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August 2005

ARC Technical Publication 275

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Auckland Regional Council
Technical Publication No. 275, 2005
ISSN 1175-205X ISBN 1877353 98-1

Printed on recycled paper

Benthic marine habitats and communities of the southern Kaipara

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Prepared for
Auckland Regional Council

NIWA Client Report: HAM2005-077

NIWA Project: ARC05212

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1 Executive Summary

In 2000, a three Tier strategy of monitoring flora and fauna living in marine benthic habitats was designed to deliver State of the Environment data for the Auckland Region. Tier I was temporally detailed (2-3 monthly sampling return) monitoring at a few intertidal sentinel sites in important harbours, aimed at detecting benthic ecological trends. Tier II focused on defining geospatial patterns of habitats and describing ecological communities present in intertidal and near-shore (<20m) subtidal areas. Tier III was broad-scale habitat mapping with only limited benthic ecological community sampling in waters greater than 20m depths. These three Tiers were interlinked with Tier I sampling providing information on the ecological relevance of changes observed in Tier II and III sampling, while the more extensive spatial coverage from Tier II would provide a broader spatial context to assist with the interpretation of Tier I sentinel site monitoring. Tier I sampling has been conducted for a number of years; however this project in the Southern Kaipara develops and delivers the first results from Tier II.

A major reason for selection of the Kaipara for the initiation of Tier II monitoring was the notification in October 2002 of proposed Aquaculture Management Areas (AMAs) for the southern half of the Kaipara Harbour in the Auckland region. Evaluation of the appropriateness of the proposed areas has been hampered by a shortage of information on the benthic ecology of the southern Kaipara. The purpose of this project was therefore threefold. (1) Design and demonstrate a sampling strategy that could be used in other areas for Tier II State of the Environment marine ecology monitoring. (2) Produce habitat and community descriptions of the Southern Kaipara, such that the range of dominant species and the geospatial patterns of any distinct community groups are identified. (3) Use the spatial information from the whole of the Southern Kaipara to place the proposed AMAs in context.

Sampling strategy. This project is an ambitious survey of half of the largest harbour in the southern hemisphere. Although in recent years we have begun to research methods for integrating new acoustic techniques with traditional biological sampling to provide ecologically relevant maps, this is ground-breaking research and there is no simple way forward. The length and shape of the Kaipara means that current flows are generally high; and the width of the harbour and its wide mouth allow considerable wave activity. The area towards the mouth is a well-known great white shark habitat. The water in the harbour is frequently turbid. All these aspects contributed to the difficulty of sampling the area. Sampling comprised three aspects: sampling continuously at a large scale by photographs (intertidal) and acoustically (subtidally); transect sampling by video (intertidal and subtidal) and dredge (subtidal); and point sampling of sediment and macrobenthos by cores (intertidal) and grabs (subtidal).

Video transects from a helicopter proved useful in extending information available from aerial photographs, and video and dredge sampling in subtidal areas provided good descriptions of epibenthic habitats. Acoustic sampling of the seafloor provided good information on seafloor types; however, much of the differentiation was between different degrees of wave and current disturbance in sandy sediments. Because of this a high degree of concordance between the acoustic data and the fauna and flora was not observed.

A major focus of the Tier II monitoring is the description of ecological communities, in particular the identification of vulnerable or unique communities. There are a number of methods for determining community associations of biological data. Generally methods for determining community associations revolve around different statistical techniques for determining clusters of like communities. Such techniques were not found to be suitable for this project, because distinct clusters of samples with a high degree of self-similarity were generally not apparent. Therefore, this project used an ecological rules based approach to determining communities. This technique also allowed us to emphasise associations with high ecological or social values, or that are easily assessed for vulnerability (which is generally associated with mobility, feeding mode and position within the sediment displayed by members of the community). This approach worked well and we would suggest its continuance in the Tier II monitoring.

The data collected by this project is summarised in a series of GIS layers, displaying the spatial distribution of physical habitat types and ecological communities. The raw data is included in the GIS files, allowing new interpolations and queries to be raised. The confidence associated with interpolations between sampling occasions are also summarised in GIS.

Ecological description and value. The Southern Kaipara has high diversity of habitats: extensive fringing mangroves and salt marshes; *Zostera* meadows and patches; non-vegetated mud and sand intertidal flats and shallow subtidal flats, as well as small areas of steep banks, deep high-flow channels and rocky reefs and cliffs. Despite the high flow and potential for wind and ocean swell generated waves, many areas of the Southern Kaipara displayed high taxonomic diversity at both a species and order level, and a number of organisms living in the harbour are large and long-lived. A number of species commonly associated with pristine environments (sponges, ascidians, bryozoans, hydroids, echinoderms and pipis) were found in the harbour.

Subtidally, the most common community type was dominated by varying densities of the sand dollar (*Fellaster*), or a *Fellaster*/gastropod mix. Areas of rich epifauna (sponges, ascidians, bryozoans, mussels) were more confined, occurring mainly in the central moderate-depth subtidal, along the channel banks and in the main channel near South Head, although hydroid habitats are found considerable distances up the Oruawharo, Tauhoa and Kaipara River arms. Intertidally, the most common communities were those dominated by deposit-feeding polychaetes. However, a number of bivalve and gastropod dominated communities occur as well. Moderate to dense mangrove areas (> 50% cover) were low in diversity supporting communities that were distinctly different from other intertidal areas.

While many of the taxa and habitats found in the Southern Kaipara occur elsewhere, some are unique. In particular, a subtidal association of tube-building worms was found in the shallow subtidal area of the main harbour comprised of high numbers of *Owenia*, *Macroclymenella*, *Euchone* and Phoronids. Subtidal *Zostera* is also comparitively rare in New Zealand. Strong differences were also recorded from different parts of the harbour; the Oruawharo Arm and Waionui Inlet both had distinctly different taxa than the main harbour. The *Atrina* beds of the Kaipara while small are particularly important for juvenile snapper.

Invasive bivalve species were observed in the harbour, the Pacific oyster (*Crassostera gigas*), the Asian mussel (*Musculista senhousia*) and a small bivalve *Theora lubrica.* Only Musculista was found frequently in high-density patches, however these patches were relatively small, never stretching from one sampling location to the next. *Musculista* is found in much of the Auckland Region, growing densely (e.g., Tamaki Inlet) and often excluding other animals, though this does not yet seem to be the case here. However, *Musculista* patches were widespread occurring in all areas of the harbour with the exception of Waionui Inlet.

Aquaculture Management Areas. The habitat survey relative to the proposed AMAs raised some important issues. AMAs fell across three types of habitats. AMA D and E lie across an area of subtidal *Zostera* and high diversity patches of sponges, suspension-feeding bivalves, filamentous seaweeds and the unique tube-dominated community. AMA C lies in a channel area, with *Fellaster* or *Fellaster*/gastropod dominated communities, offshore from some intertidal *Zostera* beds. The *Fellaster* and *Fellaster*/gastropod dominated communities are the least diverse and most common subtidal habitats observed in the Southern Kaipara and AMA C covers only a small proportion of this habitat type (< 5%). AMAs A and B overlay some of the highly diverse and encrusted rubble and rock wall habitats dominated mainly by fauna (sponges, bryozoans and mussels) and deep channel areas containing sponges. The deeper channel areas of these AMAs are similar to AMA C. Some areas of *Zostera* were observed in AMA B, which was sandier with gently sloping walls. The currents in these areas (A, B and C) suggest that build up of fine organic material below farms is unlikely, and the major effects of mollusc farms is likely to come from deposition of shell material in flat or gently sloping areas, or depletion of phytoplankton. Given the diversity of the benthic habitats and taxa encompassed by these AMA's, a detailed assessment of the risks is warranted.

To conclude, while this report concentrates on descriptions of the general habitats and communities found in the Southern Kaipara, this is not the only level at which comparisons would be made if a return visit was made in 10-15 yrs time. More detailed comparison would be able to be made on a site by site basis. Natural temporal variability apparent from the sentinel monitoring sites in the region (Tier I) will need to be used to set the limit on the magnitude of effects able to be detected in the Tier II temporal comparisons.

2 Introduction

In 2000, ARC commissioned NIWA to design a State of the Environment Monitoring Programme for marine ecology in the region (Hewitt 2000). The resultant design comprised three nested Tiers of monitoring of the flora and fauna living in and on the marine substrate. Tier I was spatially constrained but temporally detailed (2-3 monthly sampling return) monitoring at intertidal sentinel sites in important harbours, aimed at detecting benthic ecological trends. Tier II focused on spatially intense sampling of intertidal and near-shore (<20m) subtidal areas with the objective of defining geospatial patterns of habitats and describing ecological communities present. Areas to be sampled were prioritised by ARC and it was envisaged that resampling would occur every 10-15 years, allowing any large changes in habitats or communities to be identified. Tier III was broad-scale habitat mapping with only limited benthic ecological community sampling in waters greater than 20m depths. The temporally intensive Tier I sampling was to provide information on the ecological relevance of changes observed in Tier II and III sampling, while the more extensive spatial coverage from Tier II would provide a broader spatial context to assist with the interpretation of Tier I sentinel site monitoring. Independent peer review of the programme design in 2002 strongly endorsed the Tiered approach.

Elements of Tier I monitoring have been in operation since 1987, and has provided important feedback for resource management and State of the Environment reporting (Hewitt et al. 1994,Cummings et al. 2003, Hewitt et al. 2004b, Thrush et al. 2004). However, Tier II monitoring was only initiated in 2003. ARC chose to initiate sampling the Kaipara within its region (hence forth referred to as the Southern Kaipara). Kaipara Harbour is the largest harbour in New Zealand, huge even by world standards. Even the southern area located in the Auckland Region is larger than that of the whole Manukau (340 km^2). The length and shape of the Kaipara means that current flows are generally high; and its width and wide mouth allow considerable wave activity. The area towards the mouth is a well-known great white shark habitat, and a number of commercially important fish species inhabit the harbour (Fishing for the future: a strategy for the fisheries of the Kaipara Harbour). The intertidal area (250 km^2) is mostly low intertidal, often with extensive *Zostera* beds. The water in the harbour is frequently turbid, probably due both to resuspension of seafloor sediments and input from the land.

A major reason for selection of the Kaipara for the initiation of Tier II monitoring was the notification in October 2002 of proposed Aquaculture Management Areas (AMAs) for the southern half of the Kaipara Harbour in the Auckland region. Evaluation of the appropriateness of the proposed areas has been hampered by a shortage of information on the benthic ecology of the southern Kaipara. Application of Tier II methodology to the southern Kaipara was therefore given priority so that it could provide this urgently needed information. The purpose of this project was therefore threefold:

- Design and demonstrate a sampling strategy that could be used in other areas for Tier II State of the Environment marine ecology monitoring. The strategy was to provide data of sufficient accuracy for use in (i) determining the spatial extent and arrangement of habitats and benthic communities present, (ii) distinguishing areas of habitat complexity from areas of uniformity, and (iii) identifying potentially representative, unique or rare habitats and communities. Meaningful changes in the aerial extent or distribution of habitats and communities (e.g., mangrove habitat expansion or replacement of sandy substrate by muddy habitat) should be able to be identified if the sampling was repeated in 10 – 15 years time. The habitat and benthic community descriptions should be useful for determining the vulnerability of areas to various activities likely in the coastal marine area (such as marine farming, increased sedimentation, sand extraction and construction of structures).
- Produce habitat and community descriptions of the Southern Kaipara, such that the range of dominant species and the geospatial patterns of any distinct community groups are identified.
- Use the spatial information from the whole of the Southern Kaipara to determine the amount of specific habitats covered by the proposed AMAs.

In recognition of the cultural significance of the Kaipara harbour to mana whenua and their interest in the ecological monitoring project, liaison was established with Ngati Whatua Ngä Rima o Kaipara. Ngä Rima includes southern Kaipara marae at Puatahi, Araparera, Kakanui Haranui and Reweti. Information on the project and relevant cultural issues were discussed during hui at Reweti, Haranui and Araparera marae. An agreement was reached between ARC, NIWA and Ngä Rima that formalised opportunities for involvement in the monitoring project, access to early reporting of project findings, and provision of final results.

2.1 Background

The sampling strategy suggested for Tier II monitoring in Hewitt (2000) focused on providing information on whether the major impact identified by ARC (increased sedimentation) was having long-term effects. However, with the need to provide a fuller inventory of ecological resources and deal with a broader category of anthropogenic impacts, the sampling strategy was changed to be more more spatially intensive.

The need to identify and sample most if not all habitats meant that broad-scale identification of major physical habitats was needed. While collecting data over large areas on land is commonplace, and techniques for reliably collecting such data in deep waters are increasingly available, in intertidal and shallow subtidal areas collection of such data is more problematic. This is particularly true in most of New Zealand's estuaries and harbours, including the Southern Kaipara, where turbid waters prevent aerial photography, satellite imagery and LIDAR from penetrating far into the water column. At the same time, use of acoustic techniques such as side-scan sonar, single beam (QTC) and multibeam are problematic (or beyond the cost of programmes such as this) in shallow waters (< 5m), which are frequently disturbed by short waves.

Given that no single technique is perfect, a suite of appropriate methods needed to be selected, from the range currently available, to deliver cost-effective, accurate and repeatable habitat information. Therefore a number of sampling techniques that allow rapid collection of data over large areas were investigated. (1) For the intertidal areas, transects videoed from a helicopter at 30 m were integrated with aerial photographs provided by ARC. (2) For areas in the low intertidal - shallow subtidal underwater video transects and dredge transects were utilised. (3) For deeper areas (> 5 m deep), underwater video, single beam QTC and side-scan sonar transects were run.

While this sampling can provide general habitat descriptions (e.g., mangroves, *Zostera* meadows, mud, underwater sand waves), the presence of different types of ecological communities (e.g., cockle beds, sponge gardens) cannot be readily or directly inferred. In most of New Zealand's estuaries, harbours and coastal areas the dominant environment is soft-sediment (ranging from muds to gravels). Determining community types, rather than the distribution of a few large emeregent species, requires time-consuming sediment sampling with cores or grabs. To be cost-effective, the location of these samples needs to be driven both by the general habitat information and other environmental characteristics known to be important (e.g., depth, distance to other habitat types, tidal currents, wave exposure Hewitt et al. 2004c).

Furthermore, to translate acoustic data into ecological communities requires extensive and well-targeted ecological sampling and, frequently, the use of sophisticated analytical techniques. Differences in the resolution of data from different methods and the need to interpolate across large areas from point or transect samples mean that habitat/community descriptions and maps can have large uncertainties built into them. Even trying to draw a boundary between different habitats can be problematic, as frequently habitats don't have distinct boundaries, but merge from one to another through transistion zones. Defining boundaries is thus partially influenced by the resolution of the sampling. It is imperative that these uncertainties are recognised when the data is being used. Thus, a final part of this work quantifies and explicitly details the uncertainties inherent in the sampling strategy of Tier II work and the descriptions of habitats and communities provided for the 440 km^2 of the Southern Kaipara.

3 Development and rationale of method selection

3.1 Intertidal sampling

3.1.1 Large-scale features

Classifications of vegetation in the intertidal area were available from ARC (Horsley 2005), in the form of shape files (see Table 1). This data was captured from aerial photographs 1999 1:10,000 scale, digitised with a 1m-pixel size. Visible vegetation boundaries were captured in GIS at a scale of 1:2,500 and broader patterns checked at scales of between 1:5,000 and 1:15,000. Vegetation was classified into categories consistent with those used in Morrisey et al. (1999). Vegetation classification was checked by ARC staff against local knowledge but received only limited ground truthing. Detailed analysis and application of the GIS based vegetation classification should therefore be treated with caution. Only the *Zostera*, salt marsh and mangrove information was used in this work, however Horsley (2005) also provided the coastline and low tide boundaries. The sand category was not used, as it is realistically a record of non-vegetated intertidal area rather than real information on sediment type.

Table 1:

Vegetation categories provided by ARC (Horsley 2005)

0-25% Mangroves
25-50% Mangroves
50-75% Mangroves
75-100% Mangroves
Coastal Bush
Coastal Scrub
Fresh Water Wetland
Grass
Rush / Reed / Sedge land
Saltmarsh
Sand
Spartina
Zostera (seagrass)

The information available from ARC left 2 major gaps in information required for defining physical habitats: (1) lack of bathymetric detail and (2) lack of sediment type detail. Collecting detailed bathymetric data by LIDAR (Box 1) was investigated, but proved too costly for this project, particularly given many intertidal benthic animals are not particularly sensitive to tidal height. Instead, it was decided to use hydrographic information derived from Navy fare sheets to separate the intertidal from the subtidal.

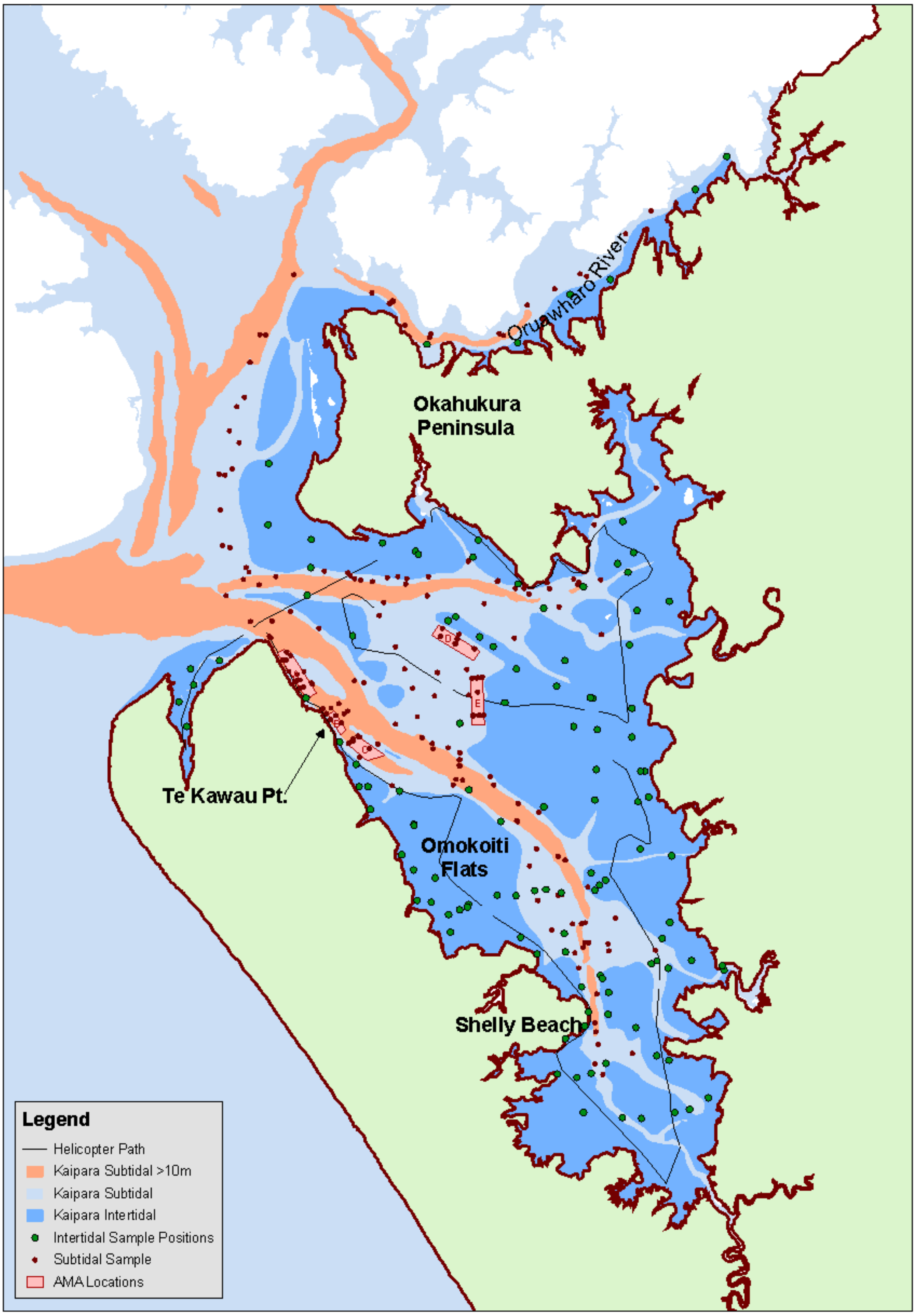
Sediment type (e.g., mud, fine-medium sand, coarse sand, shell) is, however, an important influence on many species and ecological processes. Video transects from a helicopter at 30 m were trialled to see whether large-scale changes in sediment type could be recognised. The video proved capable of providing an image from which mud, sand and shell could be separated at a resolution of 20 m, so video transects were run across the intertidal areas (Figure 1). These transects also offered the opportunity to ground truth the *Zostera* shape file provided by ARC.

