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Otahu Estuary shellfish and benthic habitat mapping (2009)

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Executive summary

In 2009 Waikato Regional Council conducted shellfish and benthic habitat mapping of the intertidal area in Otahu Estuary. Otahu Estuary was chosen because of its small size and easy accessibility. The primary goal of this project was to quantify the distribution and abundance of three species of bivalves (the cockle, *Austrovenus stutchbury;* the pipi, *Paphies australis* and the wedge shell, *Macomona liliana*) that are abundant in many Waikato estuaries. A secondary goal was to test if the estuary's intertidal substrate types can be mapped using subjective substrate categories. Three gastropod taxa (*Diloma* spp., *Zeacumantus* spp., *Cominella* spp.) were also mapped.

A total of 17,457 shellfish were found at 84 sampling sites. Bivalves were by far more numerically dominant than gastropods. *Austrovenus* was the most abundant bivalve species, with 13,411 individuals (84% of all bivalves) counted. *Austrovenus* were recorded in 71% of the samples and the average *Austrovenus* density was 851 individuals per square metre. Seventy-one per cent of the *Austrovenus* were small individuals, 28.8% were medium and only 0.2% of the *Austrovenus* sampled were classified as large. 1,759 *Paphies* were counted from 60% of the samples. The average *Paphies* density was 112 individuals per square metre. The sampled *Paphies* population was mainly composed on small individuals (89.6%), with 9.9% being medium and 0.5% large. *Macomona* were the least common bivalve with only 730 individuals counted. They were present in 40% of the samples. The average *Macomona* density was 46 individuals per square metre. *Macomona* had a more even size class distribution with medium individuals making up half the sampled population (52%) and small and large individuals roughly a quarter each (27% and 21% respectively).

The substrate mapping conducted as part of this survey produced substrate maps of Otahu Estuary based on subjective substrate categories. As expected, coarser substrate (category 'mobile sand') was found areas of high water velocity such as around the mouth of the estuary and at channel edges. The remaining substrate categories could not be distinguished in regards to their grain size distribution and therefore interpretations of their distribution throughout the estuary need to be done with caution.

Modifications to the survey protocol are recommended for future surveys. These include modifying (a) the delineation of the bivalve size classes, (b) the surface sediment substrate categories, (c) the training of field staff, (d) the way in which sampling effort is allocated throughout an estuary, and (e) the number of quadrats sampled at each sampling location.

Mapping the distribution of shellfish and surface sediments can provide an inventory of the region's natural resources; support the assessment of the effects of anthropogenic activities or the efficacy of environmental policy. Shellfish populations are a natural resource of commercial, recreational, cultural and ecological significance. If the methodology used in this survey can be refined as recommended in this report, repeating shellfish and substrate surveys over time can help identify bivalve populations that are in decline or estuaries in which habitat change might threaten the region's significant estuarine natural resources.

1 Introduction

1.1 Benthic shellfish and habitat mapping project background

Estuaries are among the most productive, diverse and ecologically important coastal environments in the Waikato region. As interfaces between land and sea, estuaries perform important ecological and biogeochemical functions. Estuaries support diverse ecological communities, and are spawning and nursery areas for many species of fish. Estuaries also function as a natural buffer between the land and sea, filtering sediment and contaminants from catchment water before it enters the coastal zone. In addition to these important ecological functions, estuaries are greatly valued by humans for cultural and recreational activities.

Estuaries are heavily used coastal areas within the Waikato region and are under increased pressure because of population growth, increased development in catchments with ensuing runoff of nutrients and sediments, and coastal developments such as marinas and marine farms that use estuarine space. These uses can potentially result in degradation of estuarine habitat and community composition through changes to water quality, increased levels of terrestrial sedimentation and other contaminants, mechanical disturbance and shellfish harvesting.

Within estuaries, shellfish provide important ecosystem services. These include food for birds, fish and other estuarine animals and the filtration of water which improves water clarity and removes sediments and nutrients from the water column. Another example is the mixing of sediments by shellfish which facilitates nutrient regeneration and oxygen supply.

While shellfish are more resilient to environmental change than many other organisms living in our estuaries, they are sensitive to changes in habitat that result from many of the anthropogenic pressures facing estuaries. For example, they are at risk of smothering by terrigenous sediments, displacement by activities such as dredging and other types of habitat modification, and habitat and water quality changes resulting from increases in nutrient runoff from land. For these reasons the community composition of benthic fauna, including shellfish, is often used to indicate the state of their environment.

Waikato Regional Council has a statutory obligation to protect the region's natural coastal resources. Due to their cultural and ecological importance, the protection of shellfish beds is a priority. In order to protect shellfish beds, or detect any changes to them arising from human activity, it is essential to know their extent (i.e. to map where they are found) and how large and dense the beds are.

Based on mapping surveys conducted by the Department of Conservation in Aotea and Kawhia Harbours (Hillock & Rohan, 2011), Waikato Regional Council has mapped shellfish beds and habitats in three estuaries: Otahu Estuary, Wharekawa Harbour and Tairua Harbour.

Otahu Estuary was the first estuary mapped by Waikato Regional Council. In addition to mapping shellfish beds, a subjective descriptive method to classify sediments was trialled as a potential alternative to costly grain size analysis.

The results of the Wharekawa Harbour survey have been reported in Graeme and Giles (2013). The results of the Tairua Harbour survey have been reported in Felsing and Giles (2011). This report presents the results of the Otahu Estuary survey.

1.2 Benthic shellfish and habitat mapping project objectives

The objectives of the estuary benthic shellfish and habitat mapping project are to:

- provide baseline information on the location of shellfish beds and substrate type within the intertidal area of Otahu Estuary; and
- provide information to assist ecologically sound resource consent decision making, policy setting and to support the sustainable management of estuaries in the Waikato Region.

1.3 Shellfish species

The Waikato Regional Council's habitat mapping project focuses on three shellfish species that are found in all the region's estuaries: the cockle (*Austrovenus stutchburyi*), the pipi (*Paphies australis*) and the wedge shell (*Macomona liliana*).

Austrovenus are endemic to New Zealand, and are an important food species for humans. They are surface suspension feeders, burrowing just below the sediment surface, and are found in muddy and sandy intertidal substrates (Gibbs & Hewitt 2004; Hillock & Rohan, 2011). *Austrovenus* grow up to 50 mm in shell length, and are sexually mature above about 18 mm.

Paphies are also surface suspension feeders, which generally burrow just below the sediment surface. Juvenile *Paphies* are normally found higher on the shore than adults, with most adult size *Paphies* beds found in areas of high water flow such as channels. While juveniles can be found in fine sand to sandy mud habitats, adults prefer coarser sediments and faster currents (Norkko et al., 2001; Thrush et al., 2004; Felsing & Giles, 2011). *Paphies* can grow up to 75 mm in length with maturity being reached around 40 mm.

Macomona are surface deposit feeders, normally found at depths of 5 to 15 cm in sediments. They grow to a maximum size of about 70 mm in shell length, and reach sexual maturity at about 22 mm shell length. They prefer habitats similar to *Austrovenus* (Cummings et al., 2002; Gibbs & Hewitt, 2004; Hillock & Rohan, 2011) although may be less tolerant than *Austrovenus* of muddy sediment (Norkko et al., 2001; Thrush et al., 2004). *Macomona* are not generally eaten by humans, but are an important food resource for birds and fish.

1.4 Otahu Estuary

Otahu Estuary is one of the smallest estuaries on the Coromandel Peninsula. It is located on the east coast of the peninsula, immediately to the south of Whangamata (Figure 1). Whangamata has a population of approximately 3,600 which can increase to as many as 25,000 during peak holiday season. Otahu Estuary has a total area of 0.89 km^2 and a catchment area of 70 km^2. It is a site of cultural significance to Hauraki iwi, and has important fisheries, wildlife and recreational values. Resident and migratory birds, including rare and threatened species, wading species, and coastal and freshwater species are frequently observed within or adjacent to Otahu Estuary. Much of the estuary consists of intertidal sandflats (~ 60%), and channels (~ 10%), with intertidal vegetated areas accounting for the remaining 30% of the total area (Graeme 2007, Figure 2). The estuarine vegetation consists of mangroves (35%), rush/sedge (30%), saltwater paspalum (24%) and saltmarsh ribbonwood (8%). Small areas of seagrass (1.8%) occur in the margins of the lower estuary and in the upper estuary. Otahu Estuary was selected to be the first estuary in which shellfish populations and benthic habitats would be mapped by the Waikato Regional Council, partly because of its small size and easy accessibility compared to other Coromandel estuaries.

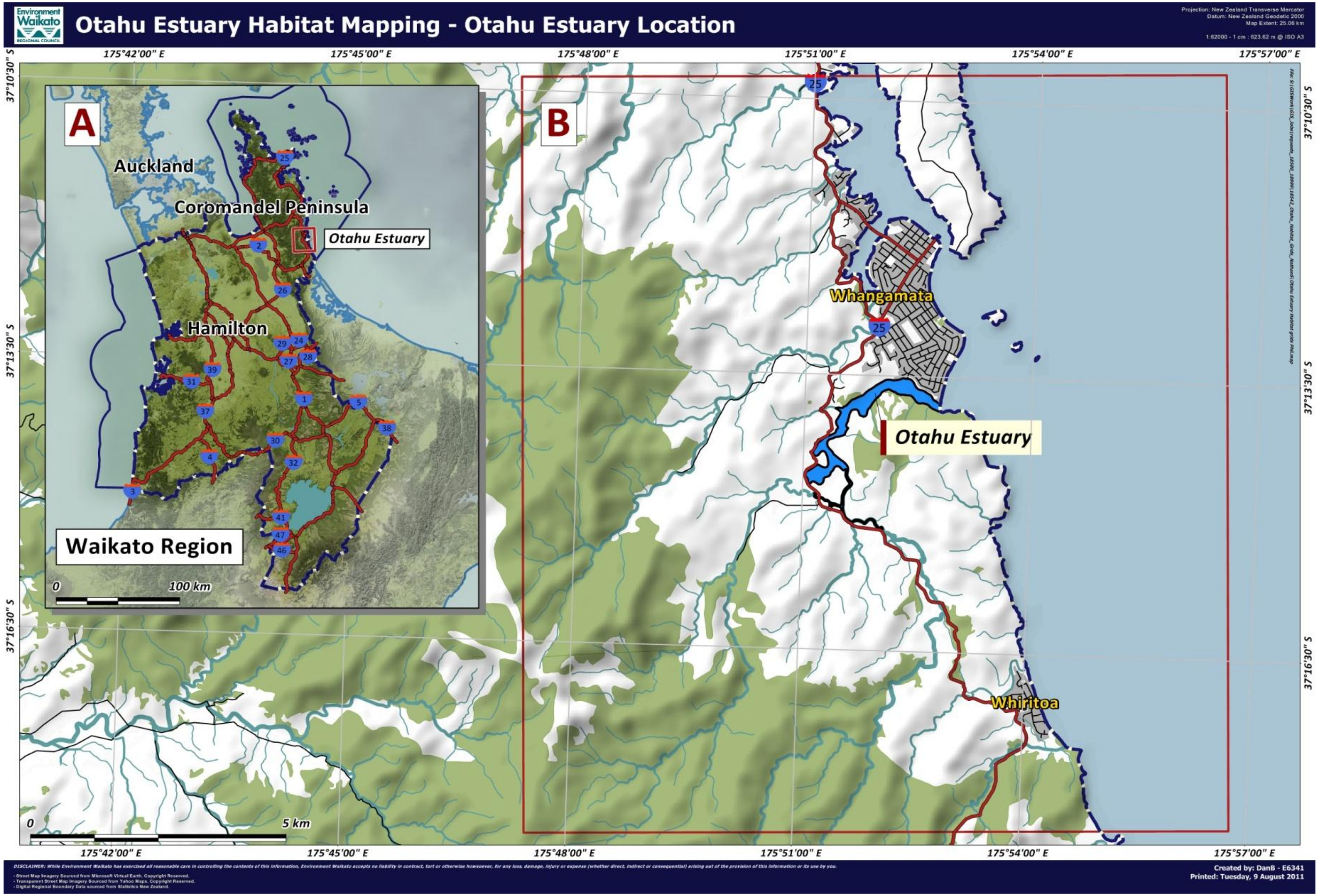

Figure 1: Maps of (A) the Waikato region and (B) south-eastern Coromandel indicating the location of Otahu Estuary.

