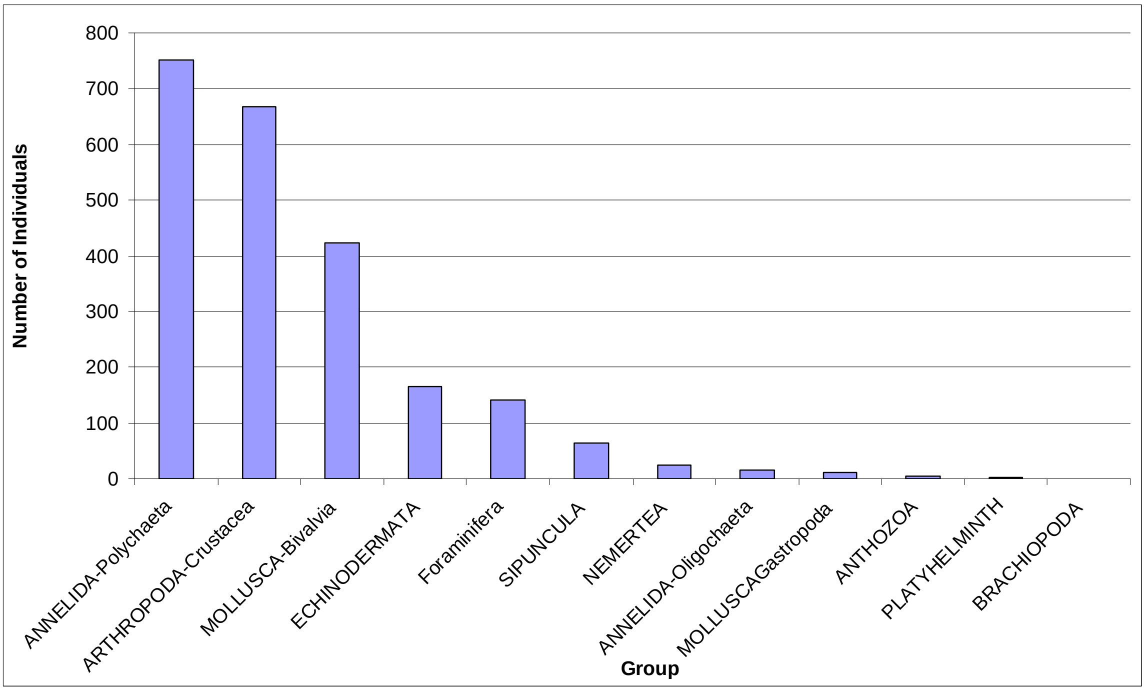

Figure 3.13 Group rank sum of all identified fauna from 118 sediment grab samples within the Bay of Plenty between 10 and 100 m depth (Mead *et al*., 2005). Samples classified at Leigh marine laboratory by graduate students.

3.5.5 BENTHIC BIOTA: SEDIMENT EPI-FAUNA

Of the 12 dredge-tows undertaken, 3 tows were empty, which is assumed to be due to malfunction of the dredge rather than an absence of organisms in the area. A total of 988 individual organisms were found in the 9 remaining dredge-tows, which covered distances of 130 – 322 m. A range of organisms were found (67 species from 9 groups – Figures 3.14 and 3.15), with individuals from 23 species and 2 groups identified that were not found in the grab samples (Mead *et al*., 2005). No known rare or endangered species were found in the dredge-tow samples.

Similar to the grab-sample data, large variations in species and abundance were found in the dredge-tow data. Polychaetes and crustaceans dominate the species found in the dredge-tow samples. Hermit crabs make up a large fraction of the crustaceans (unlike the grab-samples), with the other dominant taxa being isopods. In comparison to the grab-sample data, there is a marked relative increase in the number of bivalves and gastropods identified, which demonstrates how the dredge-tow concentrates hard-bodied organisms living at or near the sediment surface. The gastropods found in the dredge-tows were all carnivorous whelks, *Austrofucus glans* being the most common. Filter feeding bivalves identified included *Paphies australis* (pipis), *Pecten novaezelandiae* (scallops), and *Tawera spissa* (morning star). Very few deposit feeding bivalves were found.

