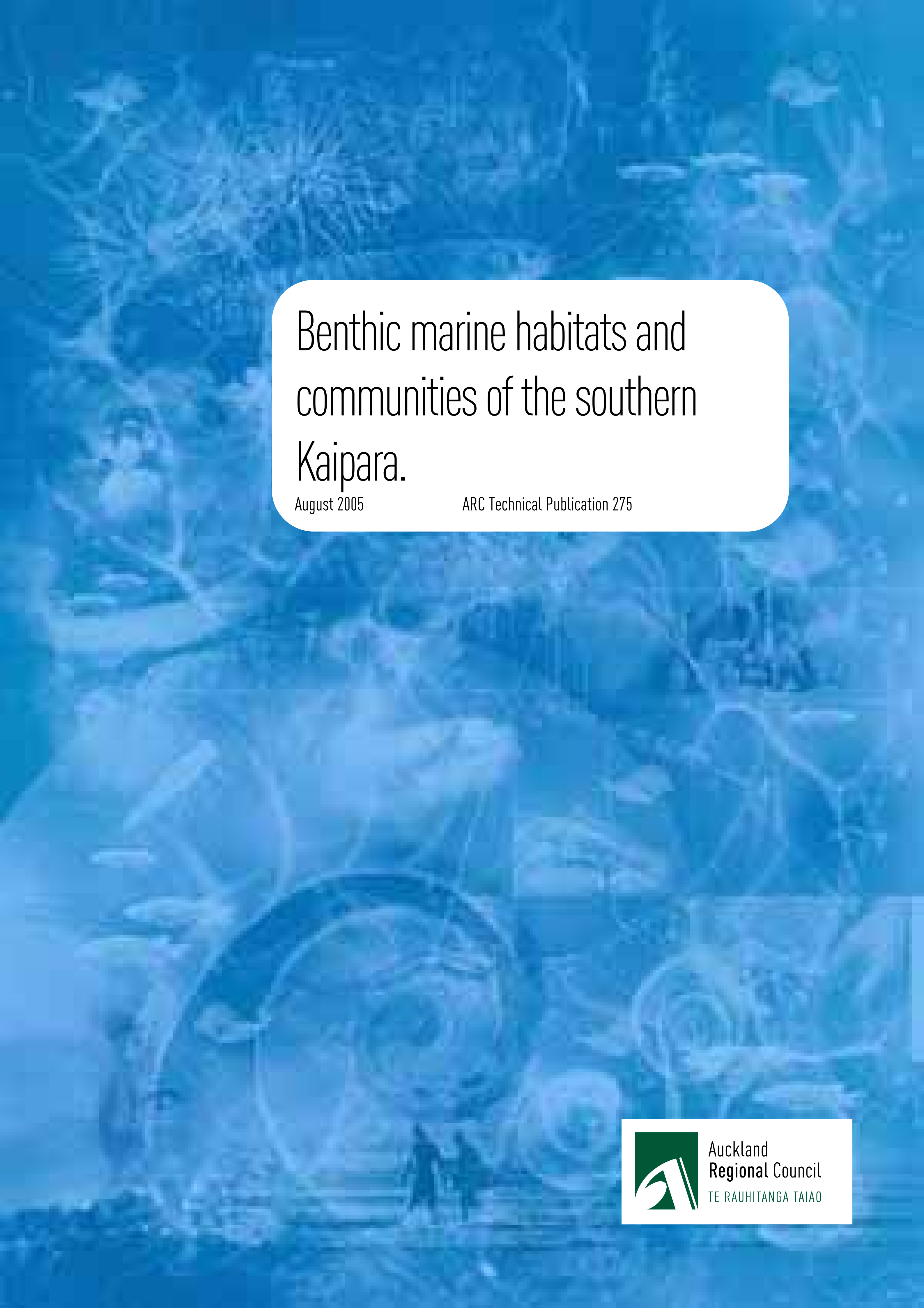

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Benthic marine habitats and communities of the southern Kaipara

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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.

<u>Ecological description and value.</u> 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.

<u>Aquaculture Management Areas.</u> 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)