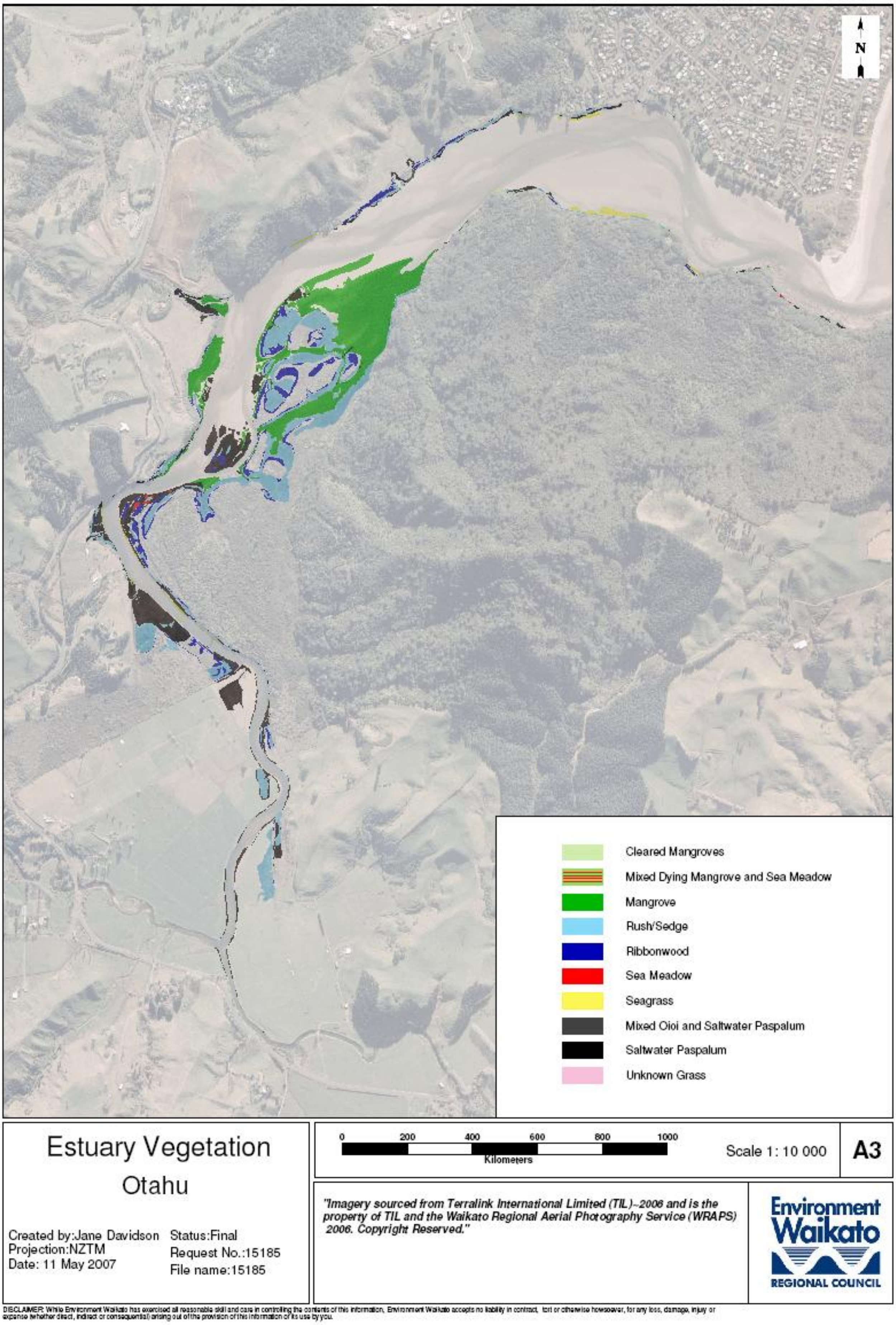

Figure 2: The distribution of estuarine vegetation in the Otahu Estuary (Graeme, 2007).

2 Methodology

2.1 Sampling sites

Shellfish and benthic habitat mapping was conducted in Otahu Estuary between January and June 2009. In the lower half of the estuary (sampled January to March 2009), transects were spaced at 100 m intervals perpendicular to the shore line (Appendix A). Benthic sampling was conducted at 20 m intervals along each transect. Fifty-five sites were sampled using this methodology. Where sampling points fell in subtidal channels their position was moved to the channel edge. This was done to ensure that *Paphies* populations, which often reach high densities along channel margins, were sampled.

Because sampling in the lower estuary took more time than anticipated, it was not possible to sample the upper estuary using the same spatial sampling protocol. Instead, benthic sampling was conducted at a further 29 sites (June 2009) spaced irregularly throughout the upper estuary (Appendix A).

At each sampling location, the following was documented:

- Characteristics of surface sediment (using substrate categories listed in Table 1);
- the approximate depth of the Redox Potential Discontinuity (RPD) layer which is an indication of sediment oxygenation;
- counts and size class classification of *Austrovenus*, *Paphies*, and *Macomona;*
- counts of epifauna including *Cominella*, *Zeacumantus* and *Diloma*; and
- vegetation type and substrate coverage.

2.2 Sediment characteristics

At each sampling location the surface sediment was described using the qualitative substrate classification of Robertson & Peters (2006) (Table 1). Note that the category 'firm mud / sand' from Robertson & Peters (2006) was not used in this survey.

At 14 randomly selected sampling locations, grain size distribution was determined. Three surface sediment grabs (2 cm sediment depth) were collected (approximately 1 m apart), combined into a single composite sample, returned to the lab and stored at -20°C. Sediment samples were later defrosted and pre-treated with 10% hydrogen peroxide to remove organic material. 1M HCl was used to remove carbonate material. Calgon was added as a dispersant and samples were placed in an ultrasonic bath for 10 minutes to aid disaggregation. Grain size distribution was then measured using a Malvern Mastersizer 2000 sediment analyser. These results were then compared to the substrate descriptions assigned to the locations where each sediment sample was collected to provide a comparison between the qualitative (substrate classification) and quantitative (grain size distribution) measures of sediment structure.

The depth where the sediment colour changed to a dark brown or black was recorded on a fresh vertical surface created by a spade cut through the sediment for each quadrat (following Robertson & Stevens, 2008). This measure can be used as a proxy for the RPD layer which indicates the depth at which sediment becomes anoxic. It is often the maximum depth at which many in-fauna will be found.

Table 1: **Surface sediment substrate classification (Robertson & Peters, 2006). The category 'firm mud / sand' was not used in this survey.**

Category	Description
Very soft mud / sand	A mix of mud and sand, surface brown and may have a black anoxic layer below. You will sink more than 5 cm
Soft mud / sand	A mix of mud and sand, surface appears brown and may have a black anoxic layer. You will sink 2-5 cm.
Soft sand	Contains over 99% sand. You will sink more than 2 cm
Firm sand	Will feel granular between your fingers; you will sink no more than 2 cm
Mobile sand	Granular sand that is rippled. You will sink less than 1 cm.
Shellbed	The surface is dominated by shell material
Gravel	Surface is dominated by gravel and cobble sized grains

2.3 Statistical analysis

All statistical analyses and associated visual display of data were carried out using STATISTICA (version 10, StatSoft Inc., www.statsoft.com). Statistical analyses were similar to those used by Felsing and Giles (2011) to examine data from the benthic shellfish and habitat mapping survey conducted in Tairua Harbour.

In order to determine whether the subjective substrate data provides an indication of sediment grain size, the substrate data were compared to the results from the grain size analysis for the 14 sampling points where both sets of data were available. For the purposes of this and following analyses, the grain size analysis data was grouped into the following grain size categories: mud (<63 um); fine sand (63-250 um); medium sand (250-500 um); coarse sand (500-1000 um); and very coarse sand (>1000 um) (following the Wentworth sediment classification). The data did not meet the required assumptions of parametric tests (homogeneity of variances and normal distribution). For this reason, the non-parametric Kruskal-Wallis test was used to test for differences in grain size data, abundance of shellfish, vegetation cover and RPD depth among different substrate categories. Post-hoc pairwise comparisons of mean ranks were done for significant results (at $\alpha<0.05$); p-values were adjusted using the Bonferroni correction.

2.4 Benthic biota

At each sampling location three 25 cm x 25 cm quadrats were randomly placed on the sediment surface. Within each quadrat counts were made of epifauna present (gastropods were identified to the genus level) and the area covered by macroalgae, microalgae or other vegetation (e.g. seagrass and mangroves) was recorded. The sediment within each quadrat was then excavated to a depth of 15 cm and sieved through a 0.5 mm mesh. All live bivalves were identified, measured and returned to the sediment close to where they were collected. Bivalves were then classified into one of the following size categories:

small:	0 – 15 mm
medium:	15 – 30 mm
large	> 30 mm

3 Results

3.1 Overview

Table 2 provides a summary of the survey results while the raw data is presented in Appendices B and C. Bivalves and gastropods were sampled from a total of 252 quadrats at 84 sites within Otahu Estuary. The substrate was categorised and vegetation described for each quadrat. A total of 17,457 individual organisms were counted, of which approximately 90% were bivalves. Firm sand was the dominant substrate type found at the sampling sites. Estuarine vegetation was recorded in less than 10% of the all quadrats. It is important to note that due to the irregular sampling site distribution, this does not reflect the proportional shellfish, substrate or vegetation distribution in Otahu Estuary.

Table 2: Overview and summary statistics for shellfish species, surface sediment categories and vegetation type recorded in Otahu Estuary. Variability of data is indicated by standard error (SE) in parentheses.

Species	**Percent of quadrats recorded in (%)**	**Total number sampled**	**Proportion in each size class (%)** Small (0-15 mm)	Medium (15-30 mm)	Large (>30 mm)	**Average density (m^{-2} ± SE)**
Bivalves						
Austrovenus stutchburyi (cockle)	71	13,411	71	28.8	0.2	851 (± 78)
Paphies australis (pipi)	60	1,759	89.6	9.9	0.5	112 (± 19)
Macomona liliana (wedge shell)	40	730	26.7	52.2	21.1	46.3 (± 5)
Total bivalves	**80**	**15,900**				**1010 (± 76)**
Gastropods						
Diloma sp.	19	99				6.3 (± 1.1)
Cominella sp.	46	304				19.3 (± 2.1)
Zeacumantus sp.	36	1,154				73.2 (± 24.7)
Total gastropods	**56**	**1,557**				**99 (± 25)**
Bivalves and gastropods	**81**	**17,457**				
Surface sediment						
Firm sand	59					
Soft sand	15					
Mobile sand	16					
Soft mud/sand	6					
Very soft mud/sand	4					
Vegetation type						
Seagrass	1.2					
Mangrove	6					
Ulva	1.2					
Algae	1.6					
Total vegetation	**9.9**					

3.2 Sediments

3.2.1 Subjective substrate classification

Firm sand, mobile sand, soft sand, soft mud/sand and very soft mud/sand were recorded at sampling site within Otahu Estuary (Figure 4). Firm sand was predominantly found in the lower portion of the estuary (Table 2 and Figure 4). Mobile sand (16%) and soft sand (15%) were the next most frequently recorded substrate types. Soft sand was for the most part reported in the middle to upper estuary, while mobile sand was reported near to the estuary mouth and at channel edge sites in the middle and upper estuary. The upper estuary contained the greatest diversity of substrate types with soft and very soft mud/sand reported in close proximity to areas of soft, firm and mobile sands. Soft mud/sand and very soft mud/sand were, with the exception of a single site, restricted to the upper estuary and generally occurred around the edges of the estuary in close proximity to mangroves.

3.2.2 Comparisons between substrate categories and grain size

The use of a subjective descriptive method to classify sediments is a potential alternative to costly grain size analysis if it can be shown to provide a consistent and meaningful description of surface sediments. The qualitative substrate results were compared with the results from 14 sites at which quantitative grain size analysis had been conducted (Figure 3). Due to the small number of samples, statistical analysis was not considered appropriate and, instead, only visual comparisons were made. Substrates classified as mobile sand were for the most part distinguishable from other substrates based on their grain size composition, in particular through the presence of substantial gravel and coarse sand fractions. In contrast, clear differences in sediment size fractions were not evident for other substrate types. Firm sand, soft sand and soft mud/sand substrate sediment samples contained substantial fractions of medium sand, fine sand and mud. The proportions of these sediment fractions were similar among the three substrate types. No grain size data were available from sites categorised as very soft mud / sand.

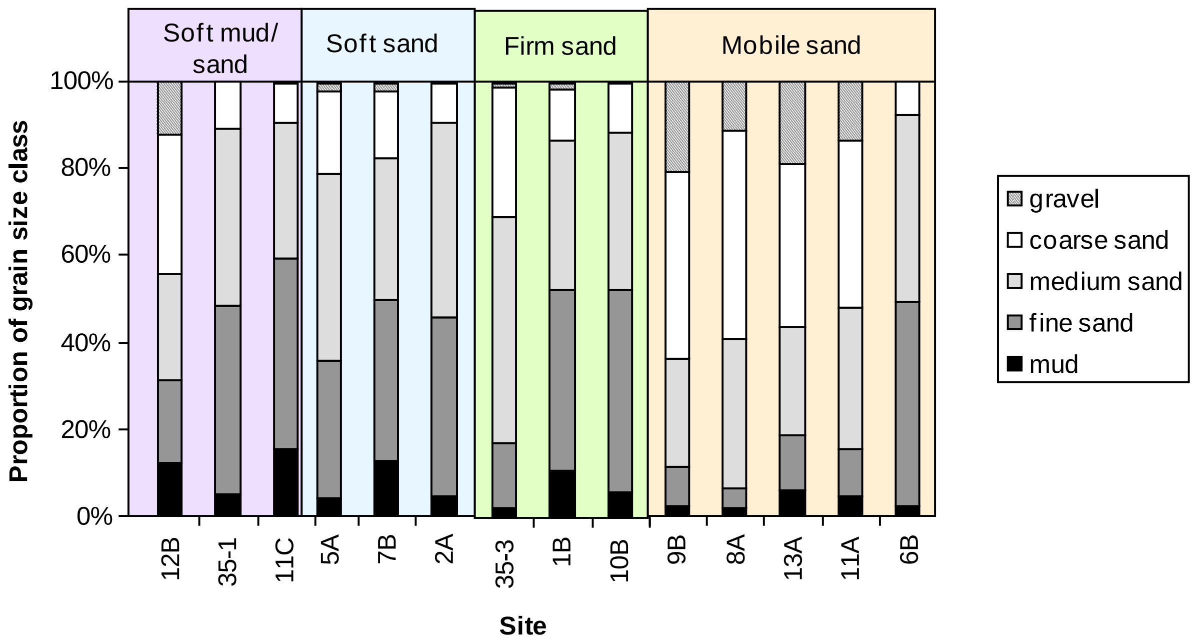

Figure 3: Grain size distribution of surface sediment samples in Otahu Estuary. Samples are grouped according to the qualitative substrate classifications designated in the field.