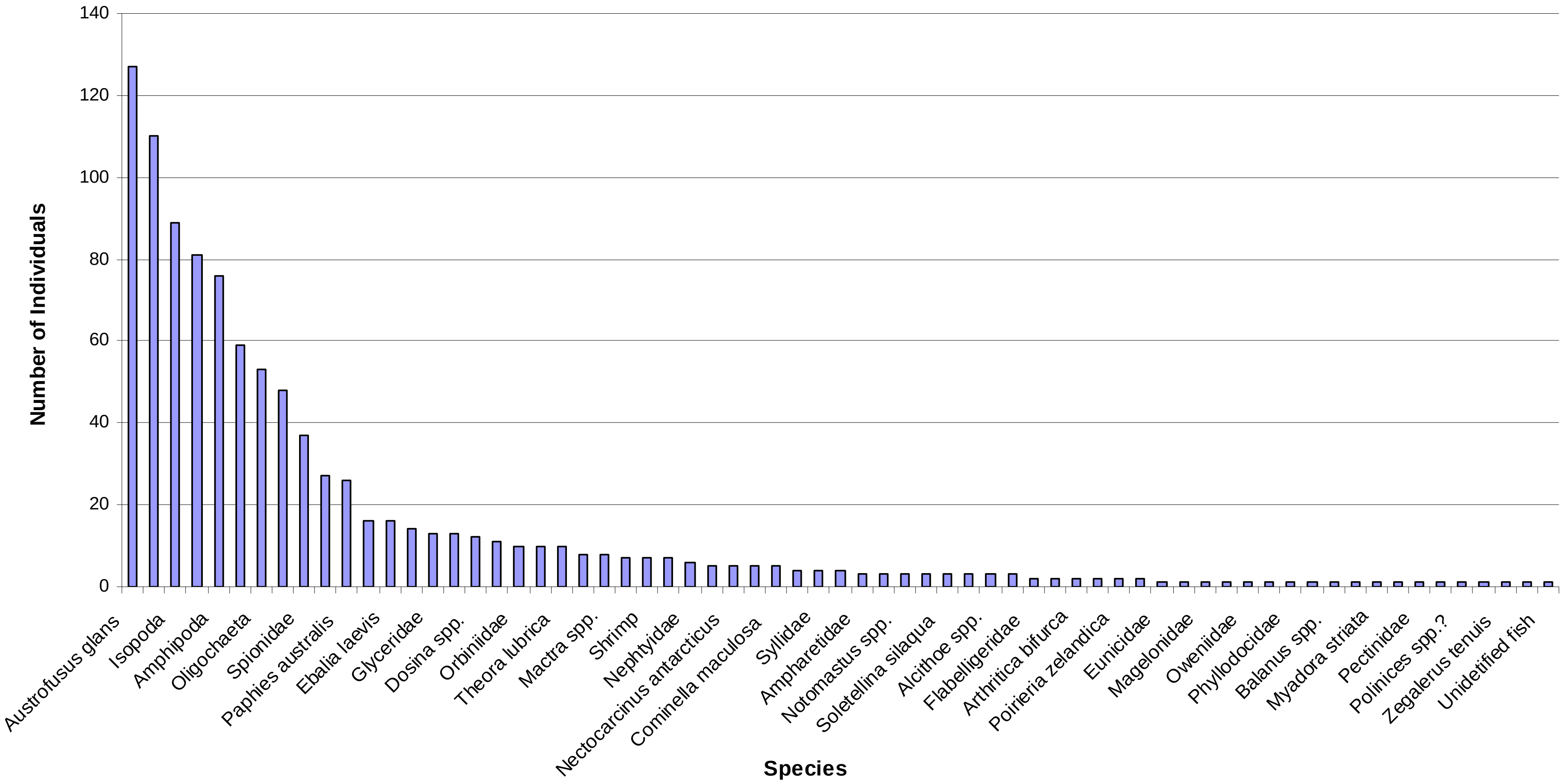

Figure 3.14 Species rank sum of all identified fauna from 12 dredge tows within the Bay of Plenty between 20 and 40 m depth (Mead *et al*., 2005). Samples classified at Leigh marine laboratory by graduate students.