Box 1

LIDAR (light detecting radar) equipment is available from Australia. It is flown from an aircraft to map bathymetry; it can penetrate into water but is limited by turbidity. In much of the Kaipara this would limit depth penetration to about 30cm water depth. LIDAR can also be used to separate different plants and benthic algal communities using reflectance of selected wavelengths, but this equipment is only available from one place in the US and information on the reflectance of New Zealand plants and animals is not available.

Figure 1: (Click for high resolution map)

Southern Kaipara with all sample positions.



3.1.2 Macrofauna

3.1.2.1 Hard substrata

The Southern Kaipara has very little rocky substrata. The only large area of this occurs to the northwest of Omokoiti flats (Figure 1), along a region of steep sandstone cliffs.

Much of the area is difficult to access by either foot or boat; however access was gained to an area north of the Omokoiti flats. The rocky substrates here were of 2 types. The first was a series of low-lying intertidal reefs surrounded by sand (Figure 2). Photographs of three replicate quadrates (0.25 m^2) similar to those used in other intertidal work for ARC (Babcock et al. 1999) were taken from 7 of these reef 'patches'. The number of replicates was reduced from the 7 used in these other studies due to the size of these patches. The second type of rocky shore was steep bedrock and boulder with a fine coating of slippery mud (Figure 2). For this shore type, a transect was run down the slope and 8 quadrate photos taken from positions ranging from low intertidal to high intertidal. Percent cover of different flora and fauna were analysed back at NIWA. Identification from the photographs were checked against specimens collected from the quadrats, after the photographs had been taken.

Figure 2:
Two types of rocky intertidal areas were observed: flat reefs and steep cliffs.

3.1.2.2 Soft substrata

Soft-sediment intertidal sampling concentrated on infauna, as they comprise the majority of the benthic community. Positions for sampling were determined using existing ARC aerial photographs (at 1:10000), hydrographic chart data and ecological knowledge. Bathymetry, intertidal area, sediment type (derived from sampling in this project), and distance to freshwater inputs were all used to determine strata within which sampling would occur. The area near Helensville, and areas near mangroves, *Zostera* or *Spartina*, together with natural heritage and conservation areas and aquaculture-designated areas were considered particularly important (Auckland Regional Plan: Coastal (2004) text and accompanying map series).

140 sites were selected for site visits. A two-Tiered adaptive sampling design was used. Site characteristics (sediment type, sediment firmness, evidence of vegetation, wave exposure or currents, presence and type of benthic animals able to be observed at the sediment surface) and the relative homogeneity of these characteristics were noted. If these characteristics were the same as those noted at the next closest site the site was not sampled further. If they were different, three sediment samples (13cm diam, 15cm deep) were taken, within a 10 by 10 m area, similar to surveys of Whitford (Norkko et al. 2001b) and the upper Waitemata (Cummings et al. 2002). This resulted in 113 sites sampled by coring (Figure 1). Where the site to be sampled displayed obvious patchiness in habitat (e.g., patches of *Zostera* interspersed with sand), samples were taken in each habitat. All sediment samples were sieved on a 1mm mesh; while this differs from many of the other sampling programmes conducted for the ARC, the question here "describing communities in sufficient detail that changes over a 14 year period can be detected" is different to the questions behind the other programmes. Thus, in this project the focus is specifically on larger and longer-lived species.

Using the 1 mm mesh restricted recruitment pulses from affecting results, this was particularly necessary because sampling took place in February, a time when many species are recruiting. Use of a 1mm mesh still allows a description of larger and longer-lived members of the communities, sufficient for the broadscale management purposes specified. For example, (Thrush et al. 2003c) found communities sampled at a 1mm level to show broad-scale changes in distribution and abundance relative to sediment mud content. Generally, very few taxa are not sampled with a 1 mm mesh; these include the smaller free-living spionid species (*Microspio* and *Minuspio*), many Oligochaetes and most Exogoninae, whose density may be underestimated with a coarser mesh. To assess the effect of sampling with the 1mm mesh on our objectives, especially in muddy mangrove areas where smaller animals may dominate, a number of sites were randomly selected to be sieved on both a 0.5 mm mesh and a 1mm mesh.

All samples were preserved in 50% Isopropyl alcohol and stained with 5% Rose Bengal. Invertebrates were sorted, identified to the lowest practical taxonomic resolution and counted.

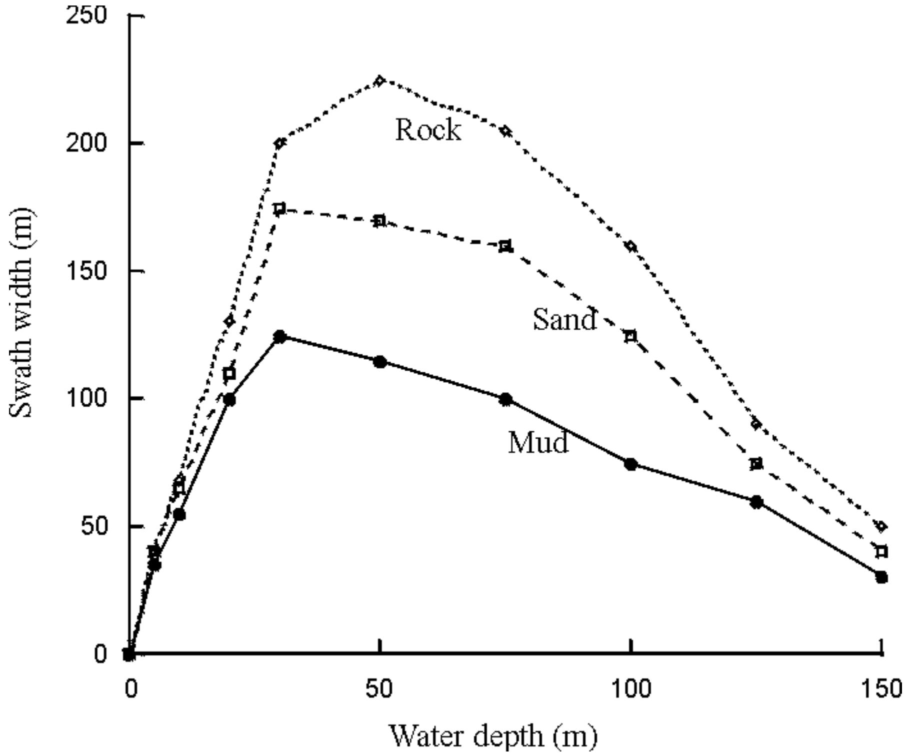
3.2 Subtidal sampling

3.2.1 Large-scale physical features

Subtidal physical habitat descriptors are commonly based on depth and sediment characteristics. Depth data can be collected either by depth sounder, QTC or multibeam sonar. However, data from any of these sources requires conversion based on the state of the tide at the time of collection. Essential to being able to convert tidally dependent depth information to depth relative to chart datum, is either a tidal model of the area or tide gauges deployed during the period of data collection. While NIWA has developed a tidal model for the coastal areas of New Zealand, this model does not work precisely within estuaries and harbours and so was not relevant for the Southern Kaipara. The cost of deploying tide gauges was beyond the scope of this project, particularly given that gross estimates were available from charts, and that similar to intertidal animals, subtidal animals are usually less sensitive to depth than to other factors (e.g., sediment characteristics, currents, waves, freshwater inputs). Use of chart data does limit our ability to differentiate by depth and accordingly depth is only used to indicate shallow areas (two categories < 3 m and 3-7 m), medium (7 – 15 m), deep (> 15 m) and channel banks (slope > 15 deg). These ranges were determined based on the potential to have effects on fauna.

Collection of continuous information on sediment characteristics over large scales is generally done using acoustic devices; indirect techniques that require ground truthing and interpretation (Bax et al. 1999, Kloser et al. 2001, Hewitt et al. 2004c). Acoustic devices are based on single or multiple transducers, sending acoustic pulses to the seafloor. The energy of the reflected signal is measured and this is affected by seafloor slope, hardness, roughness and absorption. Side-scan or multibeam sonar produces a series of individual beams that collectively are narrow in the along-track direction but wide in the across-track direction. Single-beam devices (e.g., QTC) produce a comparatively small, roughly circular beam. For both QTC and multibeam, the device is attached to a boat, resulting in the area of seafloor over which data is recorded being depth-dependent. This affects the coverage able to be obtained by the device (Figure 3) such that in 10 m depth only a 1.9 and 60 m wide area is sampled by QTC and multibeam respectively (cf 400 m for side-scan). Furthermore, the signal that is being returned is covering a different area, resulting in variable signals for a similar seafloor at different depths, confounding interpretation in shallow and variable depth situations. Multibeam corrects for this in the across transect distance, while QTC does not. Side-scan is generally flown behind the boat at a set distance above the seafloor (usually around 5 m) and coverage varies depending on frequency of the side-scan (e.g., 60, 200 and 400 m beam widths for NIWA shallow water side scans).

Figure 3:
Multibeam swath width dependence on depth and sediment type.



So in water depths < 30 m (the majority of the Southern Kaipara), side-scan is the most cost effective tool. Technically multibeam and QTC can be used in shallower waters than can side-scan (i.e., < 6m), but in reality the low coverage and the loss of signal clarity generated by small waves mean that regardless of the acoustic tool used, this depth range is rarely well sampled. For these reasons, side-scan was chosen as the large-scale sampling technique. Sampling concentrated on the channels inside the harbour, with a only a few long transects run along the open harbour mouth area. Detailed information had previously been collected in this area (Hume et al. 2001). Some side-scan transects up into shallow areas were run on each of the three side-scan field trips, but the data collected was not useable. Side-scan data was collected running down channel to maximise the ability to detect differences on the channel banks, as this is frequently an area of high biological diversity.

The ARC has previously collected QTC data for habitat maps in Whitford (Morrison et al.) and Long Bay – Whangaparaoa (Morrison et al. 1999). QTC data has also been collected in Manukau, Kawau and Mahurangi (by NIWA for Foundation-funded research) and the Firth of Thames (for DOC (Morrison et al. 2002)). Because QTC can distinguish differences amongst soft-sediment habitats that may not be detected by side scan (but see Hewitt et al. 2004c), and because QTC analysis uses statistical processes to assign data to defined substrate classes, ARC requested that if possible QTC data be collected at the same time as the side-scan data. Due to the potential for interference between these two acoustic devices, initial trials were conducted that demonstrated the QTC could be used to simultaneously collect data if the side-scan was set at low resolution. Data collected from both medium and low resolution (i.e., collecting 200m or 400 m wide strips) were compared and the low resolution was deemed acceptable for collecting information to classify patches at a 10 m scale.

Using these techniques no information was collected in areas shallower than 6 m. These areas were surveyed using video and/or dredges (see section 3.2.2).

3.2.1.1 Side-scan data collection and analysis

An initial attempt was made to determine side-scan acoustic types statistically, to try to increase the objectivity of the analysis (similar to QTC). Two long transects of side-scan (10 m wide), that ran through a number of visually distinct habitats were analysed in 10 m blocks using image analysis to determine grey-scale intensity characteristics. The resultant data were clustered using k-means and average linkage based on mahalanobis distances. The locations of the resultant clusters were compared to the visual results. Similar to other attempts in the past (Zajac et al. 2000, Funnell pers comm.), this method was not able to match the visual observations, confirmed by experienced side-scan analysts. There are a number of basic issues that the statistical process cannot cope with as well as the "expert" eye. These include orientation of the tow fish relative to bed features and variation in gain across habitat types. As a result side-scan acoustic types and their extent were determined by expert recognition. This does not invalidate the use and interpretation of side-scan images in any way or suggest that QTC necessarily is a more scientific method. While QTC uses an objective statistical method to categorise the 166 variables it measures, what exactly the variables measure is at present unknown and is not transferable between locations. With side-scan, while the categorisation is subjective, it is based on extensive scientific knowledge of seabed characteristics and is transferable between locations. It may be that QTC is equally affected by categorisation procedures but, as the variables have no specific meaning, the failures in the classification are not so obvious. Side-scan sonar also produces a more interpolatable image of the seabed, as it samples a swath rather than a single point.

3.2.1.2 QTC data collection and analysis

A new version of the QTC View data acquisition software (QTC4, version 1.0, 2004) was used to capture the raw echotrace of the first returning echo from the seabed. The waveform editor in QTC Impact seabed classification software, version 3.3 (Quester Tangent Corporation 2003) was used to pick the seabed / water column interface, and for further quality assurance of the echo traces. A reference depth of 15 metres was applied to compensate for changes in footprint size (insonified area) with changes in depth. Full Feature Vectors (FFV) were then generated to describe the shape of the echoes using 166 variables. One FFV was generated for five consecutive pings in the raw data. Each FFV record is a string of 166 numbers that describe different features of the echo signals. The data was then filtered using principle component analysis to determine the first three axes. An "unsupervised classification" procedure was then used to cluster the PCA data into groups by splitting them along one of the three principal axes in the graph. QTC Impact recommends using changes in the total score to determine the optimal level of clustering. As a dataset is subdivided, the Total Score generally decreases due to each new class having a smaller number of data points and a smaller X^2 value due to the tighter clustering. The number of classes was plotted against the Total Score for each stage of splitting, and the inflection point of the curve provided an indication of the optimal number of classes. The "Cluster Performance Index", or CPI provides another indication of the optimal split level, which is the ratio of the distance between cluster centres and the extent of the clusters in Q-Space. This is effectively a measure of signal (separation) to noise (cluster variance). The CPI value "tends to be maximum at the optimal split level" (QTC Impact User Guide).

3.2.2 Large scale biological features

Unlike terrestrial remote sampling, acoustic devices do not collect data directly related to specific biological variables (Hamilton et al. 1999, Smith et al. 2001). Visual systems allow direct estimation of epibenthic floral and faunal densities, as well as identification of bioturbation, sediment microtopography and sediment characteristics. They generally have finer resolutions and lower surveying speeds than the sonar devices, making surveying relatively costly. Thus, visual surveys need to be well targeted, and are usually nested within areas surveyed by the acoustic techniques (Hewitt et al. 2004c). In this project, we used a visual system (video camera) to ground truth the acoustic images, provide information on how communities changed across depth and acoustic transition zones, and to survey areas shallower than 6 m.

For some areas of the Southern Kaipara, water clarity compromised the use of video. In these areas, samples were collected by an Ockelmann type epibenthic sledge with a 2mm mesh size. A number of trials of this system were undertaken in the first year, to determine an appropriate mesh size and the length of tow that guaranteed the sledge's net would be sampling over the whole area of the tow. A total of 44 dredge samples were collected from tows of approximately 10 metres duration. Initial trials determined that these tows were sampling the epifauna and large benthos to a depth of 5 cm.

The video and dredges were analysed to give equivalent data, i.e., large or unusually dense epifauna. As both the video and dredge could give information on burrowing infauna (e.g., shrimps and crabs, indicated by the presence of burrows for video and abundances for dredge), data on these animals was gathered from both methods and converted to rank abundance (not present, present in low numbers, present in high numbers). Video data were analysed by characterising all footage by pattern (uniform/patchy), density (sparse/dense) and type of fauna and flora, substrate type and degree of bioturbation. Assessment in this fashion has previously been shown to match well with direct count data (Hewitt et al. 2004c).

At five locations, both dredge and video sampling was conducted to assess the comparability of results. The site characterisation for these locations revealed that a similar characterisation had been allocated to each site by both methods.

3.2.3 Macrofauna

3.2.3.1 Hard substrata

Similar to the intertidal rocky habitats, the subtidal rocky habitats were restricted in area. Initially it was planned to sample this using sampling consistent with sampling carried out in the Long Bay program (Babcock et al. 1999). However, this was contingent on finding similar habitats to those surveyed at Long Bay. Instead the rocky subtidal habitats are steep cliffs, with small amounts of rocky rubble at their base. These were sampled by a Benthos Mini-Rover Remote Operated Vehicle (ROV) with colour video camera and integrated lights and depth recording. Video footage began on the soft sediment floor of the channel ~20 m deep). The ROV was then 'flown' up the slope recording video and depth continuously, stopping for close-up views approximately every 4-5 metres. The transects were analysed to characterise the fauna, flora and substrate, as well as ripples and bioturbation (where present) by including a description of each parameter's pattern (uniform/patchy), density (sparse/dense), type and size. Slope (flat/low/med/steep) and relief (flat/complex) were also estimated.

3.2.3.2 Soft substrata

Soft-sediment subtidal sampling concentrated on both infauna and epifauna, as usually both are important. Positions for sampling were determined using acoustic data, hydrographic data, video and dredge information and ecological knowledge. The aquaculture-designated areas were particularly targetted for sampling.

117 sites were selected for site visits. Similar to the intertidal sampling, a two-Tiered sampling design was used. Unlike the intertidal sampling, site characteristics could not be determined before the sediment sample was taken. Instead a grab (0.1m^2) was taken and sieved on a 1mm mesh. The appearance of the sieved material and the sediment going through the sieve was noted. If these characteristics were similar to those noted at the next closest site the site was not sampled further. If they were different, two more grabs were taken. The 3 replicate grabs were generally taken from within 15m of each other. This regime resulted in 109 sites having samples taken from them (Figure 1). All samples were preserved in 50% Isopropyl alcohol and stained with 5% Rose Bengal. Invertebrates were sorted, identified to the lowest practical taxonomic resolution and counted.

3.2.4 Defining communities

There are a number of methods for determining community associations of biological data. Generally these revolve around different statistical techniques for determining clusters of like communities. Such techniques are not suitable for this project for a number of reasons:

1. Sampling of six intertidal areas in Manukau Harbour revealed that many intertidal species are ubiquitous (Thrush et al. 1988, Pridmore et al. 1990) such

that distinct clusters with a high self-similarity are generally not found. This proved the case for the Southern Kaipara as well. Two-dimensional ordination plots and tree dendrograms of the intertidal data, produced using nonmetric multidimensional scaling and group averaged clustering on raw species data, had high stress values (indicative of a poor 2-dimensional fit) and showed no distinct patterns. The dendrogram showed that there were a large number of groups exhibiting >50 % similarity and these generally were comprised of three or less members. K-means classification of both chord and Hellinger transformed species data suggested a variable number of groups (11 and 4 groups respectively). Generally the groups had few members and low self-similarity.

2. Use of statistical techniques such as these to determine assemblages based on few replicates at a site is problematic. Generally the number of species found at a site initially increases rapidly with the number of samples taken. Work done in Manukau, Mahurangi and Waitemata suggest that for most intertidal sandflat areas at least 12 samples is needed to accurately detect temporal changes in a species abundance. For this project, 1 – 3 replicates were taken at a site, as the objective was broad-scale descriptions of broad community types, rather than detailed descriptions of biodiversity.
3. A major aim of this project is to identify areas vulnerable to impacts, and rare or unusual biotypes. For example, do the AMA areas cover biotypes that are vulnerable to the use proposed? Are the flora and fauna found in these areas rare in the Southern Kaipara? These are ecological, not statistical, questions and an ecological "rules based" approach to determining biotypes will provide the most sensible answer.

A system of ecological classification rules was developed for both the intertidal and subtidal areas of the Southern Kaipara. The basis of the rules was threefold: key species, key functions and factors affecting vulnerability to threats. There are a number of species of demonstrated importance in New Zealand's estuaries and harbours, either recreationally (e.g., cockles, pipis, scallops), or by their effect on the surrounding community (*Zostera* (Turner et al. 1999, van Houte-Howes et al. 2004), *Macomona* (Thrush et al. 1992, Thrush et al. 1996a, Thrush et al. 1997), *Atrina* (Cummings et al. 2001, Norkko et al. 2001a, Gibbs et al. 2005)). There are also particular groups of species that are functionally important, both to the benthic communities surrounding them and to the rest of the ecosystem. For example, tube-building animals can stabilise sediment and reducing sediment resuspension (Thrush et al. 1996b). Burrowing animals can increase sediment oxygenation and exchange of nutrients between the seafloor and the overlying water (Lohrer et al. 2004). Mobile surface dwellers increase sediment resuspension (Davis 1993, Orvain et al. 2003) and suspension feeders can remove sediment from the water column increasing nutrient fluxes to the seafloor (Dame 1993, Wildish and Kristmanson 1997, Norkko et al. 2001a). While individual species will show different responses to stress, more generally different types of animals will also be differentially vulnerable to specific impacts and their loss will have specific implications to ecological function and values. For example, deposit feeders are less likely than most suspension feeders to be vulnerable to increased suspended sediment loads. Suspension feeders may also be more vulnerable to changes in flow characteristics and phytoplankton depletion (Jorgensen 1996, Wildish and Kristmanson 1997) that may result from certain types of aquaculture.