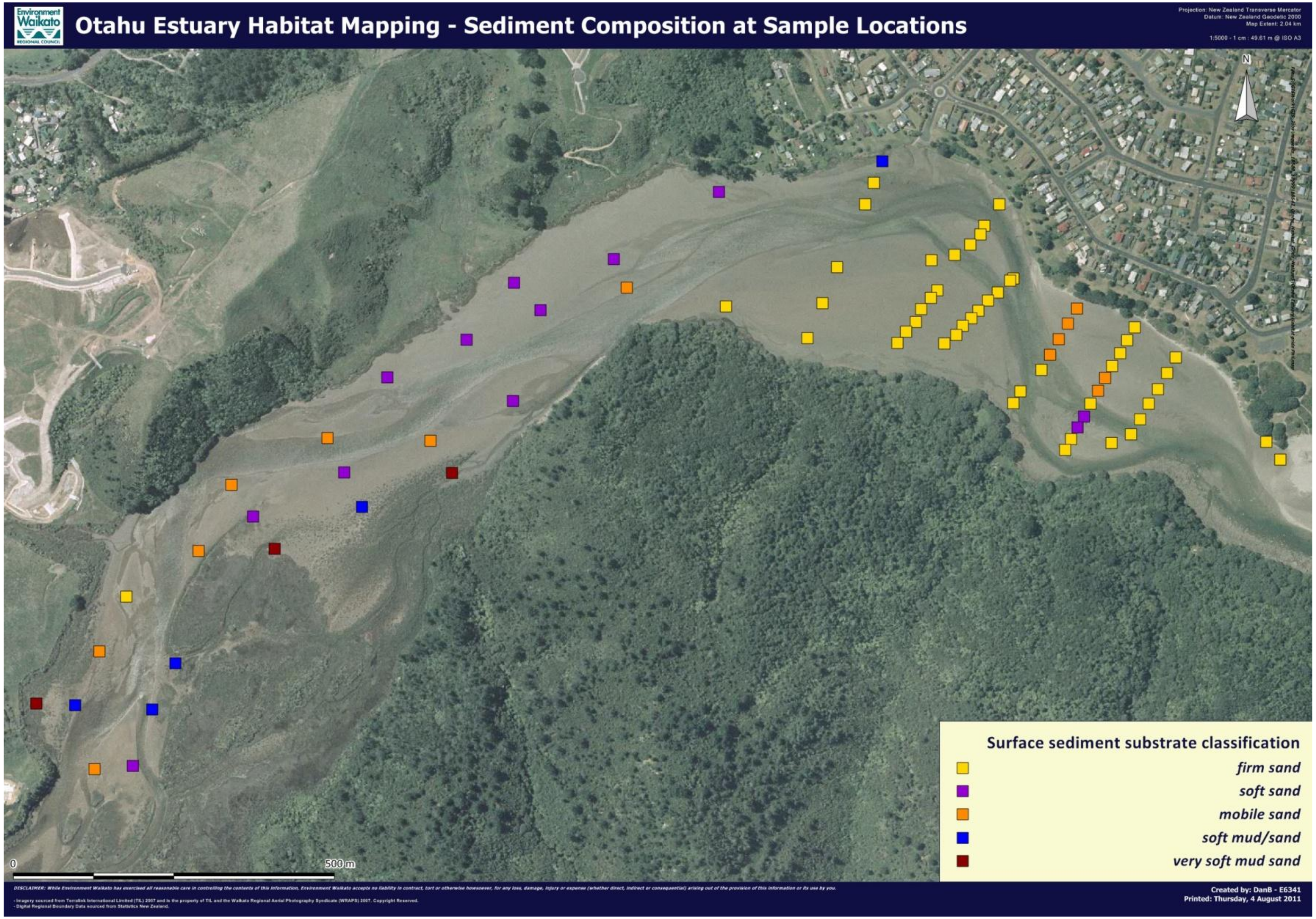

Figure 4: Classification of surface sediments at sampling locations in Otahu Estuary. Squares indicate sampling locations and the square colour indicates surface sediment substrate category as described in Table 1.

3.2.3 Comparison of subjective substrate categories with Redox Potential Discontinuity (RPD) layer depth

The depth of the RPD layer at sampled locations ranged from 0 to greater than 10 cm (Figure 6). In general, RPD layer depth was greater near the mouth of the estuary and around the lower and upper estuary channel edges. RPD layers were generally shallower through the middle reaches of the estuary and the edges of the lower estuary. There was no consistent relationship between RPD layer depth and substrate categories (Figure 5). At all sites categorised as 'very soft mud / sand' the RPD layer could not be identified.

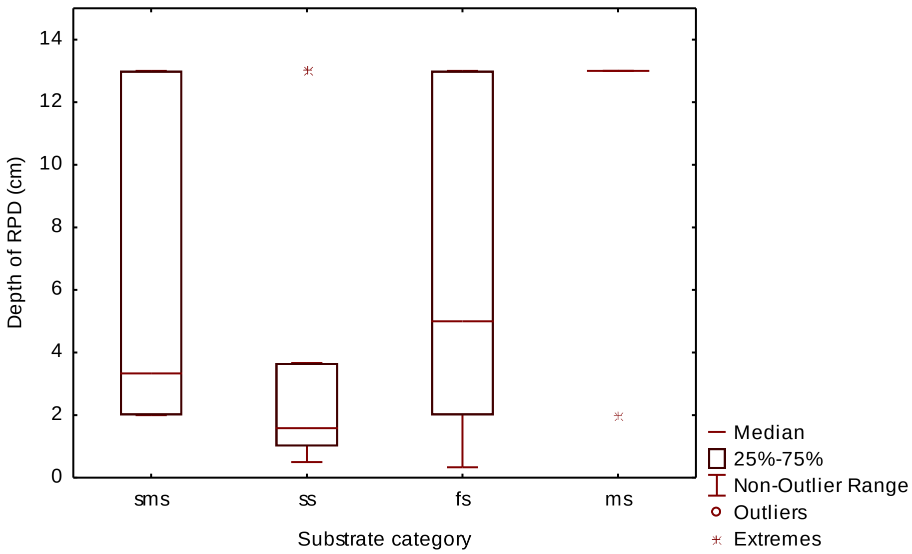

Figure 5: Boxplot[1] showing approximate depth of the Redox Potential Discontinuity (RPD) layer of sites classified into different substrate categories. Note: At some sites the RPD layer depth could not be determined; this includes all sites categorised as 'very soft mud / sand'.

[1] Boxplot: Lower and upper hinges represent 25th and 75th percentiles, respectively; the line across the box denotes the median; the ends of the vertical lines indicate the minimum and maximum data values, unless outliers are present in which case the whiskers extend to a maximum of 1.5 times the inter-quartile range; the points outside the ends of the whiskers are outliers or suspected outliers.

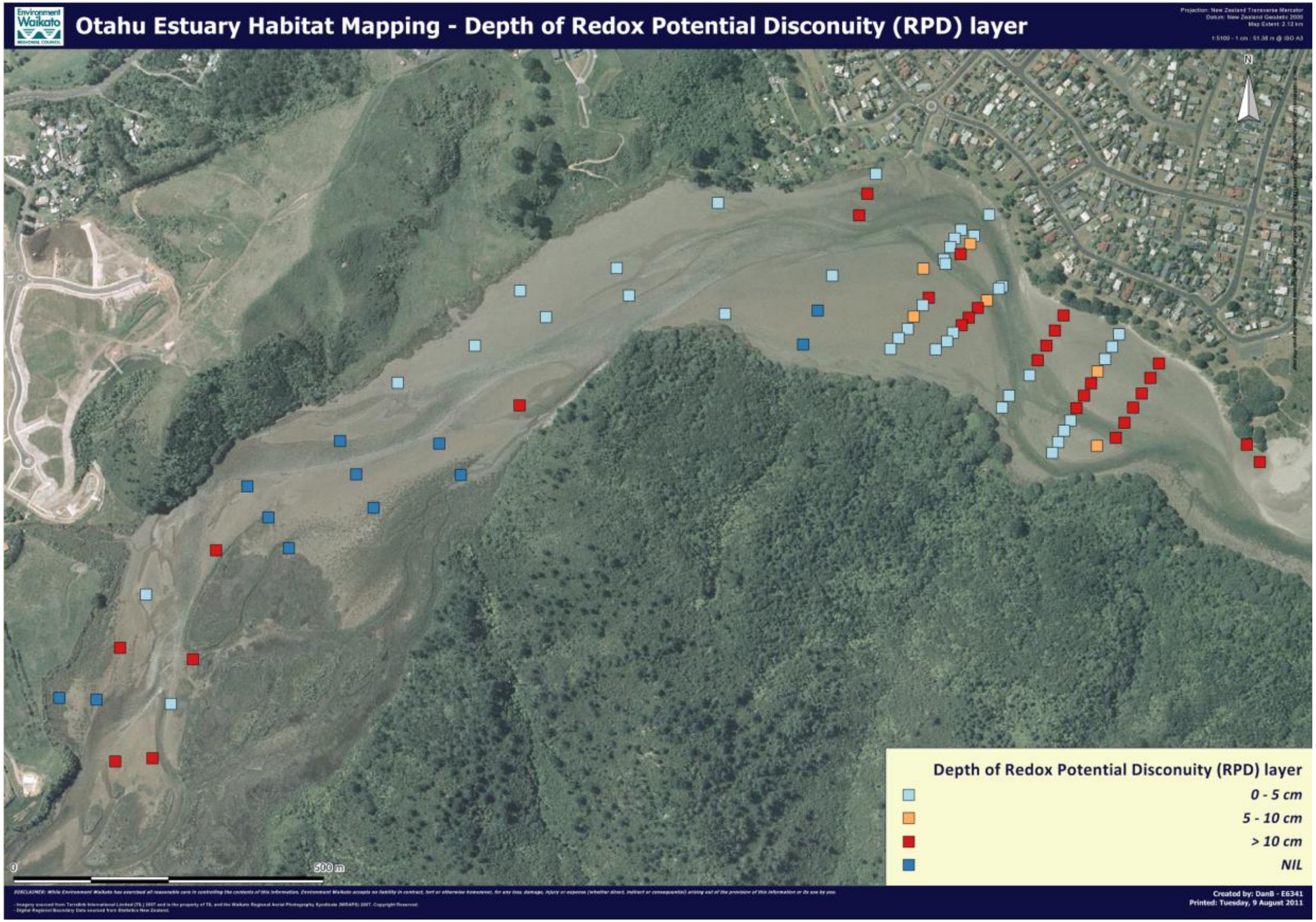

Figure 6: Redox Potential Discontinuity (RPD) layer depth at sampling locations in Otahu Estuary. At sites where the RPD layer depth is shown as NIL the RPD layer depth could not be established.

3.3 Bivalves

3.3.1 Abundance and spatial distribution

Bivalves were numerically more dominant than gastropod species (with 15,900 individuals sampled compared with 1,557 gastropods).

Austrovenus were the most abundant bivalves at the sampling sites with an average density of 851 individuals/m^2 (Table 2, Figure 7). In total 13,411 *Austrovenus* were recorded and they were found in 71% of quadrats. *Austrovenus* were found throughout the estuary near subtidal channels and on intertidal sandflats but were absent from the majority of the uppermost sampling locations and within the lower channel and northern flats towards the estuary mouth (Figure 8). Highest *Austrovenus* densities were recorded on sandflats in the lower region of the estuary (4533 m^{-2}), followed by the southern shore toward the estuary mouth (3248 m^{-2}).

Paphies were the second most abundant bivalves at the sampling sites with an average density of 112 individuals/m^2 (Table 2). A total of 1759 individuals were recorded at 60% of the sampling sites. Although most abundant near subtidal channels of the upper and lower estuary, *Paphies* were also found in smaller numbers on sand flats away from channel areas (

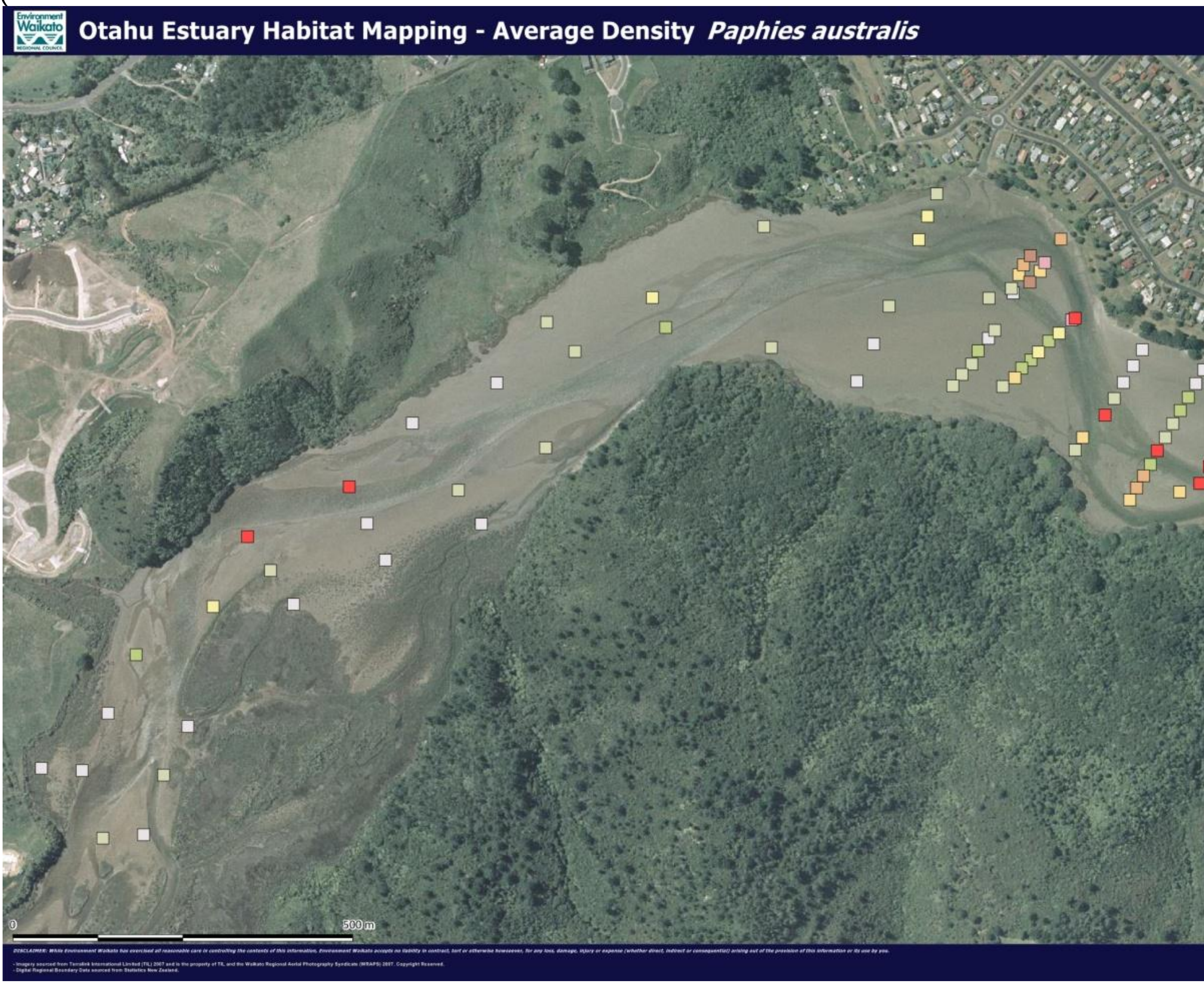

Figure 9). Highest densities of *Paphies* were found at channel edge sites near the estuary mouth (2203 m^{-2}) and adjacent to channels on the northern shore of the upper estuary (517 m^{-2}).

