Ministry for Primary Industries
Manatū Ahu Matua

Intertidal shellfish monitoring in the northern North Island region, 2015–16

New Zealand Fisheries Assessment Report 2016/49

K. Berkenbusch
P. Neubauer

ISSN 1179-5352 (online)
ISBN 978-1-77665-365-2 (online)

August 2016

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Berkenbusch, K.; Neubauer, P. (2016). Intertidal shellfish monitoring in the northern North Island region, 2015–16.

***New Zealand Fisheries Assessment Report 2016/49*. 108 p.**

New Zealand's coastal habitats support a number of bivalve species that are targeted in non-commerical fisheries. In northern North Island, these bivalves include cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*), which are the main target species in intertidal recreational and customary fisheries across different sheltered environments, such as beaches, estuaries and harbours. These coastal populations are potentially vulnerable to human activities, including fishing, and are regularly monitored in intertidal population surveys commissioned by the Ministry for Primary Industries. These surveys assess the status of the cockle and pipi populations in areas targeted by non-commercial fisheries at a number of sites in northern North Island, from the wider Auckland region to Northland, Waikato, and Bay of Plenty.

The present study continues the series of bivalve population surveys in the northern North Island region by presenting data from the 2015–16 fishing year. Sites surveyed in this study included (in alphabetical order) Bowentown Beach, Cheltenham Beach, Cockle Bay, Little Waihi Estuary, Marokopa Estuary, Ohiwa Harbour, Okoromai Bay, Pataua Estuary, Tairua Harbour, Umupuia Beach, Whangateau Harbour, and Whitianga Harbour. Data collected at each site included information of the population size and structure of cockles and pipi in areas targeted by fishing activities. The sampling in areas inhabited by cockles also included the collection of sediment data to assess the relationship between the abundance of cockles and sediment characteristics, including organic content and the proportions of sediment fines and gravel.

Cockle populations were present at ten of the 2015–16 survey sites, whereas only few individuals were present at the remaining two sites, Cheltenham Beach and Marokopa Estuary. Population estimates for this species varied across sites, ranging from the smallest total population size documented at Ohiwa Harbour of 23.01 million (CV: 14.33%) individuals to the highest population estimate of 742.44 million (CV: 7.02%) cockles at Whangateau Harbour. Other sites with comparatively large cockle populations included Pataua Estuary and Umupuia Beach, which supported an estimated 380.13 million (CV: 7.58%) and 98.88 million (CV: 15.93%) cockles, respectively. Cockle population densities in 2015–16 varied between 136 cockles per m^2 (CV: 8.48%) at Cockle Bay and 1799 cockles per m^2 (CV: 5.17%) at Bowentown Beach.

Large cockles ($\geq$30 mm shell length) are considered to be primarily targeted in fisheries, and individuals in this size class were present at most sites. Five sites supported relatively high numbers of large individuals, including Pataua Estuary, Okoromai Bay, Cockle Bay, Umupuia Beach, and Whangateau Harbour, with abundance estimates between 4.89 million (CV: 29.68%) large individuals (at Pataua Estuary) and 45.43 million (CV: 18.77%) large cockles (at Whangateau Harbour). Nevertheless, their corresponding densities were only relatively high at two sites, with 128 large cockles per m^2 at Umupuia Beach, and 98 individuals per m^2 at Cockle Bay. At most sites, the large size class contributed few individuals to the total population.

Eight of the survey sites in 2015–16 contained pipi populations, with few or no pipi at Cheltenham Beach, Cockle Bay, Okoromai Bay, and Umupuia Beach. At sites that included pipi beds, total population estimates ranged from 0.15 million (CV: 16.6%) pipi at Bowentown Beach to the largest population size of 83.84 million (CV: 16.62%) pipi at Little Waihi Estuary. Estimated pipi densities were highest at Ohiwa Harbour with 1225 pipi per m^2 (CV: 12.1%), followed by 456 individuals per m^2 (CV: 16.62%) at Little Waihi Estuary, 333 pipi per m^2 (CV: 11.26%) at Marokopa Estuary, and 327 pipi per m^2 (CV: 15.64%) at Tairua Habour. Density estimates were lower at the remaining sites, with the lowest estimated density of 10 pipi per m^2 (CV: 16.6%) at Bowentown Beach.

Large pipi ($\geq$50 mm shell length) were present in most populations (except at Marokopa Estuary), al-

though their numbers were relatively low at most sites. The highest abundance estimate for large pipi was at Ohiwa Harbour with 3.70 million (CV: 18.37%) individuals, and their corresponding density at this site was also relatively high with 110 large pipi per m^2. The pipi populations at Little Waihi Estuary and Whitianga Harbour also included a relatively high number of large individuals with 2.35 million (CV: 43.62%) and 1.91 million (CV: 22.66%) individuals in this size class, and population densities of 13 and 31 large pipi per m^2, respectively. At the remaining sites, population estimates for large individuals were considerably lower.

In addition to assessing cockle and pipi populations across northern North Island sites, the current data collection also involved sediment variables, including sediment organic content, and the proportions of fines (<63 µm grain size) and gravel (>2000 µm grain size). These data were used to examine the relationship between cockle abundance and sediment properties. Cockle abundance decreased with increasing sediment organic content, proportion of fines and proportion of gravel at the stratum level, but these relationships were tentative. It is expected that increased replication (as more data are collected over time) will improve future assessments of the relationship between bivalve populations and sediment characteristics.

1. INTRODUCTION

New Zealand's coastal waters contain a number of bivalve species that are targeted in commercial and non-commercial fisheries. The latter include recreational and customary collections of intertidal species such as cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*). Both species occur in a range of sheltered soft-sediment environments throughout the country, including high-density patches and extensive beds that may exceed 1000 individuals per square metre in localised areas (Morton & Miller 1973, Hooker 1995).

Cockles are predominantly found in the intertidal zone, but extend to shallow subtidal waters at some sites. In contrast, pipi show a preference for low intertidal and subtidal areas that are characterised by clean, coarse sands and strong tidal currents; high-density pipi beds are generally found close to mean low water and in subtidal sediments. Both cockles and pipi have been shown to be sensitive to changes in the sediment regime and, for example, show discernible decreases in their abundances in response to increases in sediment mud content (silt and clay, <63 µm grain size), i.e., by terrestrial-derived clay (Anderson 2008).

In northern North Island, cockles and pipi are the main target species in recreational and customary fisheries in a range of sheltered environments, such as beaches, estuaries and harbours (Hauraki Māori Trust Board 2003, Hartill et al. 2005). At some sites, non-commercial fishing has been identified as one of the factors causing population declines, although the exact causes for these declines remain largely unknown (Grant & Hay 2003).

Northern North Island cockle and pipi populations are regularly monitored (usually annually) in surveys commissioned by the Ministry for Primary Industries (MPI). These population surveys were initiated in 1992 for the wider Auckland metropolitan area, but were subsequently expanded to include the Auckland Fisheries Management Area (FMA 1) (see information about the surveys in Appendix A).

At each site, the field surveys record information about the abundance and population structure (size-frequency distribution) of cockle and pipi populations (most recently, Berkenbusch & Neubauer 2015). These data include the proportion of large individuals, defined as $\geq$30 mm shell length for cockles and $\geq$50 mm shell length for pipi. The data collection also includes the proportion of juveniles that are considered to be recruits, defined by shell lengths $\leq$15 mm for cockles and $\leq$20 mm for pipi. As the surveys are based on intertidal areas that have been identified as important for recreational and customary fisheries, they usually do not provide population estimates of the entire cockle and pipi populations at each site (Pawley & Ford 2007).

The present report documents the most recent survey in the series of (generally) annual MPI assessments of infaunal bivalve abundance and population structure at selected sites in the northern North Island region. The overall objective of this project was "to determine the distribution, abundance and size frequency of selected intertidal shellfish" for the 2015–16 fishing year.

The sites included in this survey were (in alphabetical order): Bowentown Beach, Cheltenham Beach, Cockle Bay, Little Waihi Estuary, Marokopa Estuary, Ohiwa Harbour, Okoromai Bay, Pataua Estuary, Tairua Harbour, Umupuia Beach, Whangateau Harbour, and Whitianga Harbour (see Figure 1).

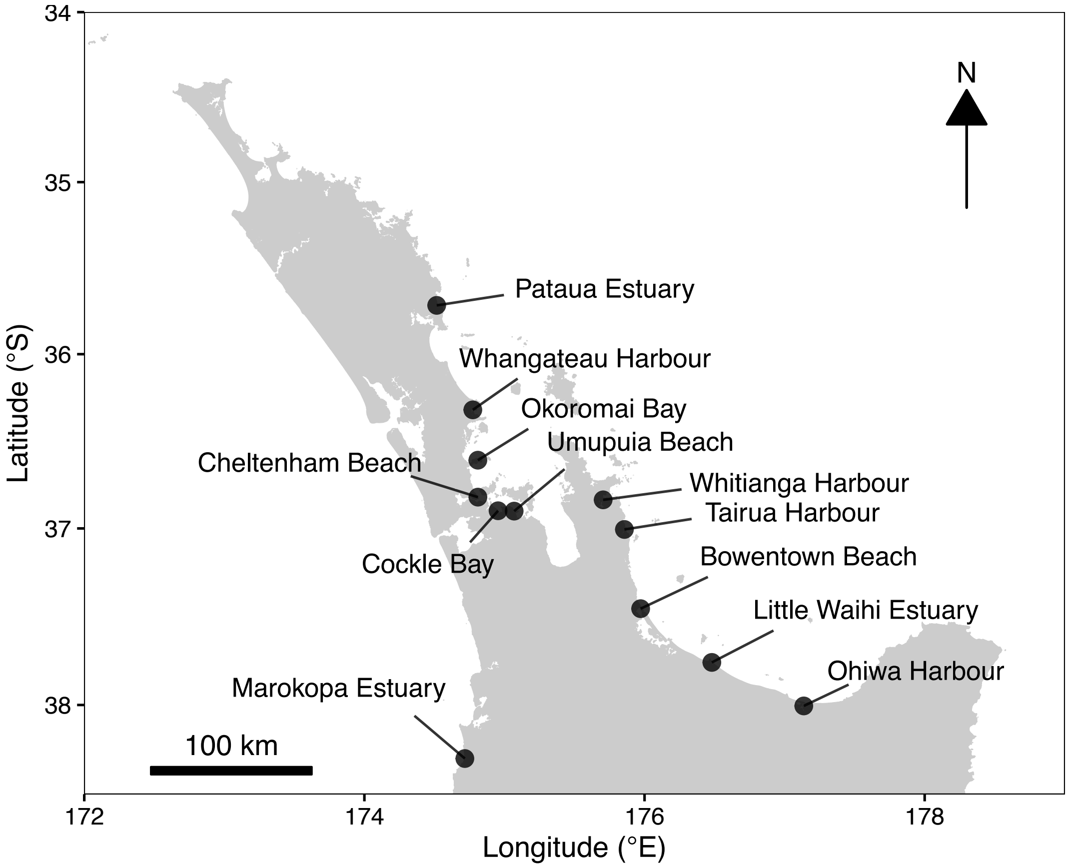


Figure 1: Sites included in the northern North Island intertidal bivalve surveys in 2015–16.

2. METHODS

To allow comparisons with previous surveys, the present study adopted the same general sampling protocol that has been used since 1996 in northern North Island bivalve surveys commissioned by MPI (e.g., Morrison & Browne 1999, Pawley 2011, 2012). Specifically, the sampling involved the combination of a systematic design and a two-phase stratified random design, used in recent surveys (Pawley & Ford 2007), where the stratification accounted for spatial variation along and down the shore.

2.1 Survey methods

At each site, the intertidal areas sampled were identified based on existing information and input from local communities and stakeholders. This preliminary exploration also included extensive reconnaissance of the sampling areas at each site, including on-site determination of population boundaries, defined as fewer than 10 individuals per m^2 (see Pawley 2011). Establishing population boundaries included the acquisition of geographical information through the use of global positioning system (GPS). GPS units were also used during sampling to determine the location of each sampling point.

Preliminary analyses of cockle densities and sediment data from previous surveys (2013–14 and 2014–15) using GPS-referenced samples indicated that the previous stratification at individual sites rarely delimited areas of similar characteristics (e.g., homogenous densities) and, therefore, did not necessarily lead to reductions in variance in the estimation of bivalve population sizes and densities. For this reason, at sites with GPS-referenced samples (Cockle Bay, Little Waihi Estuary, Okoromai Bay, Pataua Estuary, Tairua Harbour, Umupuia Beach, Whangateau Harbour), these high-resolution spatial data from previous surveys were used to re-define cockle strata based on the spatial distribution and variability of previous samples (see Appendix B for details).

The number of sampling points for each bivalve population was determined by the population size and variability within each stratum, informed by data from previous surveys. For each stratum a regular grid was generated, with the size and shape of the grid cells reflecting the desired sampling density and the orientation of the stratum. The intersection of the grid with the boundary of the stratum was taken. For each phase, a fixed number of sampling points was then allocated over all cells, with a probability proportional to the area of the cell over the maximum area of any of the cells in the grid. The position of the point within the cell was randomly allocated. With this procedure, not all the cells that were clipped by the boundary had sampling points allocated to them. The expected density of sampling points across the stratum was uniform. All sampling points were pre-calculated for two phases before the sampling began. All phase-1 points were sampled, whereas sampling of phase-2 points was only carried out when the coefficient of variation (CV) of the total abundance estimate after first-phase sampling exceeded the target value of 20% for either cockle or pipi (i.e., at one site in 2015–16).

Owing to the importance of sediment properties for infaunal bivalves, the two preceding surveys including a sediment sampling programme aimed at obtaining baseline information of sediment organic content and grain size at each site (see, Berkenbusch et al. 2015, Berkenbusch & Neubauer 2015). This sediment sampling provided general information, but the small number of sediment samples and the non-random allocation of sediment sampling points prevented formal analyses of sediment variables. For this reason, the sediment sampling design was improved in the present study, to allow the analysis of spatial patterns in sediment variables, and to assess gradients in bivalve abundance in relation to sediment properties.

The sediment sampling was restricted to cockles, as pipi populations frequently extend into subtidal waters deeper than 0.5 m, so that only parts of the population are sampled. The sediment sampling first involved re-stratification of sites for which high-resolution (i.e., GPS-referenced) spatial information was available. For the remaining sites, the stratification was based on spatial information at stratum level. Within each cockle stratum, a subset of at least six sediment sampling points was randomly allocated, each corresponding with a randomly-allocated cockle sampling point.

2.2 Field sampling–bivalves

The field component of this study was carried out in January and February 2016. At each site, the intertidal sampling was conducted during periods of low tide (see sampling dates for the present and previous surveys in Appendix A, Tables A-1, A-2).

The sampling unit consisted of a pair of benthic cores of 15 cm diameter each that (combined) sampled a surface area of 0.035 m^2 (to 15 cm depth). The sampling depth encompassed the maximum burrowing depths of the infaunal bivalves concerned, which reside in the top 10 cm of the sediment (i.e., 1–3 cm for cockles, Hewitt & Cummings 2013; and 8–10 cm for pipi; Morton & Miller 1973).

Sampling points within each stratum were located using GPS units. For pipi populations, the intertidal sampling extended to 0.5 m water depth (at low tide) in channels that included pipi populations (following the sampling approach of previous surveys). At each sampling point, the cores were pushed 15 cm into the sediment directly adjacent to each other. The cores were excavated, and all sediment from each core was sieved in the field on 5-mm mesh. All cockles and pipi retained on the sieve were counted and measured (length of the maximum dimension, to the nearest millimetre), before returning them to the benthos. The counts were conducted by using hand-held counters or by splitting the bivalves retained within each sieve into groups of ten.

For strata with population densities exceeding 2000 individuals per m^2, the recording of shell length measurements involved subsampling (see Pawley 2011). The subsampling was only used when the number of individuals in both cores exceeded 70 (equating to 2000 individuals per m^2) and there were at least 50 individuals in the first core. The subsampling consisted of recording shell length measurements for all individuals in the first core, whereas bivalves in the second core were not measured. When there were less than 50 individuals in the first core, all bivalves were measured in both cores.

2.3 Field sampling–sediment

The sediment sampling involved the collection of a subset of sediment cores (5 cm diameter, sampled to 10 cm depth) that were collected within existing cockle strata. Subsequent analyses included the grain size distribution and organic content of the sediment samples (see detailed information in Appendix C).

The grain size analysis was based on wet sieving to ascertain the proportion of different size classes, ranging from sediment fines (silt and clay, $<$63 µm grain size) to different sand fractions of very fine to very coarse sands and gravel (i.e., 125 to 2000 µm grain size) (Eleftheriou & McIntyre 2005). Each sample was homogenised before processing it on a stack of sieves to determine the proportion in each sediment grain size fractions (i.e., $>$63, $>$125, $>$250, $>$500, and $>$2000 µm). Each sediment fraction retained on the sieves was subsequently dried to constant weight at 60°C before weighing it (accuracy $\pm$ 0.00001 g).

The sediment organic content of each sample was determined by loss on ignition (4 hours at 550°C) after drying the sample to constant weight at 60°C (Eleftheriou & McIntyre 2005).

2.4 Data analysis–bivalves

For each survey site and species combination, the data analysis focused on estimating abundance, population density and the size (length) frequency distribution, both within and across strata. The data analysis followed previous analyses as outlined in Berkenbusch et al. (2015). Results from the present survey were compared with previous surveys using the MPI beach database. Comparisons with previous surveys from 1999–2000 onwards were made for estimates of abundance and population density. Length-frequency distributions from the present survey were compared with the two preceding surveys.

As in recent previous surveys, the two cores within each grid cell were considered as a single sampling unit. Bivalve abundance within the sampled strata at each site was estimated by extrapolating local density (individuals per m^2), calculated from the number of individuals per sampling unit, to the stratum size:

$$\hat{y}_k = \frac{1}{S_k} \sum_{s=1}^{S} \frac{n_{s,k}}{0.035}, \tag{1a}$$

$$\hat{N} = \sum_{k=1}^{K} A_k \hat{y}_k, \tag{1b}$$

where $n_{s,k}$ is the number of individuals in sample s within stratum k, S_k is the total number of samples processed in stratum k, and $\hat{y}_k$ is the estimated density of bivalves (individuals per m^2) within the stratum. The total number $\hat{N}$ of bivalves at each site is then the sum of total abundance within each stratum, estimated by multiplying the density within each stratum by the stratum area A_k.

The variance $\sigma^2_{\hat{N}}$ of the total abundance was estimated as

$$\hat{\sigma}^2_N = \sum_{k=1}^{K} \frac{A_k^2 \sigma^2_{\hat{y}_k}}{S_k},$$

where $\sigma^2_{\hat{y}_k}$ is the variance of the estimated density per sample. The corresponding coefficient of variation (CV, in %) is then

$$CV = 100 \times \frac{\sigma_{\hat{N}}}{\hat{N}}.$$

To estimate the length-frequency distributions at each site, measured individuals were allocated to millimetre-length size classes. Within each size class l, the number $n^m_{l,s}$ of measured (superscript m) individuals within each sample s was scaled up to the estimated total number at length within the sample ($\hat{n}_{l,s}$) by dividing by the proportion p^m_s of measured individuals within the sample, such that

$$\hat{n}_{l,s} = \frac{n^m_{l,s}}{p^m_s}.$$

The numbers at length over all strata were then calculated according to equations 1a and 1b for each length class l. The same procedure was used to estimate the abundance of large-size individuals (defined as $\geq$30 mm shell length for cockles, and $\geq$50 mm shell length for pipi) at each site, summing numbers at length of individuals greater than the reference length r for each species:

$$\hat{n}_{l \geq r,s} = \sum_{l=r}^{\max(l)} \hat{N}_l.$$

In addition to large-sized bivalves, the population assessments also considered the proportion of recruits within the bivalve populations at the sites surveyed. Recruits were defined as cockles that were $\leq$15 mm and pipi that were $\leq$20 mm in shell length.

2.5 Data analysis–sediment

The initial analysis focused on correlations between sediment data (proportion of fines, proportion of gravel, organic content) and cockle abundance using cockle samples of total and large (defined as $\geq$30 mm shell length) cockles from locations where sediment samples were obtained. A negative-binomial (NB) generalised linear mixed model (GLMM) was then used to link the sediment properties to numbers of cockle (or large cockle) found at sites with sediment samples. This general model can be written as:

$$y_{i,a,b} \sim \mathrm{NB}(\mu_{i,a,b}, \nu), \tag{2}$$
$$\log(\mu_{i,a,b}) = \alpha + \beta' * S_{i,a,b} + \omega_b + \zeta_{a,b}, \tag{3}$$

where $y_{i,a,b}$ is the cockle count for sample i in stratum a at beach (site) b, ν is the negative-binomial overdispersion parameter and $\mu_{i,a,b}$ is the Poisson (P) mean. The mean is related to the linear predictor via a log link function. The linear predictor includes a regression that relates the substrate variables at the location, $S_{i,a,b}$, to the number of cockles, with a vector of regression coefficients β, with the site and stratum level variation accounted for by random effects at each of those levels (ω_b and $\zeta_{a,b}$, respectively). The model was implemented in R (R Core Team 2015) using the glmer.nb function in the lme4 package (Bates et al. 2015).

As relationships between the number of cockles and combined sediment properties seemed highly variable among sites (see Section 4), the model was also run separately for each sediment variable, with a random, site-specific slope for the regression relationship:

$$y_{i,a,b} \sim \text{NB}(\mu_{i,a,b}, \nu), \tag{4}$$
$$\log(\mu_{i,a,b}) = \alpha + \beta_{s,b} * s_{i,a,b} + \omega_b + \zeta_{a,b}, \tag{5}$$

where $\beta_{s,b}$ is the regression coefficient for sediment variable s at site b. This model was also run separately for each sediment variable.

Cockle densities are often highly variable, and factors other than sediment characteristics can determine cockle abundance at sampling locations. This influence of non-measured variables can lead to data with unexplained variation at the sample scale. For this reason, it may be more appropriate to include all samples at each site (i.e., not only samples taken at points with corresponding sediment samples) to estimate cockle abundance in relation to sediment characteristics. By relating abundance and sediment characteristics at a larger scale, it may be possible to smooth out some of the variability occurring at smaller scales. To this end, a second set of models was used, in which correlations between sediment data (proportion of fines, organic content) and cockle densities were analysed using measurement error (also called "errors-in-variables") models in a Bayesian analysis (Gelman et al. 2004).

For this analysis, cockle densities were related to each sediment variable within individual strata, using random effects to account for density patterns at the site level. The measurement error analysis recognises that both the density and the sediment data for each stratum are estimates with an associated estimation error. The model was developed in a Bayesian setting using STAN and no-U-turn Markov Chain Monte Carlo methods (Carpenter et al. 2015). The full model with all priors can be written hierarchically as:

$$\begin{aligned}
y_{i,a,b} &\sim \text{NB}(\mu_{a,b}, \nu_{a,b}), \\
s_{k,v,a,b} &\sim \text{Gamma}(\epsilon_{v,a,b}, \epsilon/\lambda_{v,a,b}), \\
\log(\mu_{a,b}) &= \alpha + \beta * \lambda_{a,b} + \omega_b, \\
\beta &\sim \text{Normal}(0, 1000), \\
\log(\lambda_{v,a,b}) &= \gamma_v + \xi_{v,b} + \zeta_{v,a,b}, \\
\epsilon_{v,a,b}, \nu_{a,b} &\sim \text{Gamma}(\pi_{\epsilon_v,\nu}, \pi_{\epsilon_v,\nu}), \\
\pi_{\epsilon_v,\nu} &\sim \text{Gamma}(0.1, 0.1), \\
\omega_b, \xi_{v,b}, \zeta_{v,a,b} &\sim \text{Normal}(0, \tau_{\omega,\xi_v,\zeta_v}), \\
\tau_{\omega,\xi_v,\zeta_v} &\sim \text{Half-cauchy}(10).
\end{aligned}$$

In this model, the count $y_{i,a,b}$ for sample i in stratum a at site b was assumed to be negative-binomial distributed with stratum-specific mean $\mu_{a,b}$ and overdispersion $\nu_{a,b}$. This variance was estimated hierarchically using a gamma distribution with a common, estimated, prior π_ν that was used to define both the scale and rate of the gamma distribution. It was further assumed that the log of the mean count $\mu_{a,b}$ was related to the mean $s_{v,a,b}$ of the sediment characteristic v examined (e.g., proportion of fines, organic content) via a regression relationship with regression coefficients β (i.e., β is a row vector). Furthermore, $\lambda_{a,b}$ is a matrix of estimated sediment characteristics, where $\lambda_{v,a,b}$ is a column vector for sediment v of this matrix. To account for site-level effects, the regression included random effects ω_b for the site with estimated variances τ_ω. Both β and τ were estimated using vaguely informative priors. Our model thus assumed that there are site-level differences in abundance due to unmeasured factors (e.g., fishing, recruitment, or other environment variables), but that stratum differences should be explained by sediment characteristics.

The mean $\lambda_{v,a,b}$ of sediment variable v was estimated from the K samples $s_{k,v,a,b}$ taken in stratum a at site b. The variance for the sediment characteristic v, $\epsilon_{v,a,b}$, was estimated in the same way as for the cockle samples, using a hierarchical prior π_{ϵ_v}, with π_{ϵ_v} itself estimated from a vague gamma prior. The mean $\lambda_{v,a,b}$ for each sediment variable v was estimated using an overall mean γ_v for the sediment variable and site and stratum-within-site random effects (ξ_b and $\zeta_{a,b}$, respectively).

3. RESULTS

3.1 Bowentown Beach

Bowentown Beach is situated in Bay of Plenty, north of Tauranga Harbour, with the survey area located on the intertidal sandflat within Shelly Bay. There have been three previous surveys at Bowentown Beach, most recently in 2012–13 (see Appendix A, Tables A-1, A-2). The sampling extent in the current study was consistent with these previous surveys, and included the same three separate strata (Table 1). Across these three strata, bivalves were sampled in a total of 104 sampling points.