These rules were combined in a hierarchical arrangement (see Box 2).

Box 2 Ecological community description decision rules:

A Intertidal

1. Did the sites have densities of adult *Macomona, Austrovenus,* or *Paphies* (or some combination of these) greater than or equal to 226 individuals per m^2 (3 individuals per core)?
2. Did the sites have high diversity at a high taxonomic (order) level (e.g., amphipods, polychaetes, bivalves)? And if so, were there high numbers of large organisms, burrowing organisms, surface mobile bioturbators, tube builders or suspension feeders?
3. Were the sites dominated by polychaetes? And if so, were they tube-builders, deposit feeders or large predators/scavengers?
4. Were the sites dominated by bivalves? And if so, were they invasive, deposit feeders or suspension feeders?
5. If the sites were not dominated by either polychaetes or bivalves, were they dominated by large animals or surface bioturbators?

B Subtital

1. Did the sites have high densities of large sedentary surface dwelling organisms (e.g., *Atrina, Perna,* sponges, *Ecklonia, Carpophyllum* or tunicates)?
2. Did the sites have high diversity at the order level? And if so, were there high numbers of large, burrowing or surface mobile organisms or echinoderms, tube dwellers or suspension feeders?
3. Were the sites dominated by polychaetes? And if so, were they tube-builders, deposit feeders or large predators/scavengers?
4. Were the sites dominated by bivalves? And if so, were they invasive, deposit feeders or suspension feeders?
5. If the sites were not dominated by either polychaetes or bivalves, were they dominated by large animals, surface bioturbators or sedentary epibenthic animals?

4 Methods

4.1 Intertidal sampling

Large-scale data was provided by shape files of *Zostera*, salt marsh and mangrove, coastline and low tide boundaries from ARC captured from aerial photographs taken in 1999 at a 1:10,000 scale, digitised with a 1m-pixel size. Visible vegetation boundaries were captured in GIS at a scale of 1:2,500 and broader patterns checked at scales of between 1:5,000 and 1:15,000. Video transects from a helicopter at 30 m provided information on large-scale changes in sediment type and were used to ground truth the *Zostera* shape file provided by ARC.

Low-lying intertidal reefs surrounded by sand were sampled by three replicate quadrates (0.25 m^2) taken from 7 of these reefs. Steep cliffs were sampled at 1 locations by 8 quadrats taken from positions ranging from low intertidal to high intertidal.

Soft-sediment infauna were sampled at 140 sites using a two-Tiered adaptive sampling design. Site characteristics (sediment type, sediment firmness, evidence of vegetation, wave exposure or currents, presence and type of benthic animals able to be observed at the sediment surface) and the relative homogeneity of these characteristics were noted. If these characteristics were the same as those noted at the next closest site the site was not sampled further. If they were different, three sediment samples (13cm diam, 15cm deep) were taken, within a 10 by 10 m area. All sediment samples were sieved on a 1mm mesh, preserved in 50% Isopropyl alcohol and stained with 5% Rose Bengal. Invertebrates were sorted, identified to the lowest practical taxonomic resolution and counted.

4.2 Sediment particle size

At 113 intertidal sites and 117 subtidal sites, single 2 cm diam, 2 cm deep cores were taken. Samples were stored frozen until processed. Prior to analysis, the samples were homogenised and a subsample of approximately 5 g of sediment taken, and digested in ~ 9% Hydrogen peroxide until frothing ceased. The sediment sample was then wet sieved through 2000 μm, 500 μm, 250 μm and 62.5 μm mesh sieves. All fractions were then dried at 60°C until a constant weight was achieved (fractions were weighed at ~ 40 h and then again at 48 h). The results of the analysis are presented as percentage weight of gravel/shell hash (> 2000 μm), coarse sand (500 – 2000 μm), medium sand (250 – 500 μm), fine sand (62.5 – 500 μm) and mud (< 62.5 μm).

4.3 Subtidal sampling

Side-scan data was collected using a C-Max CM800 Sidescan Sonar system comprising a graphic recorder, a dual frequency tow fish operating in 100 kHz mode, with a SCX tow-cable running through a digital pulley block for displaying layback. A new acquisition file was started at the end of each swath or whenever the layback was changed. Swath width was 200m either side of the fish which was towed at between 2 and 4m from the bottom at about 4 knots boat speed. Sound velocity profiles were obtained at the start of each day using an AML SmartProbe. Adjacent swathes were mosaiced using the CODA DA50 mosaicing software and the data was formatted as a georeferenced TIFF file suitable for input into a GIS.

QTC data was collected using the data acquisition system QTC View Series 4 (manufactured by Quester Tangent Corporation, Canada) interfaced with a single-beam Echotrac DF3200 echosounder and a Trimble DSM212H GPS. The basegain setting for QTC View was 21 dB. The echosounder was operated at a transmit frequency of 200 kHz, a pulse length of 0.32 ms, and a ping rate of 10 per second, resulting in an average between sample distance of 1.25 m and a resolution of 38 – 135 m. The transducer was mounted on a pole on the starboard side of the vessel.

A visual system was used to ground truth the acoustic images, provide information on how communities changed across depth and acoustic transition zones, and to survey areas shallower than 6 m. The visual system used was a colour zoom camera mounted in a depressor frame with integrated lights and laser scaling system. The camera used was a high resolution Tritech Typhoon, with 470 lines of horizontal resolution. A total of 85 video transect samples were collected with each transect covering a minimum of 10 metres. For areas of the Southern Kaipara where water clarity compromised the use of video, samples were collected by an Ockelmann type epibenthic sledge with a 2mm mesh size. A total of 44 dredge samples were collected from tows of approximately 10 metres duration. The video and dredges were analysed to give equivalent data, i.e., large or unusually dense epifauna and information on amount of bioturbation.

Rocky subtidal habitats were sampled by a Benthos Mini-Rover Remote Operated Vehicle (ROV) with colour video camera and integrated lights and depth recording. Video footage began on the soft sediment floor of the channel (~20 m deep). The ROV was then 'flown' up the slope recording video and depth continuously, stopping for close-up views approximately every 4-5 metres. The transects were analysed to characterise the fauna, flora and substrate, as well as ripples and bioturbation (where present).

117 sites were selected for soft-sediment subtidal sampling. Similar to the intertidal sampling, a two-Tiered sampling design was used. A grab ($0.1m^2$) was taken and the appearance of the sieved material and the sediment going through the sieve was noted. If these characteristics were the same as those noted at the next closest site the site was not sampled further. If they were different, two more grabs were taken. The 3 replicate grabs were generally taken from within 15m of each other. All samples were preserved in 50% Isopropyl alcohol and stained with 5% Rose Bengal.

Invertebrates were sorted, identified to the lowest practical taxonomic resolution and counted.

4.4 Analyses

A system of ecological community description decision rules was developed for both the intertidal and subtidal areas of the Southern Kaipara. The basis of the rules was threefold: key species, key functions and factors affecting vulnerability to threats.

Sediment characteristics were analysed in 2 ways. Firstly, the relationship (if any) between sediment variables (coarse > 0.5 mm, medium and fine sediment and muds <63 um) and other environmental factors (i.e., depth, vegetation (type and %cover) and side-scan information) was assessed using generalised linear models (GLM) with data transformations where necessary. The likely distribution of sediment variables were then determined by interpolation between sampled locations using spatial kriging including appropriate covariables identified by the GLM. Secondly, a sediment habitat type was determined for each sampling location, based on the overall sediment characteristics (Table 2). This data was used to determine whether communities had specific affiliations with certain sediment types.

Table 2:

A description of the sediment types found in the Southern Kaipara.

Sediment type	Description
Coarse sands	Sediment sized > 0.5 mm comprises more than 20% of the sediment
Muds	Sediment sized < 63um comprises more than 20% of the sediment
Fine sands	Sediment sized 63 – 250 um comprises more than 90% of the sediment
Medium sands	Sediment sized 250 -500 um comprises more than 30% of the sediment
Sandy	Sediment sized 63 – 250 um comprises more than 70% of the sediment, sediment sized < 63um comprises less than 5% of the sediment and sediment sized > 0.5 mm comprises less than 20% of the sediment.
Sandy muds	Sediment sized 63 – 250 um comprises more than 70% of the sediment, sediment sized < 63um comprises more than 5% of the sediment and sediment sized > 0.5 mm comprises less than 20% of the sediment.
Coarse sandy muds	Sediment sized 63 – 250 um comprises more than 70% of the sediment, sediment sized < 63um comprises more than 5% of the sediment and sediment sized > 0.5 mm comprises greater than 20% of the sediment.

Species that were widely distributed throughout the Southern Kaipara, either intertidally or subtidally or both, were analysed to determine whether they exhibited a spatial distribution associated with sediment characteristics, vegetation, or area within the Southern Kaipara (see below).

A variety of statistical techniques were used to analyse the data:

- Analyses of differences in community structure were done using ANOSIM (Clarke 1993) on Bray Curtis similarities of untransformed data. Average dissimiliarites between communities were derived using SIMPER (Clarke 1993).
- Analyses of differences in number of taxa, number of orders and total numbers of individuals were assessed using Generalised linear modelling, using an appropriate error structure and link function, followed by a multiple contrast (McCullagh and Nelder 1989). Similar analyses were carried out for widespread taxa.
- Analyses of factors affecting species occurrences were done using logistic regression on presence/absence data for widespread species (Ysebaert et al. 2002). Factors used were depth, sediment particle size characteristics, size of ripples recorded in the side-scan data, and side-scan- and QTC-derived classes. Backwards selection was used to select the most appropriate model based on changes to the AIC (Akaike's Information Criteria, Burnham and Anderson 1998). Squared terms were included for sediment particle sizes in case the inclusion of the different catergories (e.g., mud, fine, medium and coarse sand) were not sufficient to explain unimodal responses of the taxa to sediment.
- Analyses of factors affecting numbers of taxa and orders were done using generalised linear models (as above). Factors used were depth, sediment particle size characteristics, size of ripples recorded in the side-scan data, and side-scan- and QTC-derived classes. Backwards selection was used to select the most appropriate model based on changes to the AIC.
- Discriminant analyses (mahalanobis distances) were used to determine which epibenthic characteristics explained the side-scan and QTC classes, based on video/dredge data and sediment particle size characteristics. Video/dredge data was converted into rank abundance (0- absent, 1- sparse, 2- moderate density, 3 – high density) of fauna (aggregated at order level) and degree of bioturbation. Stepwise analysis was used to select the important factors and the degree of concordance was used to demonstrate the usefulness of the factors to explain the classes.
- Interpolations were performed with a thin plate smoothing spline and environmental factors demonstrated by regression to be important as covariables using ANUspline.

4.5 Other data used

Some previous macrofaunal information was available from Britta Hietz (Spatial variability and diversity of macrobenthic communities associated with streams catchments in the intertidal flats of the South Kaipara Harbour, MPhil thesis Massey University). To determine whether this information could be incorporated in this work, and to give some guidance to the degree of change exhibited by intertidal macrofaunal communities in the Southern Kaipara, some resampling of areas from this thesis was undertaken. Core samples taken for the Hietz study were roughly the same size as the core samples in this study (15cm diam cf 13 cm) and over a similar scale (approx. 10 m). Thus one site from the Hietz study on the Omokoiti flat was resampled at low, mid and high tide zones. However, differences in taxonomic resolution between the studies in the amphipoda, isopoda and polychaeta orders and lack of data on the age sturcture of the bivalves found in the Hietz study confounded allocation of the Hietz samples to ecological communities. Also, while the lower site exhibited concordance on the two sampling dates, the mid-tide zone had patches of the Asian mussel (*Musculista senhousi*) not observed in the 2001/02 sampling. The high tide zone sampled in 2004 had fewer *Macomona*, isopoda and amphipoda than in 2001/02, but, at least, for isopoda and amphipoda, these may have been recently settled juveniles and thus likely to be temporally variable. For these reasons, the earlier data has not been incorporated in this study.

Information on subtidal *Zostera* cover in and around AMA D and E was kindly provided by Jim Dollimore. This dataset consisted of a number of transects along which measurements were made of depth and *Zostera* cover.

5 Results

5.1 Intertidal large-scale features of the Southern Kaipara

Most of the intertidal area of the Southern Kaipara is mid to low intertidal; with few areas exposed for more than 7hrs on a tidal cycle. Extensive mangroves (often densely packed) fringe much of the area, with the exception of the South Head area and the sand dunes opposite the mouth. Extensive *Zostera* beds stretch over the intertidal flats in the middle of the main harbour and near the mouth. The vegetation shape file, received from ARC, of these was limited and this survey describes much more extensive coverage (Figure 4). Much of the intertidal area between Helensville and just south of Sandy Beach is predominantly muddy sediment (Figure 5). Seaward of this point, mud is still found near the mangrove edges and small drainage channels, but much of the intertidal flats are sandy. In more exposed areas, firm packed rippled sand is common and in a few areas rocky outcrops occur.

Figure 4: (Click for high resolution map)

Sample positions where *Zostera* was observed and suggested extensions to the *Zostera* shape file.

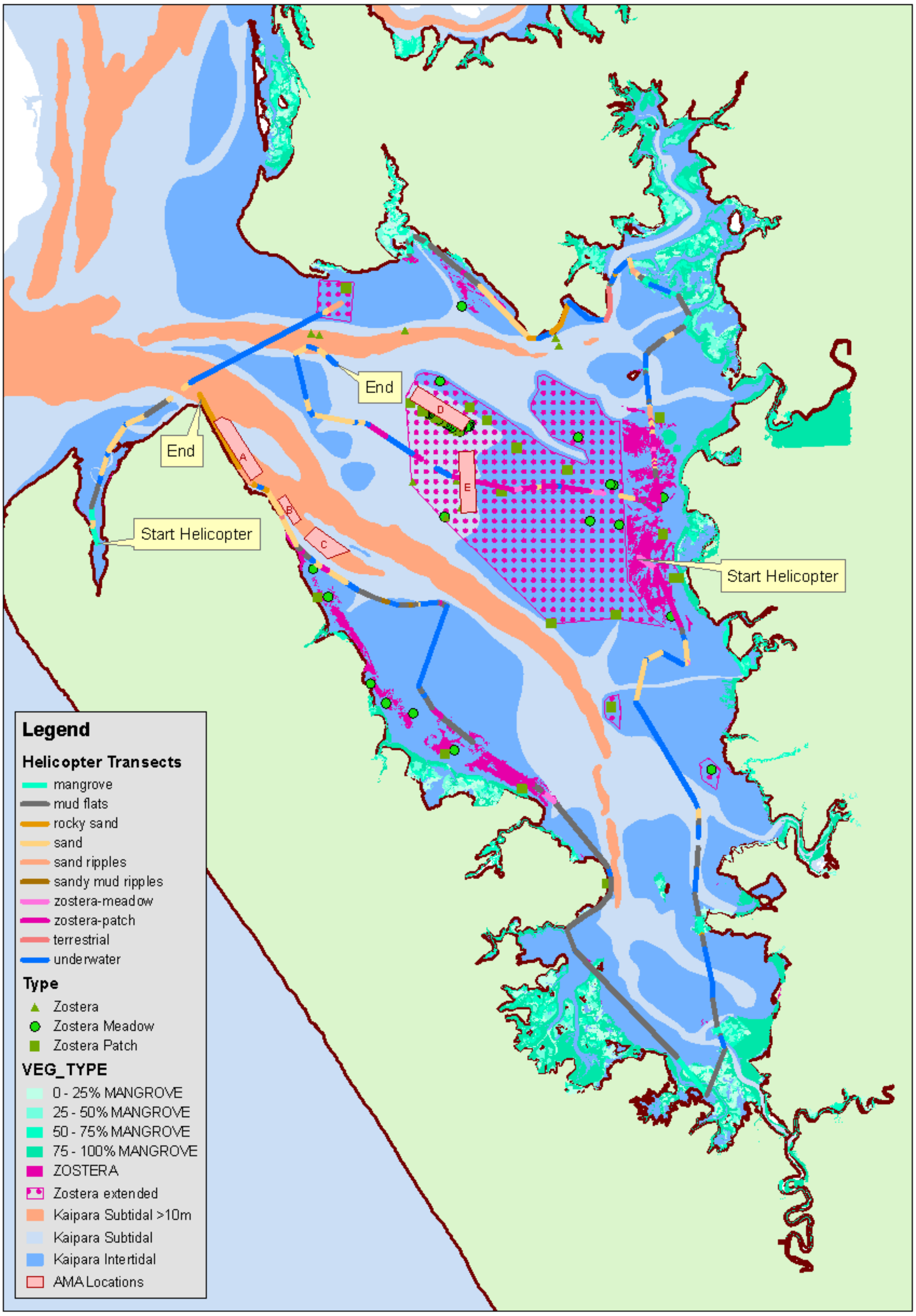
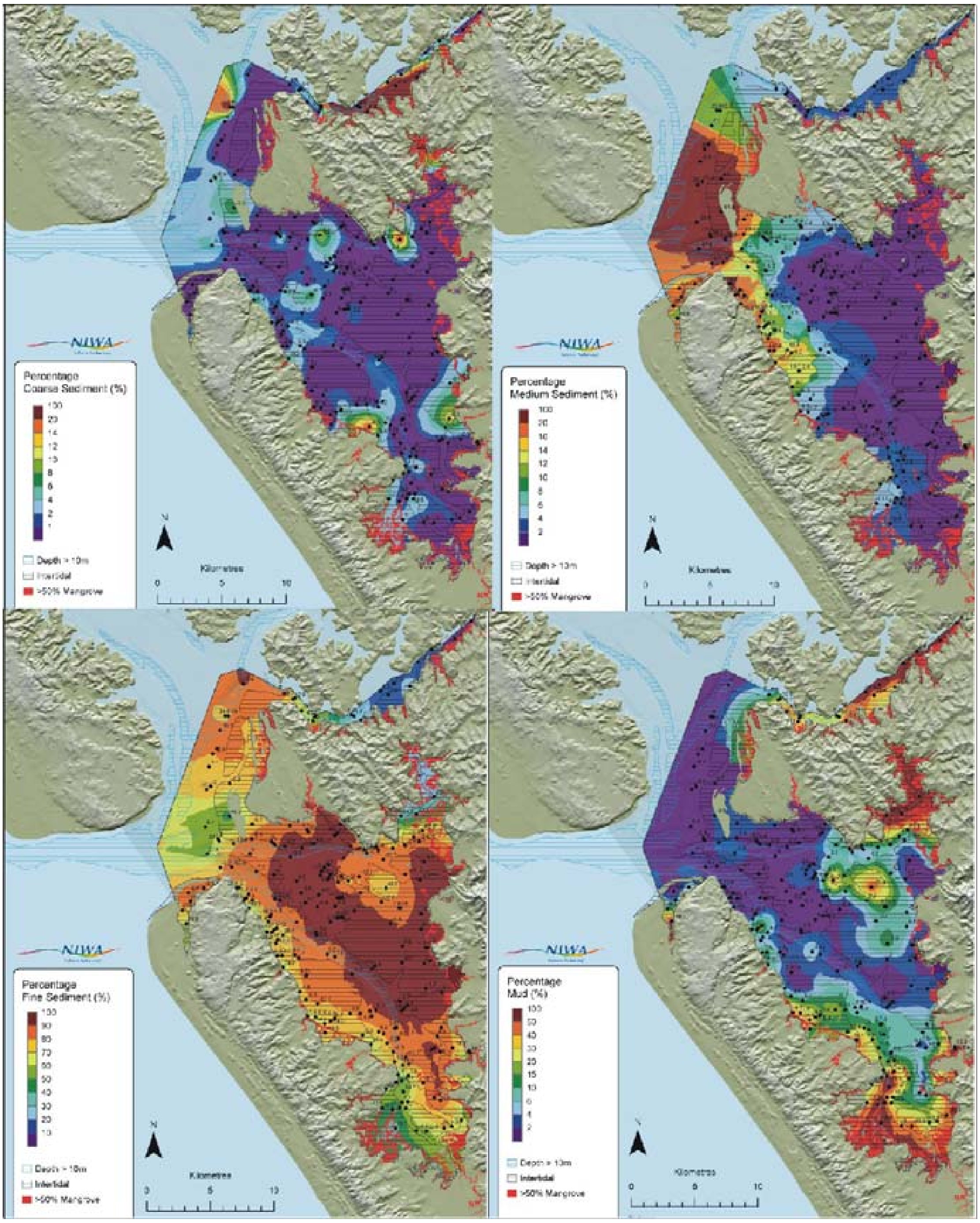


Figure 5: (Click for high resolution maps)

Interpolated plots of sediment particle size.