Macomona liliana was the least abundant of the three bivalve species surveyed with an average density of 46.3 individuals/m^2 (Table 2). They were found at 40% of the sampled locations and in total 730 individuals were recorded. *Macomona* occurred both on sand flats and near channels, scattered mainly within the middle and lower estuary (Figure 10). The highest density of Macomona was 368 individuals/m^2 on the flats in the middle harbour.

Bivalves were counted in three replicate quadrats at each sampling site. The intra-site variability of bivalve densities (as standard deviations) is shown in Figure D-1 (Appendix D).

3.3.2 Size class distribution

The majority of *Austrovenus* and *Paphies* recorded were classified as small (71% and 90% respectively, Table 2). Small and medium *Austrovenus* were found throughout the estuary, except for a few places at the estuary mouth and the very upper estuary. Large individuals were rare (0.2% of total samples) and were found close to subtidal channels (Figure 11). Small Paphies were found throughout the estuary, while medium (9.9%) and large (0.5%) sized *Paphies* were predominantly recorded in the lower estuary (Figure 12).

The population structure of *Macomona* was somewhat different to that of *Austrovenus* and *Paphies*. For *Macomona*, medium sized individuals were the most abundant size class (52%), while small and large individuals accounted for 27% and 21% respectively (Table 2). *Macomona* were largely absent from the upper estuary but all size classes were found scattered throughout the middle and lower estuary (Figure 13).

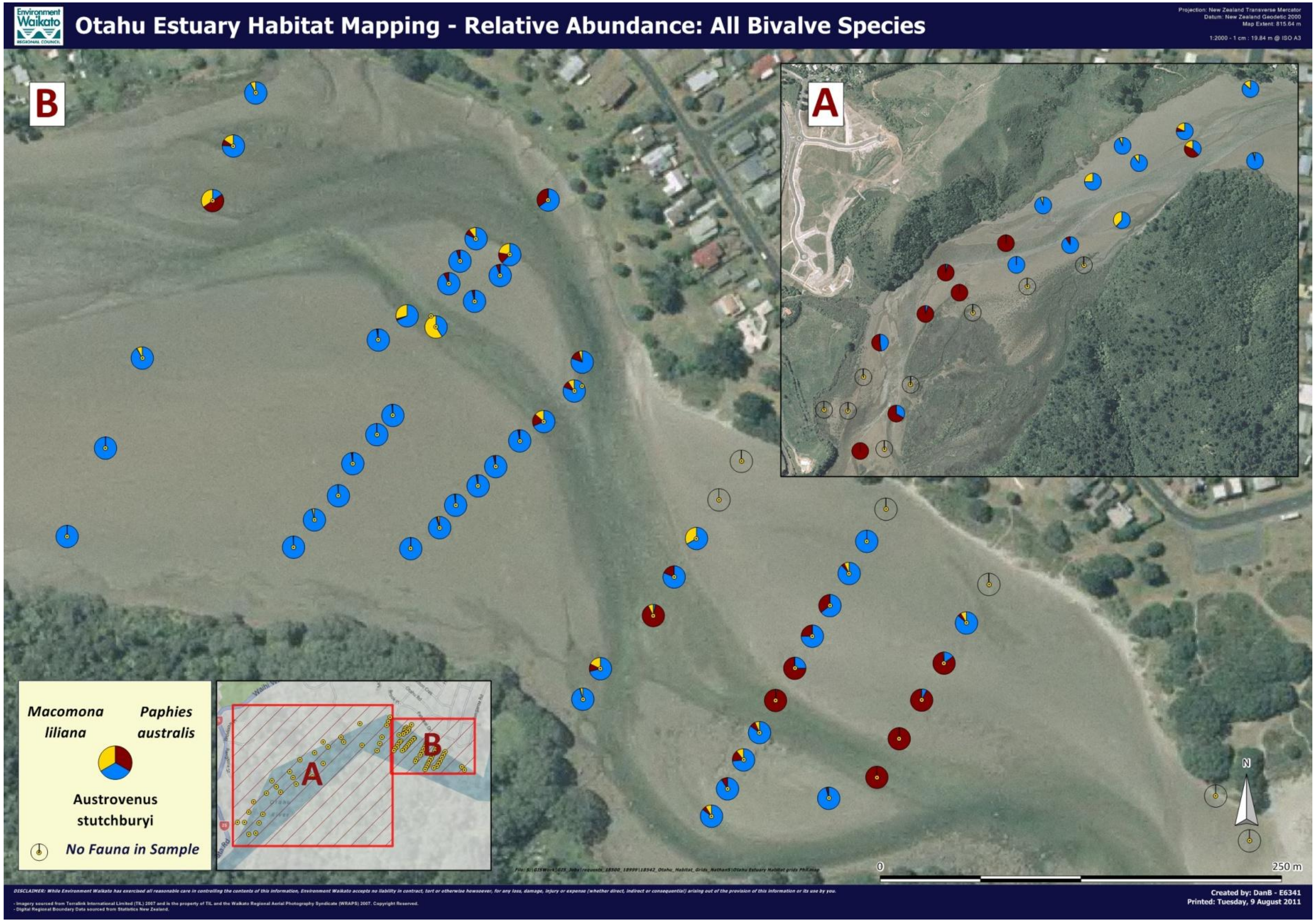

Figure 7: The relative abundance of the bivalves *Austrovenus* (cockle), *Paphies* (pipi) and *Macomona* (wedge shell) at sampling locations in Otahu Estuary.

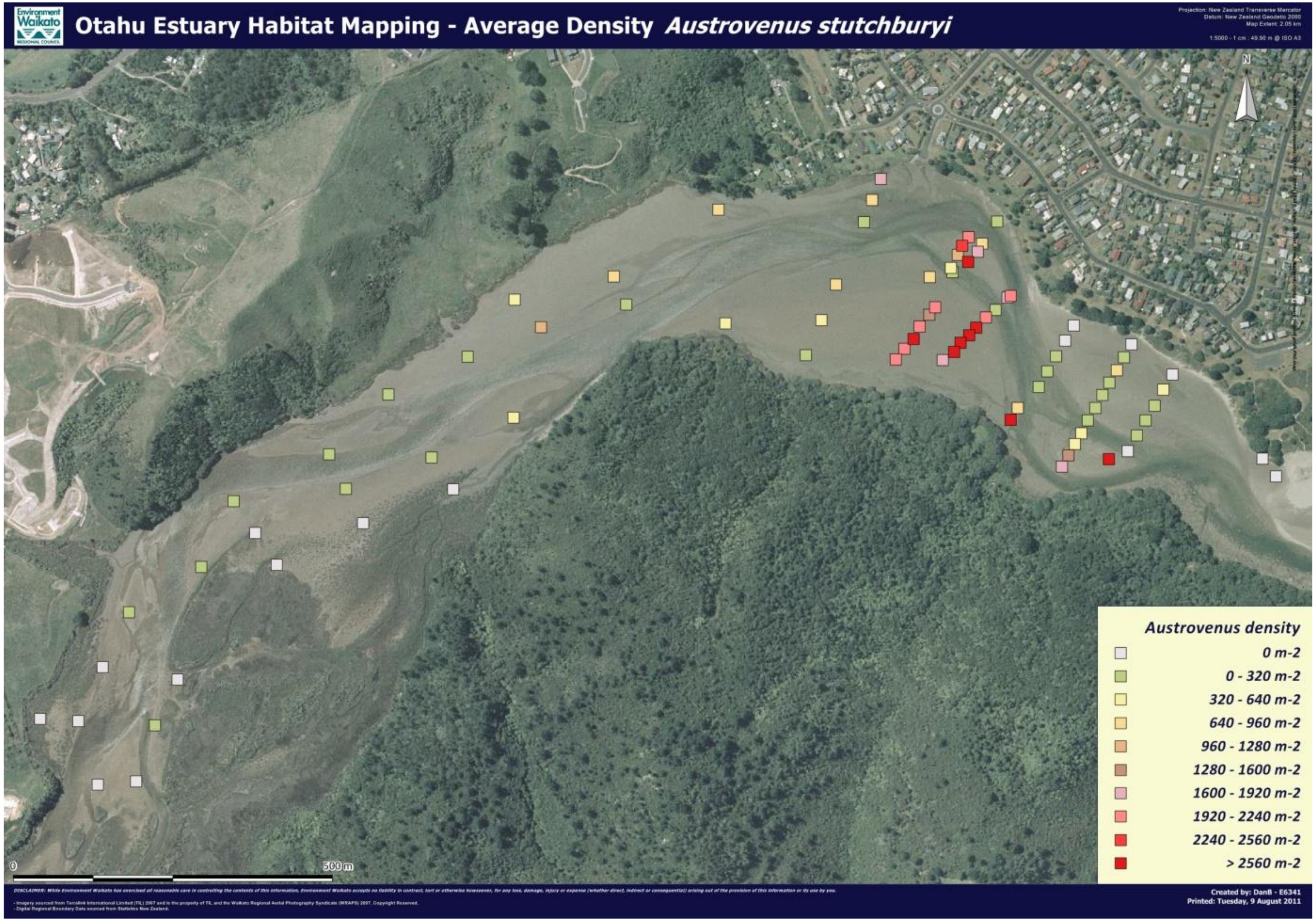

Figure 8: Density of *Austrovenus stutchburyi* (cockles) at sampled locations in Otahu Estuary.

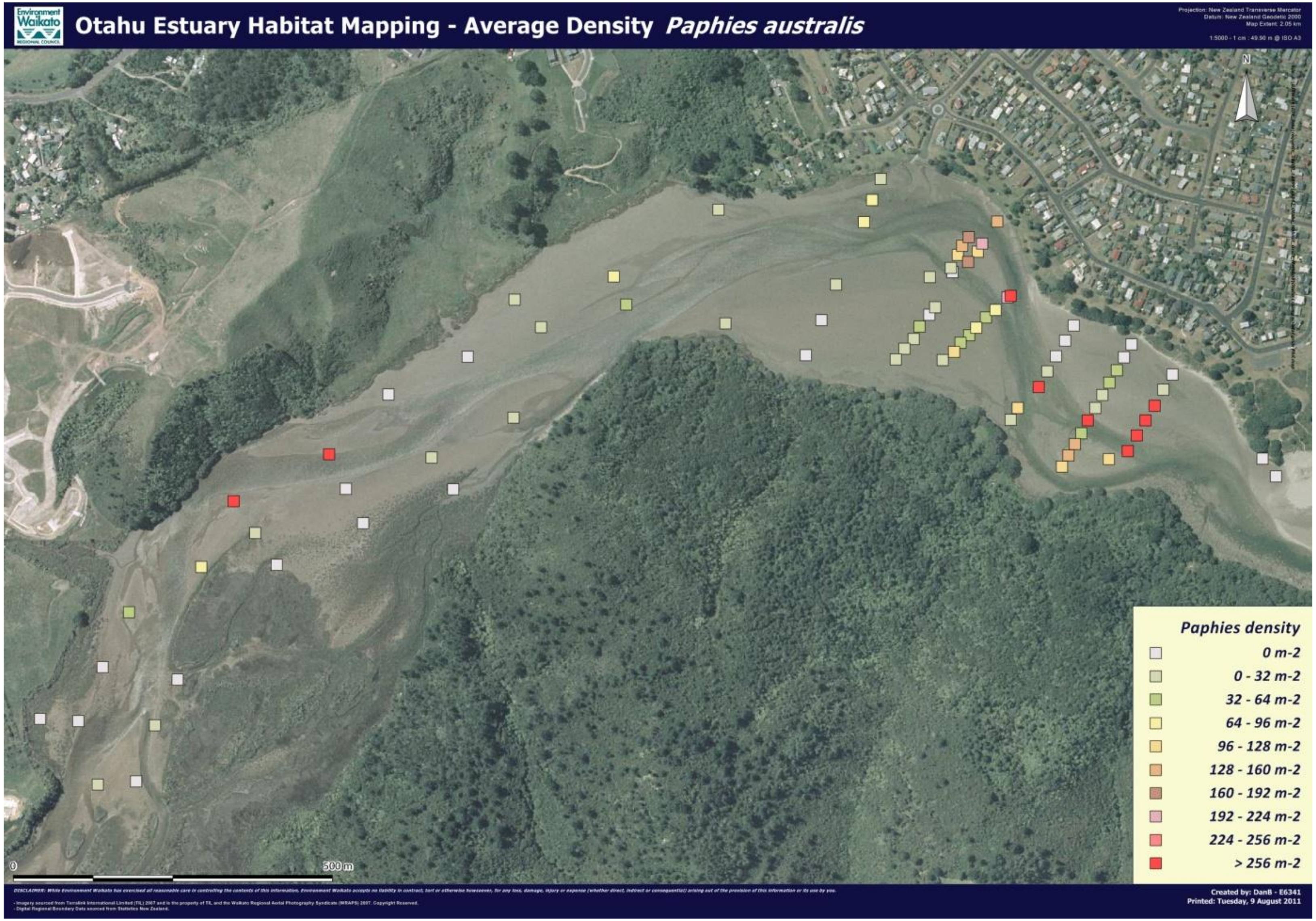

Figure 9: Density of *Paphies australis* (pipi) at sampled locations in Otahu Estuary.