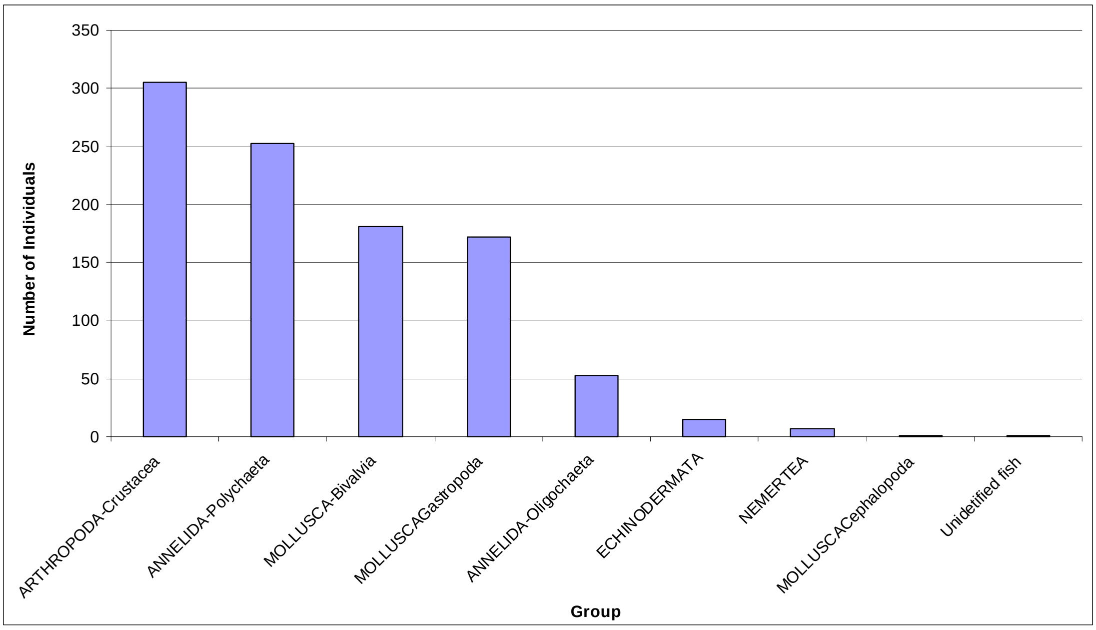

Figure 3.15 Group rank sum of all identified fauna from 12 dredge tows within the Bay of Plenty from 20 to 40 m depths (Mead *et al*., 2005). Samples classified at Leigh marine laboratory by graduate students.

3.6 ASSIMILATING BENTHIC HABITAT DATA: A CLASSIFICATION SCHEME

Sediment habitats were defined with a hierarchical rule based classification scheme utilising analysed sediment properties such as the D50 grain size, organic content, separation of bimodal peaks, and dominant in-faunal organisms (Figure 3.16 andTable 3.5), akin to that of Kostylev *et al.* (2001), Baxter (2003), Jordan *et al.* (2003) and Urbanski and Szymelfenig (2003). Figure 3.17 combines and summarises the information from the grabs, video, and multibeam surveys of the region to define habitat type based on morphology and sediment type. Muddy sediment habitats are the most predominant within the study region, covering 36% of the seabed; silty sediments cover 31% with the remainder made up of sands (29%), gravels (1%), and reef habitats (3.5%). Fine sands with low organic contents and high numbers of amphipods dominate the nearshore (< 30 m depths) of much of the study region, with coarser sands being found in the west near Pukehina, and reef areas nearshore in the east near Cape Runaway. Silty and muddy sediments make up most of the habitats deeper than 30 m, with the exception of an area of fine sands offshore from Whakatane (Figure 3.17).

Figure 3.16 Decision tree used to classify benthic habitats for their potential to assimilate the additional inputs from aqauaculture.