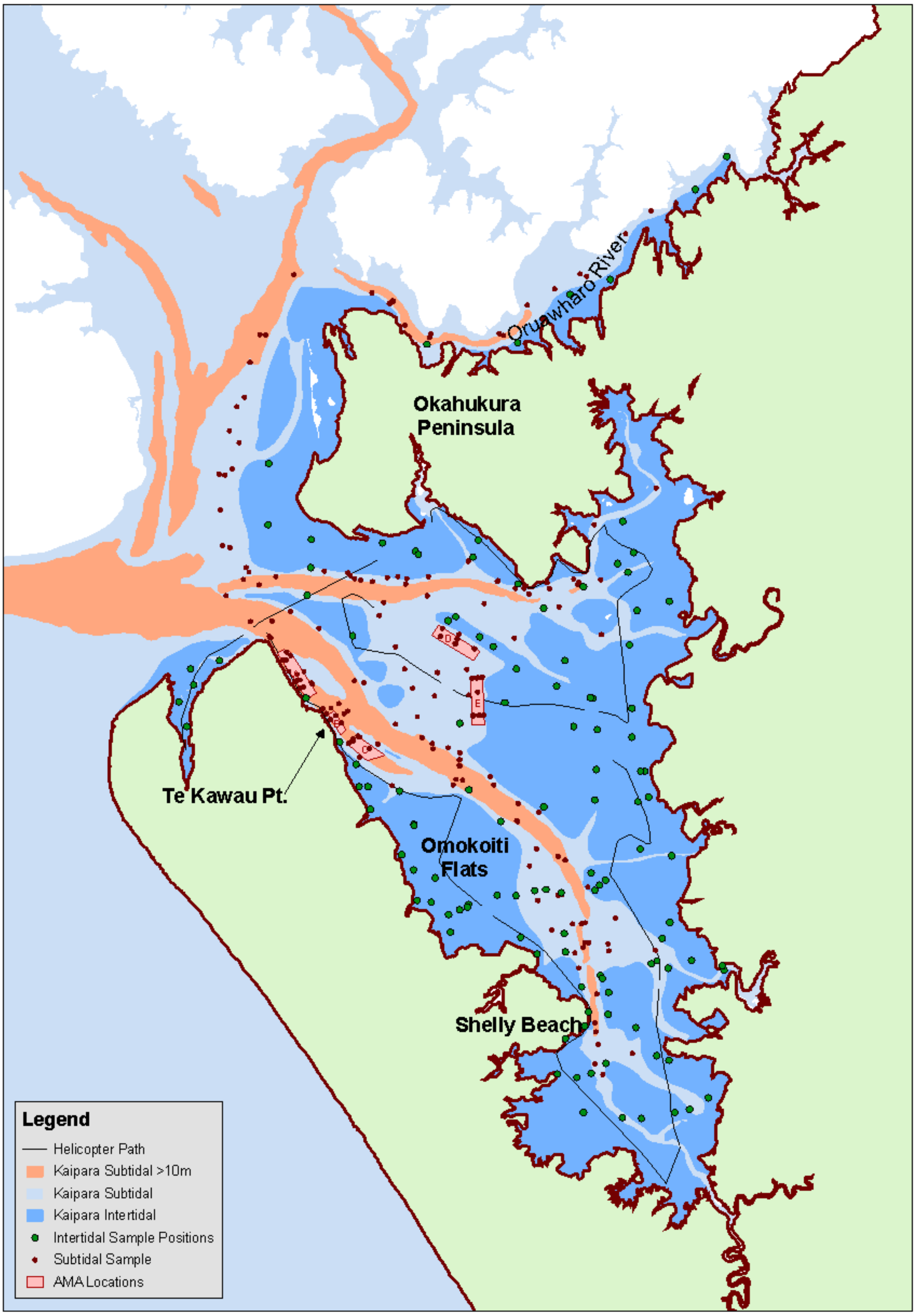
The information available from ARC left 2 major gaps in information required for defining physical habitats: (1) lack of bathymetric detail and (2) lack of sediment type detail. Collecting detailed bathymetric data by LIDAR (Box 1) was investigated, but proved too costly for this project, particularly 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.

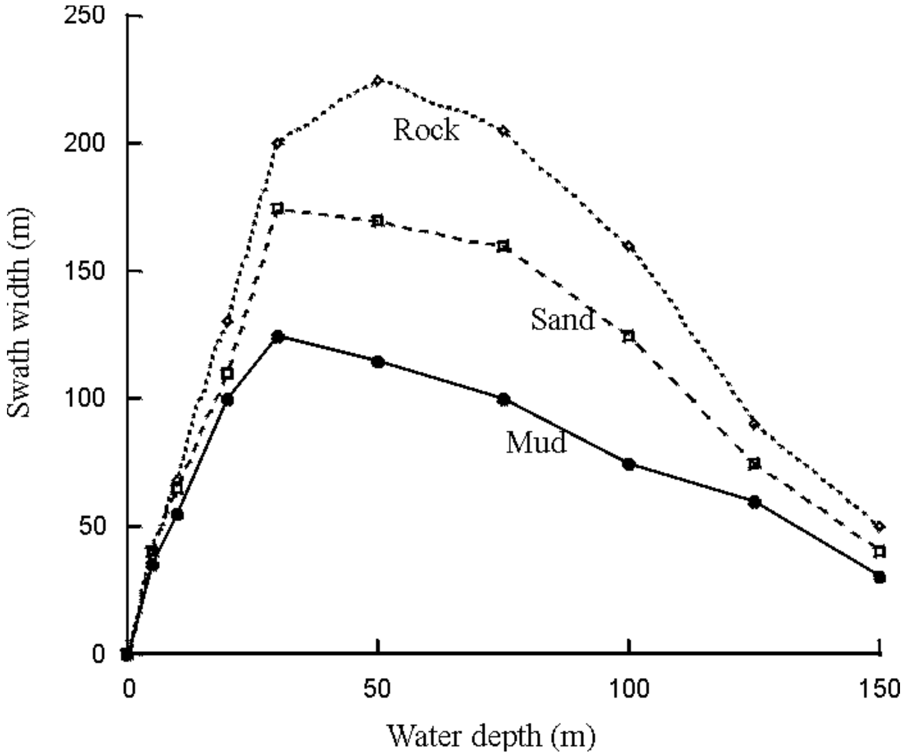
3.2 Subtidal sampling

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).