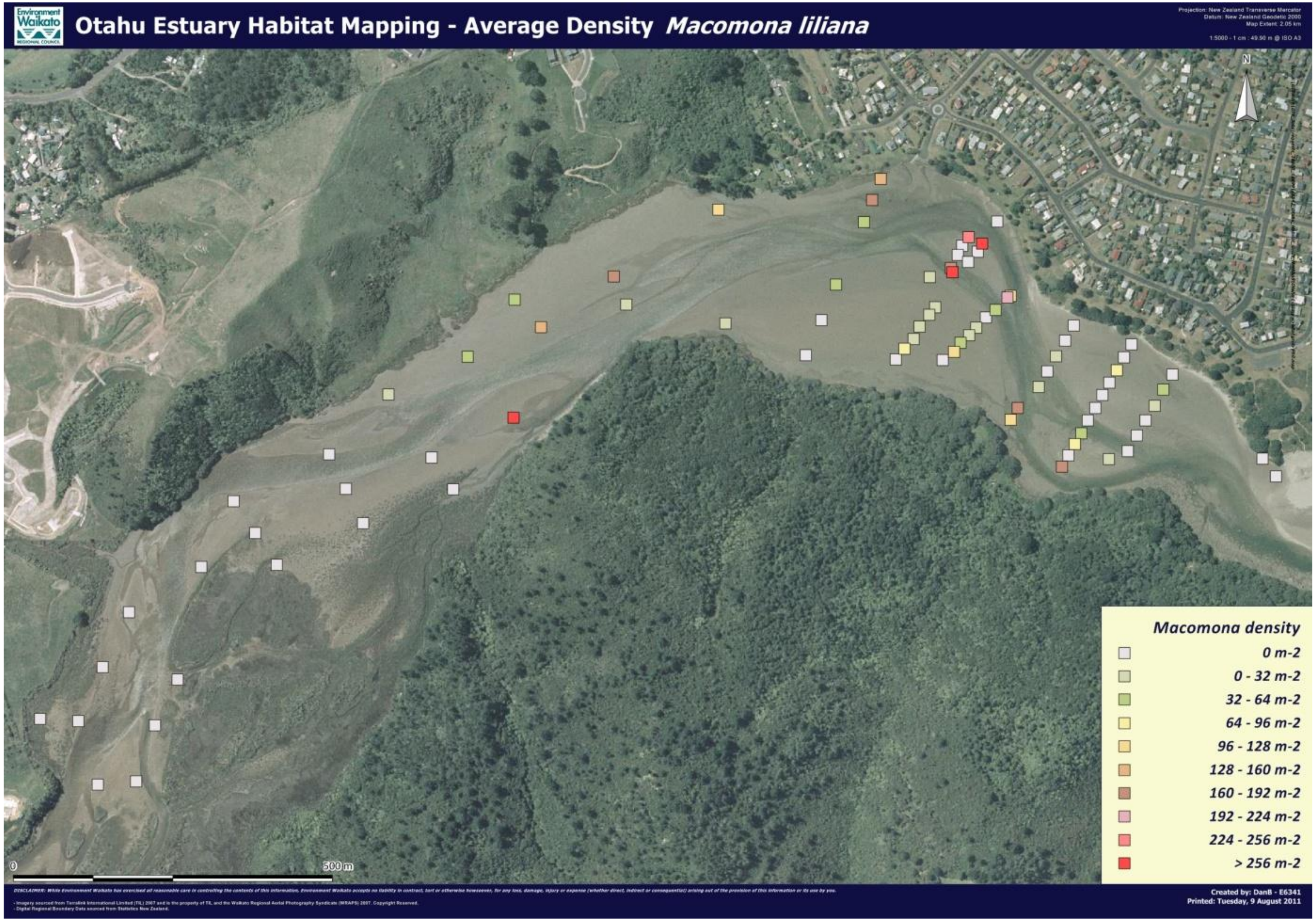

Figure 10: Density of *Macomona liliana* (wedge shells) at sampled locations in Otahu Estuary.

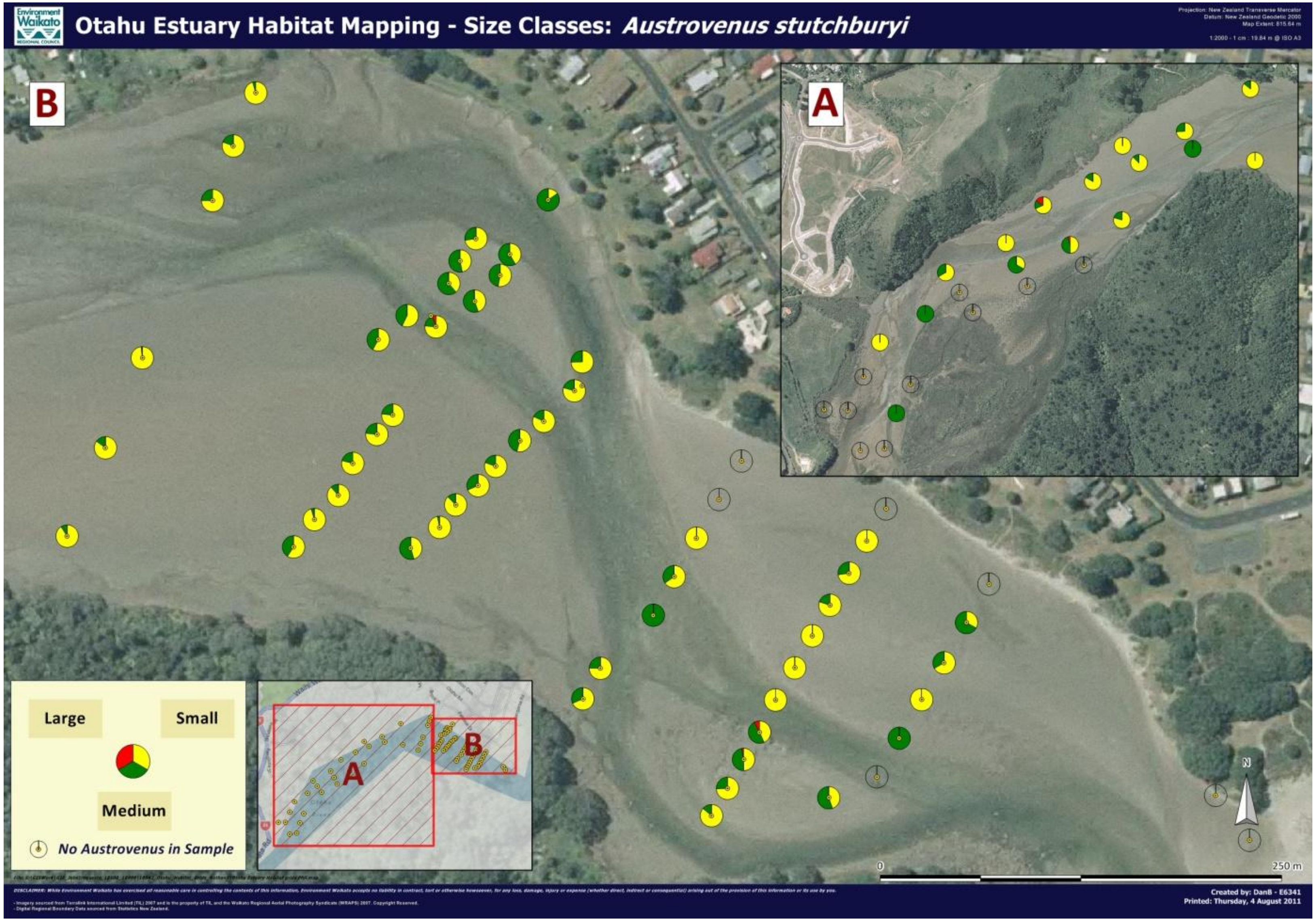

Figure 11: Relative abundance of small, medium and large *Austrovenus stutchburyi* (cockles) at sampling locations in Otahu Estuary.

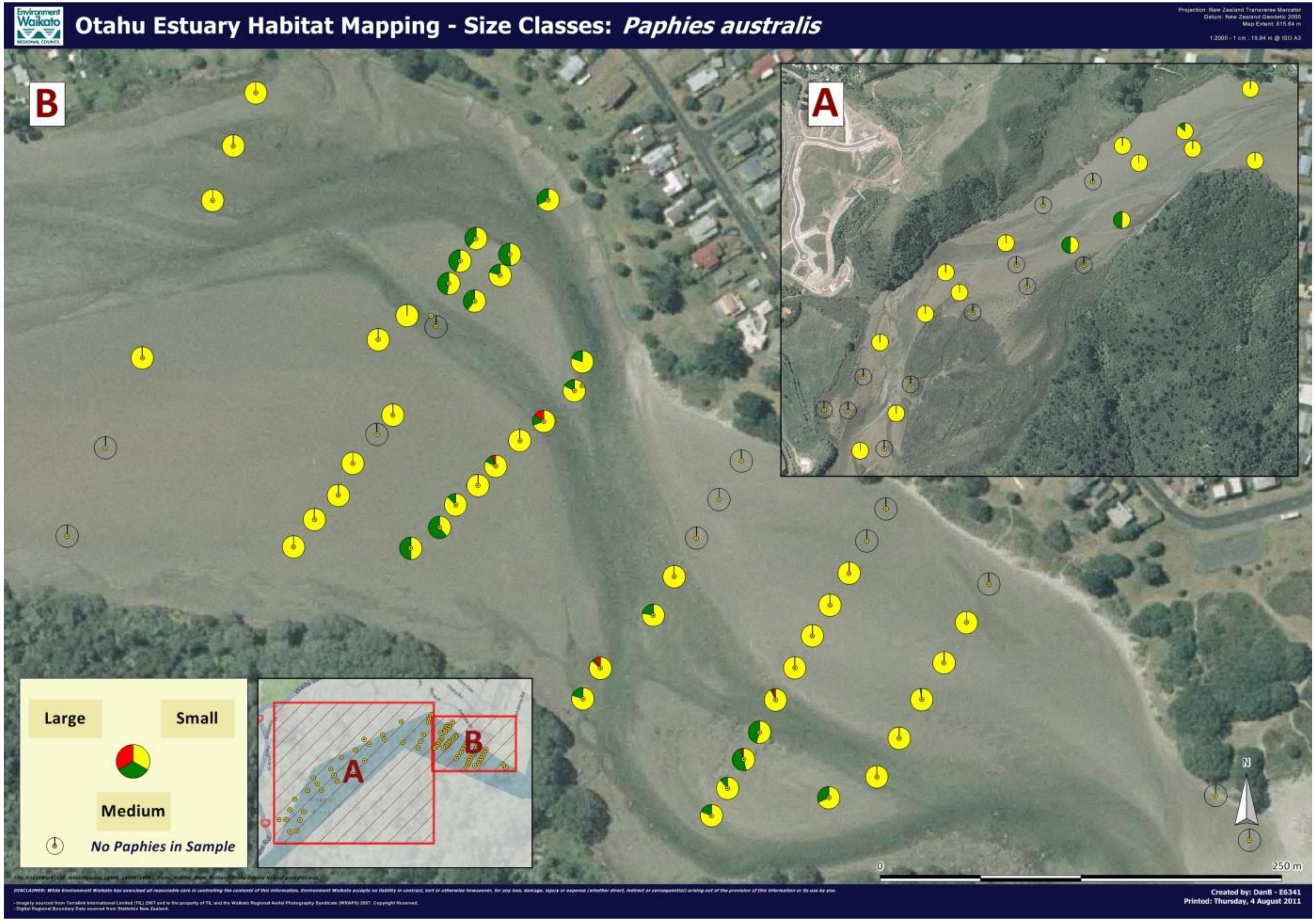

Figure 12: Relative abundance of small, medium and large *Paphies australis* (pipi) at sampling locations in Otahu Estuary.

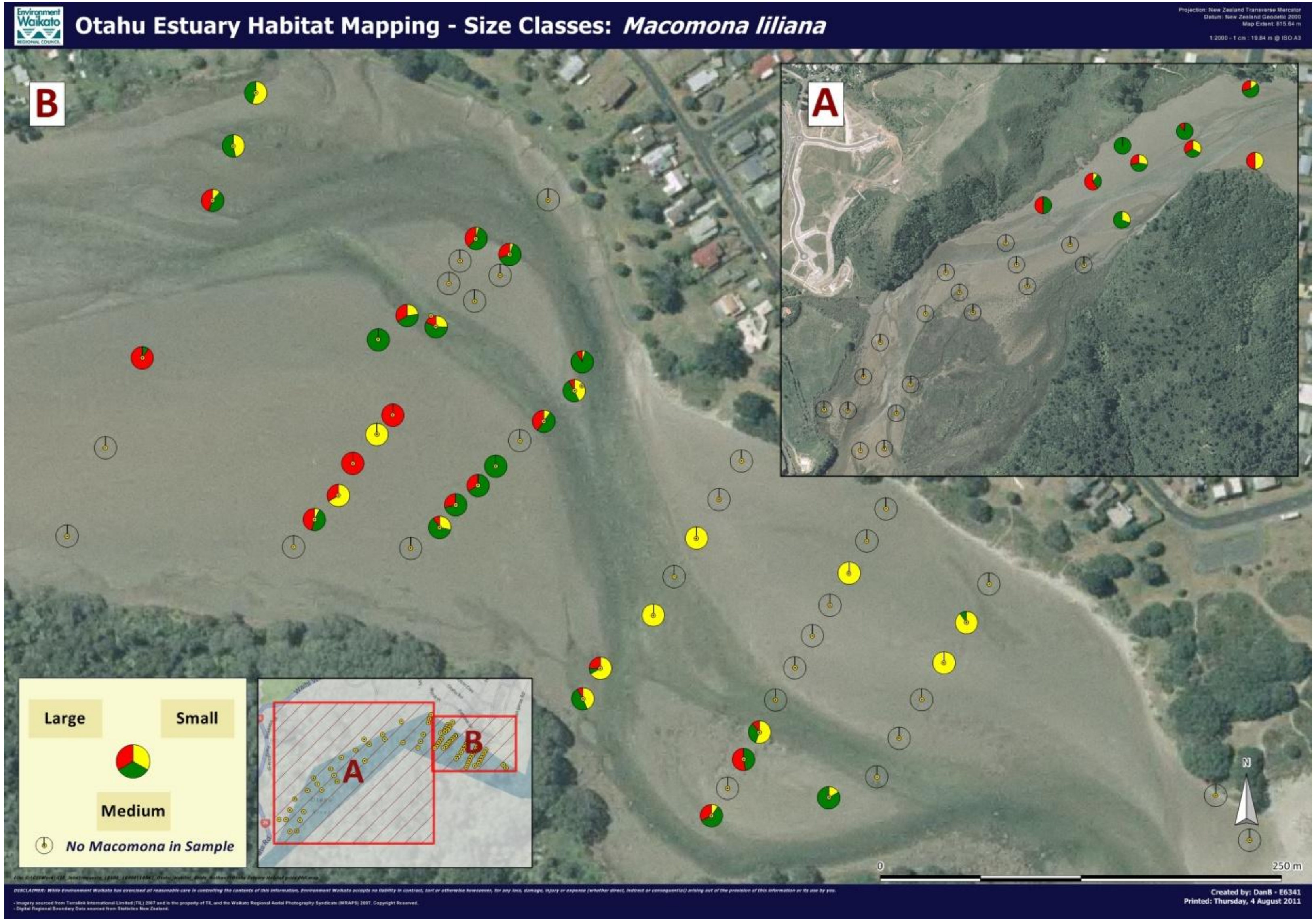

Figure 13: Relative abundance of small, medium and large *Macomona liliana* (wedge shells) at sampling locations in Otahu Estuary.