5.2 Intertidal communities of the Southern Kaipara

Three different community types were observed in the rocky intertidal. Small rocky reefs had few oysters and were dominated mainly by mussels, although on two of the reefs, small barnacles were overgrowing the mussels. Only one dense area of oysters was found on the small rocky reefs sampled. Conversely the steep bedrock area at the base of the cliffs was predominantly oysters. There was no obvious depth pattern, except that near high tide nothing grew and at the extreme low tide mark some serpulid polychaete tube mats were observed.

Fifteen different community types were defined for the soft substrata intertidal area of the Southern Kaipara (Table 3, Figure 6). The hierarchical community rules identified six communities based on bivalves: three of these were based on biomass of adult bivalves: a *Macomona* community; an *Austrovenus* community; and a *Macomona/Austrovenus* community. Some areas of dead cockle shells were also observed, e.g., on the intertidal flats out by Tauhoa Channel. No high densities of large adult pipis (*Paphies australis*) were found, although some areas of high densities of an intermediate size class were observed (20 – 40 mm). Other types of bivalve-dominated communities were those dominated by suspension feeders[1], or deposit feeders and one dominated by large numbers of the invasive Asian date mussel (*Musculista senhousia*).

High taxonomic level (order) diversity was found at a number of sites with communities within these areas dominated either by tube dwellers, large animals, suspension feeders or deposit feeders. Outside of these high diversity areas, similar to many of New Zealand's estuaries and harbours, polychaete dominated communities were widespread, displaying a mix of ecosystem functions (e.g., tube-dwellers, large predatory/scavenging polychaetes and deposit feeders). These communities occurred in all types of sediment and tidal heights and were spread throughout the harbour. Finally two communities of low diversity were observed; one dominated by surface bioturbators and the other dominated by burrowing organisms and confined to muddy sediment.

All communities identifed by the heirachical community rules were more than 80% dissimilar; most were greater than 93% dissimilar. More similarities were found between the communities dominated by either *Austrovenus* or *Macomona* and the other communities, as the similarity analysis was based on numeric data and these communities were selected by biomass. The different types of polychaete communities were also less distinct from each other than from other community types.

[1] Note that not all bivalves could be placed into these categories. For some species the information is not available, and some small individuals could not be identified.

Figure 6: (Click for high resolution map)

Distribution of ecologically significant intertidal communities found in the Southern Kaipara.

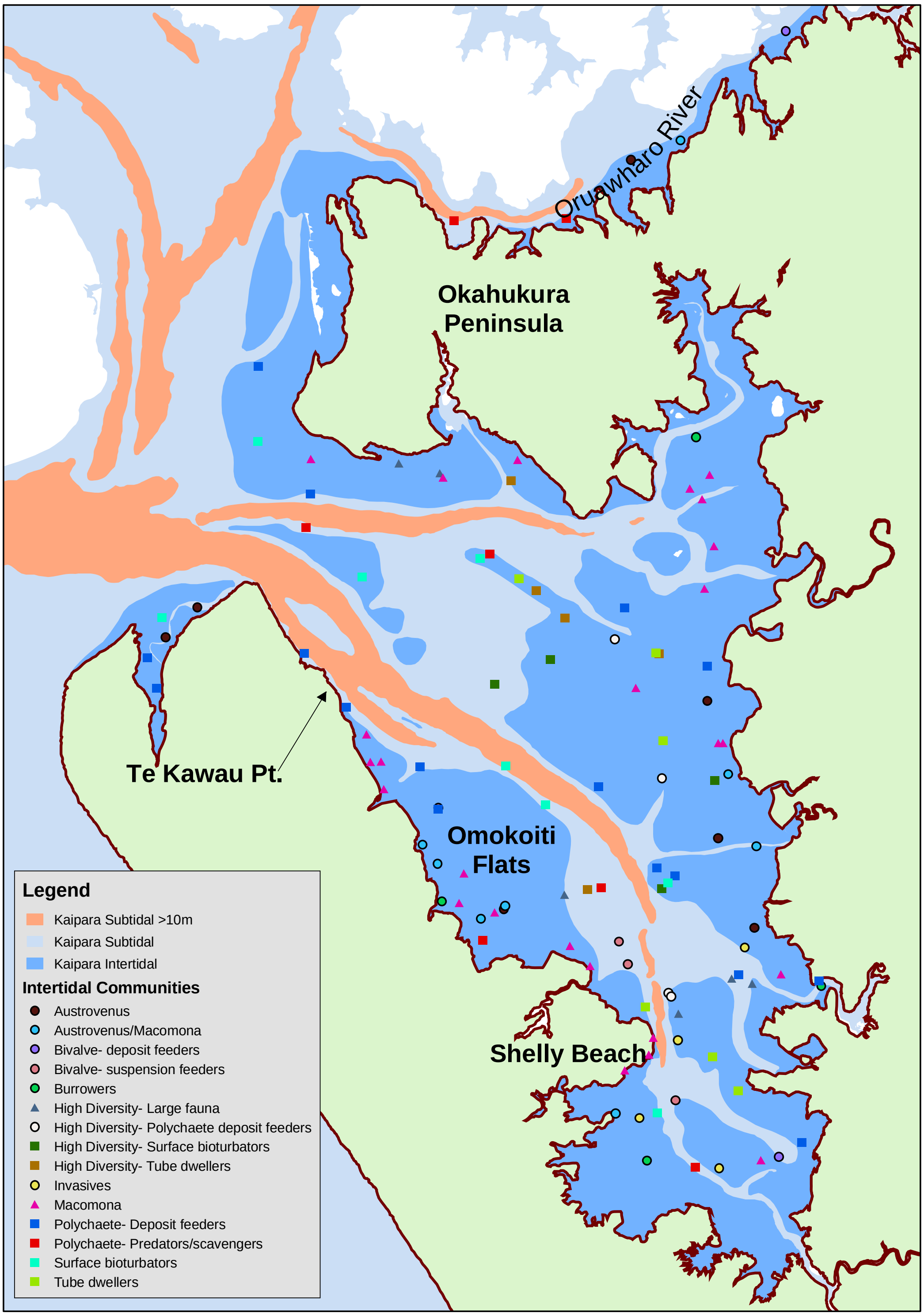


Table 3:

Ecologically important intertidal communities found in the Southern Kaipara using the hierarchical rules given in Box 2.

	Community type	Description
1	Austrovenus	Dominated by large *Austrovenus*, found in high to low intertidal in a mix of sediment types. High diversity, usually found in conjunction with anemones, limpets and small *Nucula hartvigiana*.
2	Bivalves- deposit feeders dominated	Moderate diversity, dominated by bivalve deposit feeders, often occurring with Nereid polychaetes, amphipods and decapods. Found in muddy sediments
3	Bivalves- suspension feeders dominated	Moderate diversity, dominated by suspension feeding bivalves, often co-occurring with low numbers of polychaete deposit feeders, amphipods and gastropods. Found in a range of sediment types.
4	Burrowers	Low diversity, mainly the mud crab *Helice crassa*. Found in mud and mangroves.
5	Austrovenus-Macomona	Adults of both *Austrovenus* and *Macomona* found, though the size of the *Austrovenus* were generally smaller than those found in *Austrovenus* only communities. Mid to low intertidal in mud to sand.
6	High diversity- large fauna dominated	Large gastropods, crabs, limpets and predatory/scavenging polychaetes. Found in sandy-mud to sandy sediments.
7	High diversity- polychaete deposit feeders	Dominated by deposit feeding polychaetes, but a range of other animals are found in low numbers. Often includes juvenile *Macomona*. Not found in coarser sediments.
8	High diversity- surface bioturbators	Dominated by small gastropods, amphipods and isopods, although polychaetes, amphipods and barnacles occur. Found in fine sand.
9	High diversity- tube dweller dominated	Dominated by tube dwellers, although high numbers of other large organisms including shrimps and predatory/scavenging polychaetes occur. Found in mud to sandy sediments.
10	Invasive	Dominated by the invasive bivalves *Musculista* or *Crassostera*, in densities up to 136 per core, moderate to low diversity of other organisms. Found in a range of sediment types.
11	Macomona	Dominated by large *Macomona*, found in mid to low intertidal mainly in fine sand. Moderate to high diversity, large numbers of deposit feeding polychaetes.
12	Polychaete- deposit feeders dominated	Moderate diversity, variable species but often including *Magelona*. Frequently found with burrowing organisms (crabs and/or shrimps). Found in a range of sediment types.
13	Polychaete- large predator dominated	Moderate to low diversity, variable species. Found in a range of sediment types (mud to sand).
14	Surface bioturbators	Low diversity, high to low intertidal, mainly small gastropods and amphipods. Found in a range of sediment types.
15	Tube dweller dominated	Moderate diversity, lower numbers of tube dwellers than in the high diversity group, co-occurring with low numbers of large organisms such as nemerteans and holothurians. Found in finer sediments (mud to fine sand).
	Oysters (Rocky)	Low diversity, variable cover of oysters with few chitons, limpets and gastropods. Found on rocky substrate
	Mussels (Rocky)	Low diversity, variable cover of mussels with few chitons, limpets and gastropods, some times overgrown by barnacles. Rocky substrate

5.2.1 Comparisons between habitat types.

Species data were analysed to determine whether the major intertidal habitat types (mud, sand, *Zostera*, mangroves) supported significantly different assemblages. As expected from the ecological communities, communities found in dense mangroves were different to those found in all but sparse mangrove areas. Mangrove communities were dominated by the mud crab (*Helice crassa*), with low numbers of Nereid polychaetes and, in the Oruawharo arm, the small bivalve *Arthritica bifurca*. However, although these mangrove communities were significantly different from those found in other habitat types (ANOSIM $p < 0.05$) they did not have a high within-habitat similarity (only 13%). Communities found in mud differed from those found in some of the other habitats (*Zostera*, rippled sand and all sediment types coarser than sandy mud) but were not significantly different from those living in the sparse mangrove habitat. The mud community was highly variable (low self similarity 5%); with the most similarity being driven by the presence of Nereidae and *Theora lubrica* (another invasive bivalve species) and reasonable abundances of the polychaete *Cossura consimilis*. As expected lower numbers of taxa were observed in the mangroves and muddy areas, than the sandier sediments with the lowest diversity found in the dense mangroves, similar to Ellis et al. (2004). No difference was observed between the communities observed in fine sand and those in coarser sediments, probably due to high variability of these communities. *Zostera* meadows did not support communities different to the bare sand habitats. This result is similar to that from studies in Manukau, Whangapoua and Wharekawa which found that *Zostera* beds in different locations of the same harbour are usually more different in community structure than they are to the bare sediment directly adjacent (Turner et al. 1999, Hewitt et al. 2003, van Houte-Howes et al. 2004).

5.2.2 Widespread taxa.

Fourteen taxa were found at more than 20% of sites and represented bivalves, polychaetes, Nemerteans and Cnidaria. The bivalves were those common elsewhere in the Auckland region (*Nucula hartvigiana* , *Macomona liliana* , *Hiatula siliqua* , *Austrovenus stutchburyi* , *Arthritica bifurca*) and are species monitored in the Tier 1 programme in the Manukau, Mahurangi and Waitemata harbours. They represent both deposit feeders and suspension feeders. The polychaetes represent large predators/scavengers (Nereidae, *Glycera* spp. and *Aglaophamus macroura*), tube builders (*Macroclymenella stewartensis*, *Boccardia* spp.) and deposit feeders (*Magelona* sp, *Heteromastus filiformis*, *Aquilaspio aucklandica* and *Aonides oxycephala*). All of these polychaetes, except Nereids, are monitored in at least one of the Tier 1 monitoring programmes.

5.2.3 Taxa preferences.

These fourteen taxa were analysed to determine species preferences (i.e., factors affecting their occurrence). Table 4 summarises this information. There were interesting differences between some areas of the harbour. In particular there were a number of otherwise widespread taxa not found in the Oruawharo arm or in Waionui Inlet. The majority of taxa demonstrated some relationship between occurrence and sediment particle size. For those taxa for which differences were observed between the Gibbs et al. (2004) report on preferences/aversion to sediment mud content (*Glycera*, *Boccardia*, *Heteromastus*, *Nucula* and *Arthritica*) any relationship with sediment particle size may be confounded by differences occuring between locations in the harbour (e.g., differences in recruitment potential), as all of these taxa exhibit strong spatial distributional patterns. A negative relationship between mud and number of species is frequently observed (Thrush et al. 2003b).

Figure 7: (Click for high resolution maps)

Interpolated plots of the distribution of total numbers of individuals, number of taxa and number of orders found in the cores taken from the intertidal sites.

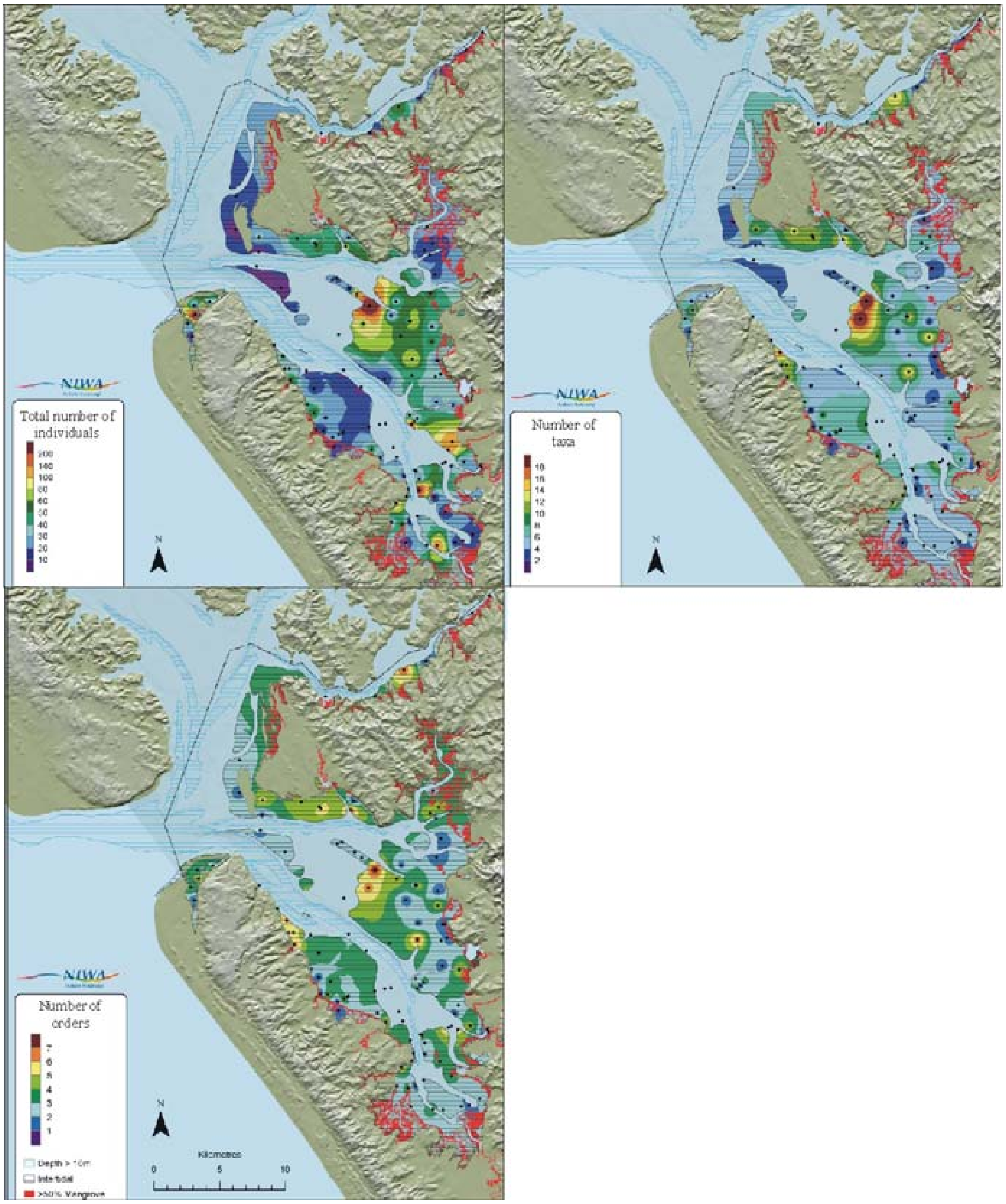


Table 4:

Locational and sediment preferences of widespread taxa found in the intertidal area of the Southern Kaipara. Sensitivity to mud reported by Gibbs et al, 2004 is given after the taxon name. SS, S = prefers sand, I = intermediate, MM,M = prefers mud.