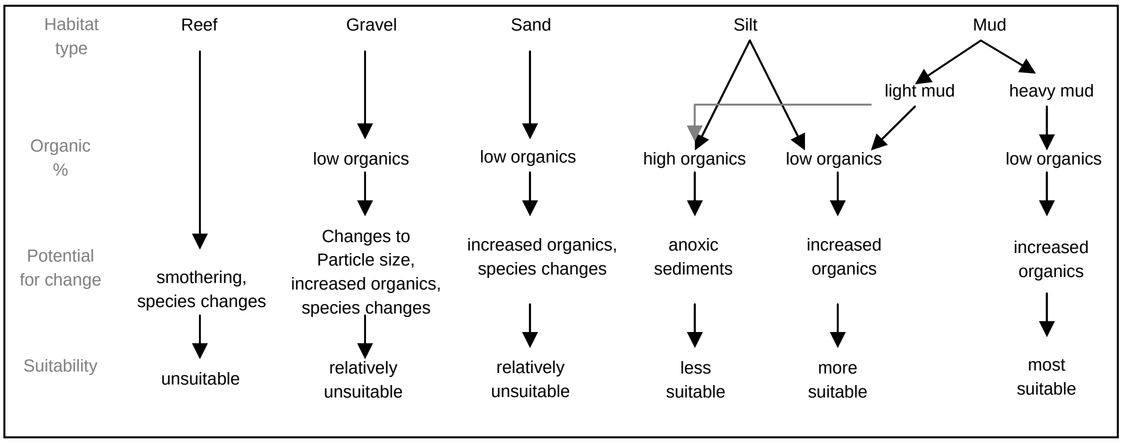

Table 3.5 Classification scheme used to define benthic habitats within the Bay of Plenty.

Habitat Level 1	**Habitat Level 2**	**Additional characteristics**	**Definition criteria**	**Potential habitat specific impacts of aquaculture**	**Aquaculture suitability**
Reef (3.5%)	Boulder reef (0.9%)	Tall plant life	Digitized from multibeam survey, charts and video observations	Smothering through increased sedimentation, shading of plants, significant changes in species composition	Unsuitable
	Patchy reef (0.03%)	Small plant life	As above	As above	Unsuitable
	Patchy cobble reef (1.6%)	No plant life	As above	Smothering through increased sedimentation, significant changes in species composition	Unsuitable
	Unknown hard substrate (0.9%)		As above, no video observations to ground truth.	As above	Unsuitable
Gravel (0.8%)		LOC[1]	Modal sediment size coarser than 0 phi (1 mm)	Sedimentation of non-native particle sizes, increased organic matter, changes in species composition	Relatively unsuitable
Sand (28.6%)	Coarse sand (2.8%)	LOC	D50 sediment size coarser than 2 phi (0.25 mm)	As above	Relatively unsuitable
	Fine sand (22.2%)	Unimodal[3], LOC, amphipods	D50 sediment size 2 - 4 phi (0.25 – 0.063 mm)	As above	Relatively unsuitable
	Fine sand (3.6%)	Bimodal[4], LOC	Bimodal peak separation > 3 phi	Increased organic matter, changes in species composition	Relatively unsuitable
Silt (30.8%)	Silty sediments (19.8%)	Unimodal, LOC	D50 sediment size 4 - 6 phi (0.063 - 0.016 mm)	Increased organic matter	More suitable
	Silty sediments (1.0 %)	Unimodal, HOC[2]	Organic content > 4.5 %	Organic enrichment may lead to anoxic conditions	Less suitable
	Silty sediments (6.9%)	Bimodal, LOC, polychaetes	Bimodal peak separation > 3 phi	Increased organic matter	More suitable
	Silty sediments (3.1%)	Bimodal, HOC, polychaetes	Bimodal peak separation > 3 phi, organic content > 4.5 %	Organic enrichment may lead to anoxic conditions	Less suitable
'Light' mud (21.4%)	'Light' mud (14.9%)	Unimodal, LOC	Mud content 75 - 90%	Increased organic matter	More suitable
	'Light' mud (4.3%)	Unimodal, HOC	Organic content > 4.5%	Organic enrichment may lead to anoxic conditions	Less suitable
	'Light' mud (2.3%)	Bimodal, HOC	Bimodal peak separation > 3 phi, organic content > 4.5 %	As above	Less suitable
'Heavy' mud (14.6%)	'Heavy' mud (10.2%)	Unimodal, LOC	Mud content > 90%	Depositional environment	More suitable
	'Heavy' mud (4.3%)	Unimodal, HOC	Organic content > 4.5%	Organic enrichment may lead to anoxic conditions	Relatively unsuitable
	'Heavy' mud (0.1%)	Bimodal, HOC	Bimodal peak separation > 3 phi, organic content > 4.5 %	As above	Relatively unsuitable