3.4 Gastropods

The three most abundant gastropod genus at the sampling sites were *Diloma* spp., *Cominella* spp. and *Zeacumantus* spp. A total of 1557 gastropods were recorded at an average density of 99 m^{-2} (Table 2).

Zeacumantus were most abundant (average density 73.2 m^{-2}; Table 2) but were recorded at fewer sampling locations than *Cominella* (average density 19.3 m^{-2}). *Diloma* were recorded at much lower densities (6.3 m^{-2}) and in the least sampling locations. There was some variation in the spatial distribution of each taxon. For example, *Zeacumantus* were most abundant in the middle portion of the estuary but confined to the southern side of the lower estuary; *Cominella* were commonly the dominant genus of gastropod in the lower estuary but were more scattered in the middle of the estuary; while *Diloma* were recorded in low densities in the middle and lower portions of the estuary. No gastropods were recorded in the upper estuary except *Cominella* and *Diloma* at one location each (Figure 14).

3.5 Vegetation

As this survey focussed on intertidal sand flats rather than the more densely vegetated estuarine fringe, estuarine vegetation was only recorded at ten sites. Where vegetation was reported during this survey, it was predominantly mangrove pneumatophores or seedlings in the upper estuary (five sites), and algae (three sites), ulva (one site) and seagrass (one site) in the lower estuary. Of the few vegetated sites sampled, the seagrass, algae and ulva of the open flats had all three bivalve species present and often also all three gastropod species. Only *Cominella* was recorded associated with mangrove pneumatophores. More detailed information on the intertidal vegetation was obtained in a previous vegetation survey of Otahu Estuary (Graeme, 2007, Figure 2).

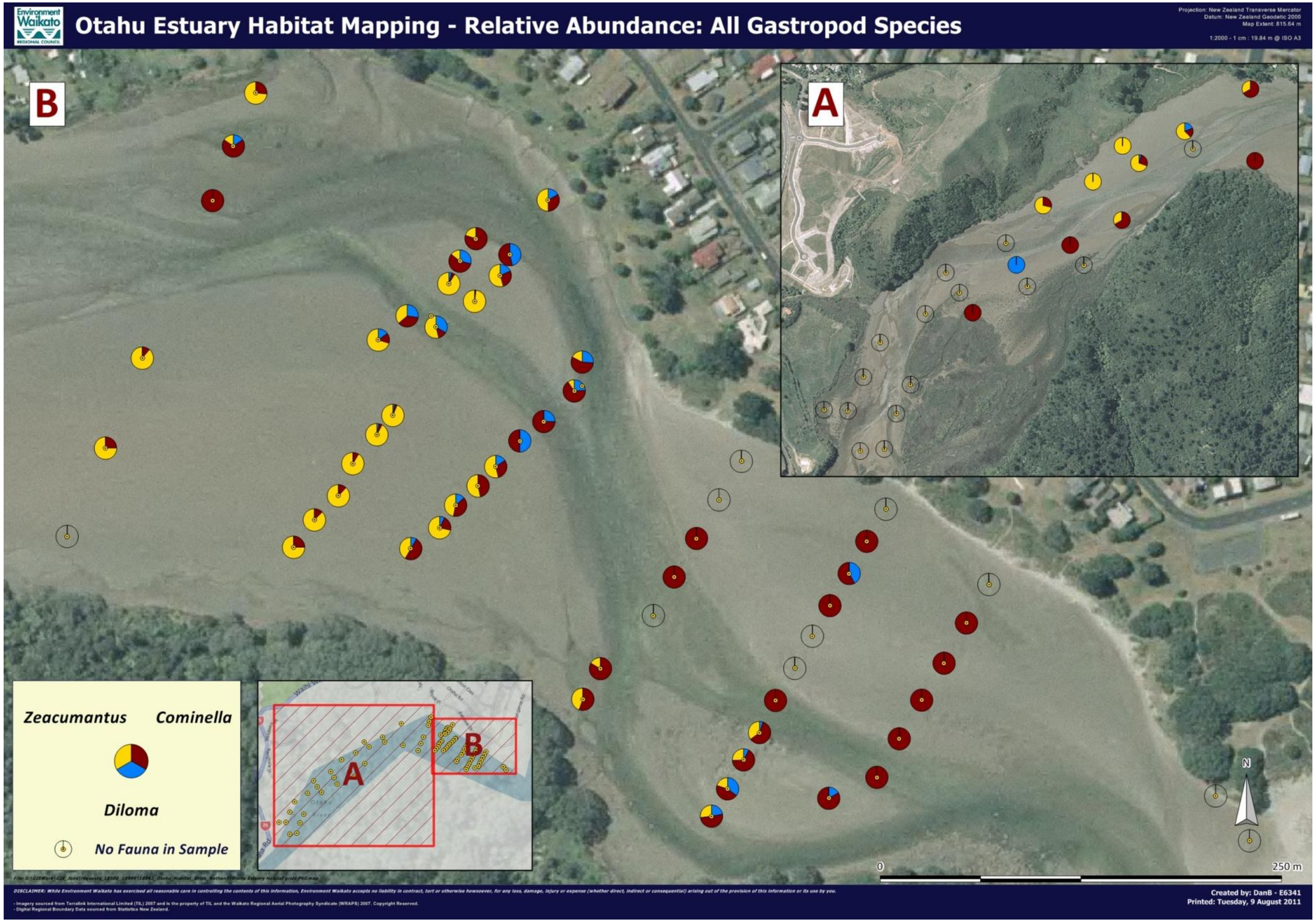

Figure 14: Relative abundance of the gastropods *Cominella*, *Zeacumantus* and *Diloma* at sampling locations in Otahu Estuary.

3.6 Relationship between bivalve density and sediment properties

No bivalves were found at the three sites categorised as ‘very soft mud / sand’ (Figure 15). All species were found at the remaining sites but densities differed substantially.

Austrovenus were mainly found at sites classified as ‘firm sand’ or ‘soft sand’ (Figure 15). At these sites the median abundances were 827 and 595 per m^2, respectively, and the maximum numbers of *Austrovenus* found were 4533 and 1269 per m^2, respectively. The median number of *Austrovenus* was much lower at sites classified as ‘soft mud / sand’ and ‘mobile sand’ (3 and 5 per m^2, respectively). Despite the low median, maximum densities at ‘soft mud / sand’ sites were occasionally high, reaching up to 1803 per m^2.

Macomona were found at similarly high maximum densities at sites classified as ‘soft sand’ and ‘firm sand’ (304 and 368 per m^2) but median densities were about ten times higher at ‘soft sand’ sites (51 compared to 5 per m^2). Median densities were zero at sites categorised as ‘soft mud / sand’ and ‘mobile sand’; however, maximum abundances reached 155 per m2 at the ‘soft mud / sand’ sites.

Paphies were most abundant at sites categorised as ‘firm sand’ with a maximum of 2203 per m^2 and a median of 53 per m^2. Maximum and median abundances decreased by approximately a quarter at sites categorised as ‘mobile sand’ (maximum of 517 and median of 16 per m^2), and ‘soft sand’ (maximum of 139 and median of 5 per m^2). Abundances were very low at sites categorised as ‘soft mud / sand’ (maximum of 11 and median of 3 per m^2).

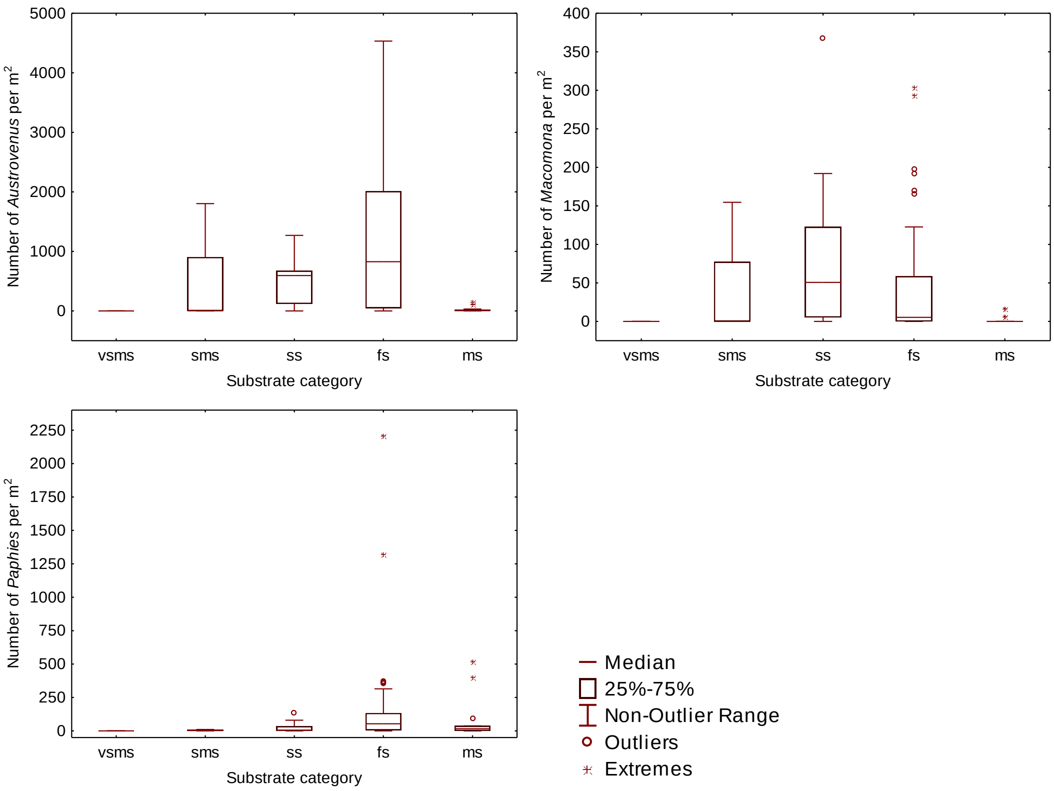

Figure 15: Boxplot showing the abundance of cockles (*Austrovenus stutchburyi*), wedge shells (*Macomona liliana*) and pipi (*Paphies australis*) at sites classified into different substrate categories. Substrate categories: VSMS = Very soft mud / sand, SMS = Soft mud / sand, SS = Soft sand, FS = Firm sand; MS = Mobile sand.

4 Summary and discussion

The Otahu Estuary shellfish and habitat mapping survey produced approximate maps of the distribution and abundances of *Austrovenus stutchburyi* (cockles), *Macomona liliana* (wedge shells) and *Paphies australis* (pipi) as well as common gastropod distribution, sediment type and vegetation cover of open intertidal flats.

4.1 Sediments

The substrate mapping conducted as part of this survey produced substrate maps of Otahu Estuary based on subjective substrate categories. These maps illustrate localised differences in substrate type. As expected, coarser substrate (mobile sand) was found in areas of high water velocity such as around the mouth of the estuary and at channel edges. The remaining substrate categories could not be distinguished in regards to their grain size distribution and therefore interpretations of their distribution throughout the estuary need to be approached with caution. No grain size data were available for sites categorised as 'very soft mud / sand'. The three sites that fell into this category are located in sheltered areas close to mangroves. It is likely that this category does reflect a higher mud content of the sediment but this could not be confirmed from the data gathered in this survey.

The poor correlation between the subjective substrate categories and grain size distribution is disappointing. Two factors have likely contributed to the poor correlations, which must be addressed before any further surveys are conducted:

- Variability in substrate classification by field workers has been identified as a possible source of error in this survey. Future survey must be preceded by a calibration session led by an experienced staff member as this would reduce the likelihood of significant inter-observer variation.

- The substrate categories might not be suitable for Waikato estuaries and should be critically assessed prior to any further habitat mapping surveys. Substrate characteristics are impacted by the presence and activities of biota and therefore might need to be described by a wider range of attributes than solely those relating to sediment grain size, shell material, and the presence of anoxic sediment.

Benthic habitat mapping conducted by the Waikato Regional Council in other estuaries since the 2009 Otahu sampling has also raised questions about the suitability of the substrate classes for classifying surface sediments in Waikato estuaries (Felsing & Giles, 2011; Graeme & Giles, 2013). In particular, recent surveys of Coromandel estuaries indicated that broader categories are required to better differentiate among the various types of surface substrate that occur in Coromandel estuaries (Needham et al., 2013).

4.2 Bivalves

As the spatial resolution of sampling in the upper estuary was less than that of the lower estuary, extrapolations of results to the whole estuary have to be made with caution. It is recommended that future sampling use a regular grid to locate sampling points evenly over open intertidal flats to obtain more accurate distributions of *Austrovenus* and *Macomona*. However, a regular sampling technique could potentially severely underestimate *Paphies* populations as *Paphies* are most abundant in and adjacent to subtidal channels. In the present survey we did not sample subtidal regions and only sampled the margins of intertidal channels when sampling points fell by chance either in or adjacent to subtidal channels. It is therefore likely that we have underestimated the distribution of *Paphies* populations in Otahu Estuary. We suggest that future bivalve surveys identifying the distribution and abundance of intertidal

Paphies should incorporate a specific channel margin sampling protocol whereby sampling points are located every 150 m either side of the main subtidal channels (in line with the recommendation by Felsing & Giles, 2011). This will help give an indication of where subtidal *Paphies* beds are and provide useful data should more in-depth *Paphies* monitoring be undertaken.