Taxa		Location	Sediment
Arthritica	I	High in Oruawharo arm, none in Waionui Inlet	+ve relationship with mud
Austrovenus	S	No relationship	+ve relationship with medium sand
Hiatula		Primarily on west coast of the main harbour, not found in Oruawharo arm	No relationship
Macomona	S	None found in Waionui Inlet	+ve relationship with fine sand
Nucula	S	Avoids exposed areas, mainly found on eastern side of the Kaipara River arm	+ve relationship with mud and fine sand
Aglaophamus		Primarily in Kaipara River arm	-ve relationship with mud
Aonides	SS	Primarily in Kaipara River arm	+ve relationship with medium sand
Aquilaspio	I	Generally low, none in Waionui Inlet	+ve relationship with mud and medium sand
Boccardia	S	Primarily up Tauhoa arm and the Eastern side of the Kaipara River arm	No relationship
Glycera	I	Rarely found in Oruawharo arm	No relationship
Heteromastus	I	Primarily in Eastern side of Kaipara River arm	+ve relationship with fine sand
Macroclymenella	S,I	Primarily in centre of main harbour and Tauhoa arm, not found in Oruawharo arm	+ve relationship with fine sand
Magelona		Primarily on eastern side of the Kaipara River arm	-ve relationship with mud
Nereid	M	Frequent in Oruawharo arm and edge of the main channel	+ve relationship with mud
Total abundance		High in Waionui Inlet, low in Oruawharo arm	No relationship
Number of Taxa		Highest diversity never occurs in the upper arms	-ve relationship with mud
Number of Orders		No relationship	No relationship

5.2.4 Mesh size.

Some samples from each habitat type were analysed to determine the effect of sampling with a mesh size of 1mm, rather than 0.5 mm, as is done in the Tier 1 monitoring. At no sites was the overall number of taxa found affected by more than

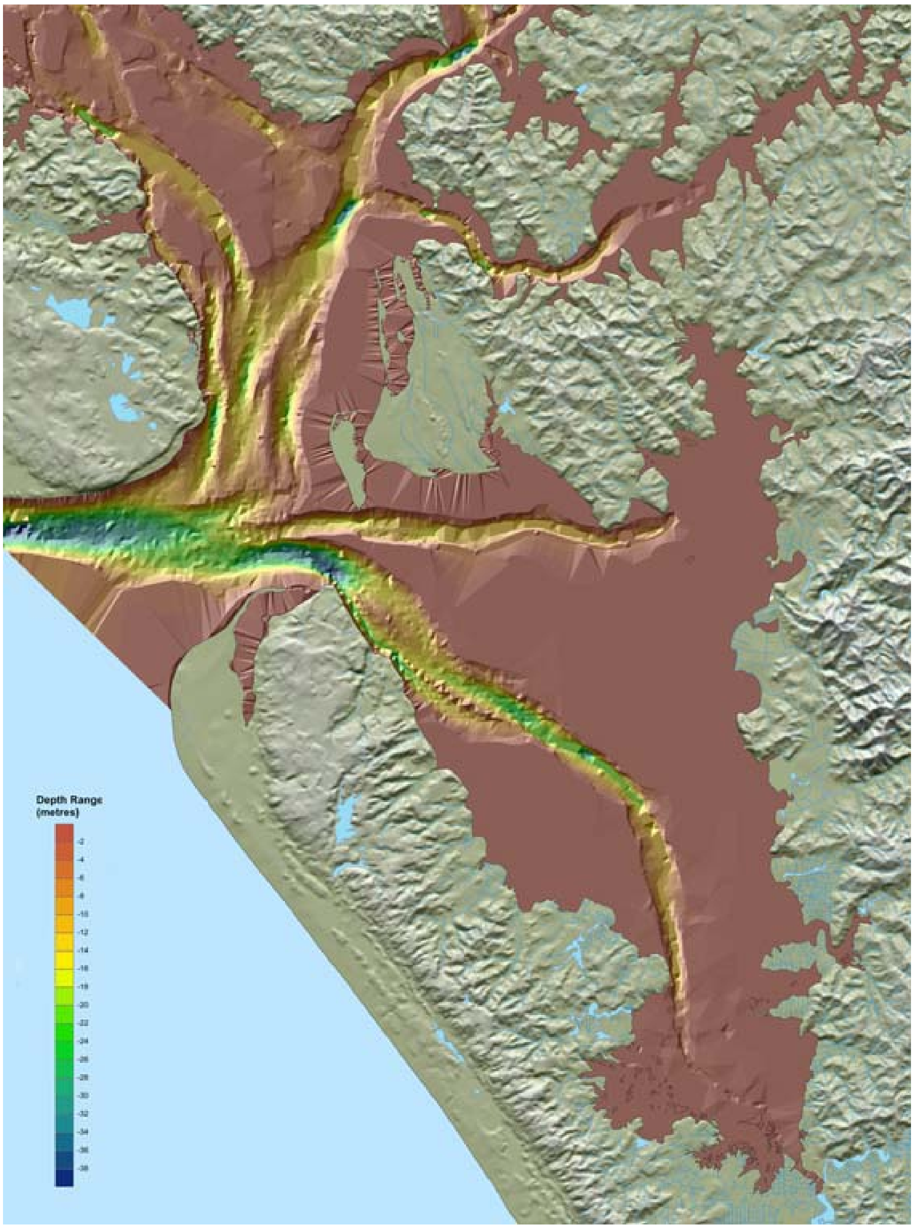
10%, i.e., the effect was within the 90% quality assurance standard. At some sites a large number of individuals were found in the 0.5 to 1mm fraction; mainly juvenile amphipods, bivalves, Nereids and *Heteromastus filiformis*. Thus, as hoped, using the 1mm mesh sieve removed the effect of recent settlements of juveniles, resulting in a data set that would be more robust for comparisons between one-off samples taken a long time apart. However, while the dataset gains in robustness to small-scale temporal variations (particularly for numbers of taxa), some smaller but numerically important taxa are missed. Taxa that were missed by the 1mm mesh sampling were, as expected, the family of small polychaetes, Exogoninae, and Oligochaetes. This should make us wary of making direct comparisons between this study of the southern Kaipara and other areas sampled by a 0.5 mm mesh, especially for mudflat and mangroves habitats because these generally have higher densities of smaller taxa. It does not preclude indirect comparisons as long as the effect of not sampling to the same degree is considered.

5.3 Subtidal large-scale features of the Southern Kaipara

The subtidal area of the Southern Kaipara comprises a number of different regions based on depth (Figure 8) and exposure to waves and currents. The harbour mouth has a deep wide channel (maximially 50 m depth), from which the seabed rises steeply to form shallow subtidal areas. The channels, banks and shoreline are very mobile as demonstrated by the beach erosion and accretion at Tapora Island. Two channels lead in to the main harbour, Tauhoa Channel and the Kaipara River channel. One channel leads north to the Oruawharo Arm. The Kaipara River channel is the deepest of the channels found in the harbour, being > 20 m in places. AMAs A,B and C are located in the deep area near the cliffs of South Head where current flow is fast. The Oruawharo and Tauhoa arm are shallower, although a couple of holes nearly 20 m deep are located in the Oruawharo Arm. The main shallow subtidal area is found at the confluence of the Tauhoa and Kaipara River channels, and is somewhat sheltered at low tide by a shoal to the northwest. Smaller shallow subtidal areas are found further up both the Tauhoa and Kaipara River channels. Shallow subtidal areas are smallest in the Oruawharo Arm.

Figure 8: (Click for high resolution map)

Depth distribution in the Southern Kaipara (uniform brown indicates intertidal or lack of depth information).



5.3.1 Side-scan images of seafloor types

A number of seafloor types were apparent from the side-scan data, based mainly on sediment characteristics. Many of the seafloor types were described in Hume et al. (2001), others are based on technical expertise (Hume pers obs). Sediment particle size characteristics were confirmed by the sediment sampling previously described.

1. In the exposed, deep channel area in front of the mouth, large sand waves (average 120 m wave length) were observed (Figure 9A). Megaripples of 1 –

5 m wavelength often were seen across the backs of the larger waves. Sediment type ranged from medium to fine sands.

2. Mega ripples (5 – 20 m wave length) were found in both the mouth and the three channel areas (Figure 9B). These ripples are generated by strong tidal currents and run transverse to the current direction. Sediment type ranged from medium to fine sands.

3. Smaller ripples, probably generated by waves were found in many places (Figure 9C). These may not be so long lasting as the previous two sand structures, being event driven. Sediment ranged from fine to coarse sands.

4. Areas of patchy sand ripples (Figure 9D) where tidally driven structures are broken down as the tide changes direction were also common. They were comprised of a range of sediment types from coarse to fine sands.

5. Shaded dark then light areas, indicating steep channel banks (Figure 9E).

6. Areas armoured in shell lag were found (Figure 9F), particularly in high flow areas around channels banks. Sediments ranged from mud to fine sands.

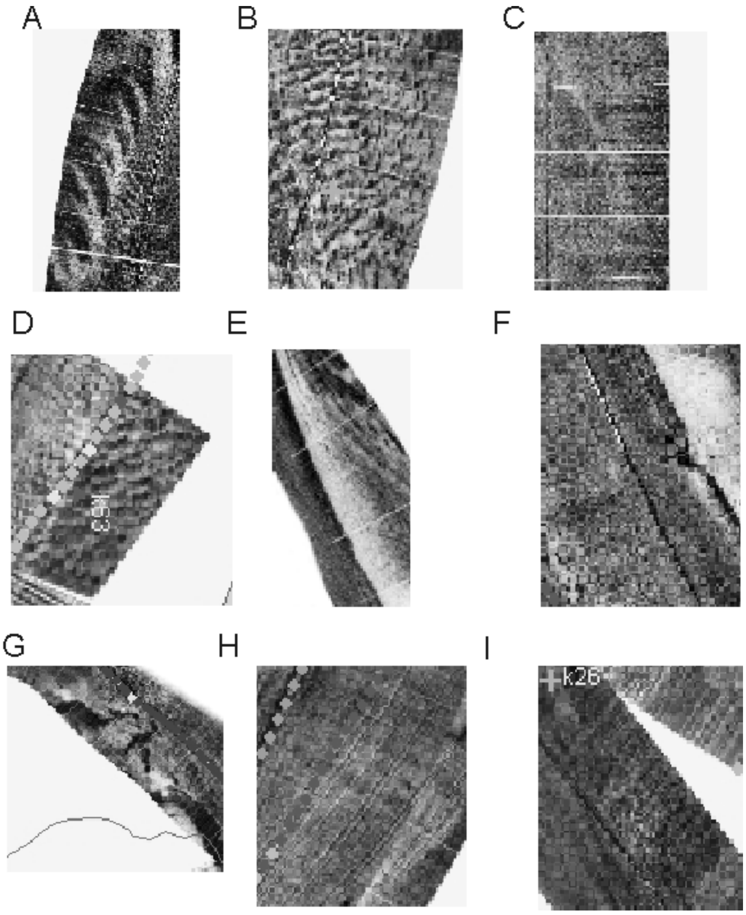
7. Rubble and rock blocks in a sand matrix were found around South Head (Figure 9G).

8. Relatively flat areas of mud or muddy sand (Figure 9H) were found in the upper arms, stretching further towards the mouth of the Oruawharo and Tauhoa arms, than the main harbour. Sediment ranged from muds to coarse sandy muds.

9. An area of smooth sand/mud with small sparse dark spots was found in the central harbour (see section 5.5).

10. Some areas of obvious artefacts (Figure 9I), and some that were possibly artefacts were found in some places (see section 5.5).

Figure 9:
Examples of seafloor types revealed by side-scan data. (A) sand waves, (B) mega ripples, (C) smaller ripples, (D) broken ripples, (E) channel banks, (F) shell lag, (G) rubble, (H) flat mud or sand and (I) potential artefacts.

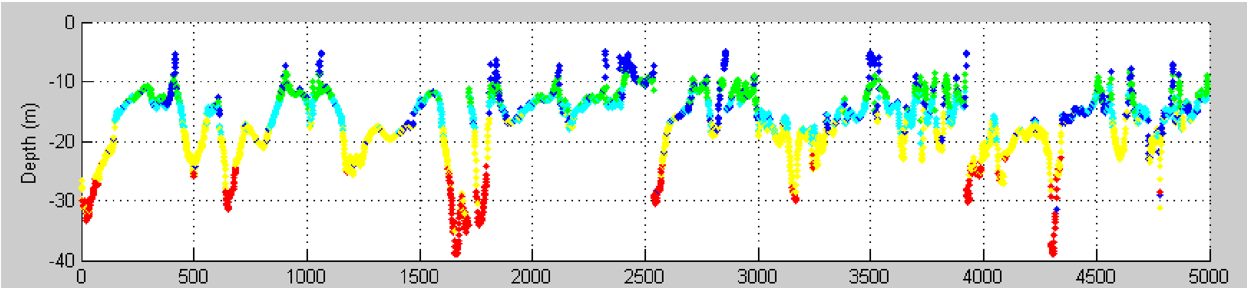


5.3.2 QTC seafloor types

From the seabed data logged by QTC View during this survey, 5 clusters of acoustic data were identified as the optimal number of classes, based on changes to the Total Score. The change in total score from 4 to 5 classes was < 5%. These clusters were strongly depth orientated (Figure 10).

Figure 10:

A strong relationship was observed between different QTC classes (represented by different colours) and depth.



5.3.3 Subtidal epibenthic habitats (based on dredge and video data).

The subtidal habitats of the Southern Kaipara fall into 5 main categories: the rocky cliff faces on the east side of South Head; areas of exposed rubble and rock in a sand matrix primarily again near South Head; areas with subtidal vegetation; areas dominated by sedentary epifauna; and primarily bare areas (Figure 11). Except for the rocky cliff and rubble areas, these main categories are dividable into a number of biogenic-habitats, dependent on the epifauna and flora (see Table 5).

The rocky cliff faces together with the rubble/rock/sand matrix found around the foot of the cliffs contained the most diverse epibenthic communities observed in the Southern Kaipara. The slopes of the cliff walls along South head vary from gently sloping to near vertical. In some areas, overhangs and small platforms are apparent. Near the bottom, substrate varied between rubble, shell in a sand matrix to hard packed shell lag. Fauna and flora changed in type, density, size and distribution with depth, substrate and slope, but was dominated by encrusting epifauna. No large algae were observed; small algae and *Zostera* were infrequently observed. Low to medium sloping areas of sand or shell generally had small sponges, starfish and gastropods. Larger sponges, mussels, barnacles and other encrusting species increased in density and size with larger, more complex relief. Vertical walls and overhangs displayed complex communities with high densities and diversity of sponges, ascidians, turfing bryozoans and other encrusting species. Shallow sandy areas observed near the tops of some slopes were generally bare except for occasional starfish or gastropods.

Figure 11: (Click for high resolution map)

Distribution of subtidal epibenthic habitats found in the Southern Kaipara.

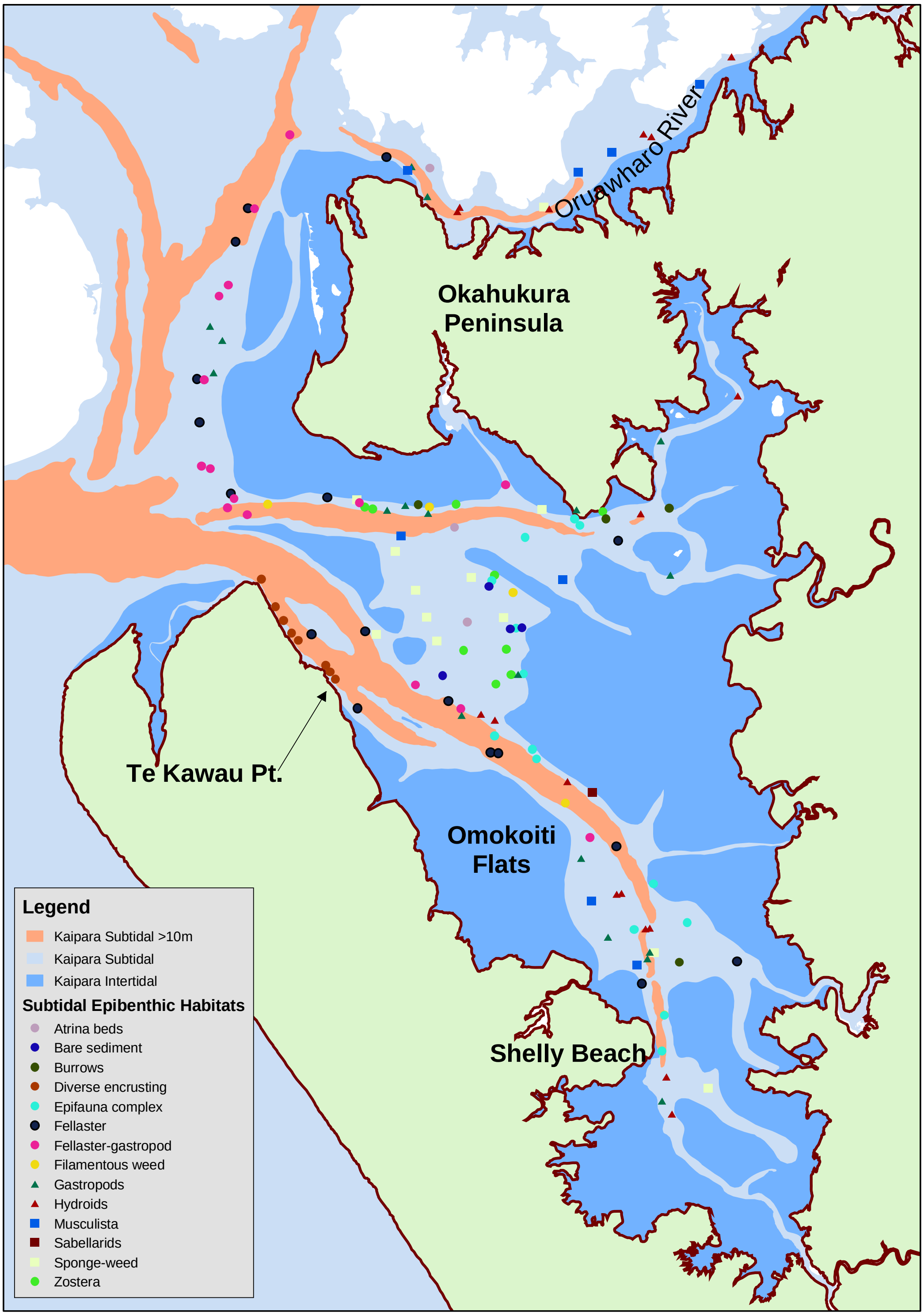
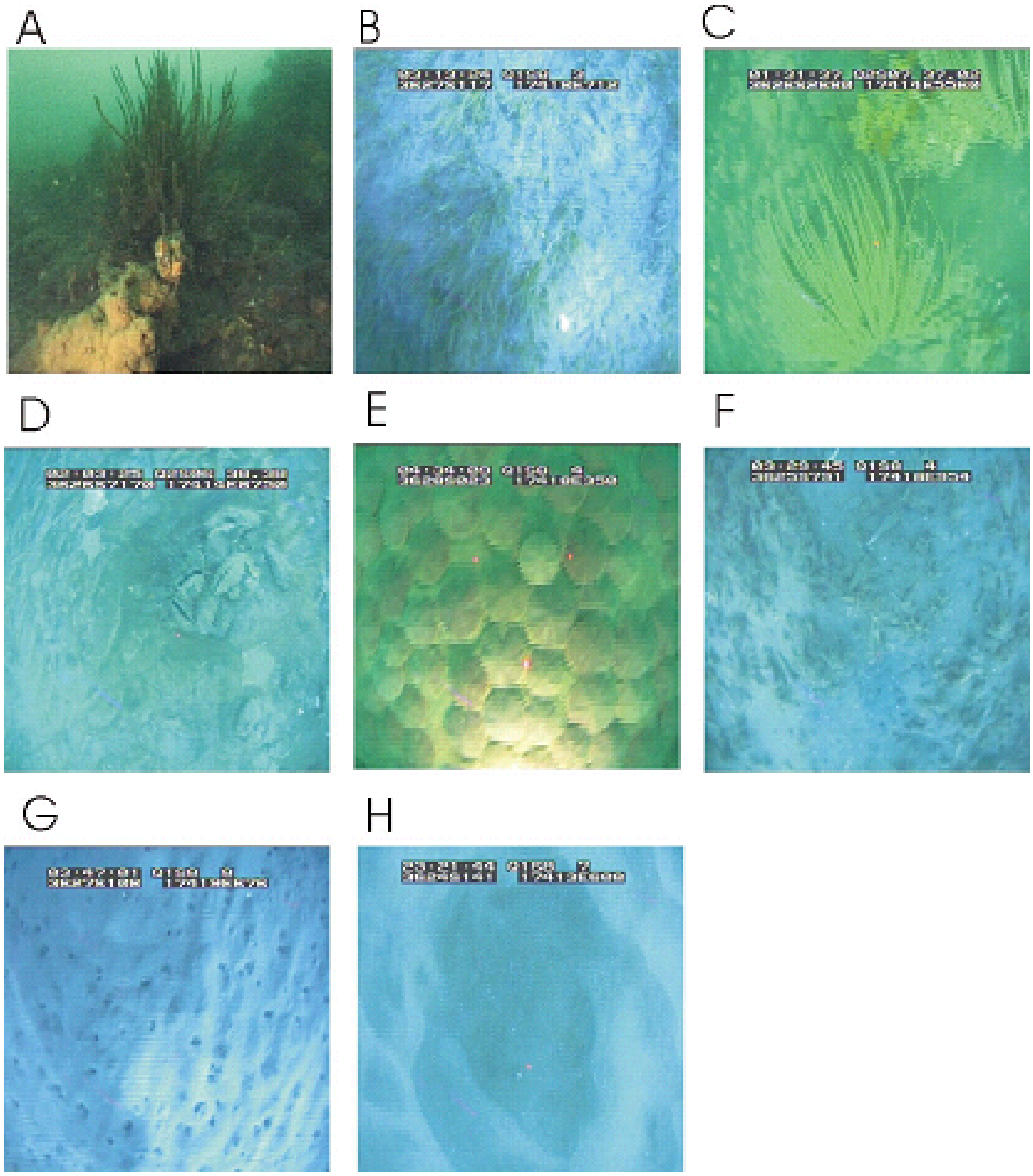


Table 5:

Subtidal epibenthic habitats of the Southern Kaipara obtained from video and dredge sampling. Figure 12 shows examples of some of these.