Sediment in the cockle strata was low in organic content with a maximum value of 2.6% (Figure 2, and see details in Appendix C, Table C-4). The proportion of sediment fines (<63 µm grain size) was also small, and the dominant grain size was fine sand (>125 µm grain size) followed by medium sand (>250 µm grain size). The proportion of gravel (>2000 µm grain size) was generally low, ranging from none to 6.9% of sediment.

Cockles were distributed throughout all three strata, with their highest number and density in stratum C (Figure 3, Table 1). The total population estimate for cockles at Bowentown Beach was 26.95 million (CV: 5.17%) individuals in 2015–16 (Table 2). The corresponding mean population density was 1799 cockles per m^2. The population contained only a small number of large cockles (≥30 mm shell length), with an estimated 0.03 million (CV: 34.77%) individuals at a mean density of 2 large individuals per m^2. These estimates reflected a continued decline of large-size individuals, and this size class only contributed 0.12% to the total population in 2015–16 (Table 3). Even though the total population showed a marked increase in abundance and density over time, there was a concomitant decrease in large cockles, and their numbers remained low in recent surveys.

There was a also small decrease in the proportion of recruits (≤15 mm shell length), with 19.83% of the population in this size class in 2015–16. The preponderance of medium-sized individuals was evident in the length-frequency distributions that consistently documented a unimodal population, with similar mean and modal shell lengths of less than 20 mm across surveys (Figure 4).

The pipi population at Bowentown Beach was surveyed across the same sampling points as cockles, and most pipi were in stratum B, although few pipi (34 individuals) were sampled overall (Figure 5, Table 4). The pipi population at this site was small, with an estimated 0.15 million (CV: 16.60%) pipi at a mean density of 10 individuals per m^2 (Table 5). These current estimates for both population parameters were less than half the values of the preceding estimates in 2012–13, although the latter included considerable uncertainty (CV: 82.82%). The population in 2015–16 included a small number of large pipi (≥50 mm shell length), with an estimated 0.01 million (CV: 72.82%) individuals in this size class.

Compared with previous surveys, the estimates for large pipi showed an increase, and the proportion of large individuals within the population was 6.21% in 2015–16 (Table 6). Similarly, the proportion of recruits (≤20 mm shell length) showed a slight increase in the current study, with 11.40% of recruits in 2015–16. Nevertheless, the mean pipi shell lengths remained unchanged at about 29 mm, with a decrease in modal size to 22 mm shell length, and a generally unimodal population (Figure 6).

In summary, both cockle and pipi populations at Bowentown Beach contained few large individuals, and this size class showed a marked decrease for the cockle population in 2015–16.

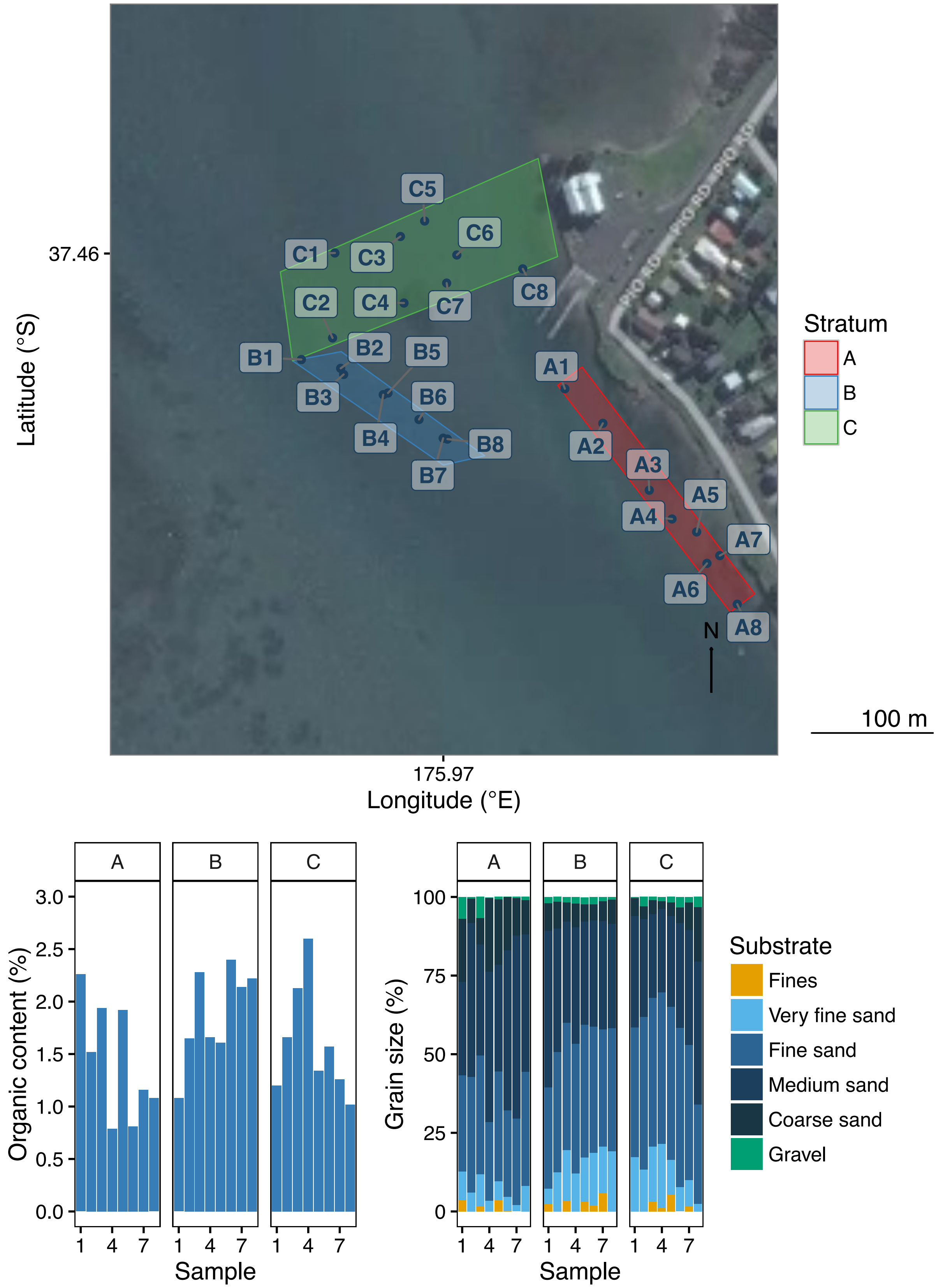


Figure 2: Sediment sample locations and characteristics at Bowentown Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.2 Cockles at Bowentown Beach

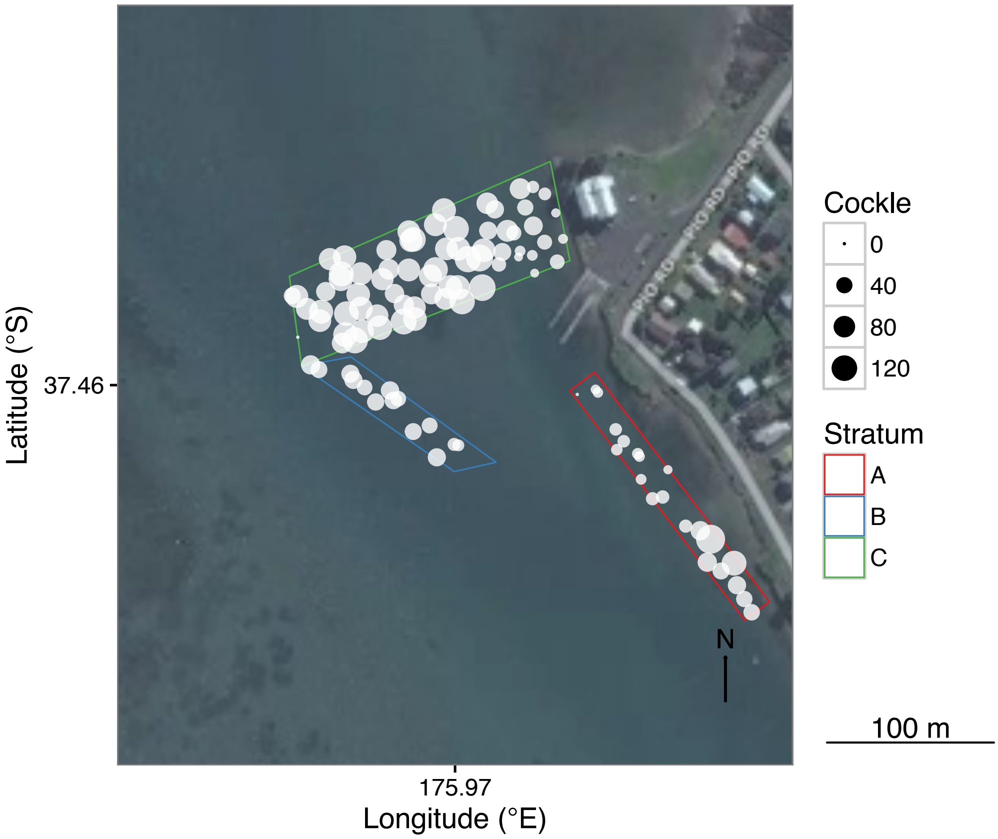


Figure 3: Map of sample strata and individual sample locations for cockles at Bowentown Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Bowentown Beach, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	21	764	3.31	1 039	22.40
B	0.2	14	601	2.71	1 227	7.63
C	1.0	69	5 275	20.93	2 184	5.54

Table 2: Estimates of cockle abundance at Bowentown Beach for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	1.6	4.75	301	5.42	1.41	89	7.61
2010–11	1.6	18.56	1 175	9.18	0.08	5	33.18
2012–13	1.6	25.05	1 586	5.59	0.07	4	42.60
2015–16	1.5	26.95	1 799	5.17	0.03	2	34.77

Table 3: Summary statistics of the length-frequency (LF) distribution of cockles at Bowentown Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of $\leq$15 mm and large individuals by a shell length of $\geq$30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	17.04	20	4–33	35.72	0.44
2012–13	18.60	20	3–32	23.91	0.27
2015–16	18.95	20	6–31	19.83	0.12

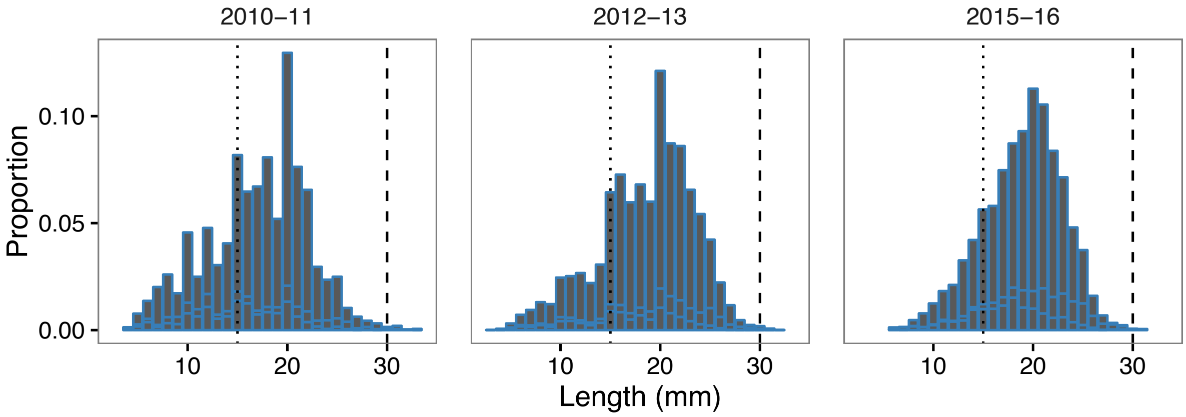


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3 Pipi at Bowentown Beach

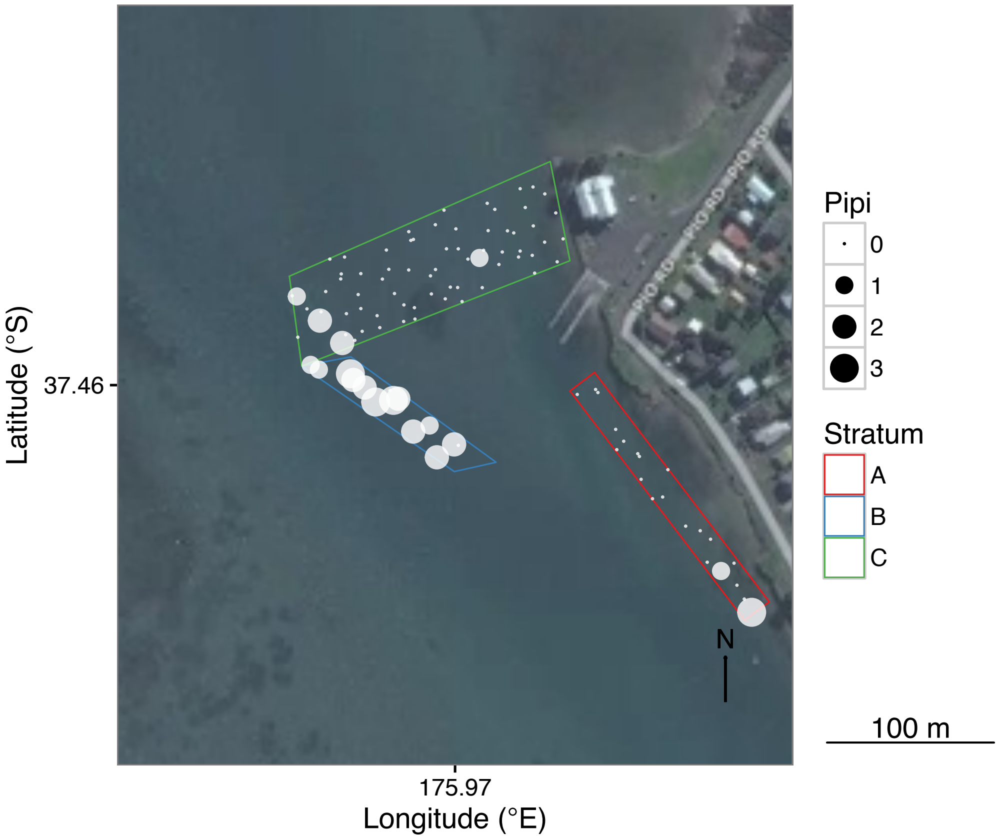


Figure 5: Map of sample strata and individual sample locations for pipi at Bowentown Beach, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 4: Estimates of pipi abundance at Bowentown Beach, by stratum, for 2015–16. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	21	4	0.02	5	77.86
B	0.2	14	24	0.11	49	15.50
C	1.0	69	6	0.02	2	51.69

Table 5: Estimates of pipi abundance at Bowentown Beach for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	1.6	0.01	<1	25.46	0.00	<1	0
2010–11	1.6	0.18	12	22.86	0.00	<1	>100
2012–13	1.6	0.34	21	82.82	0.00	0	
2015–16	1.5	0.15	10	16.60	0.01	<1	72.82

Table 6: Summary statistics of the length-frequency (LF) distribution of pipi at Bowentown Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	24.78	25	13–55	23.97	1.16
2012–13	29.59	27	11–48	6.74	0.00
2015–16	29.53	22	9–57	11.40	6.21

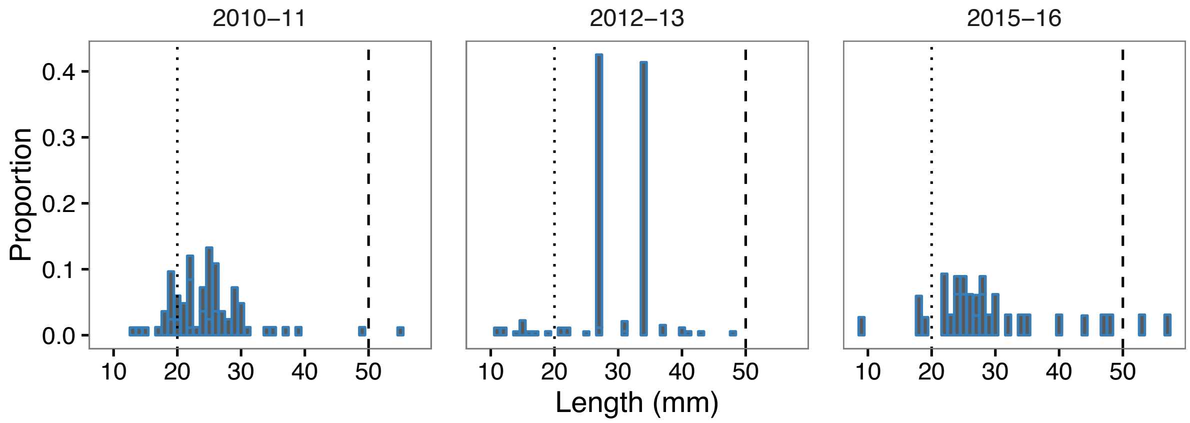


Figure 6: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4 Cheltenham Beach

Cheltenham Beach lies within a small bay in the Auckland metropolitan area, on the eastern side of Devonport. This beach was included in early bivalve surveys before 1999–2000, with the most recent previous assessment in 1998–99 (Morrison & Browne 1999). Sampling in 2015–16 involved a single stratum across the sampling extent, with the latter including the entire intertidal area of the beach (between two headlands), except for a small area at the northern end containing a rocky outcrop (Figure 8, Table 7). The current assessment was based on a total of 80 sampling points. There were no pipi at this site in 2015–16.

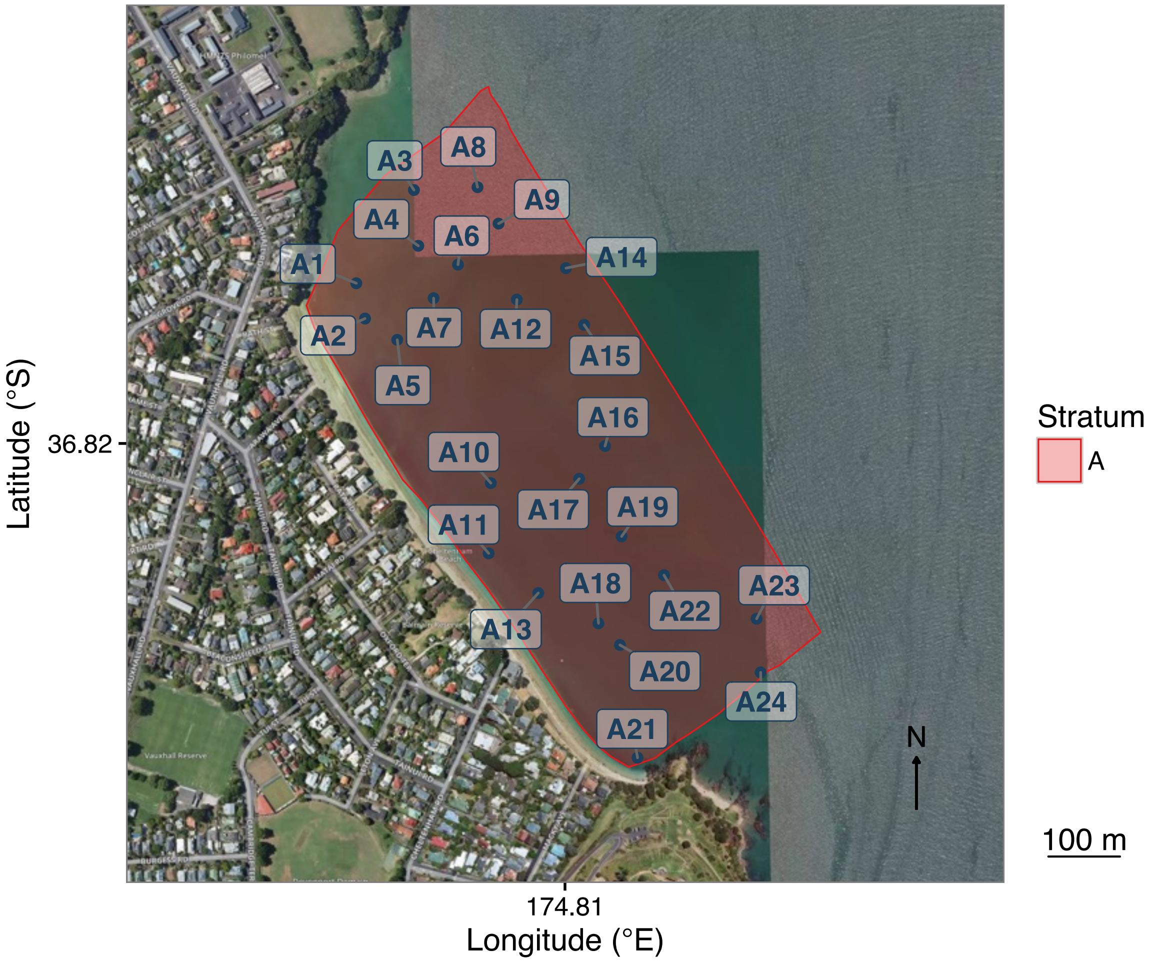
The sediment at Cheltenham Beach was low in organic content, with values below 2.7% across all samples (Figure 7, and see details in Appendix C, Table C-4). Similarly, the proportion of fines (<63 µm grain size) was small with a maximum of 1.4%, and a number of samples lacked this grain size fraction. Overall, the sediment was characterised by very fine (>63 µm grain size) to medium sands (>250 µm grain size), with the respective proportions of these sand fractions varying across sampling points. Only few samples contained gravel (>2000 µm grain size), although this grain size fraction made up 14.4% of sediment in one of the samples at this site.

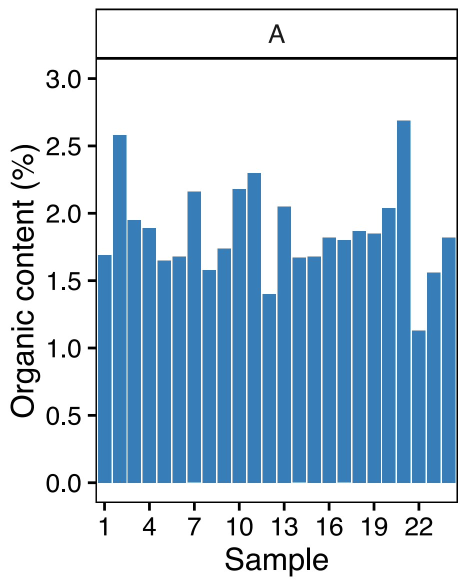
There were few cockles at Cheltenham Beach, with a total of only 14 individuals sampled in 2015–16. Owing to this small sample size, there was considerable uncertainty associated with the population estimates. The estimated total cockle population abundance was 1.60 million individuals and the total population density was 5 cockles per m^2, with a corresponding CV of 66.48% (Table 8). The scarcity of cockles, i.e., the high number of sampling points that contained no cockles (i.e., a large number of zeros in the data) meant that an increase in sampling effort was unlikely to lead to a reduction in the uncertainty.

There were few large cockles (≥30 mm shell length), with an estimated 0.23 million (CV >100%) individuals in this size class; the mean density was <1 individual per m^2. Individuals in this size class comprised 14.29% of the total population. There were no recruits (≤15 mm shell length), indicating that most cockles were of medium size (Table 9, Figure 9). The mean shell length was 25.71 mm, and the modal size was 25 mm shell length, in a unimodal population structure.

The current findings are similar to previous assessments (all conducted before 1999–2000) at Cheltenham Beach, which document low cockle numbers and a lack of recruitment for this and other bivalve species (e.g., pipi). Although Cheltenham Beach was closed to collections in 1992, subsequent surveys documented a continuing decrease in the abundance of large cockles in the late 1990s and a lack of recruits (Morrison & Browne 1999, Morrison et al. 1999). Suggested reasons for the declining bivalve populations include changes in environmental factors that adversely affect juvenile bivalve recruitment, and a decline in the number of spawning adults below a threshold level that would allow population recovery.

Cockles at Cheltenham Beach have also been surveyed as part of the Hauraki Gulf Forum community monitoring programme, but owing to the low number of cockles, this site has not been included in recent community-led surveys (Auckland Council 2013).





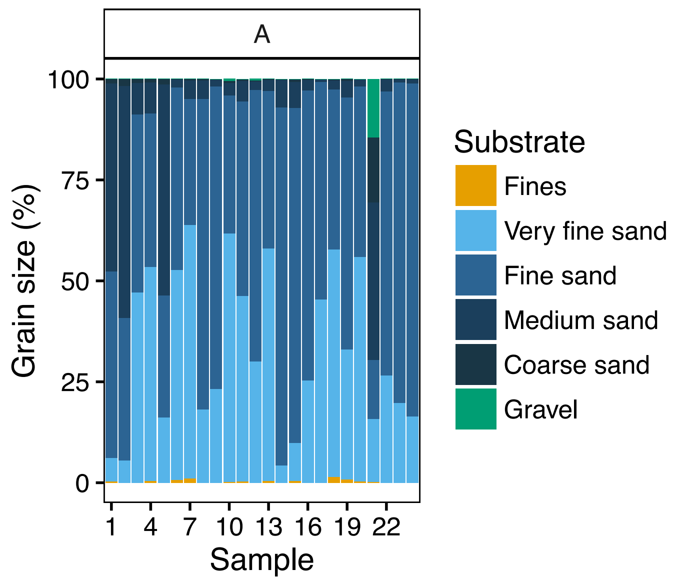


Figure 7: Sediment sample locations and characteristics at Cheltenham Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.5 Cockles at Cheltenham Beach

Figure 8: Map of sample strata and individual sample locations for cockles at Cheltenham Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 7: Estimates of cockle abundance at Cheltenham Beach, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	31.9	80	14	1.60	5	66.48

Table 8: Estimates of cockle abundance at Cheltenham Beach for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2015–16	31.9	1.60	5	66.48	0.23	<1	>100

Table 9: Summary statistics of the length-frequency (LF) distribution of cockles at Cheltenham Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2015–16	25.71	25	20–31	0.00	14.29

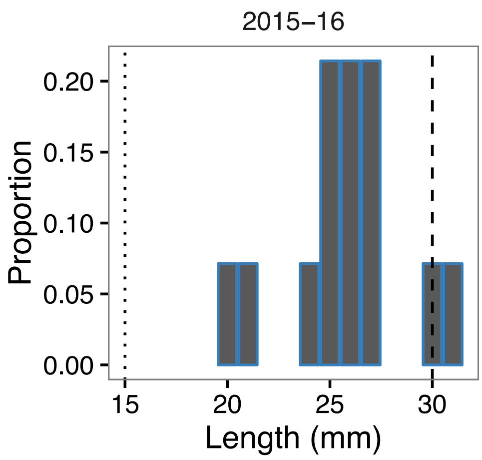


Figure 9: Weighted length-frequency (LF) distribution of cockles for the present survey at Cheltenham Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Cockle Bay

Cockle Bay is a small beach within the metropolitan Auckland area. This beach has been closed to shellfish gathering since 1 October 2008 for the period over summer (1 October to 30 April). A maximum daily bag limit of 50 cockles per gatherer per day applies at other times.