Austrovenus was the most abundant bivalve sampled, with the majority of the individuals being within the small size class (range). *Paphies* similarly had a large proportion of individuals in the small size class. It is possible that selective harvesting of larger *Austrovenus* and *Paphies* individuals might explain the rarity with which we observed medium (29% *Austrovenus*; 10% *Paphies*) and large (0.2%; 0.5%) sized individuals in the samples. However, *Austrovenus* and *Paphies* populations exhibit natural inter-annual variability resulting in good recruitment years. This is reflected as large size cohorts (i.e. large numbers of individuals in limited size classes) within a population. The size distribution of *Paphies* followed findings of other studies with the large adults favouring exposed areas such as sandbanks in the middle of the estuary or near the estuary's mouth, while juvenile *Paphies* are often found further up the estuary. The spatial distribution of *Macomona* was similar to that of *Austrovenus*; however, *Macomona* had a more even presence of all three size classes. Small, medium and large individuals were found throughout the middle and lower estuary except for the northern lower flats which had a predominance of small *Macomona.*

In this survey bivalves were assigned to three predetermined size classes (small, medium and large). As 71% of *Austrovenus* and 90% of *Paphies* sampled were classified as small, it appears prudent to reconsider the delineation between these size classes. It is preferable to collect high resolution data in the field and then group data (thereby reducing resolution) during analysis where necessary. We suggest that the classification of bivalves to 5 mm size classes (e.g. 0-5 mm, 5-10 mm, 10-15 mm, etc) would provide a better indication of the size frequency distribution of bivalve populations. Alternatively, as recommended in Felsing and Giles (2011), size categories could be done away with entirely and instead each bivalve accurately measured for length. This would allow bivalve biomass to be calculated and areas of significant recruitment (i.e. high densities of 0-5 mm bivalves) to be identified. This data could then be used to (1) better determine the contribution of each bivalve taxa to the functioning of the estuarine ecosystem and (2) to identify and manage areas of an estuary that are particularly important for the various life history stages of each species (e.g. recruitment habitat or areas high adult biomass).

Another recommended amendment to the sampling methodology is the reduction of replicate samples. We consider the intra-site variability observed in this survey acceptable for this type of mapping and consequently future surveys could be conducted in a significantly more cost-effective manner by counting shellfish in a single quadrat at each sampling site. In fact, an earlier survey by the Department of Conservation in the Kawhia and Aotea estuaries (Hillock & Rohan, 2011) as well as subsequent surveys conducted in Tairua Harbour (Felsing & Giles, 2011) and Wharekawa (Graeme & Giles, 2013) have only used one quadrat per sampling site.

Maps of the distribution of shellfish and surface sediments are valuable resource management tools. They can be used as an inventory of the region's natural resources, to assess the effects of anthropogenic activities or the efficacy of environmental policy. Shellfish populations are a natural resource of commercial, recreational, cultural and ecological significance. If the methodology used in this survey can be refined as recommended in this report, repeating shellfish and substrate surveys over time can help identify bivalve populations that are in decline or estuaries in which habitat change might threaten the region's significant estuarine natural resources.

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Appendix A: Map of sampling site locations

Figure A-1: Map of sampling sites

Appendix B: Sampling site characteristics

Table B-1: Sampling site GPS coordinates, sampling dates, vegetation type, Redox Potential Discontinuity (RPD) layer depth and substrate category.

Sampling point	GPS Easting	GPS northing	Date Sampled	Vegetation type	Mean % cover	RDP DEPTH (cm) - average	Surface sediment
013A	2763881	6436811	8/06/2009	NIL	0	> 10	mobile sand
013B	2763941	6436816	8/06/2009	NIL	0	> 10	soft sand
12A	2763791	6436914	22/06/2009	mangrove (pneumatophores/seedlings)	4.33	NIL	very soft mud sand
12B	2763851	6436911	22/06/2009	NIL	0	NIL	soft mud/sand
012D	2763971	6436904	8/06/2009	NIL	0	2	soft mud/sand
11A	2763889	6436995	22/06/2009	NIL	0	> 10	mobile sand
011C	2764007	6436976	8/06/2009	mangrove (pneumatophores/seedlings)	1.67	> 10	soft mud/sand
10B	2763931	6437081	22/06/2009	NIL	0	1	firm sand
9B	2764044	6437152	22/06/2009	NIL	0	> 10	mobile sand
8A	2764095	6437255	23/06/2009	NIL	0	NIL	mobile sand
8B	2764129	6437205	23/06/2009	NIL	0	NIL	soft sand
8C	2764162	6437155	23/06/2009	mangrove (pneumatophores)	2	NIL	very soft mud sand
7A	2764245	6437328	23/06/2009	NIL	0	NIL	mobile sand
7B	2764271	6437274	23/06/2009	NIL	0	NIL	soft sand
7C	2764298	6437220	23/06/2009	mangrove (pneumatophores)	2	NIL	soft mud/sand
06A	2764338	6437422	9/06/2009	NIL	0	1.67	soft sand
6B	2764405	6437323	23/06/2009	NIL	0	NIL	mobile sand
6C	2764439	6437273	23/06/2009	mangrove (pneumatophores/seedlings)	5	NIL	very soft mud sand
05A	2764462	6437481	8/06/2009	NIL	0	1	soft sand
05B	2764534	6437385	8/06/2009	NIL	0	> 10	soft sand
04A	2764536	6437570	9/06/2009	NIL	0	1	soft sand
04B	2764577	6437527	9/06/2009	NIL	0	0.5	soft sand
03B	2764691	6437606	9/06/2009	NIL	0	1.5	soft sand
03C	2764711	6437562	9/06/2009	NIL	0	2	mobile sand
02A	2764855	6437711	8/06/2009	NIL	0	1	soft sand
2B	2764866	6437532	24/06/2009	NIL	0	1.33	firm sand
1A	2765039	6437593	24/06/2009	NIL	0	0.67	firm sand
1B	2765016	6437537	24/06/2009	NIL	0	NIL	firm sand
1C	2764992	6437482	24/06/2009	NIL	0	NIL	firm sand
35-1	2765110	6437758	24/03/2009	seagrass	21.67	3.33	soft mud/sand
35-2	2765096	6437725	24/03/2009	NIL	0	> 10	firm sand
35-3	2765083	6437691	24/03/2009	NIL	0	> 10	firm sand
39-3	2765247	6437667	23/02/2009	algae	2	1.5	–
39-4	2765237	6437653	23/02/2009	NIL	0	2.83	–
39-5	2765230	6437639	23/02/2009	NIL	0	1.67	–
39-7	2765219	6437619	23/02/2009	algae	0.67	1.33	–
41-1	2765292	6437691	23/01/2009	NIL	0	1	firm sand
41-2	2765268	6437657	23/01/2009	NIL	0	3	firm sand
41-3	2765262	6437644	23/01/2009	NIL	0	6	firm sand
41-4	2765246	6437628	23/01/2009	NIL	0	>10	firm sand
41-5	2765222	6437612	23/01/2009	NIL	0	2.17	firm sand
41-6	2765186	6437604	23/01/2009	NIL	0	6.5	firm sand
41-7	2765195	6437557	23/01/2009	NIL	0	>10	firm sand

Table B-1 contd.

Sampling point	GPS Easting	GPS northing	Date Sampled	Vegetation type	Mean % cover	RDP DEPTH (cm) - average	Surface sediment
41-8	2765185	6437545	22/01/2009	NIL	0	3	firm sand
41-9	2765170	6437527	23/01/2009	NIL	0	6	firm sand
41-10	2765161	6437507	23/01/2009	NIL	0	5	firm sand
41-11	2765146	6437492	22/01/2009	NIL	0	2	firm sand
41-12	2765133	6437475	23/01/2009	NIL	0	4	firm sand
43-1	2765313	6437575	21/01/2009	ulva	6.67	2.83	firm sand
43-2	2765308	6437572	21/01/2009	NIL	0	1.67	firm sand
43-3	2765289	6437553	22/01/2009	NIL	0	7.33	firm sand
43-4	2765274	6437541	22/01/2009	NIL	0	>10	firm sand
43-5	2765259	6437525	22/01/2009	NIL	0	>10	firm sand
43-6	2765248	6437513	22/01/2009	NIL	0	>10	firm sand
43-7	2765234	6437501	22/01/2009	NIL	0	2.33	firm sand
43-8	2765224	6437487	22/01/2009	NIL	0	2	firm sand
43-9	2765206	6437474	22/01/2009	NIL	0	1.83	firm sand
45-1	2765412	6437528	13/01/2009	NIL	0	> 10	mobile sand
45-2	2765398	6437504	13/01/2009	NIL	0	> 10	mobile sand
45-3	2765384	6437480	13/01/2009	NIL	0	> 10	mobile sand
45-4	2765370	6437456	13/01/2009	NIL	0	> 10	mobile sand
45-5	2765357	6437432	21/01/2009	NIL	0	5	firm sand
45-6	2765324	6437399	21/01/2009	NIL	0	3	firm sand
45-7	2765313	6437380	21/01/2009	algae	2.33	2.17	firm sand
47-1	2765502	6437498	12/01/2009	NIL	0	1.83	firm sand
47-2	2765490	6437478	12/01/2009	NIL	0	0.33	firm sand
47-3	2765479	6437458	12/01/2009	NIL	0	0.67	firm sand
47-4	2765467	6437438	12/01/2009	NIL	0	6.67	firm sand
47-5	2765456	6437419	12/01/2009	NIL	0	> 10	mobile sand
47-6	2765445	6437399	12/01/2009	NIL	0	> 10	mobile sand
47-7	2765433	6437379	12/01/2009	NIL	0	> 10	firm sand
47-8	2765423	6437359	13/01/2009	NIL	0	3.67	soft sand
47-9	2765413	6437342	13/01/2009	NIL	0	1.83	soft sand
47-10	2765403	6437324	13/01/2009	NIL	0	2	firm sand
47-11	2765393	6437307	13/01/2009	NIL	0	1.23	firm sand
49-1	2765566	6437451	12/01/2009	NIL	0	> 10	firm sand
49-2	2765552	6437427	12/01/2009	NIL	0	> 10	firm sand
49-3	2765538	6437402	12/01/2009	NIL	0	> 10	firm sand
49-4	2765524	6437379	12/01/2009	NIL	0	> 10	firm sand
49-5	2765510	6437355	12/01/2009	NIL	0	> 10	firm sand
49-6	2765496	6437331	12/01/2009	NIL	0	> 10	firm sand
49-7	2765466	6437318	21/01/2009	NIL	0	5.5	firm sand
53-1	2765707	6437319	12/01/2009	NIL	0	> 10	firm sand
54-1	2765728	6437291	12/01/2009	NIL	0	> 10	firm sand

Appendix C: Shellfish abundance

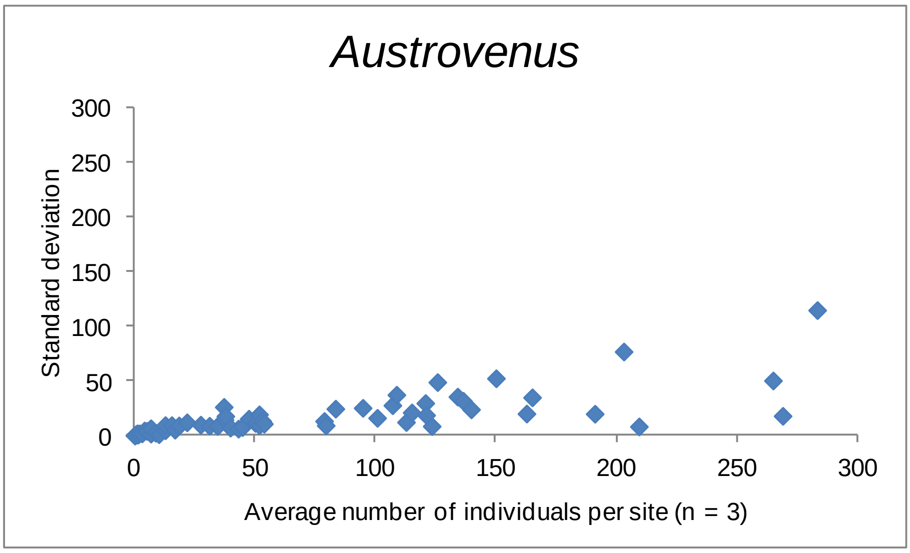
Table C-1: Shellfish abundance (total and per size class). (AS = *Austrovenus stutchburyi*, PA = *Paphies australis*, ML = *Macomona liliana*).