1. Highly diverse encrusting community	Patches of rock and rubble in a sand matrix to vertical cliff faces. Dominated by encrusting fauna, (e.g., green lipped mussels, barnacles, anemones, sponges) and coralline algae.
2. Filamentous weed	A mixture of small filamentous seaweed, gastropods and, sometimes, sand dollars (*Fellaster zelandiae*). Figure 12A.
3. *Zostera*	Subtidal *Zostera*, often patchy, with burrows, gastropods and sometimes anemones. Found in a relatively small area in the central main harbour near AMA D and E and in small patches in AMA B. Figure 12B.
4. Sponge-weed	Sponges (four genera) with filamentous seaweed or turfing algae, sometimes with gastropods and occasionally dead *Atrina*. Found in sandy areas. Figure 12C.
5. Hydroids	Dominated by hydroids, sometimes with clumps of large gastropods. Widespread, except in exposed sites near entrance.
6. Epifauna complex	Sponges with either hydroids, bryozoans or anemones. Found in sandy areas.
7. *Atrina* beds	Some medium density *Atrina zelandica* (horse mussel) beds, with or without sponges. Infrequently occurring. Figure 12D.
8. Fellaster	Areas of adult *Fellaster*, frequently forming a dense carpet. Often found in more exposed sandy areas. Figure 12E.
9. *Fellaster*- gastropod	A mix of patchy *Fellaster* and gastropods (often *Maoriocolpus roseus* or *Amalda australis*). Widespread.
10. Gastropods	Gastropods, sometimes with hermit crabs, and burrowing crabs, or starfish. Widespread. Figure 12F.
11. Burrows	Areas of relatively flat soft sediment, dominated by burrows, found up the arms of the harbour. Figure 12G.
12. Musculista	Dominated by mounds of *Musculista* , sometimes with gastropods, *Fellaster* or burrowing crabs. This habitat is mainly found in the Oruawharo arm, though there are a few scattered areas in the other two arms of the harbour.
13. Bare sediment	Areas of bare sediment with little bioturbation or epifauna. Figure 12H.
14. Sabellarids	An area of Sabellaridae tube mat was found in one location.

Figure 12:
Underwater photographs taken of the different epibenthic habitats. Some habitats were unable to be photographed due to poor visibility. A, filamentous weed. B, *Zostera*. C. sponge. D, *Atrina*. E, *Fellaster*. F, gastropods. G, burrows. H, mostly bare sediment.



5.4 Subtidal communities of the Southern Kaipara

A number of diverse ecological communities were defined from the grab sampling of the subtidal areas of the Southern Kaipara (Table 6, Figure 13). Frequently these reflect the habitats derived from the video/dredge samples, being dominated by sedentary epifauna (*Atrina*, Sponges, Nudibranchs, Hydroids and Bryozoans), filamentous weed, tube dwellers and large surface disturbing animals (*Fellaster*, Gastropods). All communities were more than 80% dissimilar; most were greater than 93% dissimilar. The different types of polychaete communities tended to be the ones that were less distinct. Interestingly, although deposit-feeding polychaetes were frequently common, there were few areas with communities dominated by them.

Figure 13: (Click for high resolution map)

Distribution of ecologically significant subtidal communities found in the Southern Kaipara.

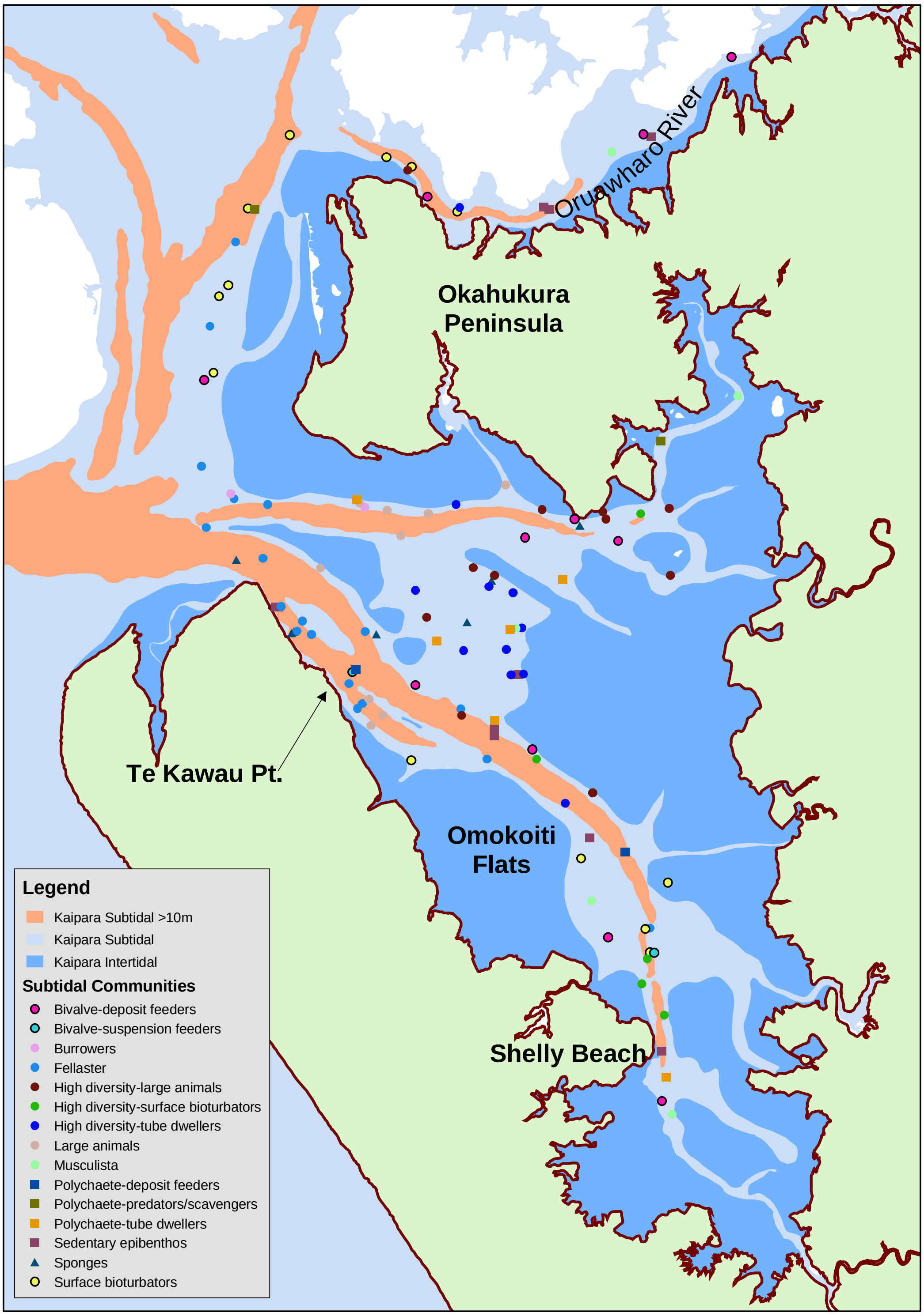


Table 6:

Ecologically important subtidal communities found in the Southern Kaipara using the hierarchical rules given in Box 2.

1. Sedentary epibenthos	Generally high taxon richness, though some lower diversity areas observed, found in fine to medium sands.
2. Sponges	Sponge communities were found mainly in the central area of the main harbour in medium to fine sands. Small filamentous seaweed clumps were often present and encrusting bryozoans were found on shell debris.
3. Fellaster	Dominated by *Fellaster*, generally of low diversity. This community was found in a range of sediments but not at the extremes of muds or coarse sediments. Higher densities were found at deeper sites.
4. Surface bioturbators	A highly variable community, representing a mix of small gastropods, hermit crabs and ophuroids and amphipods
5. High diversity- tube dwellers	A high diversity community of tube dwellers (*Macroclymenella*, *Owenia*, Phoronids and *Euchone*) with Nemerteans, a bivalve (*Myadora*) and an anemone. Found in predominantly fine sands at < 3m depth
6. High diversity- large animals	Dominated by the gastropod *Maoriocolpus* with moderate densities of the gastropod *Zegalerus tenuis* and low densities of *Paguristes* (hermit crab) and *Nucula*. Found predominantly in fine sands
7. High diversity- surface bioturbators	Low densities of *Zegalerus*, and *Maoriocolpus* found in conjunction with Corophid amphipods, found in sandy mud to coarse sediments in all but > 15 m depth
8. Bivalve- suspension feeders	Dominated by *Myadora*, found in sandy mud to fine sediments.
9. Bivalve- deposit feeders	Bivalve dominated with large numbers of *Nucula* and smaller numbers of other deposit feeding bivalves. Found in finer sediments from muds to sandy muds.
10. Burrowers	Primarily dominated by the shrimp (*Pontophilus australis*) and occurring in sandy to medium sand.
11. Large animals	A community of low density *Fellaster*, with Holothurians, and large swimming crabs (*Ovalipes carthaus*, *Nectocarcinus benetti*). Found in sandy muds to medium sands.
12. Musculista	Dominated by *Musculista* , found in mud to fine sand.
13. Polychaete- predators/scavengers	Dominated by the predatory/scavenging polychaetes *Glycera*, Siglionidae and *Lumbrineris*, found in mud to fine sands
14. Polychaete- tube dwellers	A lower diversity community of tube dwellers (*Macroclymenella*, *Owenia*, Phoronids and *Euchone*) found over a wide range of sediment types at shallow depths.
15. Polychaete- deposit feeders	An infrequently found community, very variable in species composition.

5.4.1 Comparisons between habitat types

Species data were analysed to determine whether the major habitat types (as defined by the video/dredge sampling) supported significantly different assemblages. Not surprisingly results varied. Epibenthic habitats comprised of *Fellaster* were most distinctly different to the other habitats; they were of low diversity, frequently comprising nothing but *Fellaster*. The Epifauna complex, Sponge and Hydroid habitats also supported communities that were different from other habitats, though not from each other. Similar to the intertidal results, the *Zostera* habitat did not support a distinct community.

The ecological communities derived from the grab data correlated well with the epibenthic habitats for dense Fellaster, Fellaster/gastropod, Gastropod areas. Areas with sparse Fellaster or gastropods were more likely to be allocated to other ecological community types. Some differences were observed for epibenthos that were highly clumped (Sponge, Epifaunal complex, Hydroids) as the epibenthic habitats were based on observations of larger-scale data and therefore integrated over highly clumped data, whereas the grab data would often miss these.

Some differences between communities in different sediment type and at different depths were found. Communities found in the mud, sandy mud and fine sand sediment type differed from each other and from those found in all other sediment types ($p < 0.05$). Communities found at < 3 m deep were dissimilar to those at all other depths. However, similar to the intertidal results, the communities found with in these sediment types and depth strata were highly variable (self similarity < 10%).

5.4.2 Widespread taxa

Seventeen taxa were found at more than 20% of subtidal sites and represented a more diverse array of taxonomic orders than were found in the intertidal areas (bivalves, polychaetes, gastropods, echinoderms, holothurians, decapods, phoronids, nemerteans, ophiuroids and cnidaria). There were four widespread bivalves (*Nucula* spp., *Musculista*, *Myadora* spp. and *Felaniella zelandica*) representing both deposit feeders and suspension feeders. Unlike the intertidal area, the widespread polychaetes were mainly tube builders (*Macroclymenella stewartensis*, *Owenia* sp., *Euchone* sp.) with only one large predator (*Aglaophamus* sp.). Two decapods, the common shrimp *Pontophilus australis* and the hermit crab *Paguristes setuous* were wide spread, as were bryozoans (erect and encrusting) and cnidaria (four genera), but each of the other orders were represented by one species.

5.4.3 Taxa preferences

The seventeen widespread taxa were analysed to determine species ranges in a similar way to the intertidal taxa (see Table 7). For taxa occurring in both intertidal and subtidal areas similar responses to location and sediment were observed. Generally more species preferred the shallow subtidal area of the central main harbour (Figure 14). Interestingly, the difference between taxa found in the Oruawharo arm and elsewhere was not as marked with subtidal taxa as it was with the intertidal taxa. Relationships between taxa and sediment particle size were more common than for the intertidal taxa. Only three taxa did not show some relationship with sediment particle size. *Pontophilus* and *Paguristes* generally exhibit a wide tolerance to particle size and the Phoronid exhibited a close association with the presence of other tube dwellers.

Figure 14 : (Click for high resolution map)

Interpolated plots of the distribution of total numbers of individuals, number of taxa and number of orders found in the grabs taken from the subtidal sites.

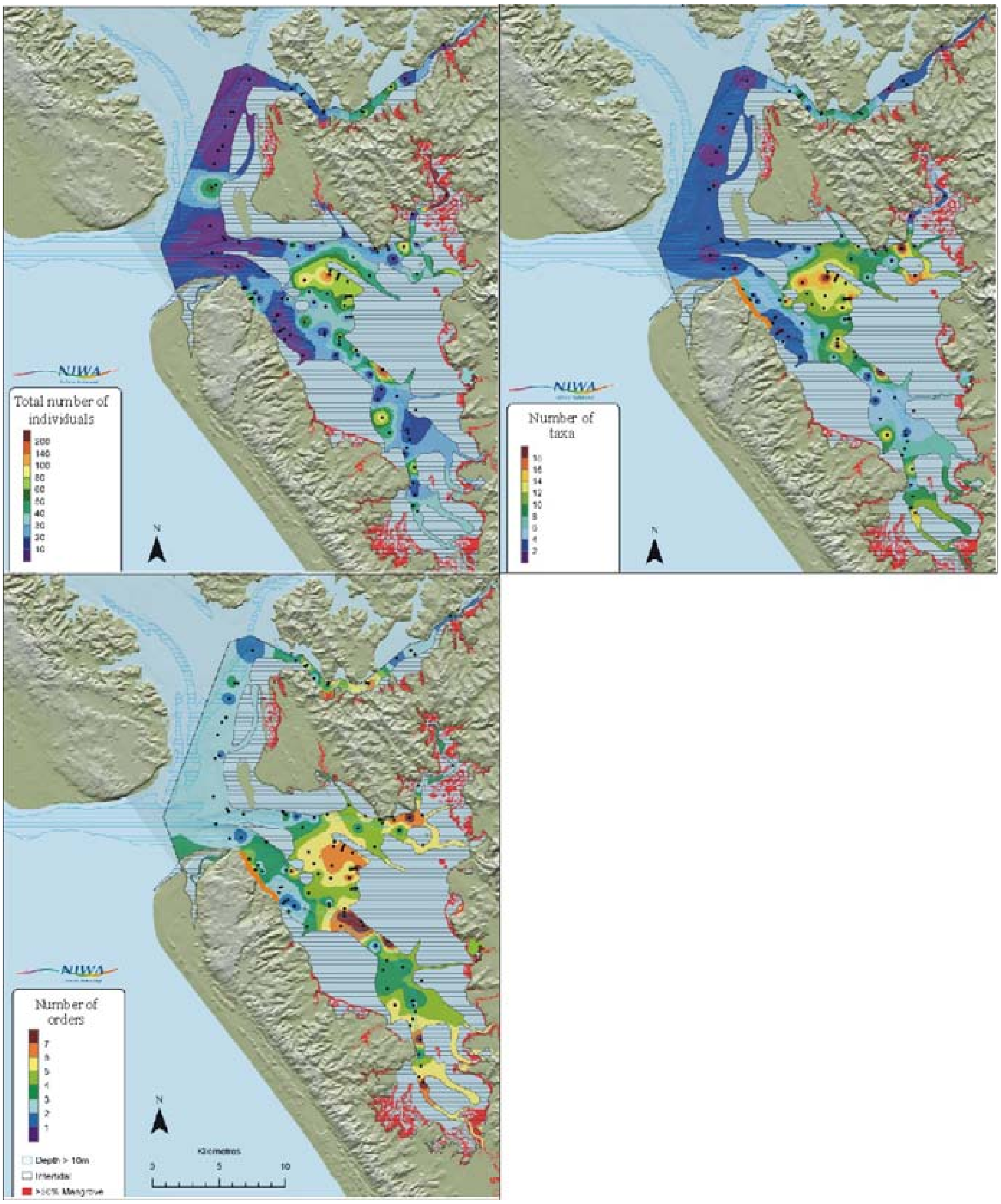


Table 7:

Location and sediment preferences of widespread taxa found in the subtidal area of the Southern Kaipara. Sensitivity to mud reported by Gibbs et al, 2004 is given after the taxon name (wherever possible). SS, S = prefers sand, I = intermediate, MM,M = prefers mud.

Taxa		Location	Sediment	Depth
Felaniella		Mainly in shallow central area of main harbour	+ve relationship with fine sediment	Highest in shallow subtidal
Musculista	S	Higher in shallow, sheltered areas	-ve relationship with medium sediment	No relationship
Myadora		Mainly in shallow central area of main harbour and Tauhoa arm	+ve relationship with fine sand and -ve relationship with medium sand	Highest in shallow subtidal
Nucula	S	Mainly in shallow areas and upper arms	+ve relationship with mud and fine sand	No relationship
Aglaophamus		Primarily in the centre of the main harbour	+ve relationship with mud and fine sand	No relationship
Euchone		Very localised around the shallow central area of main harbour	-ve relationship with medium sediment	Highest in shallow subtidal
Macroclymenella	S	Not in the Oruawharo arm or in exposed areas	+ve relationship with fine sand and -ve relationship with medium sand	Highest in shallow subtidal
Owenia		Mainly in shallow central area of main harbour	-ve relationship with medium sediment	No relationship
Anemones		Mainly in shallow central area of main harbour	No relationship	No relationship
Fellaster	S	Not in the Oruawharo arm	+ve relationship with medium sand	Highest in deeper water, particularly >15 m
Amphiura rosea		Not found in exposed areas or upper arms	+ve relationship with fine sediment and mud	No relationship
Bryozoans		Mainly near AMA B and C	-ve relationship with fine sediment and mud	Highest in deeper water, particularly >15 m
Phoronid		Mainly in shallow central area of main harbour	-ve relationship with medium sand	No relationship

Table 7 continued:

Taxa	Location	Sediment	Depth
Pontophilus	Mainly in upper arms	No relationship	No relationship
Paguristes	Highest in deep exposed areas	No relationship	Highest in > 15 deep water
Total abundance	No relationship	No relationship	No relationship
Number of taxa	Highest in shallow subtidal in main harbour	+ve relationship with mud and fine sand	Highest in shallow subtidal
Number of orders	Highest in shallow subtidal in main harbour	+ve relationship with mud and fine sand	No relationship
Number of large animals	Highest in shallow subtidal in main harbour	No relationship	Highest to 7m
Number of sedentary epifauna	No relationship	No relationship	No relationship

5.5 Integrating communities, sediments and large-scale features

5.5.1 Communities and acoustic sampling

Subtidal sampling by video, dredge and/or grab had been taken in each of the seafloor types identified by side-scan. Comparison between the descriptions derived from the video/dredge samples and the seafloor types revealed that while the physical description matched (e.g., sand waves, rubble, flat mud or ripples), in most cases the epibenthic habitats were variable (Table 8).

Table 8:

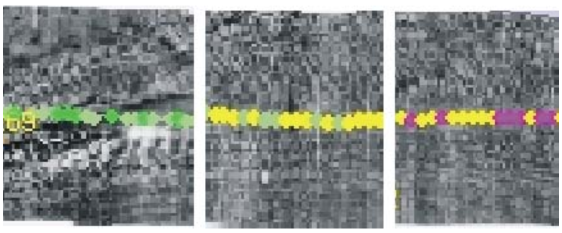
Subtidal epibenthic habitats (derived from video and dredge) and ecological communities (derived from grab sampling) observed in the different side-scan derived seafloor types.