This site was included in four previous surveys, most recently in 2013–14 (see Appendix A, Tables A-1, A-2). The current survey was based on the same sampling extent as recent previous surveys, and involved two strata following re-stratification (Figure 10, Table 10). Across the 82 sampling points, there were only two pipi sampled. Owing to this small sample size, pipi are not further reported on in this section.

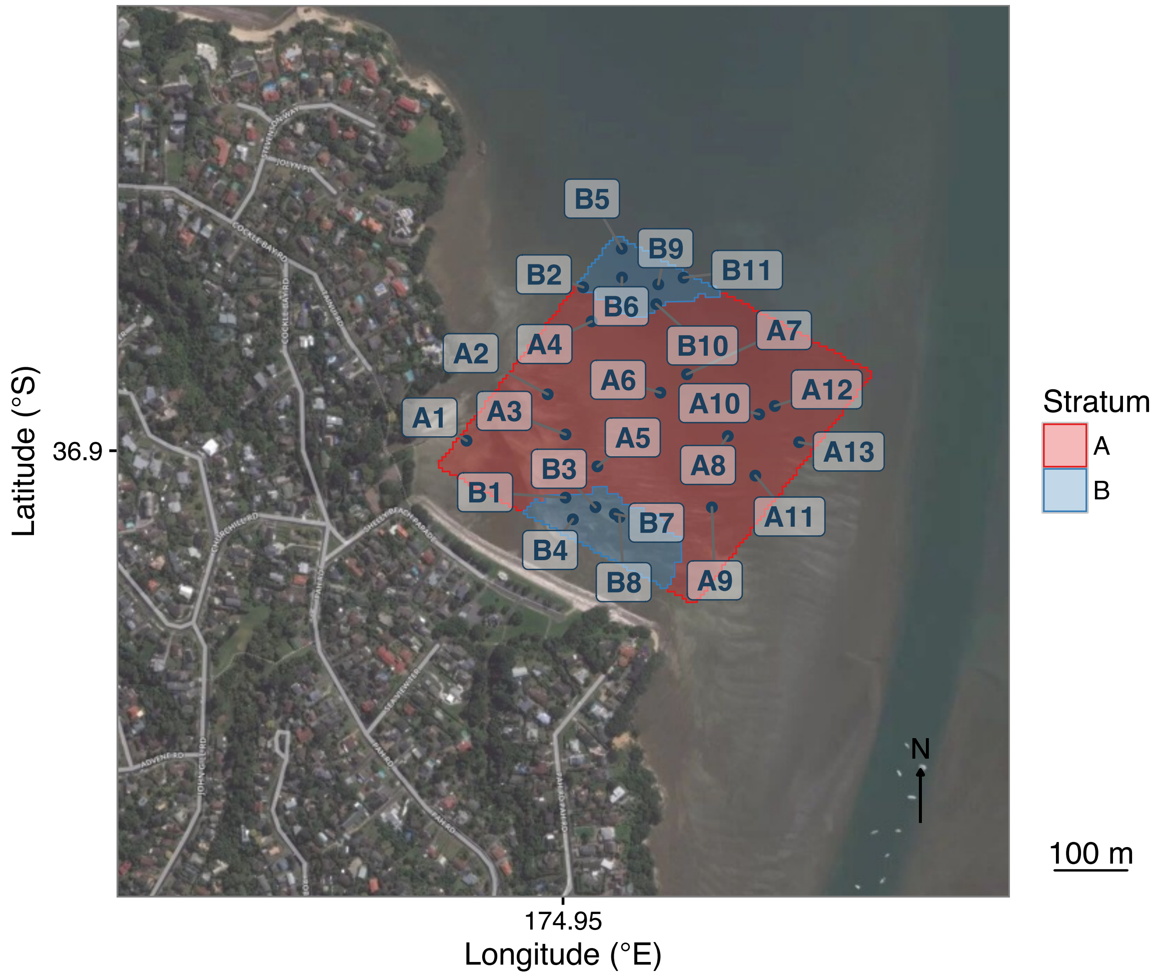
Sediment samples at Cockle Bay were characterised by a low proportion of organic matter, with values ranging from 0.8 to 1.8% (Figure 10, and see details in Appendix C, Table C-4). Sediment grain size distributions showed some variation across sampling points, particularly in the proportions of fines (>63 µm) and gravel (>2000 µm). Although a small number of samples contained no fines, this grain size fraction made up 16.3 to 28.8% of the sediment in four samples. All of the samples included some gravel, and the highest proportion of this grain size fraction across samples was 44.2%.

Most cockles at this site were distributed across stratum A, with fewer cockles in stratum B (Figure 11, Table 10). The total population estimate for this species in 2015–16 was 21.46 million (CV: 8.48%) individuals, with a mean density of 136 cockles per m^2 (Table 11). This population estimate included a substantial number of large cockles (≥30 mm shell length), with an estimated 15.37 million (CV: 10.77%) individuals in this size class. The mean density of large cockles was 98 individuals per m^2. These current estimates for both the total population and the large-cockle size class were lower than estimates in the previous survey in 2013–14. They reflect a continuing decrease in the total population size since 2010–11, although estimates for large cockles showed some variation over this period.

Large cockles contributed an estimated 71.65% of individuals to the total population in 2015–16, and this contribution has been consistently over 60% since 2012–13 (Table 12). At the same time, the proportion of recruits (≤15 mm shell length) was small, with 5.66% of individuals in this size class in 2015–16, similar to the preceding population assessment.

The mean size of cockles at Cockle Bay showed little change in recent surveys, it was 31.82 mm shell length in the current study (Table 12, Figure 12). At the same time, there was an increase in modal size to 37 mm shell length in 2015–16, reflecting the increase in the proportion of large cockles. Length-frequency distributions illustrate the prevalence of large cockles at this site, with a consistently unimodal population showing an increase in the size of individuals since 2012–13.

Cockle Bay is one of the sites included in the Hauraki Gulf Forum community monitoring programme (see for example, Auckland Council 2013). Although this programme uses different methods and a smaller sampling extent, some of the findings are comparable to those in the present survey series. For example, regular community monitoring since 2005 at Cockle Bay documents the presence of large cockles (30 to 35 mm shell length) within the population, and this size class showed marked increases in recent community surveys (i.e., in 2011 and 2012). The community monitoring also shows fluctuations in the cockle population, with an average population density of 201 individuals per m^2, and a density of 339 cockles per m^2 recorded in 2011.



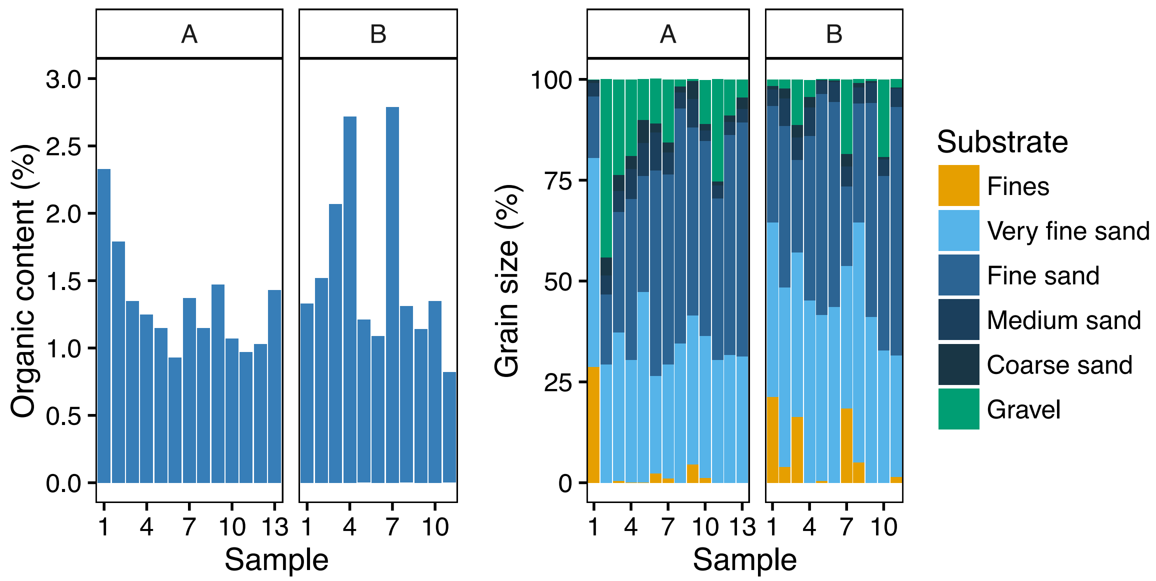


Figure 10: Sediment sample locations and characteristics at Cockle Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.7 Cockles at Cockle Bay

Figure 11: Map of sample strata and individual sample locations for cockles at Cockle Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 10: Estimates of cockle abundance at Cockle Bay, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	13.2	68	373	20.73	157	8.66
B	2.5	14	14	0.73	29	39.22

Table 11: Estimates of cockle abundance at Cockle Bay for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2009–10	16.0	59.54	372	5.60	6.27	39	12.48
2010–11	16.0	72.20	451	5.61	21.29	133	8.15
2012–13	16.0	54.67	342	7.51	36.46	228	8.78
2013–14	15.8	33.68	214	8.14	21.02	133	9.50
2015–16	15.8	21.46	136	8.48	15.37	98	10.77

Table 12: Summary statistics of the length-frequency (LF) distribution of cockles at Cockle Bay. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	30.40	32	6–44	1.53	66.69
2013–14	29.99	34	6–45	6.09	62.41
2015–16	31.82	37	7–50	5.66	71.65

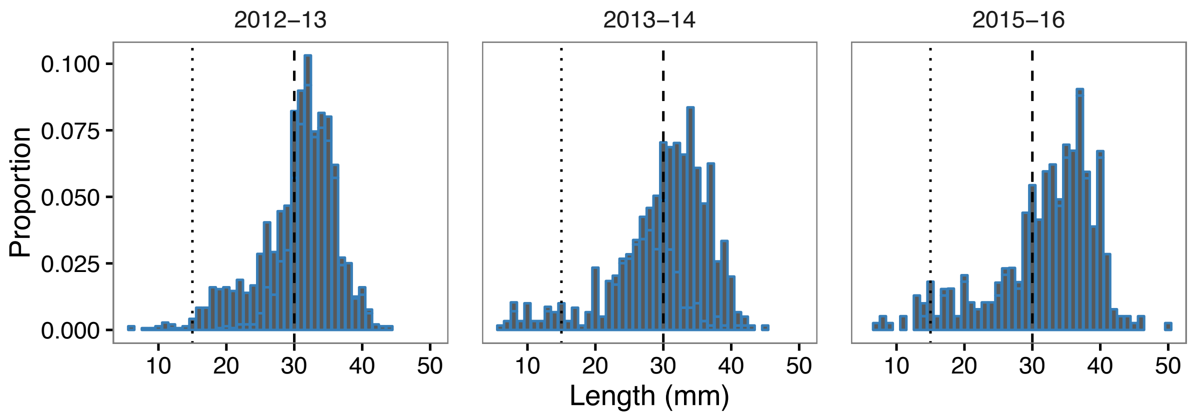


Figure 12: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Cockle Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Little Waihi Estuary

Little Waihi Estuary is a small Bay of Plenty estuary, situated east of Tauranga. Bivalves in this estuary have been surveyed in eight previous population assessments since 2000–01 (see Appendix A, Tables A-1, A-2). Initial surveys were based on a relatively small sampling extent, which was markedly increased in 2009–10. Since then, the sampling extent has remained similar, extending across an area close to the entrance of the estuary. In the current survey, the sampling extent was re-stratified, resulting in two strata, A and B (Figure 13, Table 13). Bivalves were sampled in a total of 192 sampling points, including 82 sampling points in phase 2.

Sediment at Little Waihi Estuary contained little organic matter with a maximum of 2.8% of organic content across all samples (Figure 13, and see details in Appendix C, Table C-4). At the same time, sediment grain size distributions documented a low proportion of fines (grain size <63 µm), with the highest value of 3.1% and a number of samples lacking this size fraction. In general, sediment samples consisted primarily of fine and medium sands (i.e., grain sizes >125 µm and >250 µm), although coarser size fractions were prevalent in several samples, particularly in stratum A. These samples contained up to 62.1% coarse sand (grain size >500 µm) or up to 48.9% gravel (grain size >2000 µm).

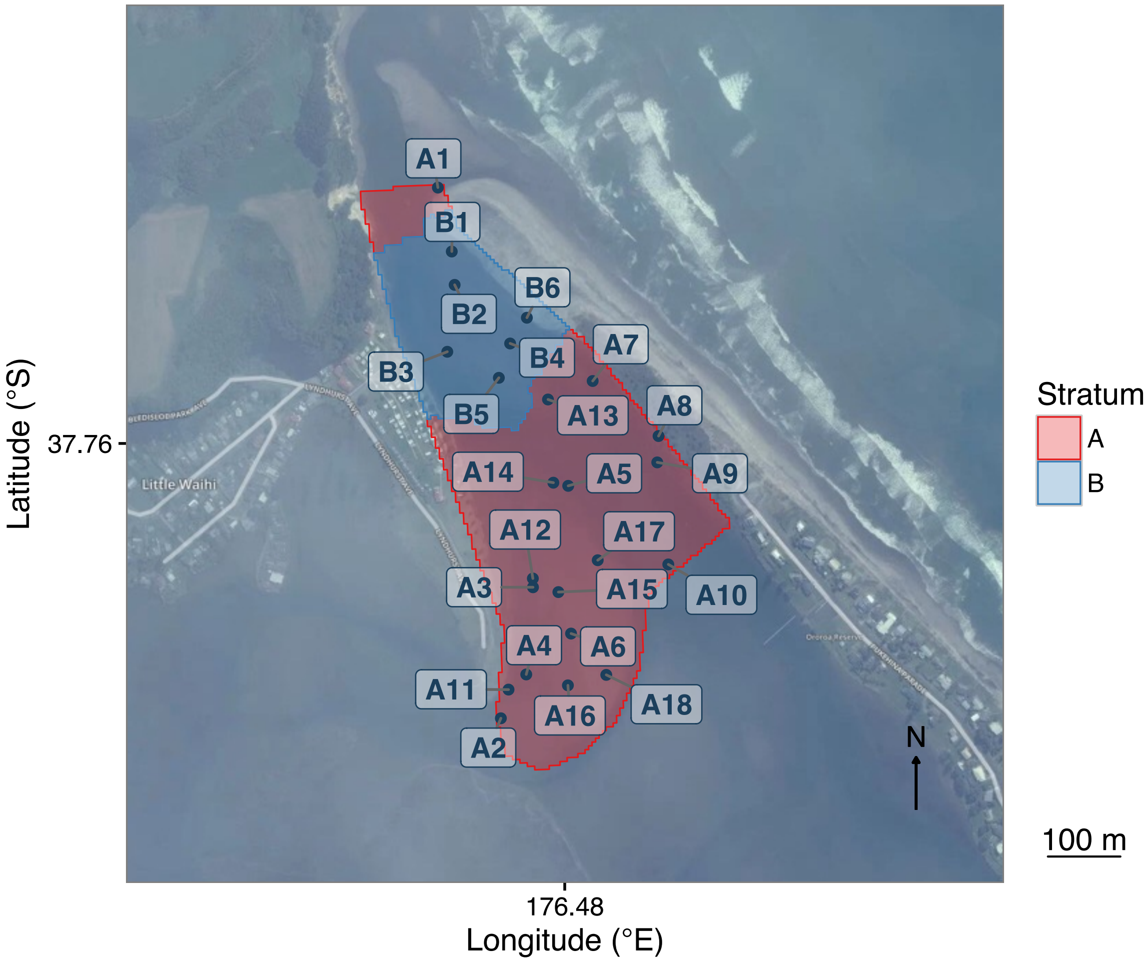
The cockle population in Little Waihi Estuary in 2015–16 was restricted to stratum A, where it was mostly distributed across the south-western side, with fewer cockles in other areas of this stratum (Figure 14, Table 13). There were no cockles in the entrance area of stratum A, nor in stratum B. There were an estimated 30.40 million (CV: 12.74%) cockles in the total population in 2015–16, at a mean density of 165 cockles per m^2 (Table 14). The population included a small number of large cockles (≥30 mm shell length), with an estimated 0.26 million (CV: 51.69%) large individuals. The corresponding mean density was 2 large cockles per m^2. These population estimates were similar to estimates in the preceding survey in 2013–14.

Based on the small number of individuals, the large size class contributed a small proportion (0.86%) of individuals to the total cockle population (Table 15). Instead, the population contained a considerable proportion of recruits (≤15 mm shell length), with 36.45% of individuals in this size class in 2015–16. The small sizes of individuals in the cockle population were reflected in the mean and modal sizes of 17.68 mm and 15 mm shell length, respectively.

These findings were consistent with the two preceding surveys, indicating a cockle population dominated by recruits and medium-sized individuals (Figure 15). A small decrease in the number of recruits in the two most recent surveys resulted in a change from a bimodal to a unimodal cockle population.

Pipi in Little Waihi Estuary were sampled across the same strata as cockles (Figure 16, Table 16). Most of the pipi population was in the north-eastern part of stratum A (but not near the entrance), with few pipi in stratum B. The estimated total population size for this species in 2015–16 was 83.84 million (CV: 16.62%) pipi, occurring at a mean density of 456 individuals per m^2 (Table 17). The population included a small number of large pipi (≥50 mm shell length), with an estimated 2.35 million (CV: 43.62%) large individuals at a mean density of 13 individuals per m^2 (Table 17). The current population estimates reflected marked decreases in the pipi population; both the total population abundance and density were less than half the values than in 2013–14, with a similar decline in the estimates for the large size class.

Within the pipi population, large-sized individuals were only a small component, contributing 2.81% to the total population in 2015–16 (Table 18). In comparison, recruits (≤20 mm shell length) made up 16.01% of the population overall. These data indicate that the majority of the population consisted of medium-sized pipi, and mean and modal shell lengths were 31.88 mm and 32 mm, respectively. The prevalence of medium-sized pipi resulted in a unimodal population size structure, which consistently included recruits and large individuals in recent surveys (Figure 17).



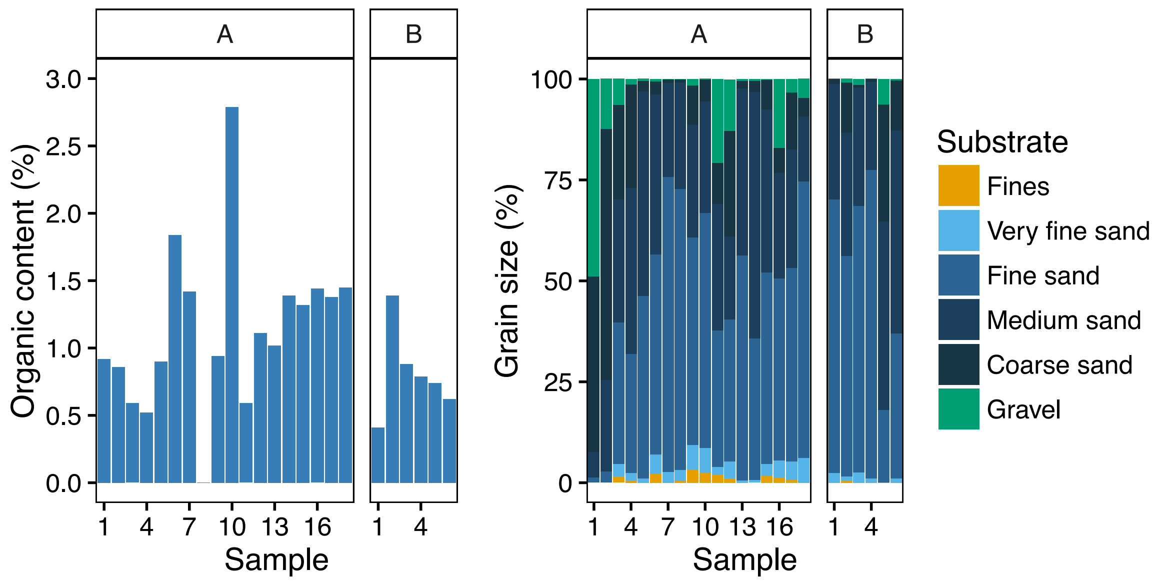


Figure 13: Sediment sample locations and characteristics at Little Waihi Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.9 Cockles at Little Waihi Estuary

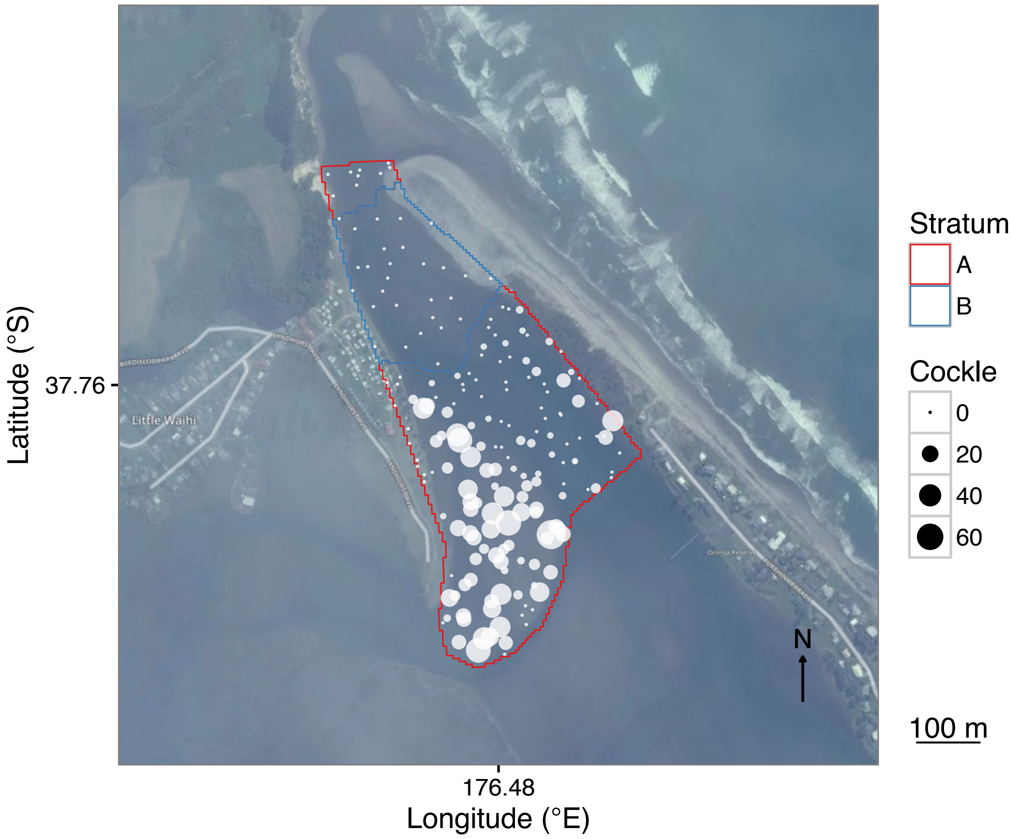


Figure 14: Map of sample strata and individual sample locations for cockles at Little Waihi Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of cockle abundance at Little Waihi Estuary, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	13.6	165	1 290	30.40	223	12.74
B	4.8	27	0	0.00	0	

Table 14: Estimates of cockle abundance at Little Waihi Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	3.0	4.44	148	11.06	0.95	32	9.2
2002–03	3.0	0.96	32	5.98	0.07	2	20.47
2003–04	3.1	3.92	125	8.01	0.40	13	15.92
2004–05	3.8	3.73	99	9.65	0.17	7	18.32
2006–07	3.2	2.09	66	18.32	0.01	<1	>100
2009–10	13.9	20.55	148	16.57	0.08	<1	76.43
2012–13	15.4	17.77	115	18.58	0.20	1	56.95
2013–14	17.1	27.32	160	16.62	0.35	2	59.9
2015–16	18.4	30.40	165	12.74	0.26	2	51.69

Table 15: Summary statistics of the length-frequency (LF) distribution of cockles at Little Waihi Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of $\leq$15 mm and large individuals by a shell length of $\geq$30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	15.72	20	2–45	45.25	1.15
2013–14	17.77	22	6–33	35.50	1.27
2015–16	17.68	15	4–35	36.45	0.86

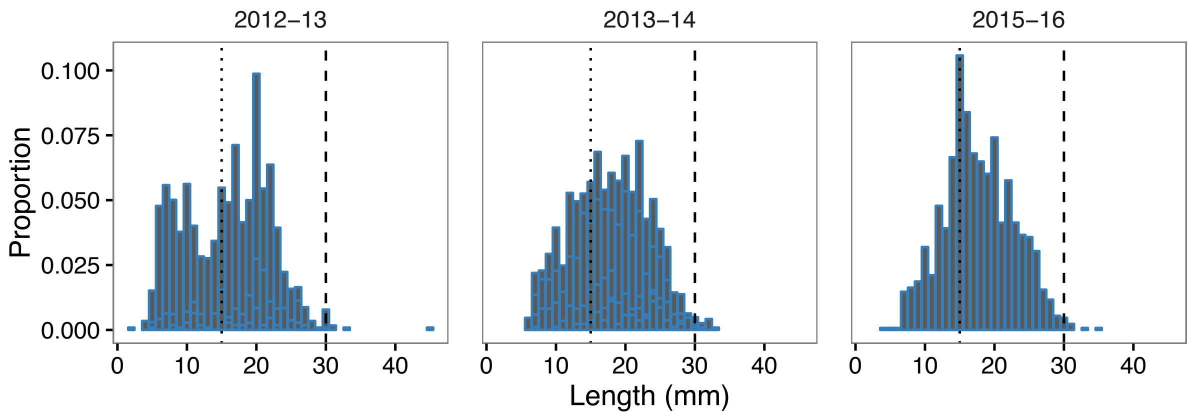


Figure 15: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10 Pipi at Little Waihi Estuary