[1] Low Organic Content (LOC, < 4.5%), [2]High Organic Content (HOC, > 4.5%), [3]Unimodal sediment distribution, [4]Bimodal sediment distribution

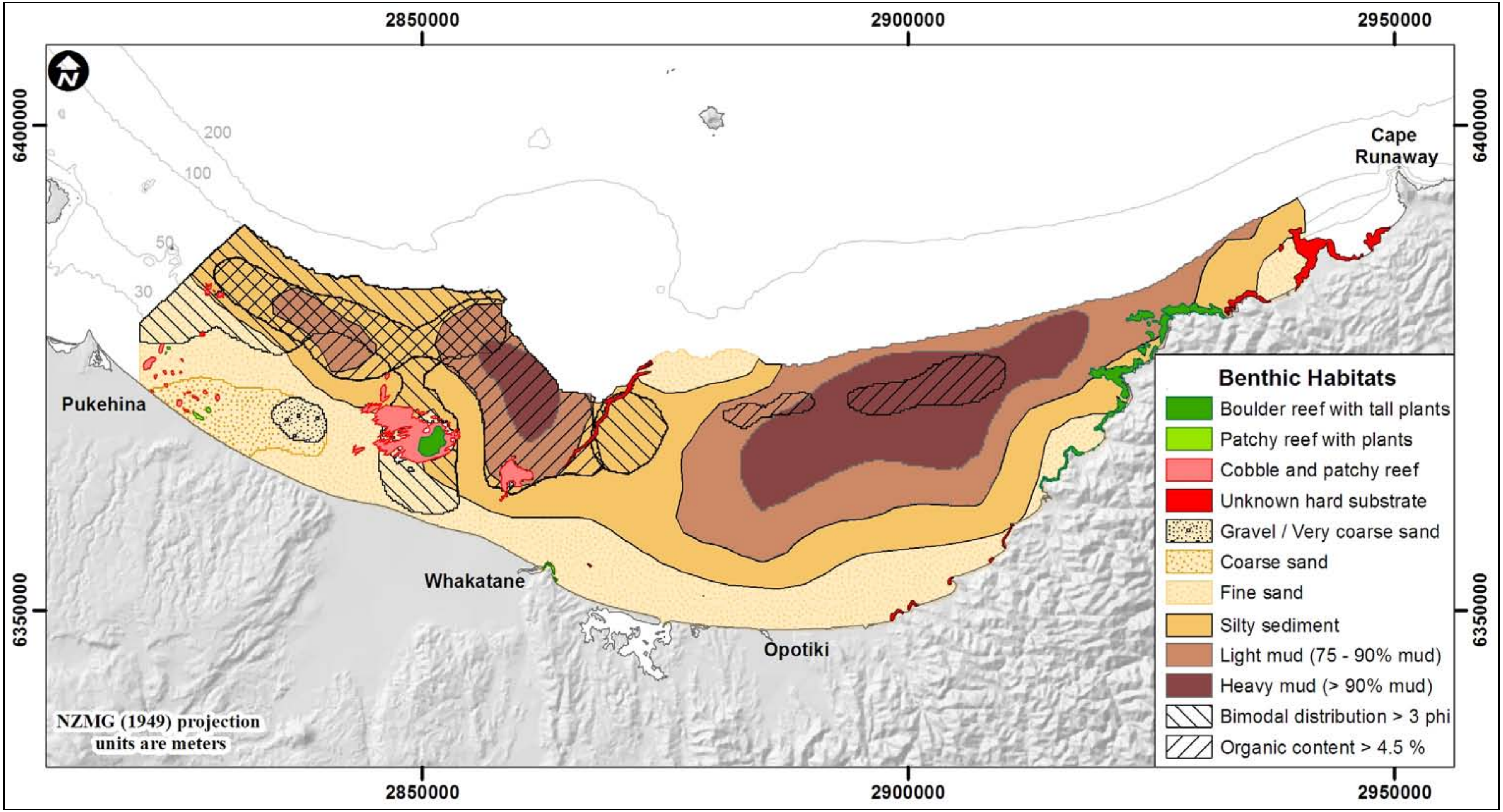

Figure 3.17 Benthic habitats within the Bay of Plenty, schematised using a rule-based classification scheme of 118 analysed sediment grab samples, 200 video observations and multi-beam bathymetric soundings.

3.7 EVALUATING BENTHIC HABITATS AND POTENTIAL INPUTS FROM BIVALVE AQUACULTURE

Potential impacts of suspended bivalve aquaculture vary depending on the benthic environment over which the aquaculture is located. Benthic habitats within the Bay of Plenty are graded into four groups to quantify their suitability to have suspended bivalve aquaculture located in the waters above. In order of increasing suitability these groups are, 'Unsuitable, relatively suitable, less suitable, more suitable' (Table 3.5 and Figure 3.18).

3.7.1 REEF ENVIRONMENTS

Areas of hard substrate, including reef areas are not generally depositional environments and should be avoided as the biologic communities are ill equipped to deal with potential inputs from bivalve aquaculture. Though they are often sites of high currents, which may mitigate potential impacts significantly, they make up a small percentage of the study area (3.5 %, Table 3.4) and so are of high preservation value. Within the Bay of Plenty, areas of reef and hard substrate have been graded as 'unsuitable' to be located beneath suspended bivalve aquaculture (Table 3.5 and Figure 3.18). This is consistent with recommendations made by Black (2001) and Pillay (2004).

3.7.2 SOFT SEDIMENT ENVIRONMENTS