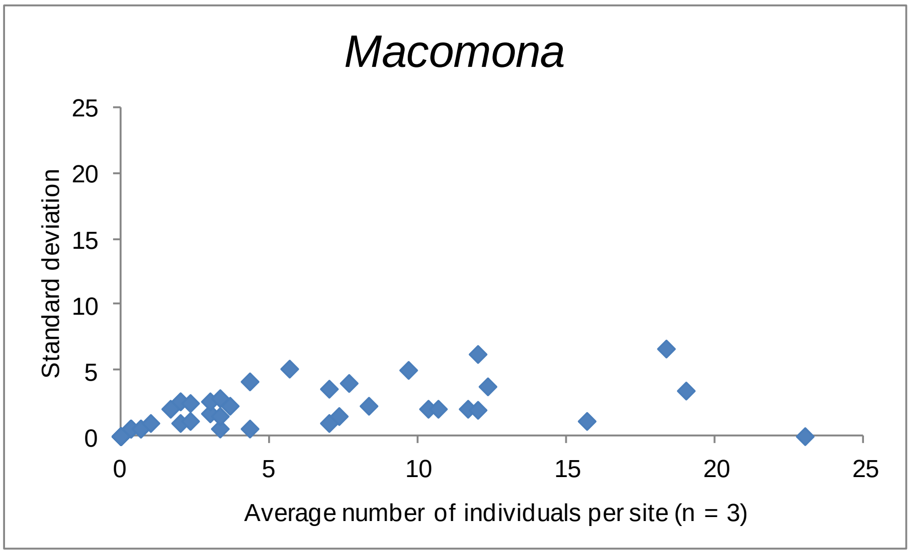
	Total average abundance						Bivalve size class groups (total average abundance)									Average density (per m^2)		
Sampling point	**AS**	**PA**	**ML**	***Diloma* sp.**	***Cominella* sp.**	***Zeacumantus* sp.**	**AS small**	**AS medium**	**AS large**	**PA small**	**PA medium**	**PA large**	**ML small**	**ML medium**	**ML large**	**AS**	**PA**	**ML**
013A	0.00	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	0.00	0.00	0.00	0.00	26.67	0.00
013B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012D	0.33	0.67	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	5.33	10.67	0.00
11A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
011C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10B	3.00	3.33	0.00	0.00	0.00	0.00	3.00	0.00	0.00	3.33	0.00	0.00	0.00	0.00	0.00	48.00	53.33	0.00
9B	0.33	6.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	6.00	0.00	0.00	0.00	0.00	0.00	5.33	96.00	0.00
8A	1.00	25.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00	25.00	0.00	0.00	0.00	0.00	0.00	16.00	400.00	0.00
8B	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	5.33	0.00
8C	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7A	0.33	32.33	0.00	0.00	0.00	0.00	0.33	0.00	0.00	32.33	0.00	0.00	0.00	0.00	0.00	5.33	517.33	0.00
7B	5.00	0.00	0.00	0.33	0.00	0.00	1.67	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.00	0.00	0.00
7C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
06A	12.67	0.00	0.67	0.00	0.67	1.67	8.67	2.00	2.00	0.00	0.00	0.00	0.00	0.33	0.33	202.67	0.00	10.67
6B	6.67	0.67	0.00	0.00	0.33	0.00	3.33	3.00	0.33	0.33	0.33	0.00	0.00	0.00	0.00	106.67	10.67	0.00
6C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05A	10.00	0.00	3.33	0.00	0.00	0.67	8.33	1.67	0.00	0.00	0.00	0.00	0.33	1.00	2.00	160.00	0.00	53.33
05B	37.33	0.67	23.00	0.00	0.67	0.33	29.67	7.67	0.00	0.33	0.33	0.00	7.00	16.00	0.00	597.33	10.67	368.00
04A	37.00	0.33	2.33	0.00	0.00	3.00	37.00	0.00	0.00	0.33	0.00	0.00	0.00	2.33	0.00	592.00	5.33	37.33
04B	79.33	0.67	8.33	0.33	2.00	5.33	69.33	10.00	0.00	0.67	0.00	0.00	2.33	3.67	2.33	1269.33	10.67	133.33
03B	50.00	5.00	12.00	1.00	1.00	3.33	37.00	13.00	0.00	4.33	0.67	0.00	0.00	10.67	1.33	800.00	80.00	192.00
03C	2.00	2.33	1.00	0.00	0.00	0.00	0.00	2.00	0.00	2.33	0.00	0.00	0.33	0.33	0.33	32.00	37.33	16.00
02A	44.67	0.33	7.00	0.00	2.67	1.33	38.33	6.00	0.33	0.33	0.00	0.00	1.00	4.00	2.00	714.67	5.33	112.00
2B	21.67	0.33	0.67	0.00	0.33	0.00	21.67	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.33	346.67	5.33	10.67
1A	43.00	0.33	3.67	0.00	0.67	5.33	42.33	0.67	0.00	0.33	0.00	0.00	0.00	0.33	3.33	688.00	5.33	58.67
1B	31.00	0.00	0.00	0.00	0.67	2.00	26.33	4.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	496.00	0.00	0.00
1C	18.33	0.00	0.00	0.00	0.00	0.00	16.67	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	293.33	0.00	0.00
35-1	112.67	0.33	9.67	0.00	1.67	4.67	107.67	5.00	0.00	0.33	0.00	0.00	5.33	4.33	0.00	1802.67	5.33	154.67
35-2	51.67	6.00	10.67	0.67	3.00	0.67	41.67	10.00	0.00	6.00	0.00	0.00	5.00	5.67	0.00	826.67	96.00	170.67
35-3	1.33	4.33	3.00	0.00	0.33	0.00	1.00	0.33	0.00	4.33	0.00	0.00	0.33	1.33	1.33	21.33	69.33	48.00
39-3	123.33	12.00	15.67	0.00	2.67	0.67	89.33	34.00	0.00	7.33	4.67	0.00	0.67	9.00	6.00	1973.33	192.00	250.67
39-4	150.00	8.33	0.00	0.67	1.33	0.33	70.00	80.00	0.00	4.67	3.67	0.00	0.00	0.00	0.00	2400.00	133.33	0.00
39-5	78.67	6.33	0.00	1.33	1.67	30.00	30.67	47.67	0.33	3.33	3.00	0.00	0.00	0.00	0.00	1258.67	101.33	0.00
39-7	27.33	1.00	11.67	1.00	1.33	1.33	15.67	11.67	0.00	1.00	0.00	0.00	2.67	5.00	4.00	437.33	16.00	186.67
41-1	15.33	8.33	0.00	1.33	2.67	4.00	2.33	13.00	0.00	5.67	2.67	0.00	0.00	0.00	0.00	245.33	133.33	0.00
41-2	53.00	13.67	19.00	2.00	2.33	0.00	22.00	31.00	0.00	6.67	7.00	0.00	1.00	12.33	5.67	848.00	218.67	304.00
41-3	107.00	6.67	0.00	0.67	1.00	2.00	56.67	50.33	0.00	5.33	1.33	0.00	0.00	0.00	0.00	1712.00	106.67	0.00
41-4	283.33	11.00	0.00	1.00	3.00	179.33	126.33	154.67	2.33	6.67	4.33	0.00	0.00	0.00	0.00	4533.33	176.00	0.00
41-5	12.67	0.00	18.33	4.33	1.67	7.00	9.67	2.33	0.67	0.00	0.00	0.00	4.67	10.33	3.33	202.67	0.00	293.33
41-6	51.67	1.00	0.33	1.33	1.33	6.33	30.00	21.67	0.00	1.00	0.00	0.00	0.00	0.33	0.00	826.67	16.00	5.33
41-7	120.67	1.67	0.33	1.00	1.33	35.33	92.67	28.00	0.00	1.67	0.00	0.00	0.00	0.00	0.33	1930.67	26.67	5.33
41-8	94.67	0.00	0.33	1.00	1.67	31.33	72.67	22.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	1514.67	0.00	5.33

Table C-1 contd.

	Total average abundance						Bivalve size class groups (total average abundance)									Average density (per m^2)		
Sampling point	**AS**	**PA**	**ML**	***Diloma* sp.**	***Cominella* sp.**	***Zeacumantus* sp.**	**AS small**	**AS medium**	**AS large**	**PA small**	**PA medium**	**PA large**	**ML small**	**ML medium**	**ML large**	**AS**	**PA**	**ML**
41-9	139.67	2.67	0.67	0.00	1.33	14.00	110.33	29.33	0.00	2.67	0.00	0.00	0.00	0.00	0.67	2234.67	42.67	10.67
41-10	209.33	0.33	2.00	0.00	1.00	7.33	185.33	24.00	0.00	0.33	0.00	0.00	1.33	0.00	0.67	3349.33	5.33	32.00
41-11	136.33	0.67	4.33	0.00	0.67	4.67	130.00	6.33	0.00	0.67	0.00	0.00	0.33	2.00	2.00	2181.33	10.67	69.33
41-12	134.00	1.00	0.00	0.00	2.00	6.00	79.33	54.67	0.00	1.00	0.00	0.00	0.00	0.00	0.00	2144.00	16.00	0.00
43-1	121.00	22.00	7.33	2.00	4.33	1.33	90.33	30.67	0.00	17.67	4.33	0.00	0.33	6.33	0.67	1936.00	352.00	117.33
43-2	108.67	13.33	12.33	1.67	4.67	0.67	86.33	22.33	0.00	11.00	2.33	0.00	5.33	6.00	1.00	1738.67	213.33	197.33
43-3	16.67	4.33	3.33	0.33	1.00	0.00	13.67	3.00	0.00	3.00	0.67	0.67	0.33	1.67	1.33	266.67	69.33	53.33
43-4	125.67	3.67	0.00	0.33	0.33	0.00	68.00	57.67	0.00	3.67	0.00	0.00	0.00	0.00	0.00	2010.67	58.67	0.00
43-5	162.67	5.67	0.33	0.67	1.33	2.33	131.00	31.67	0.00	4.67	0.67	0.33	0.00	0.33	0.00	2602.67	90.67	5.33
43-6	165.00	3.33	2.00	0.00	2.33	2.67	113.33	51.67	0.00	3.33	0.00	0.00	0.00	1.33	0.67	2640.00	53.33	32.00
43-7	269.00	2.67	2.33	0.67	2.00	2.33	236.33	32.67	0.00	2.33	0.33	0.00	0.00	1.67	0.67	4304.00	42.67	37.33
43-8	265.00	7.67	7.00	0.33	1.00	3.33	256.33	8.67	0.00	3.00	4.67	0.00	2.00	4.33	0.67	4240.00	122.67	112.00
43-9	115.00	0.67	0.00	0.33	2.00	1.67	52.33	62.67	0.00	0.33	0.33	0.00	0.00	0.00	0.00	1840.00	10.67	0.00
45-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45-3	0.67	0.00	0.33	0.00	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	10.67	0.00	5.33
45-4	8.67	2.00	0.00	0.00	1.33	0.00	5.67	3.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	138.67	32.00	0.00
45-5	0.67	19.67	1.67	0.00	0.00	0.00	0.00	0.67	0.00	15.33	4.33	0.00	1.67	0.00	0.00	10.67	314.67	26.67
45-6	47.33	7.33	12.00	0.00	1.67	0.33	35.67	11.67	0.00	6.33	0.33	0.67	8.00	1.00	3.00	757.33	117.33	192.00
45-7	191.00	1.67	7.67	0.00	1.67	1.33	130.67	60.33	0.00	1.33	0.33	0.00	3.33	3.67	0.67	3056.00	26.67	122.67
47-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47-2	0.67	0.00	0.00	0.00	2.67	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.67	0.00	0.00
47-3	53.67	3.00	4.33	1.67	2.33	0.00	39.00	14.67	0.00	3.00	0.00	0.00	4.33	0.00	0.00	858.67	48.00	69.33
47-4	6.67	3.67	0.00	0.00	1.67	0.00	5.33	1.33	0.00	3.67	0.00	0.00	0.00	0.00	0.00	106.67	58.67	0.00
47-5	1.00	0.33	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	16.00	5.33	0.00
47-6	0.33	1.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	5.33	16.00	0.00
47-7	0.33	23.33	0.00	0.00	0.33	0.00	0.33	0.00	0.00	21.67	0.67	1.00	0.00	0.00	0.00	5.33	373.33	0.00
47-8	37.67	3.67	3.00	0.33	4.00	2.33	16.33	18.33	3.00	2.00	1.67	0.00	1.67	1.00	0.33	602.67	58.67	48.00
47-9	39.67	8.67	5.67	1.00	8.67	3.33	19.67	19.00	1.00	4.00	4.33	0.33	0.00	2.67	3.00	634.67	138.67	90.67
47-10	83.33	8.67	0.00	2.33	3.00	1.33	62.00	21.33	0.00	7.67	1.00	0.00	0.00	0.00	0.00	1333.33	138.67	0.00
47-11	100.67	7.00	10.33	3.00	7.00	3.67	86.67	14.00	0.00	5.67	1.33	0.00	1.00	6.00	3.33	1610.67	112.00	165.33
49-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49-2	34.33	2.00	3.33	0.00	2.00	0.00	11.33	23.00	0.00	2.00	0.00	0.00	3.00	0.33	0.00	549.33	32.00	53.33
49-3	4.00	23.00	0.33	0.00	1.00	0.00	2.67	1.33	0.00	23.00	0.00	0.00	0.33	0.00	0.00	64.00	368.00	5.33
49-4	1.33	16.33	0.00	0.00	0.33	0.00	1.33	0.00	0.00	16.00	0.33	0.00	0.00	0.00	0.00	21.33	261.33	0.00
49-5	0.33	82.33	0.00	0.00	0.33	0.00	0.00	0.33	0.00	82.33	0.00	0.00	0.00	0.00	0.00	5.33	1317.33	0.00
49-6	0.00	137.67	0.00	0.00	1.00	0.00	0.00	0.00	0.00	137.33	0.33	0.00	0.00	0.00	0.00	0.00	2202.67	0.00
49-7	203.00	6.33	2.00	0.33	1.67	0.00	90.33	112.67	0.00	4.33	2.00	0.00	0.33	1.67	0.00	3248.00	101.33	32.00
53-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D: Variability of bivalve abundance





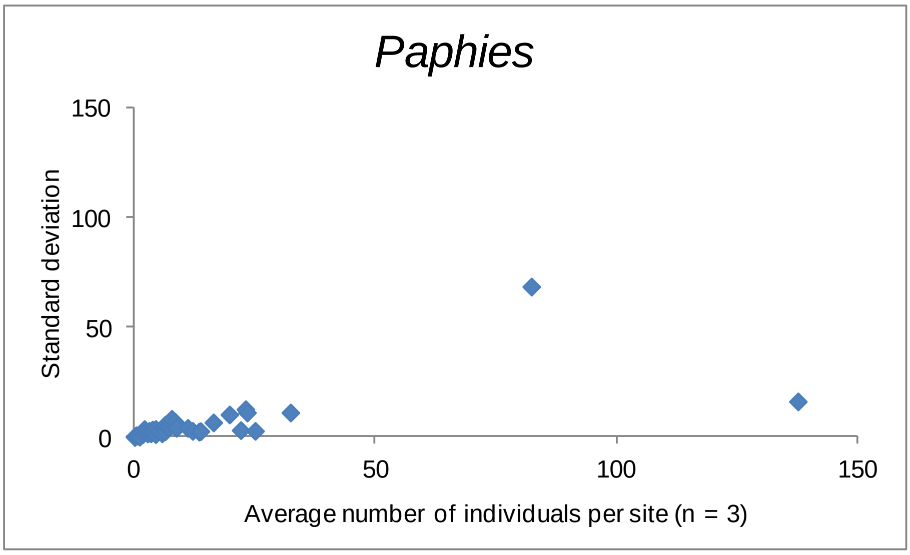


Figure D-1: Standard deviation of bivalve abundances calculated from three replicate samples.