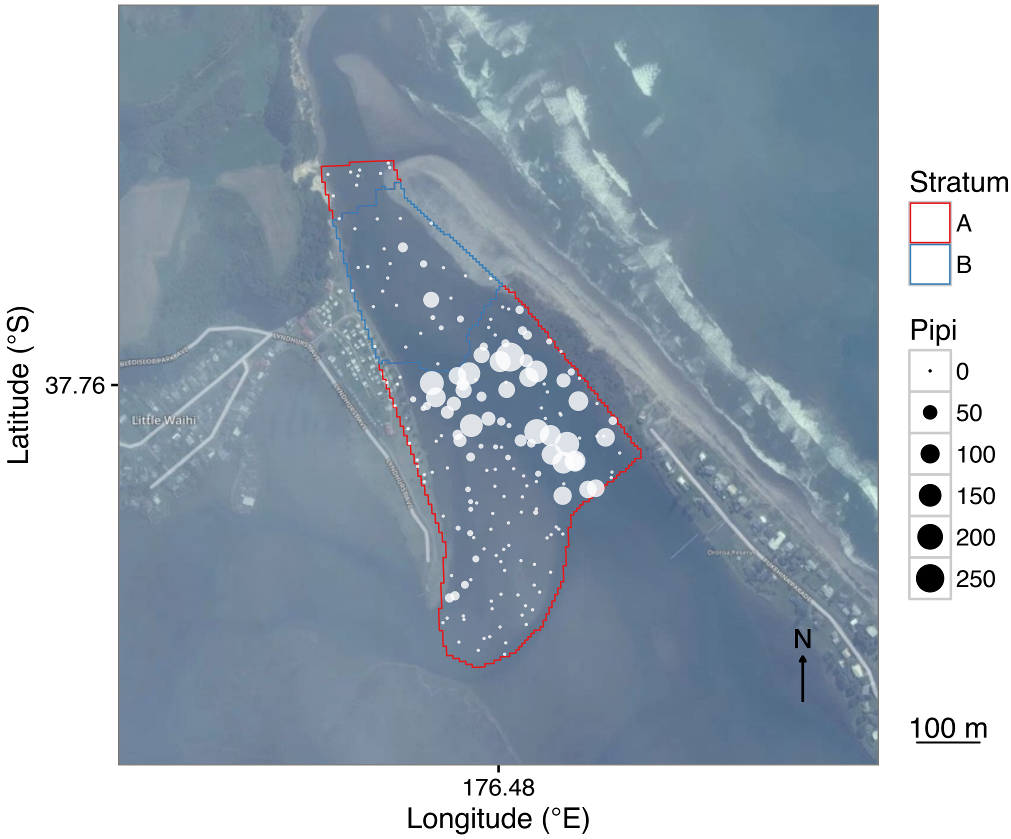


Figure 16: Map of sample strata and individual sample locations for pipi at Little Waihi Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 16: Estimates of pipi abundance at Little Waihi Estuary, by stratum, for 2015–16. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	13.6	165	3 358	79.14	581	17.12
B	4.8	27	93	4.69	98	69.31

Table 17: Estimates of pipi abundance at Little Waihi Estuary for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	3.0	28.69	956	8.78	3.74	125	8.46
2002–03	3.0	5.82	194	7.38	0.48	16	9.56
2003–04	3.1	7.05	226	9.15	0.84	27	13.52
2004–05	3.8	48.00	1 280	6.16	1.90	51	10.25
2006–07	3.2	44.52	1 409	7.47	2.00	75	10.76
2009–10	13.9	271.99	1 954	11.54	10.12	90	20.25
2012–13	15.4	219.43	1 423	7.88	10.26	67	27.03
2013–14	17.1	170.82	1 000	12.70	4.58	27	31.30
2015–16	18.4	83.84	456	16.62	2.35	13	43.62

Table 18: Summary statistics of the length-frequency (LF) distribution of pipi at Little Waihi Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of $\leq$20 mm and large individuals by a shell length of $\geq$50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	33.16	40	5–59	15.32	4.68
2013–14	31.49	42	8–57	17.71	2.68
2015–16	31.88	32	5–57	16.01	2.81

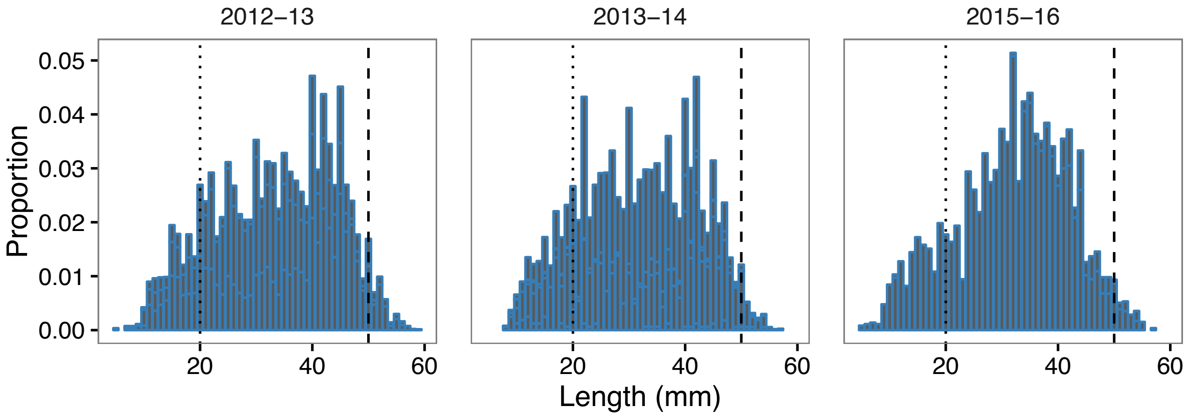


Figure 17: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Marokopa Estuary

Marokopa Estuary is a small estuary on the Waikato west coast. This site was included in two previous bivalve surveys, in 2005–06 and 2010–11 (see Appendix A, Tables A-1, A-2). Sampling at this site has focused on three strata A to C within the main channel of the estuary (Figure 18, Table 19). In 2015–16, bivalves were sampled in a total of 90 sampling points across the three strata. As there were only 18 cockles sampled across all sampling points, cockles are not further reported on in this section.

Pipi were abundant in strata B and C, with few pipi in stratum A. The total population estimate for this species was 8.62 million (CV: 11.26%) pipi in 2015–16 (Table 20). The corresponding mean density was 333 pipi per m^2. Both population estimates were a marked increase from previous estimates. There were no large pipi ($\geq$50 mm shell length) in the population, and this finding was consistent across the three surveys conducted at this site.

In contrast, recruits ($\leq$20 mm shell length) contributed 27.71% of individuals to the total population in 2015–16, and this value was similar to the proportion of recruits in the preceding survey (Table 21). Similarly, mean pipi size was consistent with the previous assessment at 27.35 mm shell length. Nevertheless, there was an increase in modal size in 2015–16 to 40 mm shell length. Length-frequency distributions highlight the increasing proportion of recruits in the pipi population in the two most recent surveys (Figure 19). Initially, there were few individuals in this size class, and the pipi population was unimodal in 2005–06. Since then, the proportion of recruits made up a second mode, resulting in a bimodal population in 2010–11, with less distinct modes in 2015–16.

Overall, the pipi population at Marokopa Estuary has consistently been dominated by medium-sized pipi, lacking large individuals. Information from local residents (e.g., K. Hohaia, pers. comm.) confirmed this finding, and indicated that pipi at Marokopa Estuary are characterised by their medium size.

3.12 Pipi at Marokopa Estuary

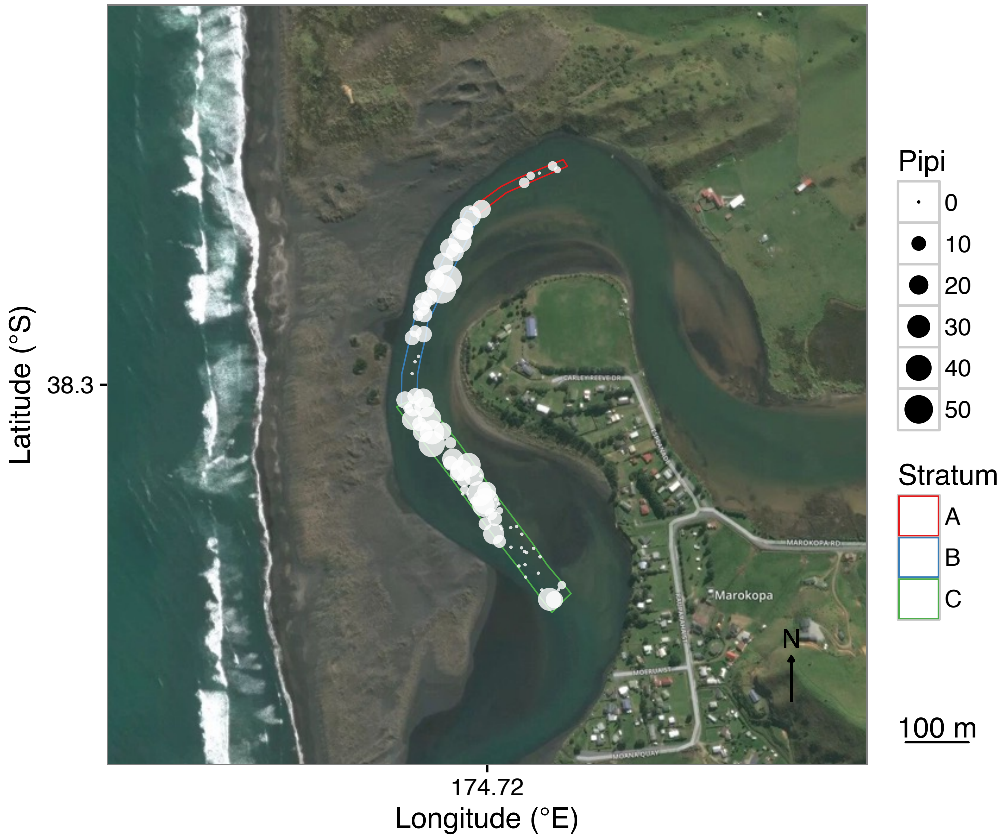


Figure 18: Map of sample strata and individual sample locations for pipi at Marokopa Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of pipi abundance at Marokopa Estuary, by stratum, for 2015–16. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.2	7	28	0.24	114	60.01
B	0.7	26	432	3.34	475	15.56
C	1.7	57	602	5.03	302	16.02

Table 20: Estimates of pipi abundance at Marokopa Estuary for all sizes and large size ($\geq$50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population $\geq$ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2005–06	2.4	4.34	185	9.24	0.00	0	
2010–11	2.4	3.03	129	15.03	0.00	0	
2015–16	2.6	8.62	333	11.26	0.00	0	

Table 21: Summary statistics of the length-frequency (LF) distribution of pipi at Marokopa Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2005–06	31.13	33	9–45	3.67	0.00
2010–11	27.41	30	7–47	30.80	0.00
2015–16	27.35	40	8–46	27.71	0.00

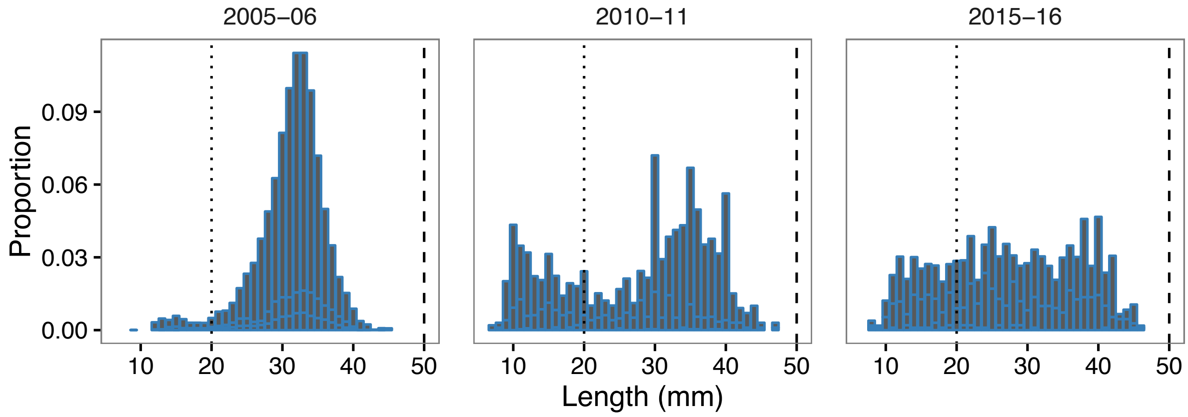


Figure 19: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Marokopa Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.13 Ohiwa Harbour

Ohiwa Harbour is a large estuary in Bay of Plenty. Bivalves at this site have been assessed in five previous assessments, most recently in 2012–13 (see Appendix A, Tables A-1, A-2). Across surveys, bivalve sampling at this site has generally focused on Motuotu Island, which is located in the eastern part of the harbour, just south of the entrance. The island is surrounded by two channels, the main harbour channel to the north and west, and a second, large channel (“Kutarere channel”) on the eastern side.

Throughout the survey series, the sampling extent at Motuotu Island has consisted of disjunct strata that predominantly targeted cockles or pipi. Movement of the two channels has frequently led to changes in strata and sampling extent. The two main cockle strata have been relatively consistent in recent surveys, involving two areas south-east of the island, extending along the edge of Kutarere channel. Pipi strata have been located at the northwestern and northern edge of the intertidal sandflat that extends northwards from the island, with some changes in their location and sizes across surveys.

In the present study, one of the previous cockle strata (stratum A) was moved upshore as movement of Kutarere channel since the preceding 2012–13 survey resulted in submergence of large parts of the stratum area, so that most sampling points were inaccessible (i.e., deeper than 0.5 m depth at low tide); few (12) cockles were found at the nine sampling points that were accessible. For this reason, this stratum was moved sideways, placing it directly adjacent and parallel to its previous location.

In addition, changes to the channel at the northeastern end of the island’s sandflat made two previous pipi strata inaccessible, and no pipi were found during the pre-survey reconnaissance. Information from local pipi gatherers and recreational estuary users confirmed that pipi in this area had disappeared recently (i.e., within the past 18 months), and indicated that another area supported a substantial pipi bed. This area was next to a sandbank within Kutarere channel, and included as a new stratum in the present study. Overall, the 2015–16 survey involved five strata and a total of 125 sampling points across the sampling extent (Figure 20, Table 22).

The sediment in the cockle strata at Ohiwa Harbour was generally low in organic content (less than 4%), and also in the proportion of sediment fines (grain size <63 µm) (Figure 20, and see details in Appendix C, Table C-4). The most prevalent grain size was fine sand (grain size >125 µm), followed by very fine sand (grain size >63 µm), although a number of samples also included gravel (grain size >2000 µm). The highest proportion of this coarse sediment grain size was 32.3%.

Cockles at Ohiwa Harbour occurred in four of the five strata, with highest abundances in strata A and B (Figure 21, Table 22). Based on the survey data, there were an estimated 23.01 million (CV: 14.33%) cockles in the total population at this site in 2015–16, and the estimated mean density was 683 cockles per m^2 (Table 23). The population included few large cockles ($\geq$30 mm shell length), with an estimated abundance of 0.26 million (CV: 30.87%) individuals in this size class, at a mean density of 10 large cockles per m^2. These current population estimates were the highest values in the survey series, even though the sampling extent differed across some of the surveys, including smaller and also larger sampling areas than used in the current study.

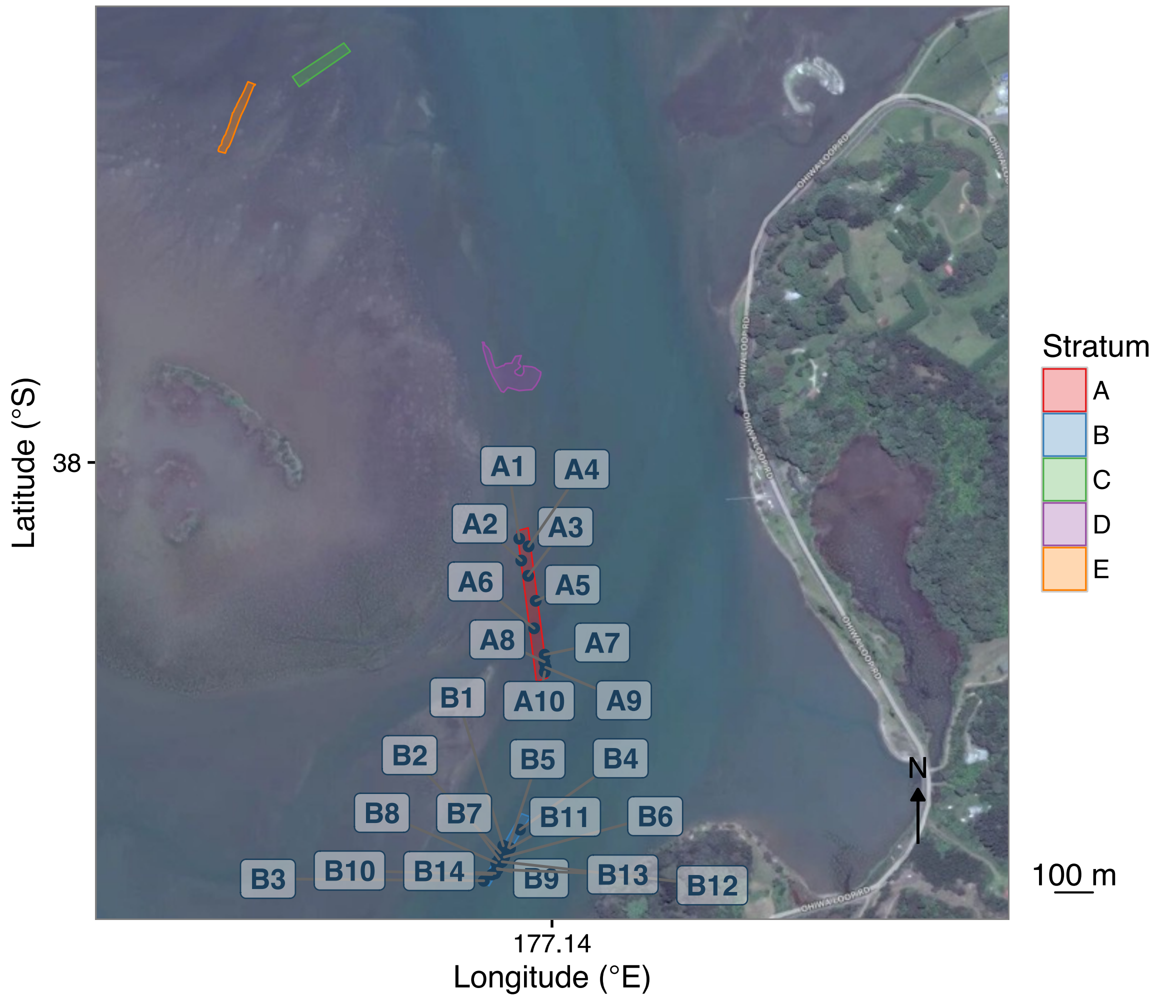
Large cockles only made up a small part of the total population with 1.13% of individuals in this size class (Table 24, Figure 22). In contrast, recruits ($\leq$15 mm shell length) constituted 25.08% of the total population, a slight decrease from 33.31% in the previous survey in 2012–13. Mean and modal sizes of 19.17 mm and 22 mm shell length, respectively reflected the prevalence of recruits and small individuals within the population. Considering length-frequency distributions from the three recent surveys, recruits and medium-sized individuals consistently dominated the population structure, including in 2015–16, when recruits constituted a second, small cohort in the previously unimodal population.

The pipi population at Ohiwa Harbour was concentrated in two strata, D and E, with few pipi in the remaining strata (Figure 23, Table 25). Stratum D included the newly-added pipi bed, whereas stratum E was also part of previous surveys. The total population size of pipi at this site was estimated at 41.26 million (CV: 12.10%) individuals, with an estimated mean density of 1225 individuals per m^2 (Table 26).

These population estimates were similar to estimates in 2012–13, although the current sampling extent was larger than in the preceding assessment. There was a considerable number of large pipi ($\geq$50 mm shell length) included in the population, with an abundance estimate of 3.70 million (CV: 18.37%) large individuals, and a mean density of 110 large pipi per m^2. These estimates for the large size class were substantially (about three times) higher than the preceding values, although there has been some fluctuation across surveys.

The increase in large pipi was also evident in their increasing proportion in the total population, which was 8.96% in 2015–16 (Table 27, Figure 24). Nevertheless, recruits ($\leq$20 mm shell length) continued to make up the main part of the pipi population at Ohiwa Harbour, with 53.42% of individuals in this size class. Mean and modal shell lengths were 25.71 mm and 20 mm, respectively. The large number of recruits was evident in their strong cohort, with a second, smaller cohort of medium-size and large pipi in the bimodal population. This population structure was similar to that in the previous assessment in 2012–13.

Previous surveys included strata C and E to sample pipi (Pawley 2011, Pawley & Smith 2014). Stratum C used to be situated next to the channel at the northwestern edge of the sandflat, but substantial changes in the morphology and substrate of this area meant that this stratum was 100 m distance from the channel in 2012–13 (Pawley & Smith 2014). It remained in the middle of the intertidal sandflat in the current study, with only five pipi sampled in this stratum. The preceding assessment in 2012–13 included a new stratum at the channel edge (termed ”F”), which supported high numbers of predominantly small pipi. This stratum was included in the current study (stratum E) and continued to support a dense bed of small-sized and juvenile pipi.



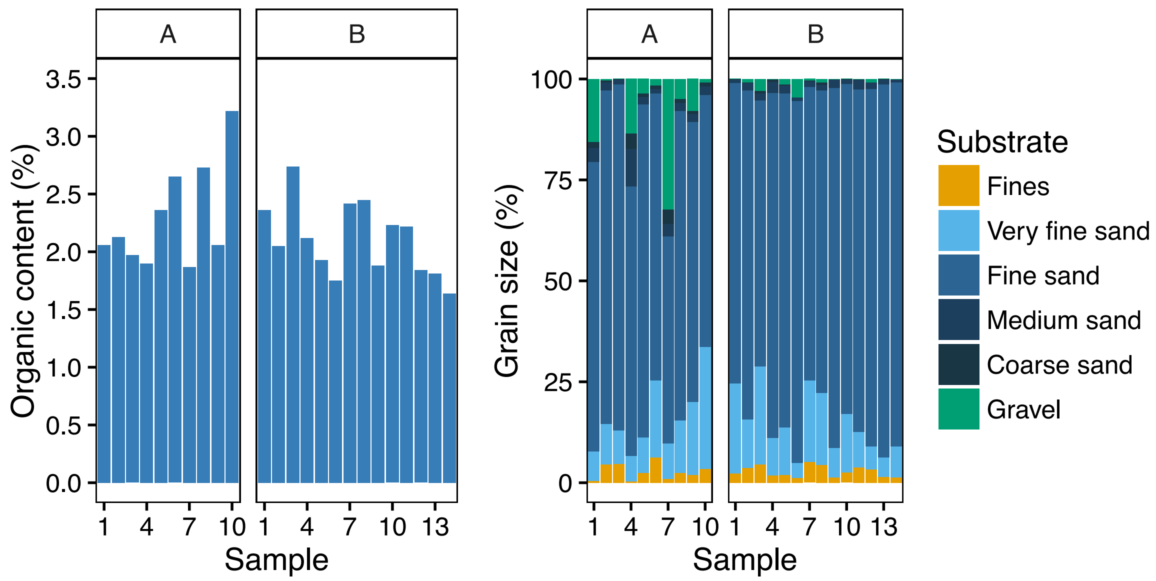


Figure 20: Sediment sample locations and characteristics at Ohiwa Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.14 Cockles at Ohiwa Harbour

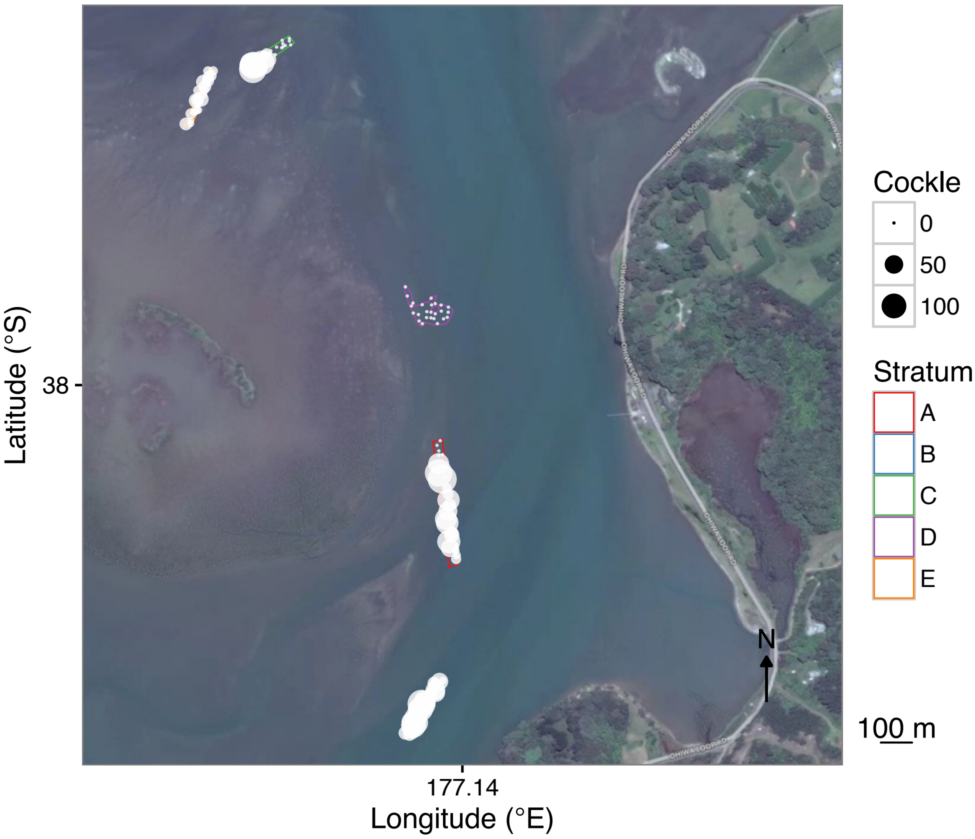


Figure 21: Map of sample strata and individual sample locations for cockles at Ohiwa Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 22: Estimates of cockle abundance at Ohiwa Harbour, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	1.2	24	856	12.20	1 019	24.23
B	0.5	32	1 285	5.32	1 147	14.54
C	0.5	23	672	4.03	835	30.21
D	0.8	25	0	0.00	0	
E	0.4	21	259	1.45	352	15.03