Within New Zealand, aquaculture farms are 'almost always' sited over soft sediment habitats (Gibbs, 2004). The choice remains, however, whether to locate over relatively coarser silty sediments or finer muddy sediments. The international literature contains recommendations for both (*e.g.* Crawford *et al.*, 2003; Hartstein and Rowden, 2004; Mallet *et al.*, 2006).

Relatively coarser silt sized sediments are generally indicative of a more active hydrodynamic regime, where the potential for build up of bio-deposits is reduced (Hartstein and Rowden, 2004). Where sediments are frequently resuspended by wind and storm events, the ability of the sediments to remain oxygenated and prevent the build up of bio-deposits is enhanced (Mallet *et al.*, 2006). Hartstein and Rowden (2004) found minimal impacts on the benthos (organic enrichment and species assemblages) when a mussel farm was located in a relatively high energy hydrodynamic environment, over relatively coarse sediments (4.5 ϕ or 0.044 mm). Farms located over sandy sediments can, however, displace some native species as pseudo-faeces and bio-deposits are finer than the native sediments (Grange and Cole, 1997). Sediment particle size has a strong influence on seabed ecology, implying that aquaculture induced deposition of particles with non-native grain sizes will potentially impact on benthic fauna. Sandy sediments found within the Bay of Plenty also had very low organic contents (< 1.5 %), indicating the associated biota will be less able to cope with the potential inputs from aquaculture (Mallet *et al.*, 2006). For the purposes of aquaculture zoning within the Bay of Plenty, areas of coarse and fine sand sized sediments with very low organic contents have been graded as 'relatively unsuitable' (Table 3.5 and Figure 3.18).