Side-scan seafloor type	Epibenthic habitat	Ecological community
1. Sand waves	Mainly bare, *Fellaster*, *Fellaster*/gastropod, Gastropod	Epibenthos, *Fellaster*, Bivalve-suspension feeders
2. Mega ripples	Mainly bare, *Fellaster*, *Fellaster*/gastropod, Filamentous weed, Hydroids (only in sheltered areas, with smaller ripples)	*Fellaster*, Large animals, Bivalve-deposit feeders, Bivalve-suspension feeders, Surface bioturbators, Sedentary epibenthos, Polychaete- deposit feeders
3. Small wave ripples	Hydroids, *Fellaster*/gastropod, Gastropods, Mainly bare	*Fellaster*, Surface bioturbators, *Musculista* , Bivalve- suspension feeders, Bivalve-deposit feeders, Epibenthos
4. Confused ripples	*Fellaster*, *Fellaster*/gastropod , Gastropod, Hydroids, *Zostera*, Filamentous weed,	*Fellaster*, Large animals, Bivalve-deposit feeders, High diversity-surface bioturbators, Surface bioturbators, Burrowers
5. Channel banks	*Fellaster,* Hydroids, Sponge-weed	*Fellaster,* Bivalve- suspension feeders
6. Rubble	Rubble, Mainly bare	*Atrina*, Sponges, High diversity-large animals
7. Shell lag	Fellaster, Musculista	Fellaster, Musculista
8. Flat mud/sand	Gastropod, Epifauna complex, Hydroids, Sponge-weed, *Musculista* , Burrows, *Atrina*	Bivalve- deposit feeders, *Fellaster*, All high diversity community types, Sponges, Large animals, Sedentary epibenthos, Tube-dwellers, Surface bioturbators
9. Smooth sand with sparse dark spots	Mainly bare with high density patches of *Fellaster* and dead gastropod shells	Fellaster
10. Potential artefacts	*Fellaster*, *Fellaster*/gastropod, Sponge-weed, Hydroids	*Fellaster*, Large animals, Sedentary epibenthos, Polychaete predators/scavengers, Surface bioturbators

Examination of the video and dredge samples suggested shell lag areas could be comprised of broken shells, Umbonium shells and, sometimes, live *Fellaster*. The occasional dark spots observed in the side-scan data area in the central harbour seemed likely to be composed of patches of dense *Fellaster* or dead gastropods. Areas of potential artefacts in the side-scan image harboured a range of epibenthic habitat types (*Fellaster*, Gastropods, Sponges and Hydroids), which may well have been being picked up by the side-scan. Ecological communities found in the different seafloor types were equally varied (Table 8). Comparisons made between the seafloor types, and the count data for all taxa derived from the grab samples revealed that none of the seafloor types exhibited a significantly different community ($p > 0.05$). Furthermore, there were no significant differences in the numbers of taxa found in different side-scan seafloor types. However, while the side-scan seafloor types could not discriminate ecological communities, some taxa and ecological information were well related. Discriminant analysis between the side-scan seafloor types and the video and dredge data revealed that, with a spatial component (Easting) built in, % of coarse sediment, degree of bioturbation and rank abundance of *Musculista* and sponges were related to some of the seafloor types (1,3,5,7,8,9). A further attempt was made to link the side-scan data to the ecological data using the size of the ripples recorded in the side-scan as a predictor. However, no significant relationships were observed for any of the widespread taxa.

Visual inspection of the QTC data revealed that, while frequently a single class covered an extensive area, some areas were comprised of a mix of two QTC classes (Figure 15). This led to an extension of the QTC classes to 9. The extended classes comprised: a mix of class 2 and 4; a mix of class 4 and 5; a mix of class 3 and 5; and a mix of class 1 and 5. Comparison of the QTC classes with the count data from the grab samples revealed that no significant difference was apparent between communities in the different classes. While the p-value for this was barely nonsignificant ($p = 0.056$), pairwise comparisons revealed only two comparisons significant at the 0.1 level (differences between classes 4 and 1, and between classes 5 and 6). There was also no significant differences between different QTC classes In terms of number of taxa, number of orders or total number of individuals ($p > 0.05$).

Figure 15:
Sections of side-scan with mixed classes of QTC data superimposed. Different QTC classes are displayed with different colours. Mixed colours over a small area suggest a different habitat than an area with only one colour.



Nor was there a better relationship between the QTC classes and the epibenthic habitats derived from the video and dredge data, or the ecological communities derived from the grab sampling (Table 9). Although there were some habitats and communities that only occurred in certain classes (e.g., class 5 had a number of the large epifauna communities), there was also considerable overlap. Similar to the side-scan data, however, while the QTC classes could not discriminate ecological communities, some taxa and ecological information was well related. Discriminant analysis between the QTC classes and the video and dredge data revealed that depth and rank abundance of *Fellaster* and gastropods were related to the QTC classes. When depth was removed, bioturbation, and rank abundance of seaweed and *Zostera* became important, but the relationship decreased to an association with classes 4 and 5 only.

The original five QTC classes all overlapped a number of side-scan seafloor types (see Table 9, Figure 16). However, 2 of the 4 derived classes were comprised of a single side-scan seafloor habitat. In both cases these habitats were not spatially extensive nor did the side-scan seafloor type they represented occur only in that QTC class.

Figure 16:
A QTC class (yellow dots) overlapping a number of different seafloor types observed with side-scan data.

Table 9:

Side-scan derived seafloor types, subtidal epibenthic habitats and ecological communities observed in the different QTC-derived classes.

QTC class	Sediment type	Epibenthic habitat	Ecological community	Seafloor type
1	Fine to medium sand	Only one sample 9	1,2,3	3,8,9,
2	Mud to medium sand and coarse, sandy muds	2,4,5,6,9,10	8,9,1,6,7,5,11	5,4,2,8,1
3	Mud to medium sands	7,11,9,8,6,10,5	9,10,3,6,7,12,11 ,15,4	5,4,7,2,8,10,3,1
4	Fine to coarse sands	8,10,5,3,4	1,3,6,5,15,4	5,9,10,1,2,3
5	Fine to sandy muds	2,8,10	1,3,5,4,2	2,8,10,3,4
6	Fine to medium sands	3,4,6,8,9	10,3,7,11,14	4,2
7	No samples	No samples	No samples	2, 4
8	Fine to medium sands	1	2,3,6,8,11	6
9	No samples	No samples	No samples	3

Past research has demonstrated that difficulties in linking acoustic data to ecological data is frequently due to: variability in ecological data at a scale below that of the resolution of the acoustic data (Thrush et al. 2003a); a heterogeneous but not strongly differentiated substrate to which the ecology responds in a variable way (Hewitt et al. 2004a); or ecological responses that are not completely driven by the environmental factors that the acoustic data reflect (e.g., predation, recruitment). With the strongly rippled surface that comprises much of the surface of the Southern Kaipara seafloor, it is not surprisingly that the ability of acoustic data to detect smaller relief features such as bioturbated areas, sponges or *Atrina* is limited. Furthermore, it is important to remember that associations between environmental factors (e.g., depth, sediment type, current speed) and ecology only represent what may be found, assuming other factors do not compromise the relationship (e.g., over fishing, water clarity, chemical contamination).

The variable epibenthic habitats and subtidal communities found in the side-scan seafloor habitats and the QTC classes make it difficult to use these data to generate ecologically significant habitat maps. For this reason, we have provided these data as GIS layers but have not produced a habitat map from them.

Over the range in depths sampled in the Southern Kaipara, only three depth classes contained significantly different communities (the intertidal, the shallow subtidal and the > 3 m), although a number of taxa also demonstrated a preference for > 15 m. Generally, large-scale features did not prove particularly useful for the mapping of either sediment particle size or ecological characteristics. As expected from previous work, the flora and fauna of both the intertidal and subtidal areas of the harbour displayed the ability to occupy a number of different sediment types and physical environments. Even *Zostera* beds did not contain distinctly different communities overall. The one large-scale feature that did have a distinctly different community was the mangroves (> 50 % cover), with community change gradually occurring from this habitat to low density mangroves and non-vegetated mudflats through to areas with coarser sediments.

5.5.2 Final habitat and ecological descriptions of the Southern Kaipara

There were distinct differences between the types of fauna and communities found in some areas of the harbour. Prompted by the obvious spatial differences observed in the widepread taxa (Tables 4 and 7), the Southern Kaipara was divided into 7 intertidal and 8 subtidal areas (Figure 17). The 7 intertidal areas were the Oruawharo (O) and Tauhoa arms (T), the upper part of the Kaipara River arm (U), the eastern and western areas of the outer Kaipara River arm (E and W), the area of sand dune areas oppposite the mouth (Ex), and Waonui Inlet (I). The 8 subtidal areas were the Oruawharo (O) and upper Tauhoa arms (UT), the upper and middle area of the Kaipara River arm (U and M), the high current area near South head (H), the shallow subtidal area between the Kaipara River and Tauhoa arm (S), the exposed deep area in the mouth (Ex) and the outer area of the Tauhoa arm (OT).

These splits were confirmed by analysis of dissimilarlities between the species found in areas, with all areas being different from at least one other area ($p < 0.05$ ANOSIM). In the subtidal area, the high current (H) and shallow subtidal areas (S) were different to all other areas. Other differences were UT compared to Ex and M, Ex compared to M, O and UT, M compared to O, OT and UT, and O compared to OT and UT. There were differences within these areas driven by sediment characteristics. There were more overlaps between areas intertidally but a number of differences still occurred: W compared to W and I, U compared to E, O compared to T, Ex, E and I, T compared to Ex and I, Ex compared to E and E compared to I. The strong differences found between species observed in sand, mud, mangroves and Zostera habitats led to each intertidal areas being further subdivided on this basis.

Area U (the upper area of the Kaipara River arm) had five main habitat types: mangroves of varying densities, unvegetated intertidal mudflats ranging from muddy to very muddy (>50% mud) and sandflats; a small area of intertidal *Zostera* and subtidal muds. The mangrove communities were all dominated by burrowing animals, while the communities in the mud were more variable, comprised of deposit-feeding bivalves and polychaetes, surface bioturbators, tube dwellers and polychaete predators/scavengers. The *Zostera* supported a *Macomona* community, the unvegetated sand areas also had *Macomona* dominated comunities, as well as deposit-feeding polychaetes, suspension-feeding bivalves, *Austrovenus* and tube dwellers[2]. The subtidal area was composed of 4 ecological community types: deposit-feeding bivalves, tube dwellers, sedentary epifauna and surface bioturbators.

The Tauhoa arm had a similar range of intertidal habitat types. Similar to the upper area of the Kaipara River arm, the mangrove and *Zostera* communities were predominantly

[2] The presence of invasive communities is discussed in a separate section

burrowers and *Macomona*-dominated respectively. However, in the low density mangroves some *Macomona* were also observed. In the sandy areas deposit-feeding polychaetes, *Macomona* and tube-dwellers were dominant. The subtidal area was divided into an upper and outer area, although these were not statistically significant from each other. The upper area was generally comprised of finer sediments and was shallower (< 7 m) with a more diverse range of ecological communities (deposit-feeding bivalves, surface bioturbators, tube-dwellers, predatory/scavenging polychaetes, large fauna and invasives). The outer area displayed burrowing, tube dweller and large fauna communities. Both areas frequently had high order diversity.

Area S (the shallow subtidal area between the Kaipara River and Tauhoa arms) was one of the most diverse areas. The sediments were predominantly fine sand and a number of ecological communities were observed (deposit-feeding bivalves, sedentary epibenthos, sponges, tube-dweller, large fauna, surface bioturbators and invasives).

Although mangroves on the eastern side of the Kaipara River arm were not sampled, the overall similarity in communities found in the mangroves across the Southern Kaipara suggest they are dominated by burrowing animals. The muddy areas were dominated by tube dwellers. The *Zostera* communities were very variable; dominated by *Austrovenus*, *Macomona*, deposit-feeding polychaetes, tube dwellers, polychaete predators/scavengers or surface bioturbators and varying from high to moderate diversity. Sandy areas were also variable in fauna, varying from *Austrovenus*, *Macomona*, deposit-feeding polychaetes, tube dwellers to surface bioturbators, although diversity was generally lower than in the seagrass.

Mangroves on the western side of the Kaipara River arm again were dominated by burrowers, although in lower density areas an *Austrovenus*- *Macomona* community was observed. Muddy areas supported *Austrovenus*, *Macomona* and tube-dweller communities. *Zostera* communities were dominated by *Austrovenus* and *Macomona*, while the unvegetated sand supported a number of different communities (suspension-feeding bivalves, deposit-feeding polychaetes, tube-dwellers, polychaete predators/scavengers, surface bioturbators and *Macomona* dominated); frequently of high diversity.

Area M (the middle subtidal area of the Kaipara River arm) was generally of low diversity with sandy muds to fine sands. Ecological communities varied from suspension-feeding bivalves, tube-dwellers, surface bioturbators, large fauna and *Fellaster* dominated.

The high current area by South Head was another very diverse area, comprising the steep rock walls, the rubble habitat and the sandy channel bottom. Apart from the highly diverse communities on the rock walls and rubble, Fellaster, surface bioturbators, sedentary epifaunal communities were common.

Waionui Inlet had no *Zostera* and the mangoves were not sampled. Unvegetated mud communities were dominated by deposit-feeding polychaetes; these were also found in the sandy areas. Other sandy communities were dominated by *Austrovenus* and surface bioturbators.

Zostera was also not observed in the Oruawharo arm. Mangrove communities in this arm were different to those in other mangrove areas, often having the small deposit-feeding bivalve (*Arthritica*) and polychaete predators/scavengers as well as burrowers. The muddy areas were dominated by either polychaete predators/scavengers or deposit-feeding bivalves. The sandy areas were usually sandy mud and were dominated by *Austrovenus*, often with *Macomona*. Subtidal areas in this arm were mainly muddy comprised of deposit-feeding bivalves, sedentary epifauna and *Fellaster*-dominated communities. Further towards the mouth, more surface bioturbators, tube-dwellers and communities dominated by large fauna were found.

The three main habitats opposite the mouth were intertidal *Zostera* and sand and subtidal sand. *Zostera* communities were dominated by a mix of large animals and dead cockle shells were common. The intertidal sand area communities were variable with *Macomona*, tube-dwelllers, surface bioturbators, deposit-feeding bivalves and polychaete predators/scavengers dominated communities found. Subtidal communities were predominantly *Fellaster* and surface bioturbating gastropods.

Figure 17:
General habitat areas of the Southern Kaipara.

6 Conclusions

6.1 Tier II monitoring design guidelines

This project is an ambitious survey of half of the largest harbour in the southern hemisphere. Although in recent years we have begun to research methods for integrating new acoustic techniques with traditional biological sampling to provide ecologically relevant maps, this is ground-breaking research and there is no simple way forward. This section will discuss the philosophy of the Tier II monitoring design, information requirements, the cost-effectiveness of various sampling methods and the use of various analytical techniques. The Tier II section of ARC's regional monitoring network focuses on providing resource information (i.e., spatial patterns of habitats and descriptions of ecological communities). This information has to be both extensive enough and precise enough to enable assessments of major change over a 10 – 15 yr time scale.

Sampling large-scale habitat features

A first step in habitat surveys is generally to focus on large-scale habitat features that can be sampled continuously (or nearly so) in a cost-effective fashion.

Intertidal

Intertidally, such features are generally sampled by aerial photography. However, extensive aerial photographs covering the whole of the intertidal that are not compromised by cloud cover and actually have been taken at dead low water are difficult and frequently expensive to achieve. The larger the area, the more difficult and expensive. Furthermore, frequently the aerial photographs are not taken in the same year as the other sampling (as in this project). While effort should be placed into gaining aerial photographs, it is important that the effort is only proportional to the information they provide (i.e., estimates of mangrove, *Spartina*, *Zostera* and non-vegetated areas). This information, while important in providing a map of ecological resources, is not information that will reveal vulnerabilities to many anthropogenic impacts or provide a strong base from which to describe ecological values at a less general level (e.g., biodiversity, shellfish distribution and abundance). Our work in this project using a helicopter suggests that video transects run from a helicopter can be useful in (a) quickly ground truthing aerial photographs and determining whether old photographs are still useful, (b) providing more information on sediment type and (c) replacing aerial photography when weather and/or size of the area makes aerial photography[3] excessively costly. In future, if increases in satellite coverage continue, satellite imagery may prove to be a useful alternative for characterising broad-scale features. At present, lack of tidal height data is a difficulty, particularly for smaller estuaries where even the limited chart data available for the Southern Kaipara is non-

[3] Infra-red aerial photography that allows better definition between vegetation types and vegetated and non-vegetated areas should be used whenever possible.

existent. However, in future bathymetric information may be more readily available as the necessity for assessing risks associated with storms and tsunamis becomes more accepted.

Subtidal

Subtidally, the usefulness of collecting continuous large-scale data is less clear. Increasingly in subtidal areas continuous large-scale data is becoming synonymous with acoustic data. In the methods section, three available tools and the rationale for selecting side-scan for use in this project are discussed. To recap, in water depths < 30 m (which the majority of the Southern Kaipara is), side-scan is the most cost effective tool. There are a number of problems associated with the use of acoustic techniques.

(1) Technically multibeam and QTC can be used in shallower waters than can side-scan (i.e., < 7 m), but in reality the low coverage and the loss of signal clarity generated by small waves, and vessel safety issues, mean that regardless of the acoustic tool used, this depth range is difficult to sample.

(2) Acoustic data is expensive to collect over large areas, for example collecting and analysing the data in the Southern Kaipara (which excluded both the shallow subtidal and the extensive area near the mouth) took 40% of the study cost. An area the size of Kawau Bay would cost much more, resulting in the necessity to take a transect approach with all the resultant errors associated with interpolation between transects.

(3) A final problem, well demonstrated in this project, is the ability to separate the acoustic data into physical or ecological habitats. In this project, neither the side-scan nor QTC data were well related to ecological habitats, although the side-scan did represented a number of distinctive physical features. This finding is location specific and probably related to the strong tidal currents and wave energy in the harbour; side-scan data in other locations has related well to ecological habitats. Most of the area in the Southern Kaipara, deep enough to be acoustically surveyed, is predominantly sand disturbed by waves or currents. Importantly, the high degree of small-scale variability such as has been found in the Southern Kaipara has always proven to be difficult to capture using acoustic techniques (Thrush et al. 2003a, Hewitt et al. 2004a).

At the heart of the problem of linking ecology and acoustic techniques are two factors. (i) Some areas have high small-scale ecological variability, which can not always be resolved with increased sample replication. If these areas have ecological communities that, although highly variable, do not occur elsewhere then they may be identified and separated out, although their descriptions may be of little use to someone attempting to monitor changes. If, however, as often occurs, some of these communities also occur in other areas, this may prove to be an untractable problem. (ii) However, the analytical tools for analysing acoustic information in relation to ecology is still in its infancy. It is now recognised that advances can only occur as analytical techniques are tested and developed over a number of different areas; fortunately the acoustic information gathered in the Southern Kaipara can be re-analysed as new techniques became available.

All these problems mean that it is important that acoustic imagery is not seen as a panacea. It is expensive to collect over large areas and, until a very good integration over all sedimentary and ecological habitat types has been established, an equal effort needs to be placed into collecting ecological data. Thus, subtidal surveys will continue to be expensive and, for large areas such as the Southern Kaipara and Kawau Bay, best done utilising transects rather that fully covering the area.

This has important implications for the Tier III monitoring, which is focused on collecting large-scale acoustic data with a small amount of ecological data for ground truth purposes. It suggests that, if ecological information rather than purely physical habitat descriptions is an important focus of the Tier III monitoring, Tier III monitoring should be implemented in stages, with the effectiveness of the results carefully monitored.

Less continuous subtidal information can be collected by video. The video information collected by this project proved useful in determining epibenthic habitats that were driven by both physical environments and ecology, and in reflecting ecological community characteristics of the infauna. In areas too turbid for video to be of use, dredge data was successfully collected and integrated with the video data. There are a number of problems with dredging: the dredge could fill before the dredge is pulled up; the dredge may not dredge to a consistent depth; the area covered may be very heterogeneous. However, if dredging is done carefully and grab sampling is used to investigate variability, dredging can be a useful technique for broad-scale ecological mapping. To conclude, in small areas, video/dredging is likely to be cost-effective and information rich compared with acoustic techniques. In larger areas, use of an acoustic device (either side-scan or multibeam) to help interpret and interpolate the video data is still recommended, although continuous coverage is probably not cost-effective.

Point sampling

To collect information on which to base ecological descriptions or ground truth acoustic habitats, point sampling is the standard technique, but the sampling device, size and resolution of sample, and the allocation of effort into replicates or sites varies depending on substrate type and study focus:

- In this project, the sampling device and its size was chosen to be consistent with other studies carried out for ARC and in other areas of New Zealand. Thus, a 13 cm diam x 15 cm deep core was used in the intertidal soft-sediment areas, a 0.1 m^2 grab in the subtidal soft sediment areas and a 0.25 m^2 quadrat in intertidal rocky areas. The subtidal rocky sampling was not consistent with other ARC sampling as no rocky reefs were encountered, rather cliff faces were surveyed using an ROV. For the soft-sediment sampling, a 1 mm mesh sieve was used. This worked well to remove recently settled juveniles from the analysis; a valid precaution when deriving a description that will be able to be compared with another one-off sampling occasion in 10 –1 5 yrs. This is also likely to be a cost-effective choice in East Coast areas of the Auckland Region, where the average sediment particle size is coarser.