Table 23: Estimates of cockle abundance at Ohiwa Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	2.2	4.53	201	7.82	0.16	7	22.37
2005–06	2.7	3.69	137	7.07	0.17	9	15.69
2006–07	5.7	17.48	307	10.59	1.12	20	14.47
2009–10	2.1	6.47	308	8.79	0.03	1	51.49
2012–13	2.6	9.05	344	10.49	0.05	3	36.42
2015–16	3.4	23.01	683	14.33	0.26	10	30.87

Table 24: Summary statistics of the length-frequency (LF) distribution of cockles at Ohiwa Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	17.20	20	5–35	35.11	0.51
2012–13	17.41	20	4–31	33.31	0.56
2015–16	19.17	22	5–33	25.08	1.13

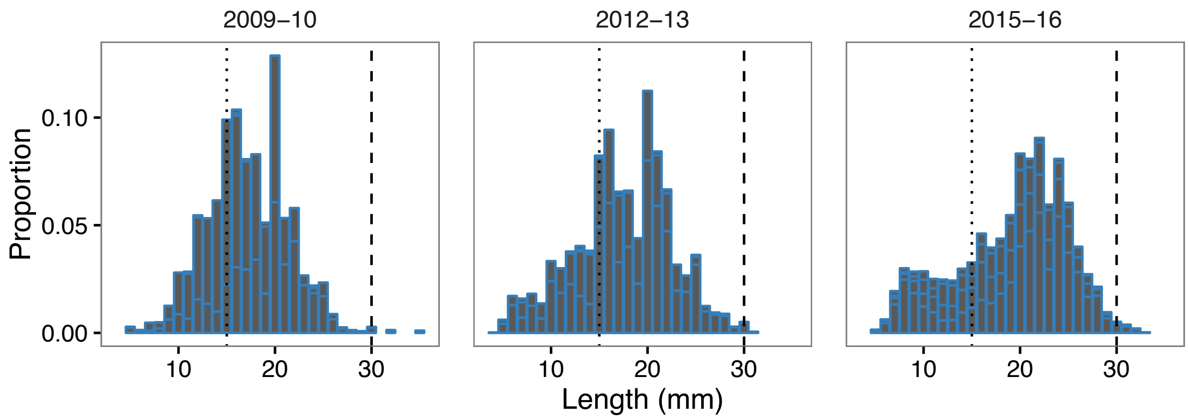


Figure 22: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ohiwa Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.15 Pipi at Ohiwa Harbour

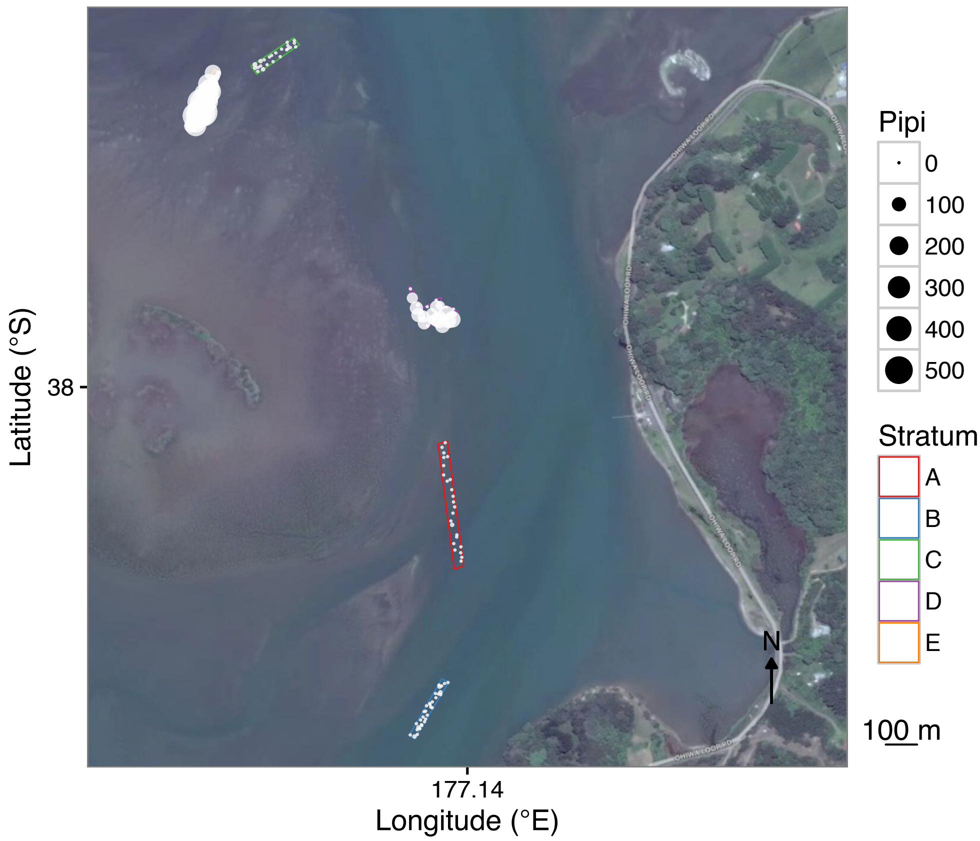


Figure 23: Map of sample strata and individual sample locations for pipi at Ohiwa Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 25: Estimates of pipi abundance at Ohiwa Harbour, by stratum, for 2015–16. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	1.2	24	1	0.01	1	>100
B	0.5	32	4	0.02	4	47.52
C	0.5	23	5	0.03	6	49.73
D	0.8	25	1 267	11.73	1 448	18.18
E	0.4	21	5 246	29.46	7 137	15.31

Table 26: Estimates of pipi abundance at Ohiwa Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	2.2	5.67	252	6.88	2.14	95	7.46
2005–06	2.7	3.40	126	7.27	2.52	93	6.36
2006–07	5.7	8.27	145	10.52	2.14	79	13.78
2009–10	2.1	15.25	726	14.46	1.63	78	18.77
2012–13	2.6	41.59	1 581	14.39	1.03	39	31.52
2015–16	3.4	41.26	1 225	12.10	3.70	110	18.37

Table 27: Summary statistics of the length-frequency (LF) distribution of pipi at Ohiwa Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	39.87	45	10–58	1.27	10.79
2012–13	26.81	12	3–56	50.22	2.48
2015–16	25.71	20	7–64	53.42	8.96

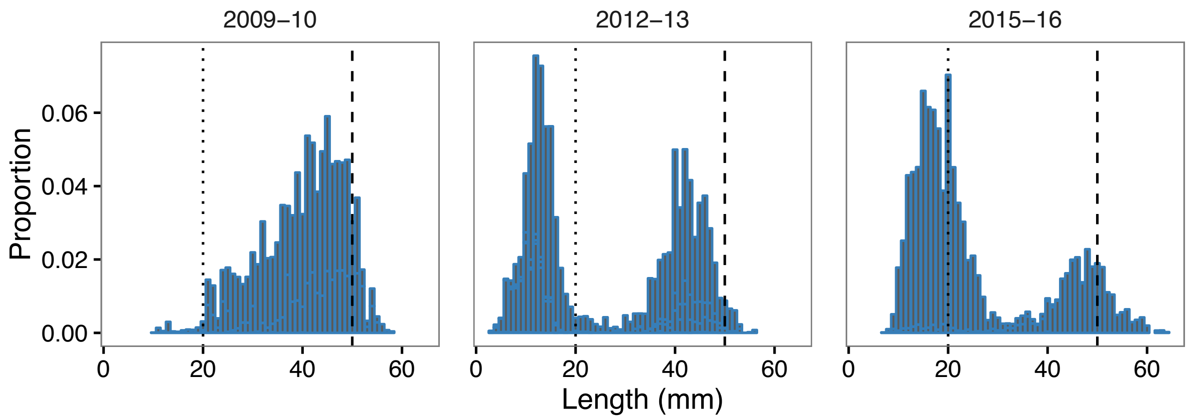


Figure 24: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ohiwa Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.16 Okoromai Bay

Okoromai Bay is a southern bay on Whangaparoa Peninsula, north of Auckland. This site has been frequently included in the bivalve surveys, with the most recent previous assessment in 2013–14 (see Appendix A, Tables A-1, A-2). The sampling extent has remained consistent throughout the survey series, containing two strata A and B. In the current study, the sampling extent was re-stratified, but retained two strata (Figure 25, Table 28). There was a total of 110 sampling points across the sampling extent.

The sediment sampling at this site documented sediment that had a consistently low organic content of less than 3% (Figure 25, and see details in Appendix C, Table C-4). The proportion of fines (grain size <63 µm) varied across samples, from none to 8.6%. The dominant grain size fractions were very fine and fine sands (grain sizes >65 µm and >125 µm, respectively), with no or little sediment in the other size fractions.

Cockles at this site were distributed across most of the sampling extent, with their highest abundance in the southwestern part of stratum A (Figure 26). The total population estimate in 2015–16 was 34.78 million (CV: 19.45%) cockles, and their estimated mean density was 175 individuals per m^2 (Table 29). Both estimates were increases from the previous survey, and the highest estimates since 1999–2000. Similarly, large cockles ($\geq$ 30 mm shell length) showed a population increase in 2015–16, doubling between the preceding and the current survey to 8.48 million (CV: 19.44%) large cockles at an estimated mean density of 43 large individuals per m^2.

Large cockles constituted about a quarter of the population in 2015–16, with 24.37% large individuals in the total cockle population (Table 30). At the same time, recruits ($\leq$15 mm shell length) also contributed a considerable proportion of the population, with 29.64% of individuals in this size class. The mean shell length was similar to the preceding cockle size at 21.73 mm, while the modal size showed an increase at 16 mm shell length in 2015–16.

Considering the cockle population structure across the three most recent surveys, the population changed from a unimodal length-frequency distribution with a strong mode of large cockles in 2012–13 to a bimodal population consisting of two smaller modes of recruits and large individuals in the current survey in 2015–16 (Figure 27).

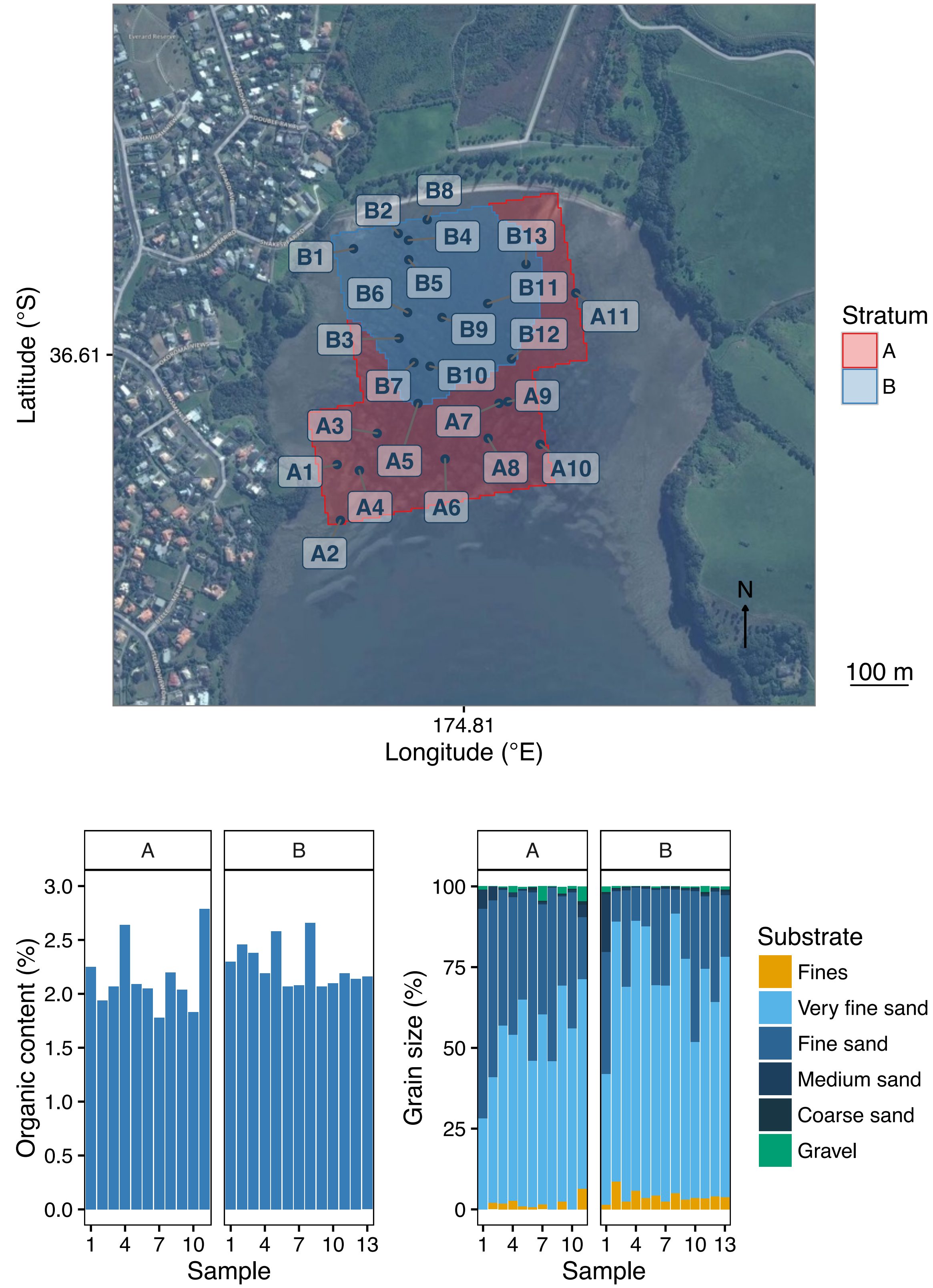


Figure 25: Sediment sample locations and characteristics at Okoromai Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.17 Cockles at Okoromai Bay

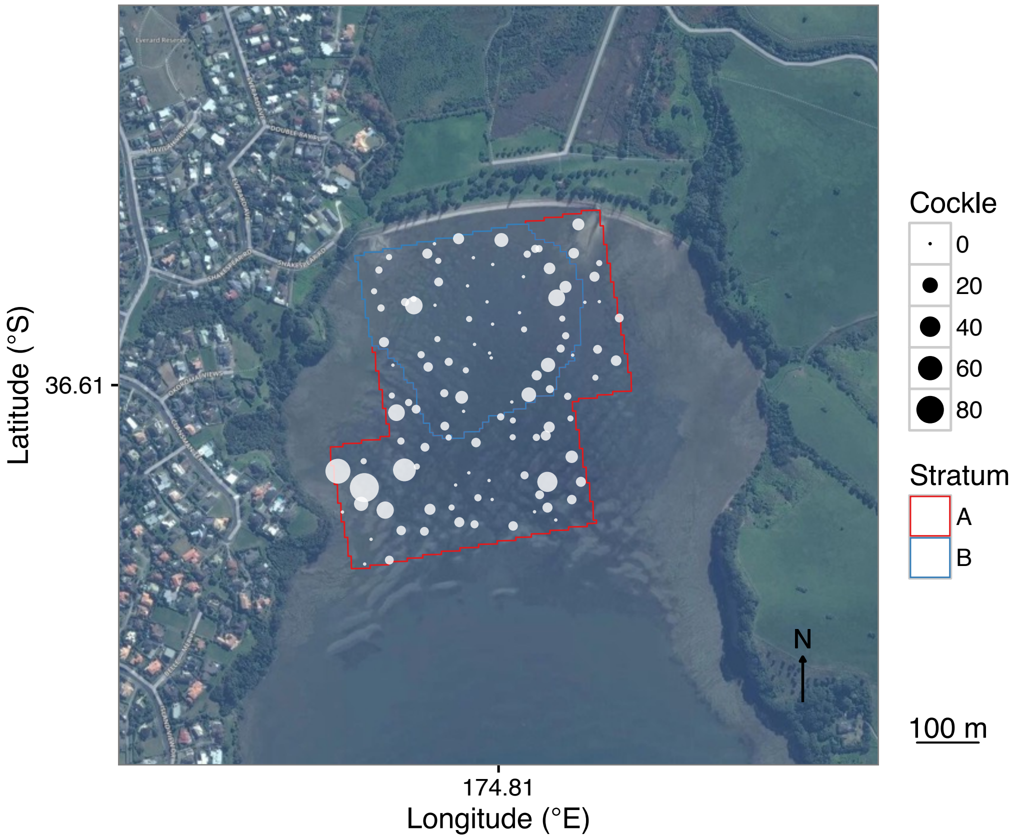


Figure 26: Map of sample strata and individual sample locations for cockles at Okoromai Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 28: Estimates of cockle abundance at Okoromai Bay, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	11.0	60	464	24.24	221	26.39
B	8.9	50	208	10.54	119	20.89

Table 29: Estimates of cockle abundance at Okoromai Bay for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	20.0	90.05	450	4.26	24.38	122	5.30
2001–02	24.0	27.26	114	7.78	8.66	36	8.31
2002–03	20.0	26.86	134	5.10	7.05	35	6.56
2003–04	20.0	27.96	140	11.48	12.01	60	10.62
2004–05	20.0	34.50	172	7.44	13.80	69	4.37
2006–07	20.0	17.39	87	9.08	7.03	35	12.18
2009–10	20.0	29.62	148	9.60	13.07	65	10.84
2012–13	20.0	28.50	142	10.61	13.61	68	11.92
2013–14	19.8	28.14	142	12.69	4.48	23	19.47
2015–16	19.8	34.78	175	19.45	8.48	43	19.44

Table 30: Summary statistics of the length-frequency (LF) distribution of cockles at Okoromai Bay. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	27.79	30	5–45	6.83	47.75
2013–14	21.38	12	7–39	28.09	15.91
2015–16	21.73	16	6–41	29.64	24.37

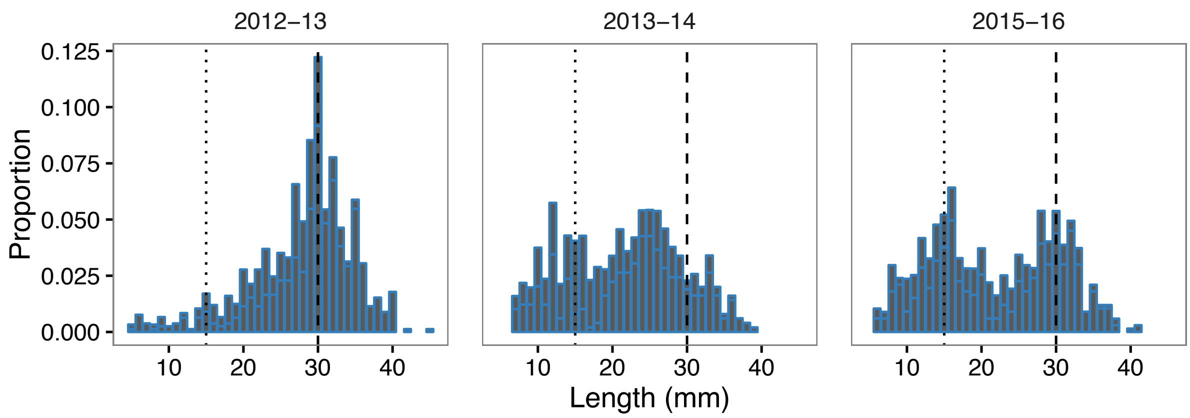


Figure 27: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Okoromai Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.18 Pataua Estuary

Pataua Estuary is in Northland, north of Whangarei. This estuary has been included in five previous bivalve surveys, most recently in 2013–14 (see Appendix A, Tables A-1, A-2). In this preceding survey, the sampling extent was extended relative to earlier surveys to include the cockle beds in the western strata in their entirety. In the current study, the sampling extent was re-stratified, resulting in three western strata on intertidal mudflats, and one stratum within the channel close to the estuary entrance (Figure 28, Table 31). Across the sampling extent, bivalves were assessed in a total of 150 sampling points.

Sediment in the cockle strata was relatively low in organic content, with values ranging between 1.4 and 5.5% (Figure 28, and see details in Appendix C, Table C-4). Although the sediment consisted primarily of fine sand (grain size >250 µm), there was some variation in the grain size distributions across samples, particularly in the proportions of fines (grain size <63 µm) and gravel (grain size >2000 µm). Fines were present at all but one sampling point, with a maximum of 12.9% recorded in one sample. At the same time, all samples contained gravel, including relatively high values, to a maximum of 77.0% at one sampling point in stratum A.

The cockle population was distributed throughout strata A and B, with a considerably greater abundance and density in the latter stratum (Figure 29, Table 31). There were few cockles (i.e., five individuals each) in the remaining strata. The total cockle population size was estimated at 380.13 million (CV: 7.58%) individuals in 2015–16, with a corresponding mean density of 1368 cockles per m^2 (Table 32). Population estimates based on a sampling extent similar to previous surveys included a total of 138.14 million cockles (CV: 13.33%) at a mean density of 1371 cockles m^2. There was a small number of large cockles ($\geq$30 mm shell length) within the population, with an estimated 4.89 million (CV: 29.68%) individuals in this size class. Their mean density was also low at 18 large cockles per m^2. The current estimates were lower than estimates in the preceding survey in 2013–14.

The low number of large cockles was reflected in their minor contribution to the total population, with 1.29% of all individuals in this size class, similar to the value in the preceding survey (Table 33). In contrast, recruits ($\leq$15 mm shell length) made up 21.80% of the total population. Although their proportion within the population remained high, this estimate was a decrease from 31.81% of recruits in 2013–14. The mean and modal sizes in 2015–16 were 19.11 mm and 20 mm shell length, respectively, highlighting the prevalence of small to medium-size cockles in the population. Length-frequency distributions confirmed this pattern for the two most recent surveys, with small and medium-size cockles dominating the consistently unimodal cockle population at Pataua Estuary (Figure 30).

Pipi were present in all strata, but were scarce on the intertidal mudflat (strata A to C), with the population concentrated in channel stratum D (Figure 31, Table 34). The estimated population size was a total of 6.45 million pipi (CV: 14.67%) in 2015–16 (Table 35). The estimated population density was 23 individuals per m^2. There were few large pipi ($\geq$50 mm shell length) included in the population with an estimated 0.19 million (CV: 79.86%) individuals in this size class. Their estimated mean density was <1 large pipi per m^2. All of the current estimates mark decreases in the pipi population at Pataua Estuary, most notably in the population size of large pipi. Although this size class has been characterised by low abundances and densities across previous surveys, the current estimates are the lowest values since 2002–03.

The reduction in the number of large-sized pipi was evident in their contribution to the total population, which decreased to 2.94% in 2015–16 compared with 6.27% in the preceding assessment in 2013–14 (Table 36). At the same time, the proportion of recruits ($\leq$20 mm shell length) declined from 29.82% in 2013–14 to 19.52% in the current study. The decline in the proportion of recruits was reflected in the increase in modal size to 27 mm shell length, although the mean size remained similar at 31.54 mm shell length. The pipi population structure illustrated this slight shift in modal size, with a discernible increase in medium-sized pipi in the bimodal population, whereas there were fewer recruits and large pipi than in 2013–14 (Figure 32).