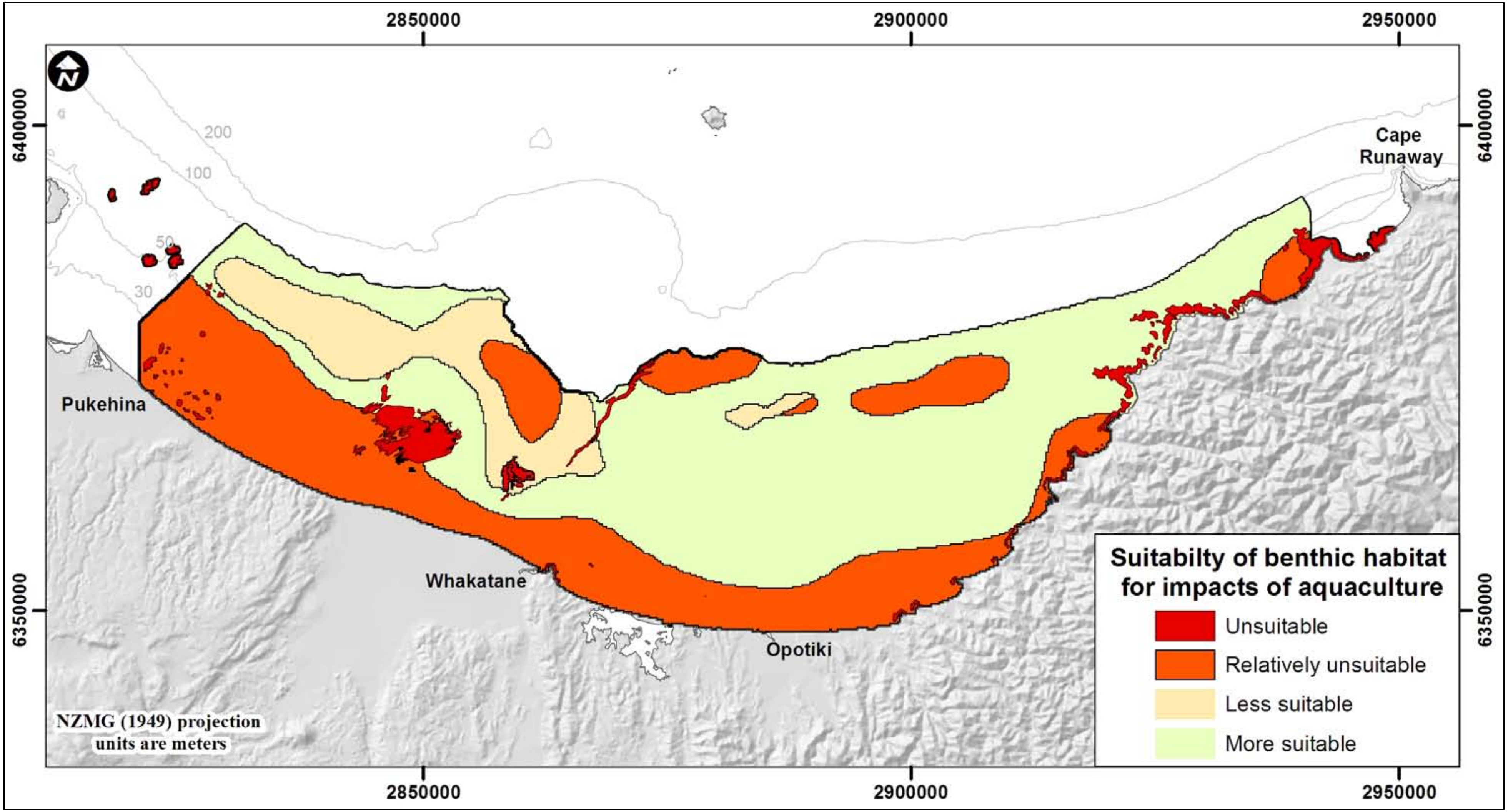

Figure 3.18 Assessed suitability of benthic habitats within the Bay of Plenty to be sited beneath suspended bivalve aquaculture.