- Most of the sampling effort was placed into spatial coverage with a maximum of three replicates collected at each site. This was consistent with other large-scale surveys carried out for ARC. The number of sites able to be sampled was increased by using a two-Tier approach based on analysing the similarity of the area (in terms of surface evidence of fauna and flora) to nearby areas before committing to sampling. In low visibility subtidal areas, a single grab was used to determine whether three replicates would be taken. Sampling locations were chosen to represent a range of environmental factors (wave exposure, currents, vegetation cover, depth, sediment types) as well as providing a good spatial coverage. In particular, areas of transition between habitats were sampled (e.g., low density mangroves, patchy *Zostera*, channel banks). We recommend that this continues to be a focus of the Tier II monitoring.

Linking intertidal and subtidal sampling

A major problem in mapping any area that incorporates both intertidal and subtidal is the interface between these two. In this project, we have left these areas separate for two reasons. (1) Lacking detailed depth and tidal information it was difficult to exactly define the interface as intertidal flats slope gently into the subtidal. (2) There was not a large overlap between the taxa found in the two areas. Large epibenthic animals primarily live in subtidal areas and the dominant bivalves frequently differ (as they did here). Polychaetes and amphipods are generally less specific but even so there are frequent differences in dominance.

Describing ecological communities

A major focus of the Tier II monitoring is the description of ecological communities, in particular the identification of vulnerable or unique communities. There are a number of methods for determining community associations from biological data. Generally methods for determining community associations revolve around different statistical techniques for determining clusters of like communities. Such techniques were not found to be suitable for this project, as distinct clusters containing a high self-similarity were generally not found. Also, such techniques frequently do not come up with associations with high ecological or social values, or that are easily assessed for vulnerability to anthropogenic threats (which is generally associated with functional characteristics displayed by the community such as mobility, feeding mode and position within the sediment). Therefore, this project used an ecological rules based approach for determining communities. It worked well and we would suggest its continuance in the Tier II monitoring.

Analysing temporal changes after a return survey

While this report concentrates on descriptions of the general habitats and communities found in the Southern Kaipara, there are two ways by which changes over time could be identified, if a return visit was made in 10-15 yrs time as part of ongoing Tier II monitoring in the ARC region. (i) Site differences can be calculated for both individual taxa and for the community, and any resultant change in ecological community description (e.g., from a bivalve-deposit feeding community to a surface-burrowing community determined. As samples were taken over a 10 m area, but were representative of a larger area; returning to within 50 m is likely to be sufficiently accurate. A GIS layer that associates distance from sampled areas to certainty is supplied to help interpret certainty. (ii) Changes to the number of and variability in ecological communities within the bounds of the general habitats described in section 5.2.2 can be assessed statistically.

The ability to detect comparatively small or subtle changes between surveys reduced when the decision to increase the number of sites (and decrease site replication and remove the 1 year repeat sampling) was taken. This does not mean, however, that only catastrophic changes can be detected by the sampling. While the low replication at a site does limit ability to detect small changes, community level analysis will act in part to increase detection ability. This will be increased further by being able to summarise changes operating over a large area (or multiple habitats).

Natural temporal variability apparent from the sentinel monitoring sites in the region (Tier I) will need to be used to set the limit on the magnitude of effects able to be detected in the Tier II temporal comparisons. This information, combined with experimental work that provides information on the taxa expected to show changes in response to specific anthropogenic impacts, and the direction and magnitude of such changes, give us confidence in our ability to separate natural variability in the Kaipara from potential anthropogenic changes. However, it is assumed that within the broad-scale assessment conducted under Tier II, more detailed impact assessments (for example, those concerned with the effect of specific marine farm or urbanisation) would be conducted at specific sites and times.

6.2 General description of ecological values of Southern Kaipara

The Southern Kaipara is a unique harbour. It is not only large, but it has high diversity of habitats: extensive fringing mangroves and salt marshes; *Zostera* meadows and patches; non-vegetated mud and sand intertidal flats and shallow subtidal flats, as well as small areas of steep banks, deep high-flow channels and intertidal rocky reefs and subtidal cliffs. Despite the high flow and potential for wind and ocean swell generated waves, many areas of the Southern Kaipara displayed high taxonomic diversity at both a species and order level, and a number of the taxa are large and long-lived. A number of species commonly associated with pristine environments (sponges, ascidians, bryozoans, hydroids, echinoderms and pipis) were found in the harbour. The harbour is ranked by the Department of Conservation as one of international significance due to its value as a feeding and roosting area of migratory birds and of national significance for its fisheries value.

Subtidally, the most common community type was dominated by varying densities of the sand dollar (*Fellaster*), or a *Fellaster*/gastropod mix. Areas of rich epifauna (sponges, ascidians, bryozoans, mussels) are more confined, occurring mainly in the central moderate-depth subtidal, along the channel banks and in the main channel near South Head, although hydroid habitats are found considerable distances up the Oruawharo, Tauhoa and Kaipara River arms. Intertidally, the most common communities were those dominated by deposit-feeding polychaetes. However, a number of bivalve and gastropod dominated communities occur as well. Moderate to dense mangrove areas (> 50% cover) were low in benthic diversity supporting communities that were distinctly different, though variable, from other intertidal areas.

There were distinct differences between the types of fauna and communities found in some areas of the harbour. Prompted by the obvious spatial differences observed in the widepread taxa, the Southern Kaipara was divided into 7 intertidal and 8 subtidal areas. The 7 intertidal areas were the Oruawharo and Tauhoa arms, the upper part of the Kaipara River arm, the eastern and western areas of the outer Kaipara River arm, the area sand dune areas opposite the mouth, and Waonui Inlet. The 8 subtidal areas were the Oruawharo and upper Tauhoa arms, the upper and middle area of the Kaipara River arm, the high current area near South head, the shallow subtidal area between the Kaipara River and Tauhoa arm, the exposed deep area in the mouth and the outer area of the Tauhoa arm. The strong differences found between species observed in sand, mud, mangroves and *Zostera* habitats led to each intertidal areas being further subdivided on this basis.

While many of the taxa and habitats found in the Southern Kaipara occur elsewhere, some are unique (at least in our present state of knowledge). In particular, a subtidal association of tube-building worms was found in the shallow subtidal area of the main harbour comprised of high numbers of *Owenia*, *Macroclymenella*, *Euchone* and Phoronids. Although these taxa occur in other areas (e.g., they have all been observed in the Tier I monitoring), either singly or together, rarely do they reach the densities observed here. Subtidal *Zostera* is also relatively unique in New Zealand; only a few areas have been recorded. Strong differences were also recorded from different parts of the harbour; the Oruawharo Arm and Waionui Inlet both had distinctly different taxa than the main harbour. The *Atrina* beds of the Kaipara, while not unique, *Atrina* being found in many areas of New Zealand, are particularly important for juvenile snapper. Recent research has suggested that in 2003 the Kaipara Harbour alone may have provided almost three-quarters of overall estuarine-based recruitment of snapper on the northeast coast (Morrison pers. obs.).

We have described the current ecological status of the Southern Kaipara, but it is important to note that significant changes have already occurred in the harbour. For example, a commercial dredge fishery for green-lipped mussel beds used to exist in the Kaipara, suggesting that relatively extensive beds once existed. These were not found, although patches were observed in the rocky areas near the South Head cliffs. Substantial native oyster (*Saccostrea glomerata*) beds were previously reported; these were badly depleted from commercial fishing by 1910 (Waitangi Tribunal 1988). Concern over decreases in snapper, scallops and, to a lesser extent, cockles and pipis have been documented (Fishing for the future: a strategy for the fisheries of the Kaipara Harbour). Invasive bivalve species were observed in the harbour in our 2003 – 5 sampling, frequently in high-density patches. These patches were relatively small, never stretching from one sampling location to the next. Species found were the Pacific oyster (*Crassostera gigas*), the Asian mussel (*Musculista senhousia*) and a small bivalve *Theora lubrica. Theora* is found in many areas (e.g., Mahurangi, Manukau) but seems to occur only in low numbers. *Crassostera* is found in many areas (e.g., Manukau), often replacing the native oyster, although it can grow in much muddier areas than *Saccostrea* could. *Musculista* is found in many areas as well, growing densely (e.g., Tamaki Inlet) and often excluding other animals, though this does not yet seem to be the case here. However, *Musculista* patches were widespread occurring in all areas of the harbour with the exception of Waionui Inlet. It appears possible that tube-dwelling communities are particularly susceptible to *Musculista* settlement and growth as frequently less dense patches were found in these communities with *Musculista* adhering to the tubes.

While the harbour may have suffered from overfishing (Fishing for the future: a strategy for the fisheries of the Kaipara Harbour), many areas within the harbour have been protected in the past from the changes in land use that result in increased delivery of terrestrial sediment to the harbour. Most harbours are usually sheltered from ocean swells by headlands and shallow entrances, but in the Kaipara, the ocean swells can enter the harbour. Furthermore the size of the inlet means that there is sufficient fetch for sizeable wind-waves to develop and affect the intertidal areas. This combined with the strong tidal currents presents many opportunities for seabed reworking, resulting in mud being winnowed away, either back into the upper arms or out to sea. This may account for the number of taxa that would be expected to be sensitive to elevated sediment (e.g., cockles, *Atrina*, sponges, *Perna* and other suspension-feeding bivalves) found in many areas of the Southern Kaipara.

6.3 Likely impacts of habitat changes

Likely impacts on habitats in the Southern Kaipara include:

- spread of mangrove cover, as mangroves trap increased amounts of sediment input associated with climatic and land use changes;
- increased muddiness of the sediment and spread of the mud areas into presently sandy habitats and decrease in water clarity again associated with climatic and land use changes;
- decreased *Zostera* cover associated with decreased water clarity or, potentially the periodic loss of *Zostera* that occasionally occurs in New Zealand, the cause of which is not known;
- changes associated with marine farms (discussed in the next section).

6.3.1 Spread of mangrove cover.

Communities found in dense mangroves were dominated by the mud crab (*Helice crassa*), with low numbers of Nereids and *Arthritica* and were different to those found in all but sparse mangrove areas. As the mangroves prograded therefore, we would expect to lose the more diverse mud communities as they became more like the low density mangrove areas, followed by more loss in diversity as the low density mangrove areas became high density areas. It is important to realise that mangrove areas in New Zealand are different to those described from tropical or sub-tropical areas. In these areas, diverse communities are usually described with mangroves being highly productive both for the rest of the ecosystem (nursery areas, production of organics) and commercially (wood and edible crab species). In New Zealand, mangroves are not commercially important, and the few ecological community studies that have been done suggest low diversity (Ellis et al. 2004). Their role in the estuarine ecosystem is still under study; Morrisey et al. (2003) suggests that export of organics is not as important as else where in the world. A study on fish species associated with mangroves in a few areas do, however, suggest that they may have a role as a nursery for some species (Morrison pers. comm.).

6.3.2 Increased muddiness.

Communities observed in the mud areas formed part of a gradient of change between mangrove habitats and exposed sand habitats. As Lundquist et al. (2003) demonstrate, muddy habitats do not necessarily exhibit low diversity and functionality. They describe a gradient of decreasing numbers of taxa, functions and large animals with increasing sedimentation rates, and muddy communities from different types of estuaries and harbours becoming more similar. Muddy habitats of the Southern Kaipara presently fit into the medium area of the Lundquist model. Increased sedimentation, even if the hydrodynamics of the Southern Kaipara prevented spread of muddy areas on to presently sandy areas, would therefore result in changes to the animals inhabiting the muddy areas, with decreased diversity and mainly mobile surface dwelling species such as corophid amphipods and the mud crab (*Helice crassa*).

If the mud habitats did spread, the taxa most likely to exhibit changes in intertidal areas can be determined using Gibbs and Hewitt (2004). Many of the taxa summarised as sensitive (SS by Gibbs et al. 2004), are widespread in the Southern Kaipara i.e., *Notoacmea helmsi*, *Asychis*, *Cominella glandiformis*, *Diloma subrostrata*). These taxa would be expected to decrease first, followed by less sensitive taxa (those designated S by Gibbs and Hewitt (2004); Lysianassid and Phoxocephalid amphipods, orbinid polychaetes, *Aonides oxycephala*, *Macomona liliana*. Finally, those preferring intermediate amounts of mud could also decrease (*Austrovenus stutchburyi* , *Arthritica bifurca*, *Aquilaspio aucklandica*, Glycerid and Syllid polychaetes, *Heteromastus filiformis*, *Macroclymenella stewartensis*, *Boccardia* spp., *Cossura consimilis* , *Aricidea* sp., and *Macropthalmus hirtipes*).

Determining likely changes in the subtidal is more difficult as less work has been done on these taxa. However, with increasing turbidity, suspension feeders (such as sponges, *Atrina*) would be likely to decrease (Ellis et al. 1999, Ellis et al. 2002, Lohrer et al. 2003). Some suspension feeders (*Crassostera*, *Perna*) are not so susceptible and would require much higher levels of elevated turbidity before exhibiting reductions (Hawkins et al. 1999). The response of grazers (such as *Fellaster* and the gastropods that comprise much of the subtidal habitat) is difficult to determine as many grazers can switch from grazing on algal species to detritus, although *Fellaster* is recorded as being sensitive to sedimentation (Gibbs and Hewitt 2004). If, as well as increased turbidity, increased sedimentation occurred (given the dynamics of the Southern Kaipara this would only be likely to occur in sheltered, low flow areas) taxa likely to exhibit changes can be determined using the field experimental results of (Lohrer et al. 2003): Sponges, asciidians, scallops, *Atrina*, Lysianassid and Phoxocephalid amphipods, orbinid polychaetes, *Fellaster*, *Echinocardium australis*, *Boccardia* spp., Glycerid and Syllid polychaetes, *Heteromastus filiformis*, *Macroclymenella* *stewartensis*, *Cossura consimilis* , *Aricidea* sp., and *Macropthalmus hirtipes*. It is likely that the unique tube-dwelling community would be affected, as *Macroclymenella* is known to prefer sand, athough no information is available for the preferences of *Euchone*, *Owenia* or Phoronids.

6.3.3 Decreased *Zostera* cover.

While research indicates that differences between communities living in *Zostera* beds and adjacent un-vegetated areas occur, these differences are not consistent between locations. As a result, there are no published studies that list taxa found primarily in *Zostera*, for example cockles may be found in higher densities in *Zostera* beds that outside in one area, but not in others. However, reduction or break-up of the extensive Southern Kaipara meadows would be expected to result in changes to the ecological communities, as Hewitt et al. (2003) suggests that the effect of *Zostera* is likely to be dependent on size of area with greater effects on community structure and diversity in large meadows than in small meadows or patches. The presence of *Zostera* also has implications to the rest of the estuarine ecosystem beyond the benthic communities. Vegetated areas are generally expected to affect organic, sediment and nutrient fluxes, trapping sediment and exporting organics and nutrients to the rest of the ecosystem, thus increasing productivity. Recent research in New Zealand, however, has demonstrated that some key species in non-vegetated areas can also enhance productivity and alter nutrient fluxes (*Atrina* (Gibbs et al. 2005), *Echinocardium* (Lohrer et al. 2004), *Macomona* and *Austrovenus* (Thrush et al. in prep)) to a similar extent as has been demonstrated for vegetated areas in other parts of the world. Similar to mangroves, *Zostera* meadows are reported internationally to be important for various fish species. In New Zealand early results reported by Morrison and Francis (2002) suggest that beds are important for juvenile snapper, trevally, parore, spotties and pipefish.

6.4 Implications of the locations of selected Aquaculture Management Areas

This section is an assessment of the vulnerability and uniqueness of the benthic communities under the AMAs to mussel and oyster farming (as these are types of aquaculture considered for the areas (D. McCarthy pers. comm)). It does not contain a review of studies investigating impacts of different aquaculture techniques as does, for example Hatton et al. (2003) or Kaspar et al. (1985).

The AMAs intended for the Southern Kaipara fall across three types of habitats.

AMA D and E are located in the sheltered shallow subtidal area of the main harbour. They lie across an area of subtidal *Zostera* and high diversity patches of sponges, suspension-feeding bivalves, filamentous seaweeds and the unique tube-dominated community discussed in the previous section. The *Zostera* is not continuous meadow, rather a number of patches of varying size and density occur over a wide area. No significant differences were observed between the samples taken within these AMAs and the samples immediately adjacent to them, or between the two AMAs, although the prevalence of tube-dominated community does decrease southwards through AMA E. Some dense areas of *Musculista* were found in these AMAs. The nearby intertidal area is a mix of *Zostera* (meadows and patches) and sandflats containing crabs, amphipods, small deposit-feeding bivalves and polychaetes. Some areas of tube-dwellers and a high-density patch of the gastropod *Umbonium* were observed.

Marine farming, particularly rack farming, is likely to cause changes in water flow. The flora and fauna of these areas are likely to be sensitive to such changes in water flow, due to both direct effects on food, oxygen and nutrient fluxes and indirect effects on rates of sedimentation of fine particles causing smothering and interfering with feeding by suspension feeders. Depending on the locality and the nature of the marine farming, marine farms may, however, provide an extra food source for the mainly deposit-feeding tube-dwellers found in this area and feeding by the farmed suspension-feeders may remove sediment from the water column, increasing water clarity around farms. Changes to sediment characteristics by deposition of shell hash underneath the farm would also be likely to affect the communities living in these areas. Affects on taxa due to phytoplankton removal are likely to occur over a larger area than the AMAs themselves and will depend on stock density and water column productivity and exchange rates; none of which are presently known. However, these likely effects need to be balanced against the areas of sensitive habitats covered by the proposed AMAs. AMA D and E occupy an area of about 200 ha which is approximately 16% of the sheltered shallow subtidal area. The percentage of the sheltered shallow subtidal area that contains *Zostera* is 33% (approximately 940 ha), of which 21% of the subtidal seagrass falls within the boundaries of AMA D and E[4] .

AMA C lies in a channel area, with *Fellaster* or *Fellaster*/gastropod dominated communities, offshore from some intertidal *Zostera* beds. The *Fellaster* and *Fellaster*/gastropod dominated communities are the least diverse and most common subtidal habitats observed in the Southern Kaipara and AMA C covers only a small proportion of this habitat type (< 5%). The currents in this area suggest that build up of fine organic material below farms is unlikely, thus the major effects of farms is likely to come from deposition of shell material or depletion of phytoplankton. While the gastropods and *Fellaster* are expected to be grazers, *Fellaster* may also be a filter feeder. Similar taxa in other parts of the world are known to raise themselves into the water column, by tilting their bodies into the flow, and intercept plankton flowing past. The density reached by *Fellaster* in many areas of the Southern Kaipara suggests that they may behave similarly.

While a section of both AMAs A and B lies in sandy channel areas similar to AMA C, a section of both encompasses the highly diverse and encrusted rubble and rock wall habitats. These habitats are dominated mainly by fauna (sponges, bryozoans and mussels) and deep channel areas containing sponges. A patch of *Zostera* was observed in AMA B, which was sandier with gently sloping walls. Generally areas sampled in the AMAs A and B had lesser slopes than the areas outside, resulting in slightly less diverse and rich communities on the cliff walls. Similar to AMA C, the currents in these areas suggest that build up of fine organic material below farms is

[4] Note that the depth information is based on sparse sampling and the *Zostera* cover is based on interpolations between data from helicopter and boat transects (the latter provided by Dollimore). This affects the confidence with which we can view these estimates

unlikely, and the major effects of farms is likely to come from deposition of shell material in flat or gently sloping areas, or depletion of phytoplankton. The benthic communities in these AMAs are likely to be particularly sensitive to depletion of phytoplankton due to the number of suspension-feeding taxa inhabiting them. The two AMAs together cover approximately 29% of the highly diverse and encrusted rubble and rock wall habitats. The high currents are likely to reduce the possibility of phytoplankton depletion becoming an issue (see NIWA current data and Gibbs et al. 2005). However, as noted previously, whether phytoplankton depletion occurs will depend on stock density, water column productivity and exchange rates. Given the diversity of the benthic habitats and taxa encompassed by these AMA's, a detailed assessment of the risks is warranted.

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8 Acknowledgements

NIWA acknowledges the extra data provided by Jim Dollimore and Britta Hietz and the help of ARC staff (D. McCarthy and S. Kelly) in providing field work and advice. Other NIWA staff involved in this project were D. Lohrer, J. Halliday, N. Hancock, M. Ladd, S. Wadhwa, L. Chiaroni, J. Drury, R. Budd, P. Geering.