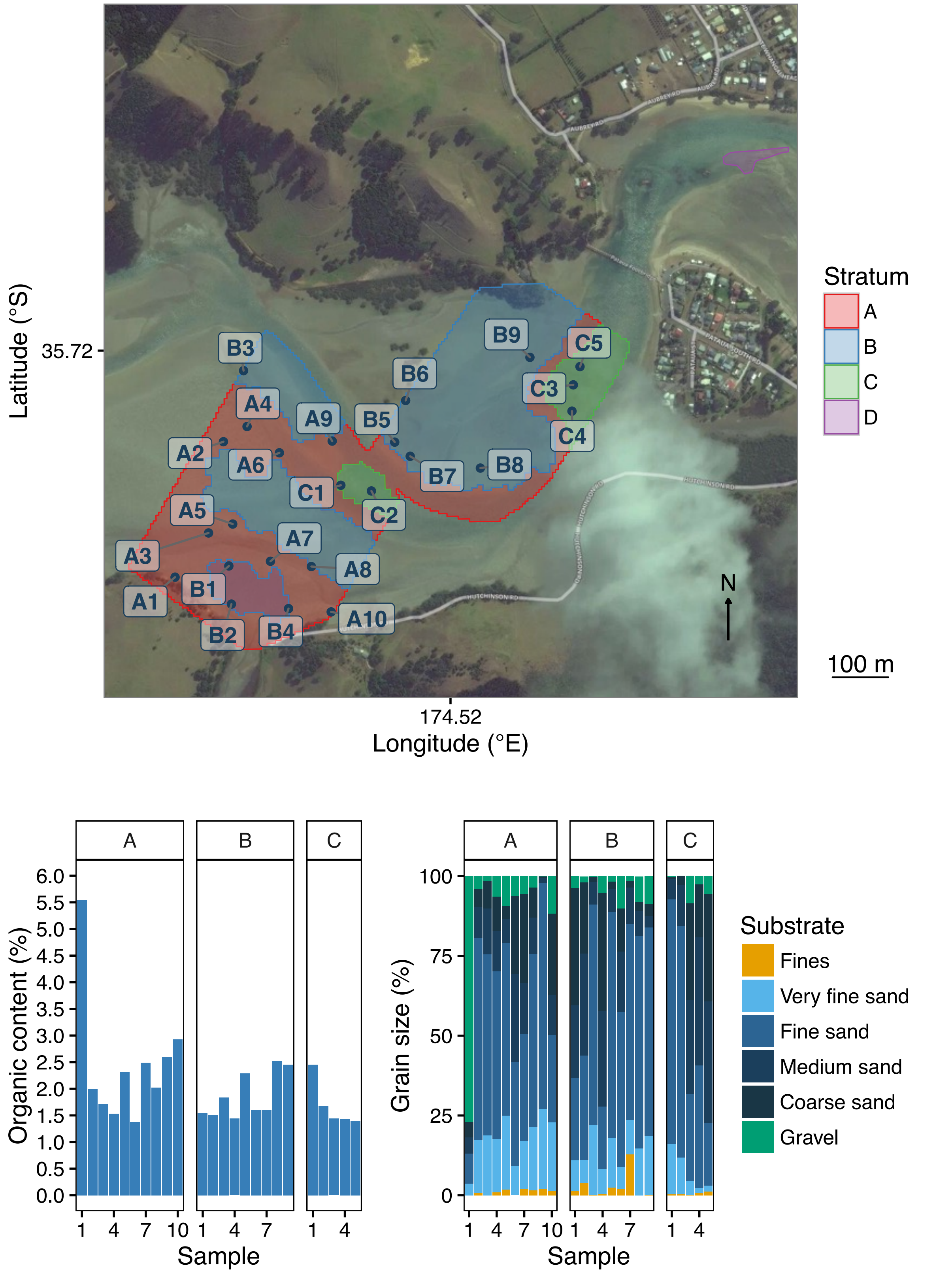


Figure 28: Sediment sample locations and characteristics at Pataua Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.19 Cockles at Pataua Estuary

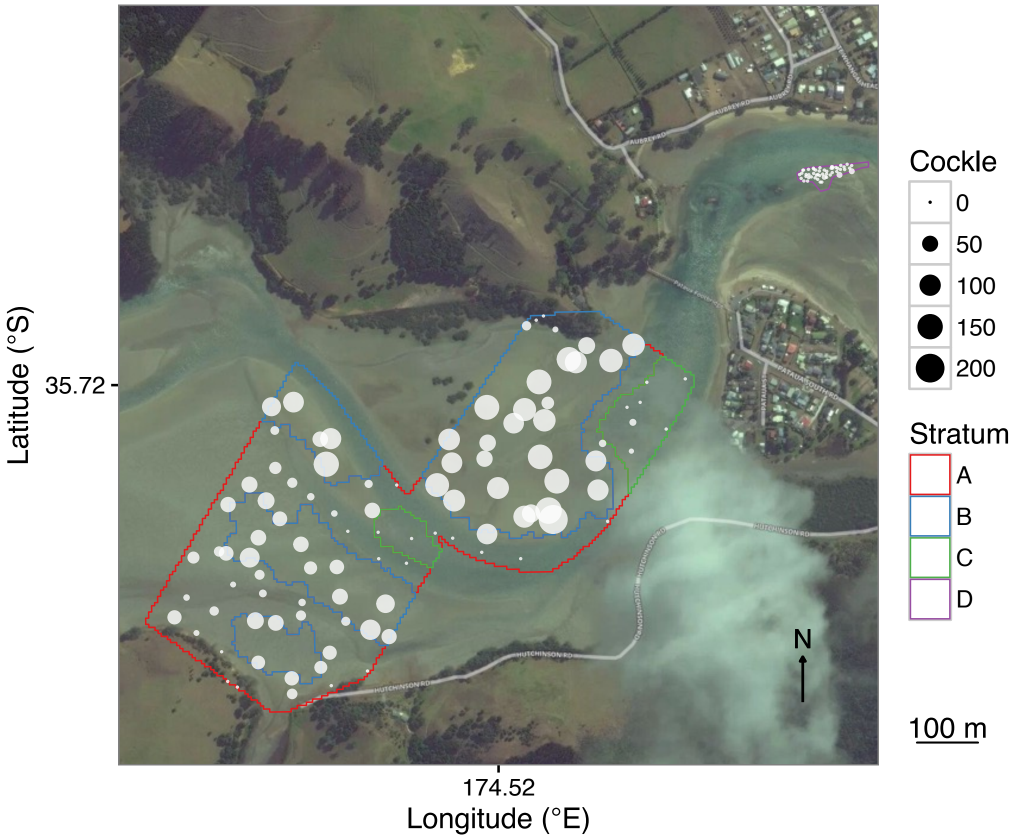


Figure 29: Map of sample strata and individual sample locations for cockles at Pataua Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of cockle abundance at Pataua Estuary, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	11.2	43	659	49.07	438	20.21
B	14.1	48	3 928	330.70	2 338	8.18
C	2.2	9	5	0.35	16	80.00
D	0.2	50	5	0.01	3	58.90

Table 32: Estimates of cockle abundance at Pataua Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent of cockle strata used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	10.7	88.64	832	4.45	21.63	203	6.94
2003–04	10.4	123.54	1 182	3.02	13.56	130	8.90
2005–06	10.4	108.08	1 034	5.18	19.87	199	7.57
2013–14	26.3	410.54	1 561	5.30	6.54	25	15.94
2013–14*	10.1	190.54	1 891	6.67	3.40	34	20.30
2015–16	27.8	380.13	1 368	7.58	4.89	18	29.68
2015–16*	10.1	138.14	1 371	13.33	2.42	24	38.78

Table 33: Summary statistics of the length-frequency (LF) distribution of cockles at Pataua Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2005–06	24.47	25	6–43	7.45	18.38
2013–14	17.97	20	4–58	31.81	1.59
2015–16	19.11	20	5–36	21.80	1.29

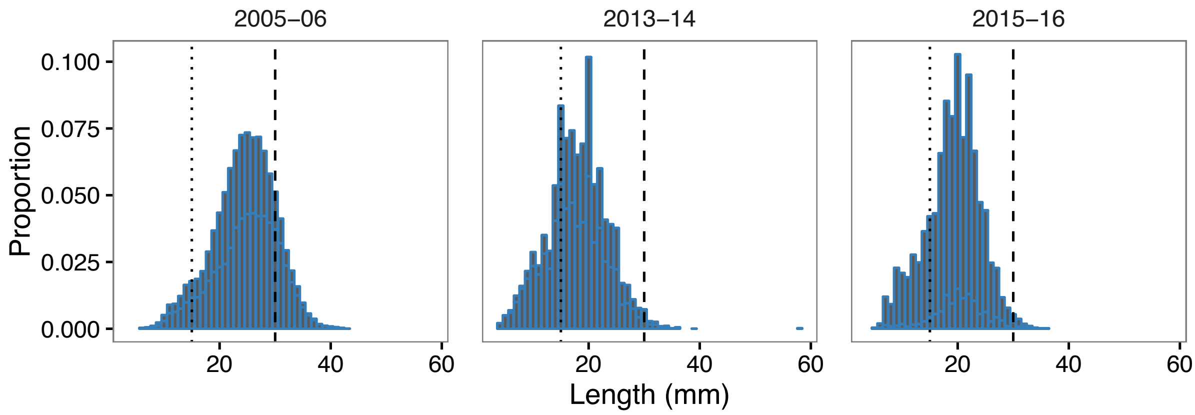


Figure 30: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.20 Pipi at Pataua Estuary

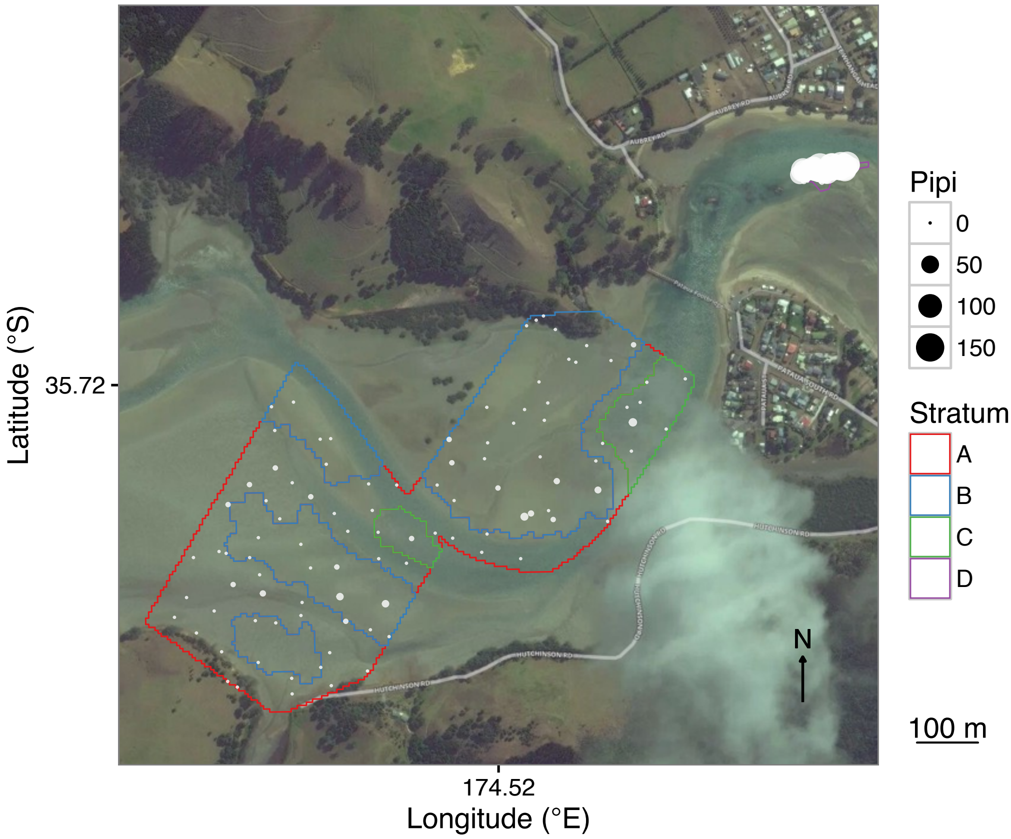


Figure 31: Map of sample strata and individual sample locations for pipi at Pataua Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of pipi abundance at Pataua Estuary, by stratum, for 2015–16. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	11.2	43	8	0.60	5	36.90
B	14.1	48	26	2.19	15	31.56
C	2.2	9	7	0.49	22	85.12
D	0.2	50	2 355	3.17	1 346	13.95

Table 35: Estimates of pipi abundance at Pataua Estuary for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	10.7	16.58	156	14.00	0.02	<1	>100
2003–04	10.4	2.21	21	11.72	0.43	4	7.94
2005–06	10.4	1.18	11	9.73	0.45	4	32.47
2013–14	26.3	7.52	29	17.28	0.47	2	60.35
2015–16	27.8	6.45	23	14.67	0.19	<1	79.86

Table 36: Summary statistics of the length-frequency (LF) distribution of pipi at Pataua Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2005–06	42.47	25	15–71	2.65	38.20
2013–14	31.28	19	7–58	29.82	6.27
2015–16	31.54	27	8–56	19.52	2.94

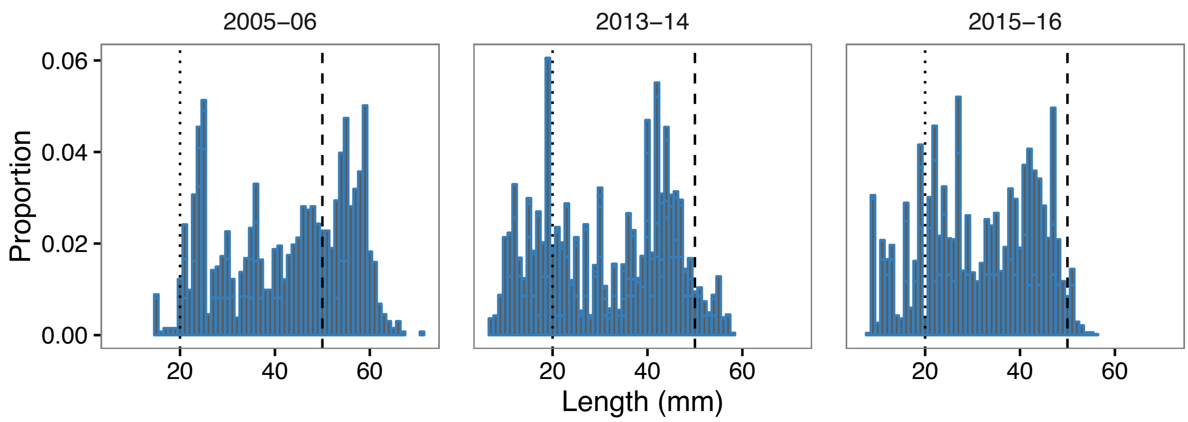


Figure 32: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.21 Tairua Harbour

Tairua Harbour is located on the eastern side of Coromandel Peninsula. Bivalves at this site have been assessed in eight previous assessments, most recently in 2013–14 (see Appendix A, Tables A-1, A-2). This previous assessment involved the largest sampling extent in the survey series, incorporating cockle and pipi beds in different areas, north and south of the main channel. The current study involved a slighter smaller sampling extent, resulting from changes in the location and size of strata containing pipi. These changes also included the omission of two previous strata (A and D in 2013–14) that were found during the reconnaissance to no longer contain pipi beds. Strata predominantly targeting cockles were re-stratified, resulting in a total of five strata (A to E) and 183 sampling points in 2015–16 (Figure 33, Table 37).

Sediment characteristics in the cockle strata at Tairua Harbour varied across samples, including organic content which ranged between 0.9 and 4.6% (Figure 33, and see details in Appendix C, Table C-4). Similarly, the proportion of sediment fines (grain size <63 µm) was variable (0.1 to 13.2%). Most samples consisted of varying proportions of very fine to medium sands (grain sizes >63 to >250 µm), although coarse sand (grain size >500 µm) and gravel (grain size >2000 µm) were prominent at some sampling points, with maximum values of 55.4% and 36.6%, respectively.

The cockle population at Tairua Harbour was primarily concentrated on the intertidal mudflat on the northern side of the main channel, in (re-stratified) strata A and B (Figure 34, Table 37). Based on the field sampling, the total cockle population size was estimated at 57.22 million (CV: 10.46%) individuals, with a corresponding mean density of 700 cockles per m^2 (Table 38). When restricting data to the sampling extent used in earlier surveys, the total population estimate was 39.91 million (CV: 10.35%) cockles, and the mean density was 1390 cockles per m^2. The population contained few large cockles ($\geq$30 mm shell length), with an estimated 0.37 million (CV: 43.97%) large individuals at a mean density of 4 large cockles per m^2. All of the current population estimates were lower than the corresponding estimates in the previous survey in 2013–14.

Considering the population overall, the proportion of large cockles was less than 1% (0.64%), and this finding was consistent with the small proportion of large individuals in 2013–14 (Table 39). Recruits ($\leq$15 mm shell length) made up about a quarter of the population in the two most recent surveys, with 18.16% of cockles in this size class in 2015–16. Mean and modal shell lengths have also remained consistent, with a mean size of 19.38 mm and a modal size of 20 mm in the current assessment. The generally small size of cockles was evident in the length-frequency distributions that documented a unimodal population dominated by small and medium-size individuals across the three most recent surveys including the present study (Figure 35).

Pipi at Tairua Harbour were sampled across all strata, but only occurred at high densities throughout stratum D and in the eastern part of stratum E (Figure 36, Table 40). The total population estimate for 2015–16 was 26.71 million (CV: 15.64%) pipi, with an average population density of 327 pipi per m^2 (Table 41). The total population estimates reflected marked decreases from estimates in 2013–14. This recent reduction in the pipi population is in part explained by the omission of two strata that no longer contained pipi in 2015–16. Nevertheless, there were also notable declines (over 40%) in the number and density of pipi in stratum E compared with the 2013–14 estimates for the same area (i.e., previous stratum C).

In the current assessment, the number of large pipi ($\geq$50 mm shell length) showed a slight decrease from the previous survey, with an estimated 0.38 million (CV: 39.85%) large individuals included in the population. Their mean density remained at 5 large individuals per m^2. This size class only made up 1.41% of the total population (Table 42). There was also only a small proportion of recruits ($\leq$20 mm shell length) within the population, with 6.72% of pipi at these small sizes. The pipi population at this site has consistently been determined by medium-size pipi, and mean and modal sizes in 2015–16 were 36.58 mm and 40 mm shell length, respectively. This medium size class dominated the unimodal population, although there has been a slight shift towards larger pipi sizes since 2010–11 (Figure 37).

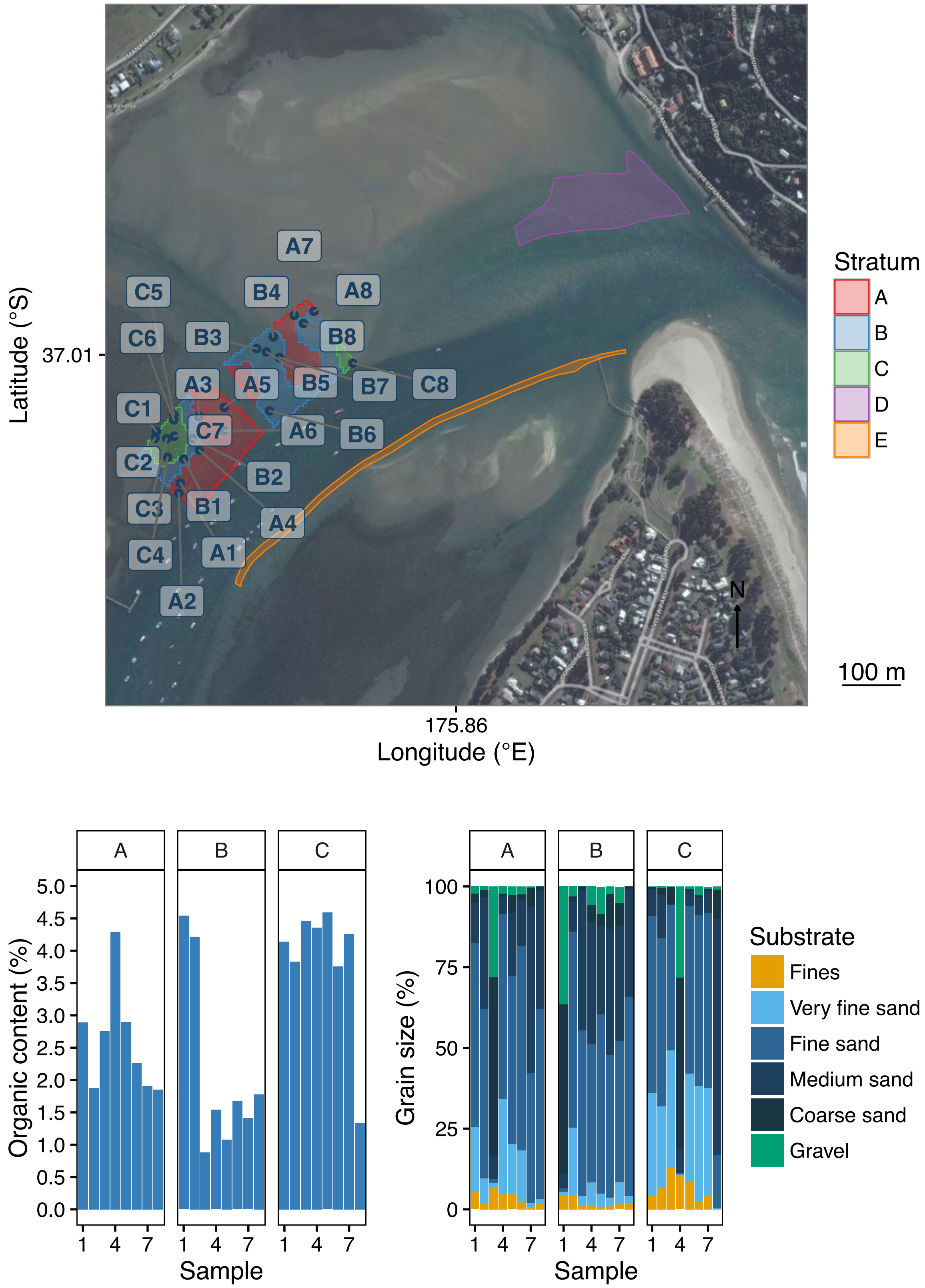


Figure 33: Sediment sample locations and characteristics at Tairua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.22 Cockles at Tairua Harbour

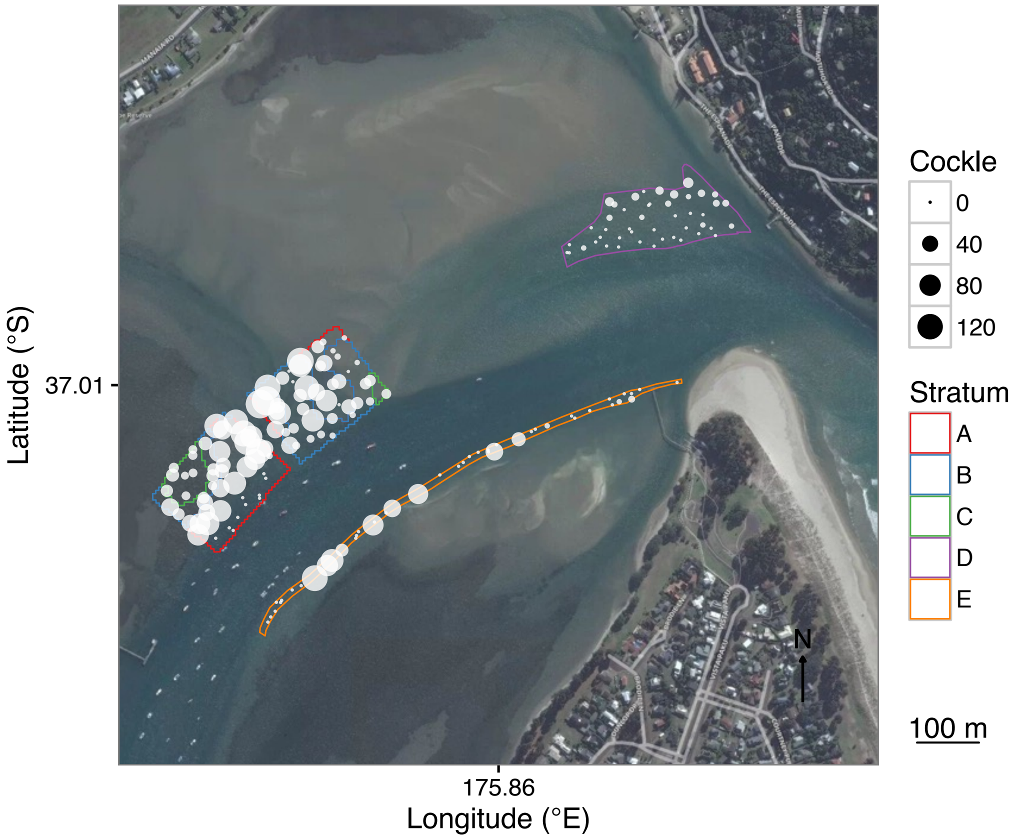


Figure 34: Map of sample strata and individual sample locations for cockles at Tairua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 37: Estimates of cockle abundance at Tairua Harbour, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	2.5	51	2 475	35.29	1 387	13.00
B	2.0	33	955	16.31	827	22.52
C	0.5	9	94	1.56	298	18.20
D	2.3	46	60	0.85	37	28.28
E	0.8	44	589	3.21	382	33.47

Table 38: Estimates of cockle abundance at Tairua Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent of cockle strata used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	3.7	61.70	1 668	8.07	17.57	475	7.95
2000–01	3.9	56.07	1 438	4.93	10.65	273	6.26
2001–02	3.9	19.04	488	6.80	4.58	117	8.07
2002–03	3.9	32.76	840	5.14	5.56	143	6.53
2005–06	3.9	23.68	607	4.74	4.71	131	6.07
2006–07	4.8	53.82	1 121	6.47	4.28	89	11.80
2010–11	5.8	25.52	440	10.69	0.87	15	47.88
2013–14	9.4	69.66	742	8.93	0.81	9	14.22
2013–14*	2.9	27.12	944	13.94	0.09	3	50.61
2015–16	8.2	57.22	700	10.46	0.37	4	43.97
2015–16*	2.9	39.91	1 390	10.35	0.08	3	50.27

Table 39: Summary statistics of the length-frequency (LF) distribution of cockles at Tairua Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	18.25	20	5–50	32.55	3.41
2013–14	19.12	20	5–49	21.98	1.16
2015–16	19.38	20	5–35	18.16	0.64

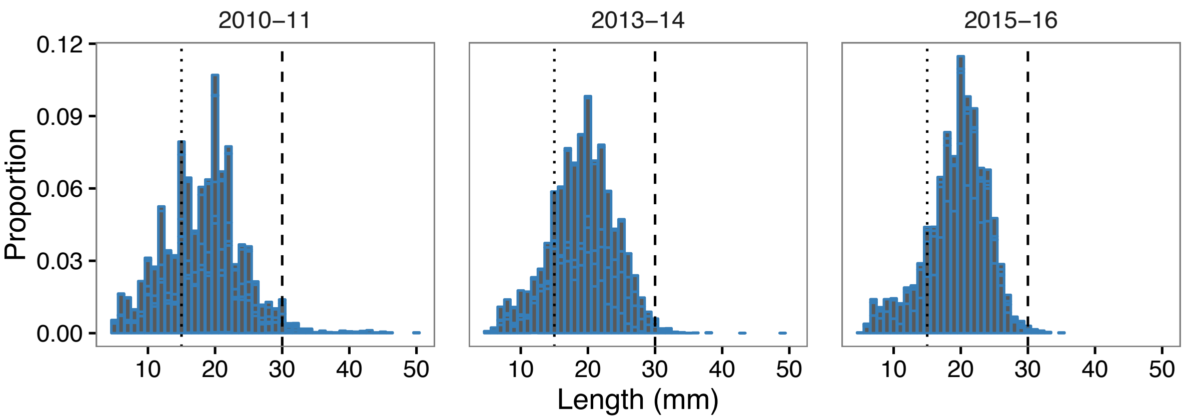


Figure 35: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.23 Pipi at Tairua Harbour