Finer sediments composed of muds and clays generally represent existing low energy and depositional environments (Dunbar and Barret, 2005), where the benthic fauna will be adapted to at least some degree of sedimentation and organic loading. However, these sediments typically have higher native organic contents (Pearson and Rosenburg, 1978; Crawford, 2003), an important factor in assessing potential aquaculture sites (Mallet *et al.*, 2006). Very high native sediment organic contents along with fine sediments (indicative of a low energy regime) increase the potential for the development of low oxygen layers and anoxia within the sediment profile (Pearson and Rosenburg, 1978). Crawford *et al.* (2003) note that sediments with high percentages of silts and clays were 'less than ideal', presumably for the reasons previously noted. There is, however, little understanding as to specific 'trigger levels' of organic matter required to initiate community level changes. Though the organic contents of sediments within the Bay of Plenty are low (< 6%) relative to many other sites, those habitats with organic contents above 4.5% have been graded as 'less suitable' (Table 3.5 and Figure 3.18) if sediments are silt sized, and 'relatively unsuitable' if there is a large (>90%) proportion of mud sized particles, enhancing the potential for anoxia.

Bivalve aquaculture has the potential to modify soft sediment benthic regimes due to the deposition of shell material (Grant *et al.*, 1995; Gibbs, 2004). In some cases the variety and density of fish and crustaceans can increase as a result of the shell litter (Grant *et al.*, 1995; Hartstein and Rowden, 2004). Over muddy sediments, bivalve aquaculture can enhance the diversity of benthic animals, bio-deposits can be ingested by deposit feeders, while shell litter *etc* can increase habitat heterogeneity and allow colonisation by species more suited to hard substrates (Grange and Cole, 1997). Muddy and silty areas with relatively low organic contents (< 4.5%) have been graded as 'more suitable' (Table 3.5 and Figure 3.18) for the purposes of aquaculture zoning within the Bay of Plenty as they represent the benthic environments most suitable to deal with the potential fallout from suspended bivalve aquaculture. These areas are generally located deeper than 35 m and are in the central and eastern regions of the Bay of Plenty.

3.8 SUMMARY

A sustainable shellfish aquaculture industry requires that impacts on the environment be minimised and mitigated. Detailed analyses during the planning stages can aid the mitigation of negative impacts. The Bay of Plenty has a range of benthic habitats and sedimentary environments which vary in their ability to cope with inputs from open coast bivalve aquaculture.

A suitability classification based on both the character of the natural environment and the potential impacts of suspended shellfish aquaculture on these environments has been developed. The most suitable areas to efficiently mitigate potential inputs from an aquaculture development are those comprising silty sediments with naturally low

(< 4.5%) organic contents. Habitats with these properties have been identified throughout the Bay of Plenty between ~40 and 100 m depths. Reef type environments and sediments with naturally high (> 4.5%) organic contents should be avoided by aquaculture planners, as these habitats are most at risk from potential inputs.

The Bay of Plenty marine environment comprises:

i. boulder reef areas covered by *Ecklonia radiata*, similar to other boulder reef environments in northeastern New Zealand, mainly located near rocky shorelines and offshore islands;
ii. unique deep reef habitats covered with encrusting red algae and sponges, not generally found at mainland locations within New Zealand;
iii. very coarse sediments nearshore off Pukehina;
iv. expanses of sediments with very high mud contents between 50 and 90 m depths between Matata (transect D) and Whakatane (E) and also between Opotiki (H) and Omaio (K);
v. strongly bimodal sediment distributions in deeper waters (> 50 m) to the west of Whakatane; and
vi. sharper gradients and greater faunal diversity in eastern areas (relative to western regions).

The grain size, organic content, and reef type distribution patterns observed are consistent with previous local scale observations. The collected data represent a significant advancement in the knowledge of Bay of Plenty shelf benthic environments and the potential impacts aquaculture developments upon them. In addition, these data act as a baseline environmental dataset to determine the scale and extent of influence of potential developments within the Bay of Plenty shelf environment. This investigation represents a significant advancement in the knowledge of benthic habitats within the shelf environment and also in the potential impacts of suspended aquaculture developments on benthic environments.