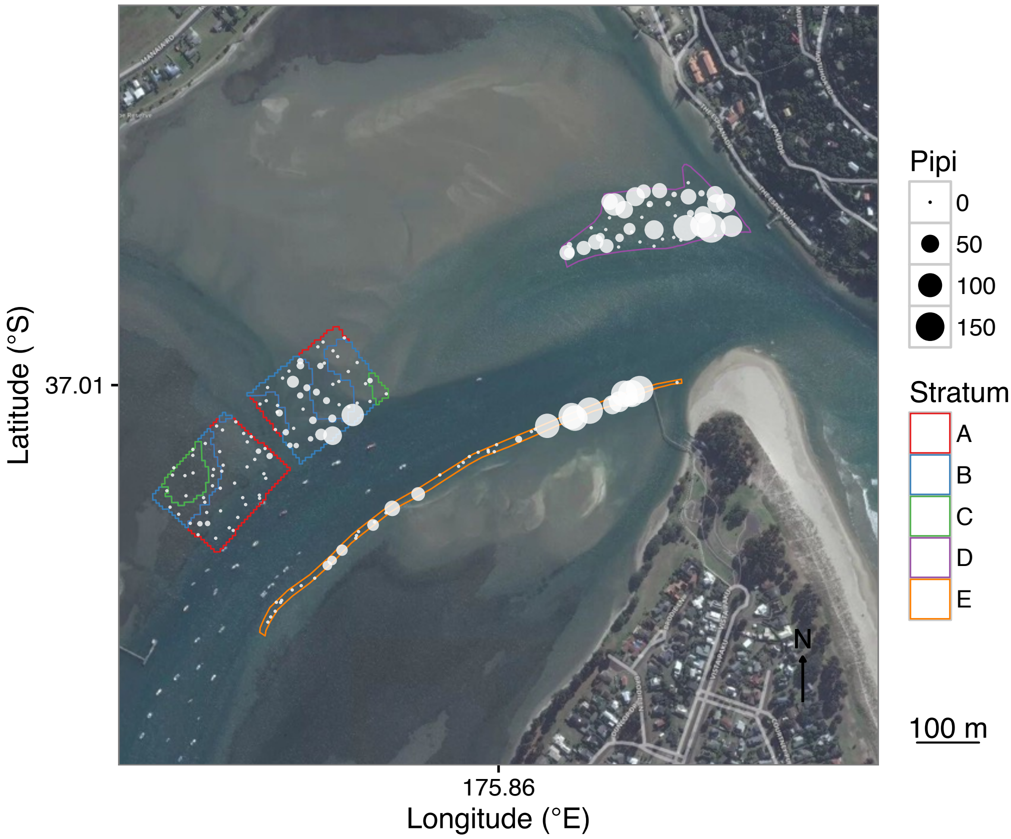


Figure 36: Map of sample strata and individual sample locations for pipi at Tairua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 40: Estimates of pipi abundance at Tairua Harbour, by stratum, for 2015–16. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	2.5	51	23	0.33	13	33.04
B	2.0	33	189	3.23	164	52.33
C	0.5	9	1	0.02	3	>100
D	2.3	46	1 203	17.13	747	20.22
E	0.8	44	1 104	6.01	717	26.83

Table 41: Estimates of pipi abundance at Tairua Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	3.7	9.41	254	6.56	3.81	103	5.79
2000–01	3.9	8.35	214	6.25	2.11	54	7.78
2001–02	3.9	4.28	110	11.30	0.84	35	8.70
2002–03	3.9	4.98	128	6.73	0.43	11	11.51
2005–06	3.9	3.01	77	9.00	0.71	79	12.62
2006–07	4.8	6.33	132	6.72	2.10	44	8.36
2010–11	5.8	25.80	445	11.26	0.84	20	25.04
2013–14	9.4	49.99	533	13.05	0.44	5	28.85
2015–16	8.2	26.71	327	15.64	0.38	5	39.85

Table 42: Summary statistics of the length-frequency (LF) distribution of pipi at Tairua Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	30.75	30	8–68	13.00	3.25
2013–14	31.39	35	5–72	9.39	0.88
2015–16	36.58	40	8–52	6.72	1.41

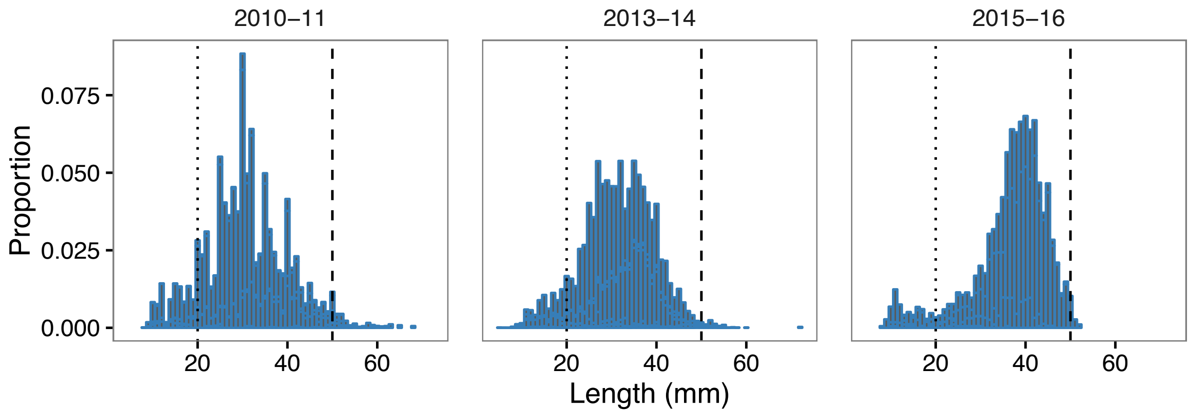


Figure 37: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.24 Umupuia Beach

Umupuia Beach is in the Auckland region, situated within Hauraki Gulf. This site had a rāhui (total closure) imposed in October 2008, prohibiting the take of cockles. Umupuia Beach has been frequently included in the bivalve survey series with 12 assessments preceding the current study (see Appendix A, Tables A-1, A-2). Bivalves at this site were last surveyed in 2013–14. The sampling extent has remained similar throughout the surveys, involving most of the intertidal area of the beach. In the current study, the sampling extent was re-stratified, and bivalves were sampled across four strata involving a total of 186 sampling points (Figure 38, Table 43). There were only ten pipi sampled across all sampling points, so that this species is not further reported on here.

Across the four strata, sediment characteristics were similar in organic content and the proportion of fines (grain size <63 µm), with generally low values for both parameters (Figure 38, and see details in Appendix C, Table C-4). The sediment largely consisted of very fine and fine sands (grain sizes >65 µm and >125 µm, respectively), but there was there was considerable variation in the proportion of gravel (grain size >2000 µm). While this grain size fraction was absent or small in the majority of samples, it made up over 20% of the sediment at two sampling points.

Cockles at Umupuia Beach were predominantly in stratum B, particularly in the mid- to low- intertidal zone (Figure 39, Table 43). There were few cockles in strata A and D, and no cockles in stratum C. Population estimates for 2015–16 included a total population size of 98.88 million (CV: 15.93%) individuals, and mean density of 292 cockles per m^2 (Table 44). These estimates were markedly lower than values in the preceding assessment in 2013–14. Similarly, there was a reduction in the number of large cockles ($\geq$30 mm shell length), with an estimated 39.12 million (CV: 10.61%) large individuals, although their mean density remained similar at 128 large cockles per m^2.

Overall, large cockles continued to be a substantial part of the population at Umupuia Beach, with 39.56% of individuals in this size class (Table 45, Figure 40). In contrast, the proportion of recruits ($\leq$15 mm shell length) was small at 2.04%, although this size class contributed 32.24% to the population in the preceding survey in 2013–14. The drop in the proportion of recruits an increase in large cockles was reflected in the mean and modal sizes in 2015–16, which were 26.80 mm and 22 mm shell length, respectively. Length-frequency distributions further highlighted the increase in cockle sizes in the population structure across the three recent surveys, with the two modes in a consistently bimodal population shifting towards larger sizes, leading to a reduction and then lack of recruits.

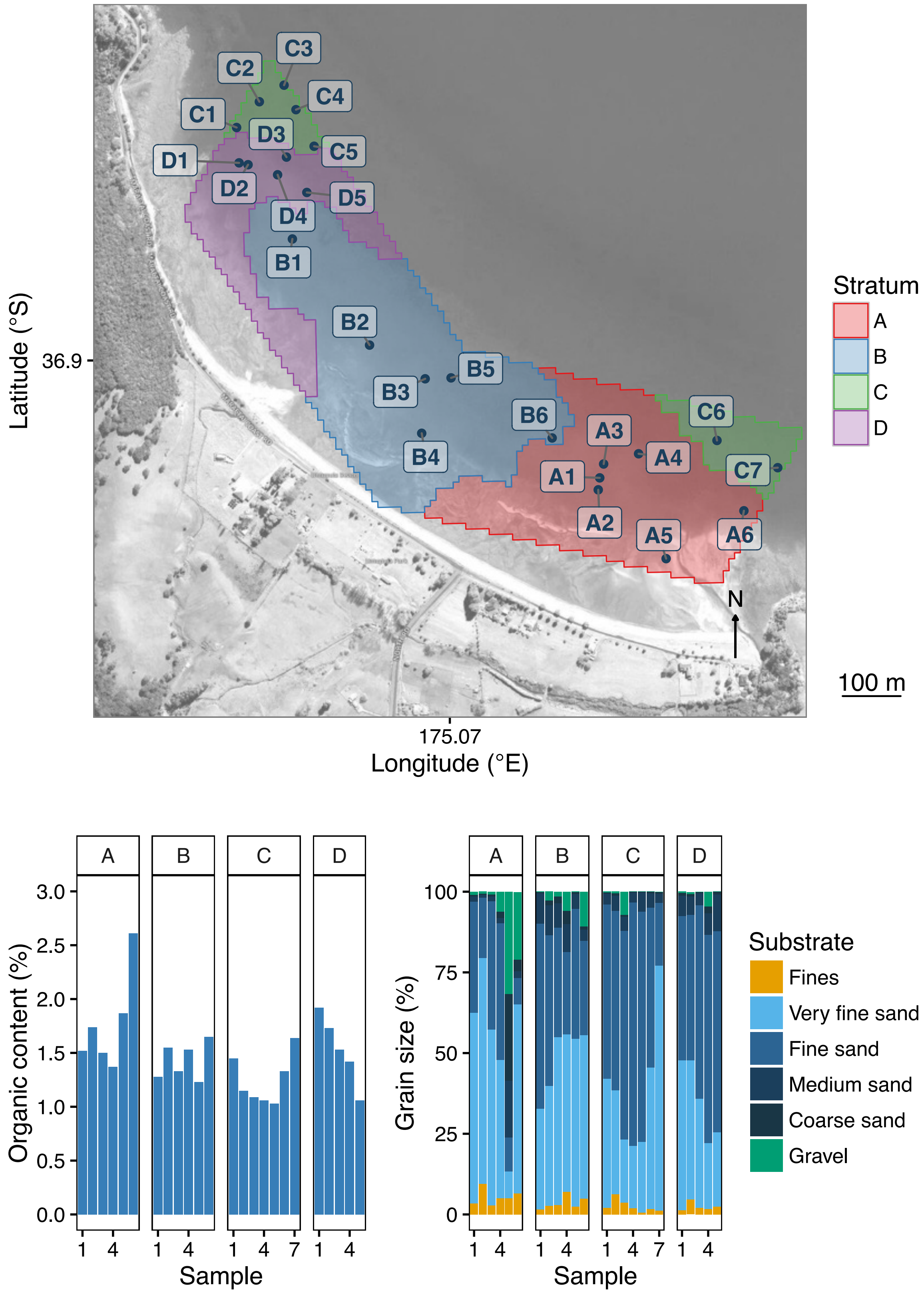


Figure 38: Sediment sample locations and characteristics at Umupuia Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.25 Cockles at Umupuia Beach

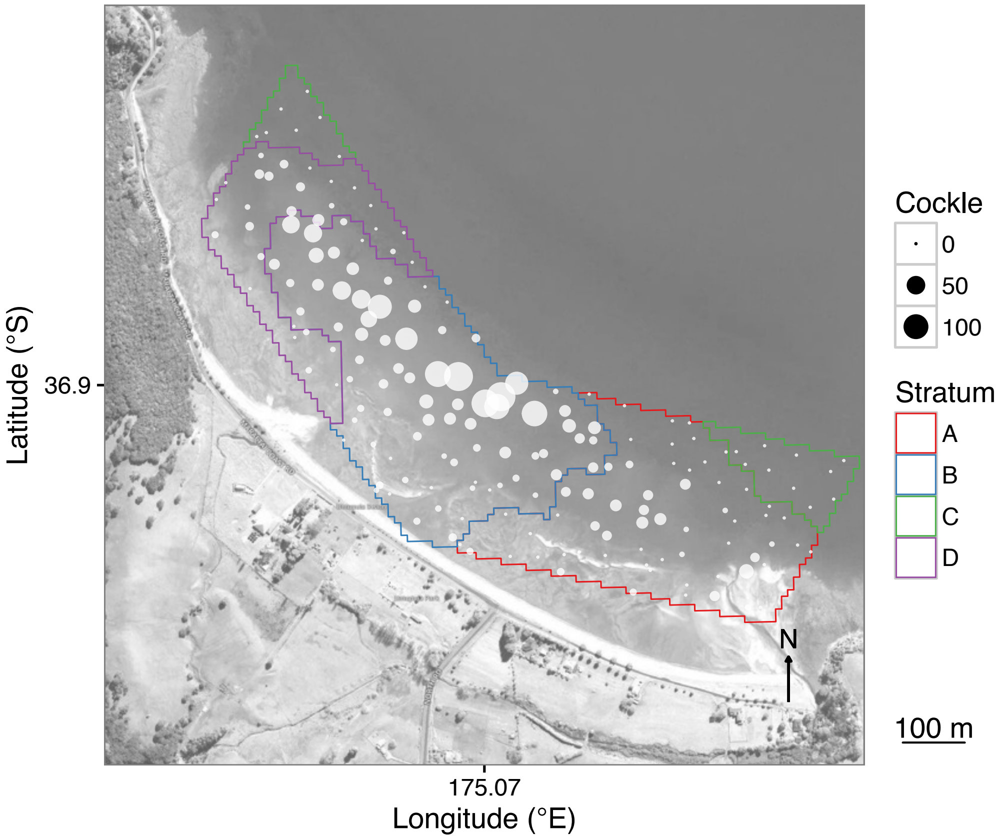


Figure 39: Map of sample strata and individual sample locations for cockles at Umupuia Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 43: Estimates of cockle abundance at Umupuia Beach, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	10.8	61	187	9.49	88	23.04
B	14.5	81	1 681	85.72	593	18.16
C	3.3	17	0	0.00	0	
D	5.3	27	65	3.67	69	29.93

Table 44: Estimates of cockle abundance at Umupuia Beach for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	25.0	84.41	338	5.51	18.59	74	7.99
2000–01	36.0	177.48	493	5.50	66.98	186	8.32
2001–02	36.0	66.22	184	7.00	29.49	82	9.42
2002–03	36.0	64.43	179	5.26	24.96	69	7.87
2003–04	36.0	29.94	83	9.53	21.62	60	11.44
2004–05	36.0	41.49	115	6.95	30.72	85	7.97
2005–06	36.0	26.86	75	9.99	14.53	40	15.93
2006–07	36.0	11.59	32	13.84	5.07	14	23.91
2009–10	36.0	61.58	171	11.30	1.89	5	20.84
2010–11	36.0	103.08	286	9.96	9.32	26	17.10
2012–13	36.0	125.18	348	14.17	47.99	133	14.64
2013–14	33.9	170.35	503	16.79	44.29	131	17.80
2015–16	33.9	98.88	292	15.93	39.12	128	10.61

Table 45: Summary statistics of the length-frequency (LF) distribution of cockles at Umupuia Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	24.87	30	2–40	17.04	38.34
2013–14	22.24	14	5–42	32.24	26.00
2015–16	26.80	22	8–43	2.04	39.56

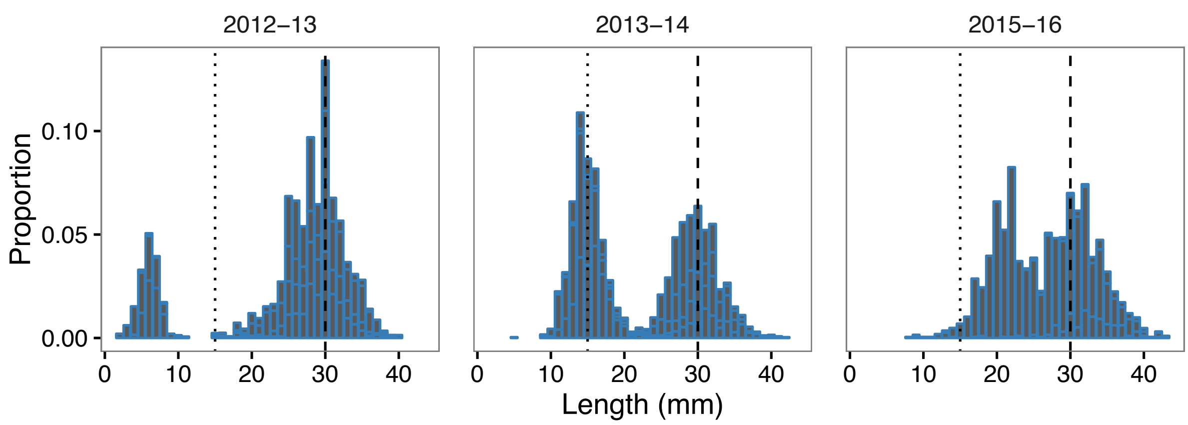


Figure 40: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Umupuia Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.26 Whangateau Harbour

Whangateau Harbour is north of Auckland, situated within Hauraki Gulf. The harbour was first closed to shellfish collections in March 2010, with a permanent closure coming into effect in January 2016. This site has been included in eight previous bivalve surveys since 1999–2000, most recently in 2013–14 (see Appendix A, Tables A-1, A-2). In the 2013–14 survey, the sampling extent was greatly expanded by extending existing strata and adding two new cockle strata. The current assessment used the same sampling extent, involving five strata following re-stratification (Figure 41, Table 46). Across this sampling extent, there was a total of 247 sampling points in the 2015–16 survey.

Sediment sampling in the cockle strata documented a consistently low organic content at 1.7% or below (Figure 41, and see details in Appendix C, Table C-4). The sediment contained no or only a low proportion of fines (grain size <63 μm), with a maximum value of 2.5% in this grain size. Instead, fine and medium sands (grain sizes >125 μm and >250 μm) were the most prevalent grain size fractions, with a number of samples also containing coarse sediment. The latter included up to 18.6% of coarse sand (grain size >500 μm) and up to 24.4% of gravel (grain size >2000 μm).

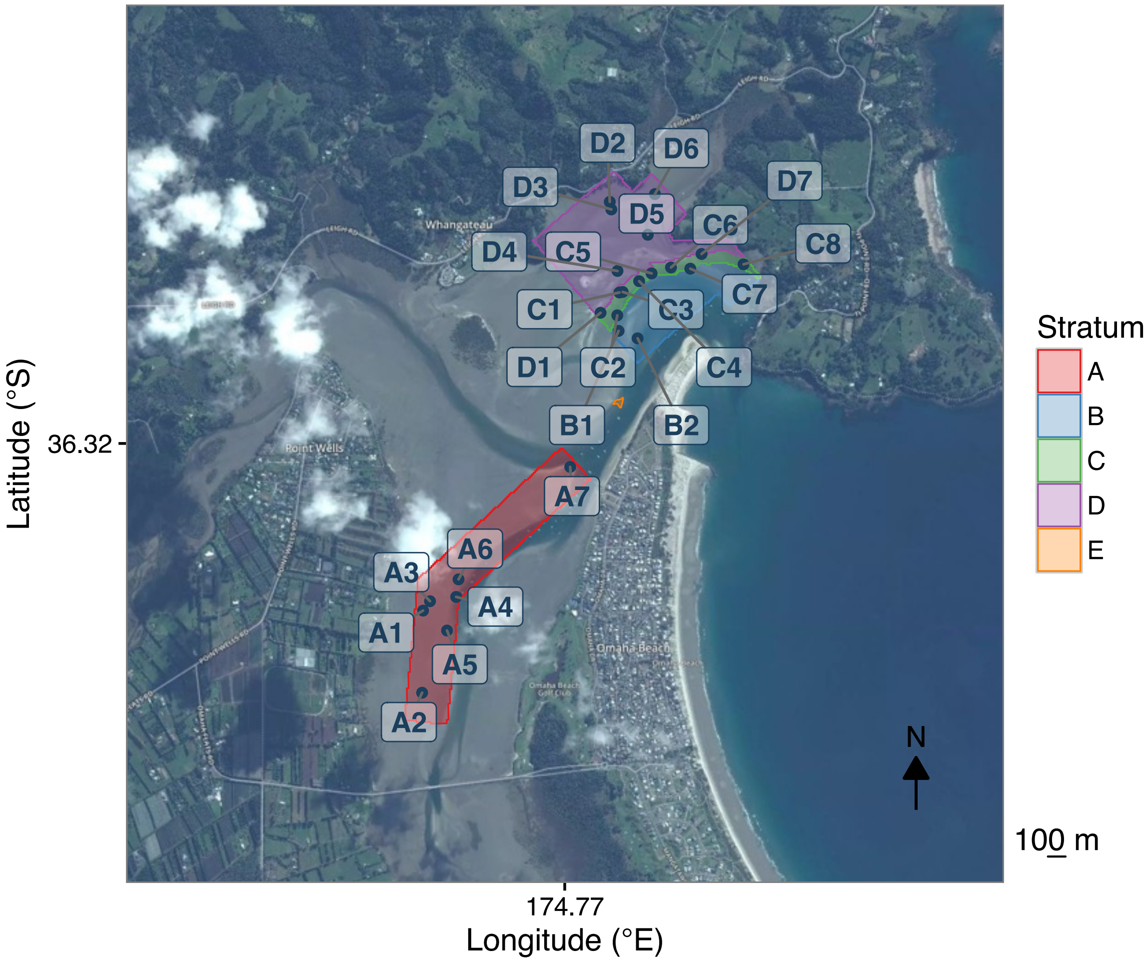
In 2015–16, cockles were highly abundant in strata A and D, and were few or no cockles in the remaining strata (Figure 42, Table 46). Across all strata, the size of the total cockle population was estimated at 742.44 million (CV: 7.02%) individuals in 2015–16, at a mean density of 671 cockles per m^2 (Table 47). Based on a similar sampling extent to early surveys, the population estimates were a total 487.01 million (CV: 8.04%) cockles and a mean density of 801 individuals per m^2. The population contained a number of large cockles ($\geq$30 mm shell length), with an estimated 45.43 million (CV: 18.77%) individuals in this size class. Their mean density was 51 individuals per m^2. These current population estimates were increases from the previous assessment.

Within the cockle population, the proportions of large individuals and of recruits ($\leq$15 mm shell length) remained similar to values in previous surveys; large cockles contributed 6.12% of individuals to the population in 2015–16, while the proportion of recruits was 23.81% (Table 48, Figure 43). Similarly, mean and modal sizes remained at 19.88 mm and 20 mm shell length, respectively, close to sizes in the preceding two surveys. Medium-sized cockles made up a single, strong cohort in the population, with a consistent unimodal population structure across recent surveys.

Whangateau Harbour is also included in the Hauraki Gulf Forum community monitoring programme (Auckland Council 2013). The community monitoring uses different survey methods and areas, but some of findings are comparable to the present study. For example, average cockle densities in recent community surveys were 448 and 662 cockles per m^2 in two areas sampled, and the most frequent cockle sizes were 15 to 25 mm shell length. These values reflected marked reductions for one of the areas (Lews Bay), which was attributed to a mass mortality event in 2009.

The pipi population in Whangateau Harbour was largely confined to the main channel (stratum E) (Figure 44, Table 49). The total population estimate for this species was 15.00 million (CV: 23.20%) pipi in 2015–16, and the corresponding population density was an average of 14 pipi per m^2 (Table 50). There was only a small number of large individuals ($\geq$50 mm shell length) within the population, with an estimated 0.40 million (CV: 9.04%) individuals in this size class. Their mean density was <1 individual per m^2. These population metrics document notable declines in the pipi population since the previous survey in 2013–14.

Across recent surveys, the large size class consistently contributed few individuals to the total population, and in 2015–16, 2.68% of all pipi were within this size class (Table 51, Figure 45). In comparison, almost a third of the pipi population consisted of recruits ($\leq$20 mm shell length), although their proportion of 32.19% in 2015–16 was a reduction from previous recent surveys, such as 50.19% in 2013–14. At the same time, mean and modal sizes increased to 26.26 mm and 26 mm shell length, respectively. The pipi population structure remained unimodal, although the single cohort of medium-sized pipi was not as uniform as in previous assessments.



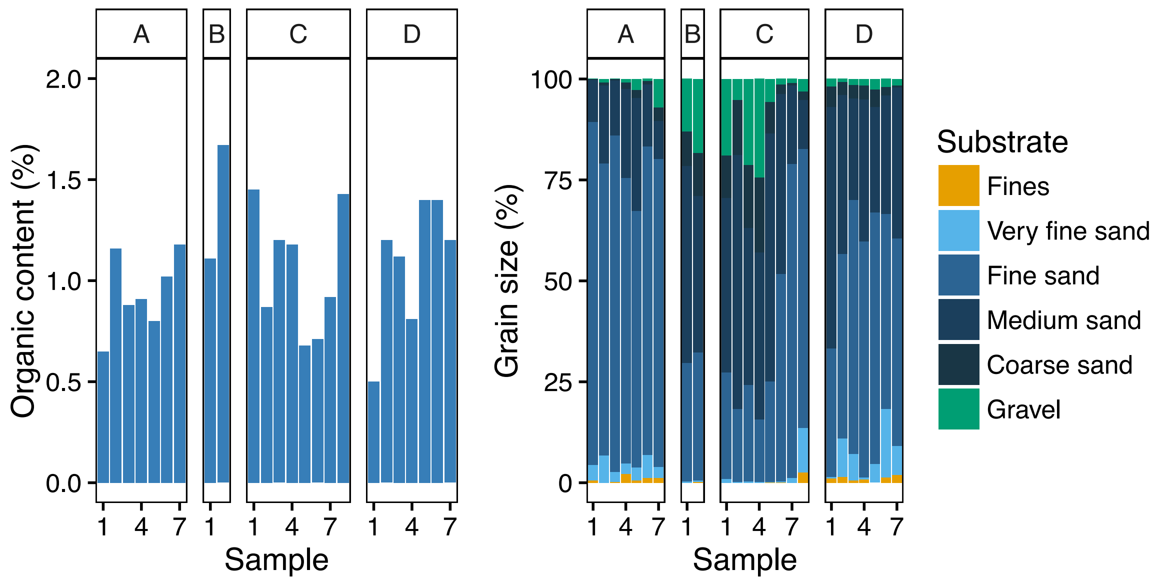


Figure 41: Sediment sample locations and characteristics at Whangateau Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.27 Cockles at Whangateau Harbour

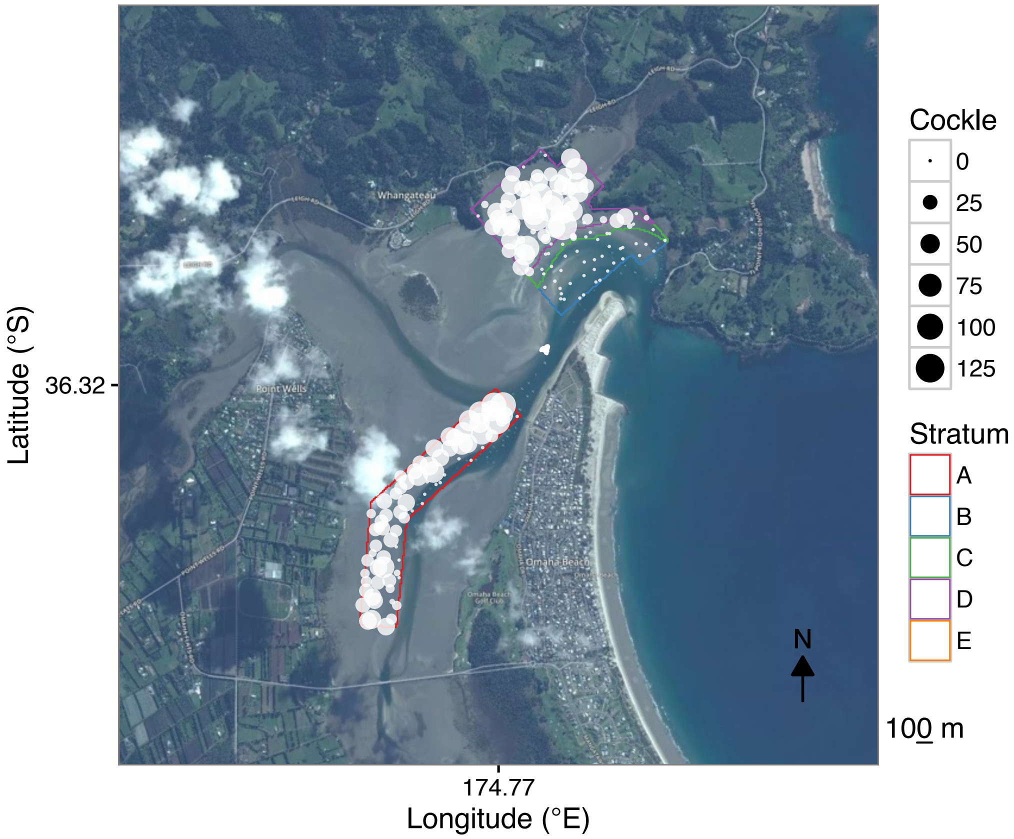


Figure 42: Map of sample strata and individual sample locations for cockles at Whangateau Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 46: Estimates of cockle abundance at Whangateau Harbour, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	43.0	76	2 072	334.88	779	10.35
B	20.9	31	0	0.00	0	
C	7.1	15	5	0.68	10	56.06
D	39.5	63	2 272	406.88	1030	9.57
E	0.1	62	2	0.00	<1	70.13

Table 47: Estimates of cockle abundance at Whangateau Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent of cockle strata used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	64.2	253.26	395	6.51	62.36	97	16.17
2003–04	64.2	376.68	587	5.80	56.85	89	12.66
2004–05	64.2	349.04	544	8.52	59.52	93	13.12
2006–07	64.2	266.04	415	8.24	35.20	55	21.91
2009–10	64.5	230.55	357	7.16	16.16	25	25.71
2010–11	64.2	239.27	373	5.06	19.77	31	16.19
2012–13	64.2	363.72	567	5.87	30.84	48	14.67
2013–14	110.9	730.89	659	5.70	44.50	40	13.45
2013–14*	60.8	417.17	686	6.13	18.64	31	18.25
2015–16	110.7	742.44	671	7.02	45.43	51	18.77
2015–16*	60.8	487.01	801	8.04	23.35	38	31.15

Table 48: Summary statistics of the length-frequency (LF) distribution of cockles at Whangateau Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	20.28	20	3–39	22.70	8.48
2013–14	19.97	20	5–44	24.64	6.09
2015–16	19.88	20	4–44	23.81	6.12

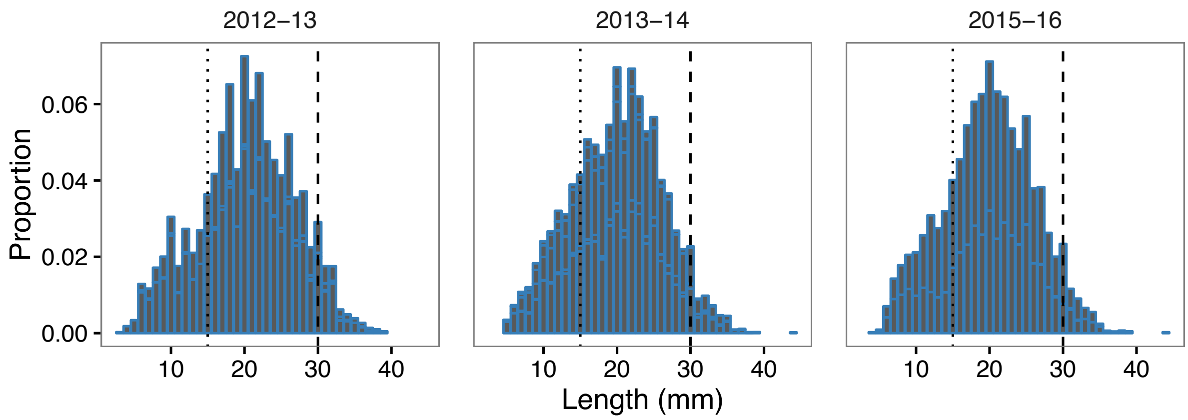


Figure 43: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.28 Pipi at Whangateau Harbour

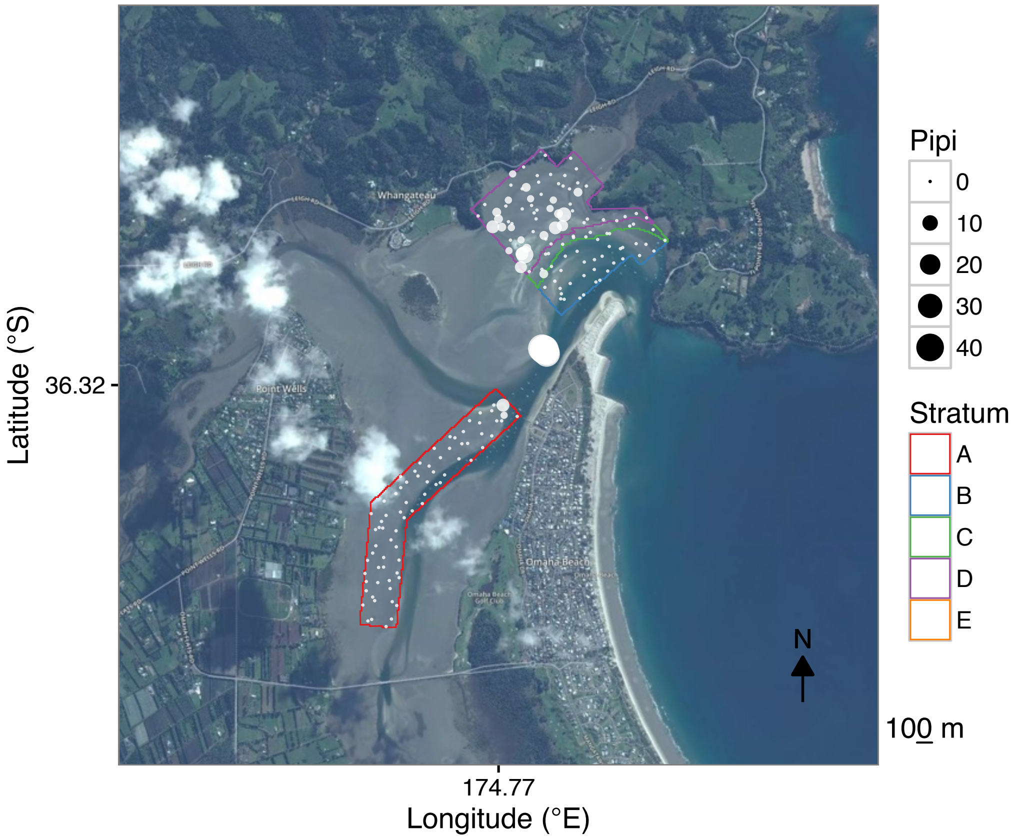


Figure 44: Map of sample strata and individual sample locations for pipi at Whangateau Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 49: Estimates of pipi abundance at Whangateau Harbour, by stratum, for 2015–16. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	43.0	76	7	1.13	3	86.71
B	20.9	31	0	0.00	0	
C	7.1	15	2	0.27	4	>100
D	39.5	63	72	12.89	33	25.8
E	0.1	62	1 074	0.71	495	8.28

Table 50: Estimates of pipi abundance at Whangateau Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	64.2	1.83	3	31.83	0.31	<1	>100
2003–04	64.2	0.48	<1	10.18	0.42	212	9.85
2004–05	64.2	6.85	11	22.46	0.58	1	9.72
2006–07	64.2	10.56	16	33.78	0.05	<1	>100
2009–10	64.5	17.58	27	33.35	0.11	<1	>100
2010–11	64.2	9.31	15	17.74	1.57	2	22.52
2012–13	64.2	19.58	30	16.89	0.60	2	42.05
2013–14	110.9	55.39	50	26.92	0.68	<1	24.04
2015–16	110.7	15.00	14	23.20	0.40	<1	9.04

Table 51: Summary statistics of the length-frequency (LF) distribution of pipi at Whangateau Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	19.86	12	7–67	62.16	3.06
2013–14	21.22	21	7–69	50.19	1.23
2015–16	26.26	26	9–67	32.19	2.68

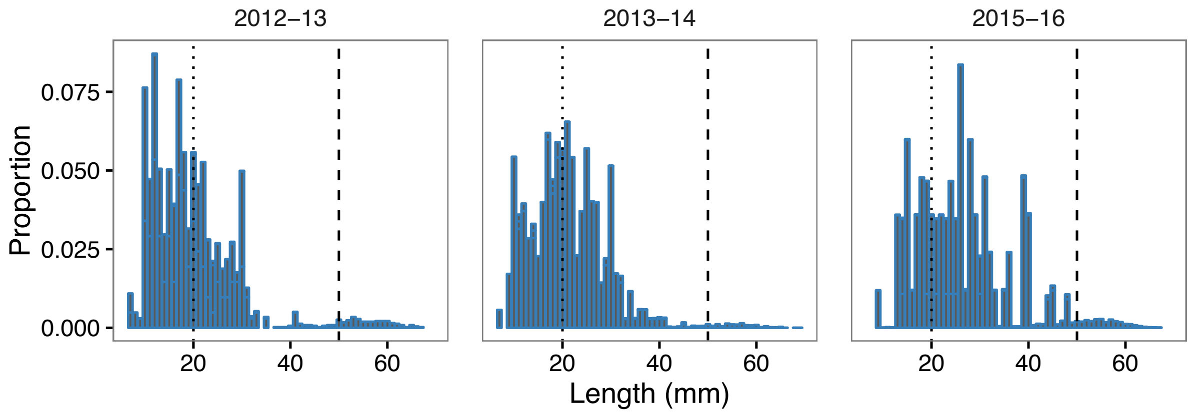


Figure 45: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.29 Whitianga Harbour

Whitianga Harbour is on the eastern side of Coromandel Peninsula. This site was added to the survey series in 2012–13, and the initial assessment was the only survey that preceded the current study (see Appendix A, Tables A-1, A-2). The previous survey focused on pipi only, in an area along the entrance channel and the beach outside the harbour. The present study focused on the same pipi bed, and also assessed cockles in an area on the intertidal mudflat adjacent to the harbour channel (Figure 46, Table 52). Cockles in this latter area have been regularly sampled as part of the Hauraki Gulf Forum community monitoring programme (e.g., Auckland Council 2013). Sampling in the present study in 2015–16 involved 95 sampling points across both strata.

Sediment samples across the cockle stratum revealed a similar organic content of about 3% in most samples (Figure 46, and see details in Appendix C, Table C-4). The proportion of fines (<63 μm grain size) varied between none and 6.8%, with most of the sediment consisting of fine sand (>250 μm grain size). Varying proportions of gravel (>2000 μm grain size) were present in all samples, and the highest proportion of this grain size was 11.8%.

The cockle population at Whitianga Harbour was restricted to stratum B (Figure 47, Table 52). The total population estimate for this species was 51.98 million (CV: 9.16%) individuals. Cockles occurred at an average density of 852 individuals per m^2 (Table 53). There were no large cockles (≥30 mm shell length), and most of the population consisted of recruits (≤15 mm shell length), with 66.41% of cockles in this size class in 2015–16 (Table 54, Figure 48). The prevalence of recruits was reflected in the population structure, which consisted of a unimodal population of recruits and small individuals at a modal size of 15 mm shell length. The mean shell length was 13.76 mm.

Although the Hauraki Gulf Forum community monitoring programme uses different methods, the current findings are consistent with data from the community monitoring (Auckland Council 2013). The latter programme regularly surveys cockles in this area at Whitianga Harbour, with documented population densities ranging between 464 and 1081 individuals per m^2. Cockle sizes recorded in the community monitoring programme ranged from 10 to 20 mm shell length, in a unimodal population with a modal size of 15 to 20 mm shell length and few large individuals.

Pipi at Whitianga Harbour were distributed throughout stratum A, at the harbour entrance (Figure 49, Table 55). There were an estimated 6.36 million (CV: 18.17%) pipi, in the total population, and the average population density was 104 pipi per m^2 (Table 56). These estimates were markedly lower (i.e., less than half) than total population estimates in the previous survey in 2012–13. Although the current estimates were based on smaller sampling extent, the boundaries of stratum A were defined by the boundaries of the pipi bed in this area.

There were an estimated 1.91 million (CV: 22.66%) large pipi (≥50 mm shell length) included in the population, similar to the preceding abundance estimate. Their corresponding density slightly increased to 31 large individuals per m^2. In view of the small total abundance, large pipi constituted 30.03% of the total population (Table 57). At the same time, the proportion of recruits (≤20 mm shell length) was small at 2.41%. In comparison, in 2012–13, large pipi and recruits made up 10.68% and 21.85% of the total population, respectively. The population structure at this site underwent a corresponding shift between the two surveys: mean and modal sizes increased to 45.13 mm and 46 mm shell length, respectively, and the population structure changed from a bimodal to a unimodal population (Figure 50).

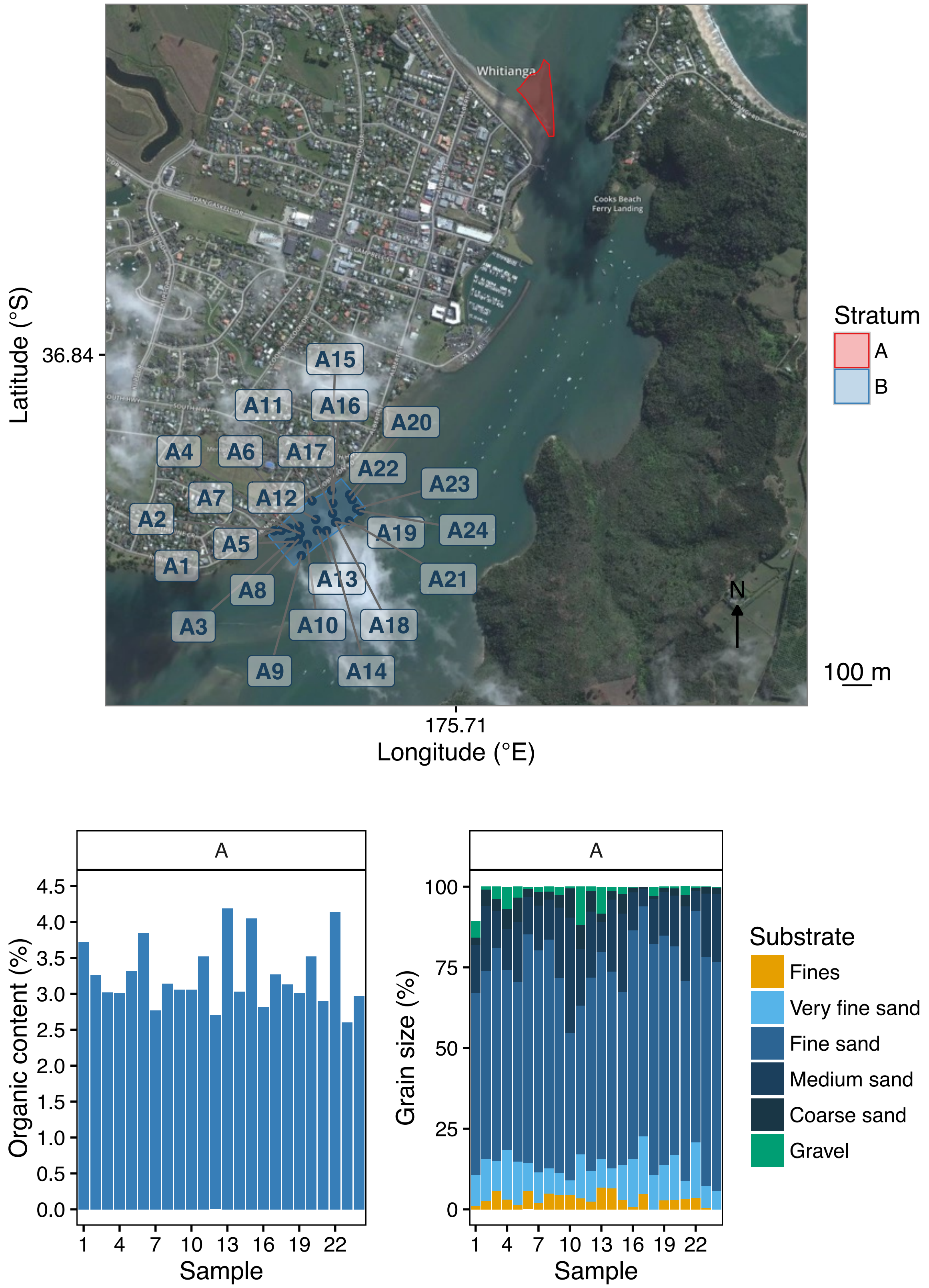


Figure 46: Sediment sample locations and characteristics at Whitianga Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table C-4).

3.30 Cockles at Whitianga Harbour

Figure 47: Map of sample strata and individual sample locations for cockles at Whitianga Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 52: Estimates of cockle abundance at Whitianga Harbour, by stratum, for 2015–16. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	1.7	38	1	0.01	<1	>100
B	4.4	57	2 353	51.97	1179	9.16

Table 53: Estimates of cockle abundance at Whitianga Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2015–16	6.1	51.98	852	9.16	0.00	0	

Table 54: Summary statistics of the length-frequency (LF) distribution of cockles at Whitianga Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of $\leq$15 mm and large individuals by a shell length of $\geq$30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2015–16	13.76	15	5–26	66.41	0.00

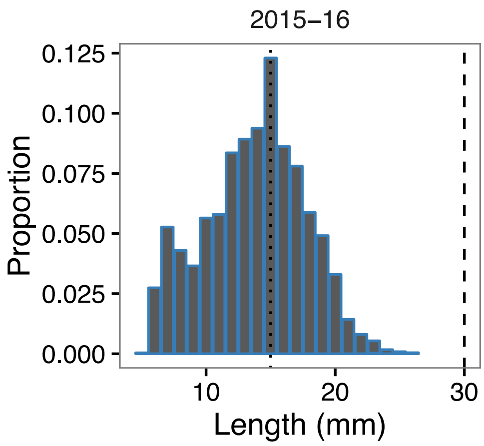


Figure 48: Weighted length-frequency (LF) distribution of cockles for the present survey at Whitianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.31 Pipi at Whitianga Harbour

Figure 49: Map of sample strata and individual sample locations for pipi at Whitianga Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 55: Estimates of pipi abundance at Whitianga Harbour, by stratum, for 2015–16. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	1.7	38	497	6.34	374	18.23
B	4.4	57	1	0.02	<1	>100

Table 56: Estimates of pipi abundance at Whitianga Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2012–13	7.1	18.65	263	18.39	1.99	28	22.27
2015–16	6.1	6.36	104	18.17	1.91	31	22.66

Table 57: Summary statistics of the length-frequency (LF) distribution of pipi at Whitianga Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	34.38	36	3–68	21.85	10.68
2015–16	45.13	46	8–62	2.41	30.03

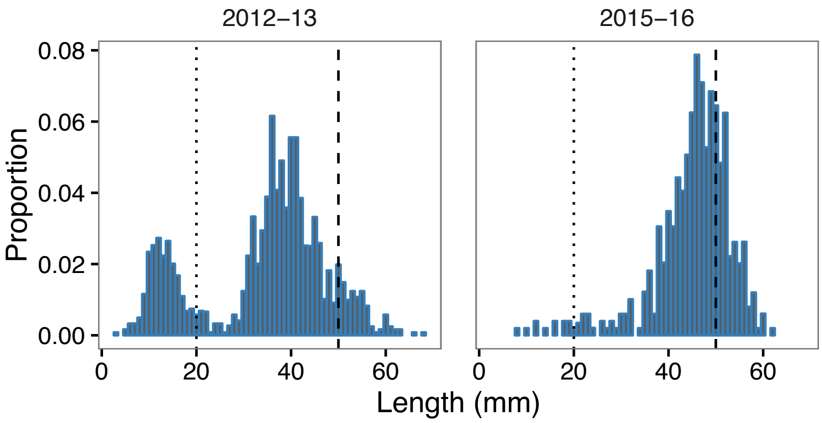


Figure 50: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whitianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. COCKLE ABUNDANCE AND SEDIMENT VARIABLES

Sample-level analysis of cockle abundance in relation to sediment characteristics suggested that none of the three sediment variables included in the analysis (organic content, proportions of fines and gravel) were significantly correlated with cockle abundance (Table 58). Both the combined model (Equation 3) and the random slope models (Equation 5) suggested considerable uncertainty about the relationship between sediment variables and cockle abundance for both large and all cockle sizes, reflecting contradictory site-level relationships between sediment and cockle samples (Figures 51, 52). Nevertheless, it was also evident that for the proportions of fines and gravel, individual data points with high proportions of the respective variable had a large impact on regression slopes at individual sites (e.g., proportions of fines and gravel at Pataua Estuary; Figure 51).

Table 58: Estimates of regression coefficients and 95% credible intervals for the combined generalised linear mixed model (combined; Equation 3) and single-variable analyses with random slopes (organic content, proportion of fines, and proportion of gravel; see Equation 5), for total cockles and large ($\geq$ 30 mm shell length) cockles.

Model	Organic content			Fines			Gravel		
	Estimate	0.25%	0.975%	Estimate	0.25%	0.975%	Estimate	0.25%	0.975%
Combined	-0.10	-0.30	0.11	0.16	-0.05	0.36	0.00	-0.28	0.28
Combined, large cockle	0.07	-0.26	0.40	-0.18	-0.54	0.19	-0.08	-0.57	0.41
Organic content	0.28	-0.27	0.83						
Organic content, large cockle	-0.24	-0.88	0.41						
Fines				0.26	-0.07	0.59			
Fines, large cockle				0.10	-0.52	0.71			
Gravel							-0.40	-1.25	0.45
Gravel, large cockle							0.01	-0.46	0.48

The measurement error model relating stratum mean densities to mean sediment characteristics suggested that total cockle abundance was decreasing with increases in all three variables (Figures 53, 54, 55); the expected numbers of cockles per sample were lower with increases in mean gravel concentration (β_{gravel} = –0.54, 95% highest posterior density (HPD) interval: –1.12, –0.04). This negative relationship was found to be the most certain correlation of cockle numbers with sediment variables ($P(\beta_{\text{gravel}} > 0) = 0.01$). For the proportion of fines and organic content, the parameter estimate for the regression coefficient β was also negative, with β_{fines} = –0.27 (HPD interval: –0.98, 0.93) and β_{organic} = –0.90 (HPD interval: –2.39, 0.62), respectively, suggesting a negative association, albeit with lower certainty ($P(\beta_{\text{fines}} > 0) =$ 0.27 and $P(\beta_{\text{organic}} > 0) = 0.11$, respectively).

Large cockle abundance was inversely related to gravel and organic content (Figures 53, 54, 56): large cockles decreased per sample with increases in the mean proportion of gravel (β_{gravel} = –0.18, HPD interval: –0.71, 0.37), but this relationship was uncertain ($P(\beta_{\text{gravel}} > 0) = 0.24$). The parameter estimate for the proportion of organic content was also negative, with β_{organic} = –1.01 (HPD interval: –3.54, 1.30). The effect size (i.e., the magnitude of β) for this relationship was larger than for gravel, but still with relatively low certainty in the effect itself ($P(\beta_{\text{organic}} > 0) = 0.15$). There was, however, a relatively strong and consistent positive relationship ($P(\beta_{\text{fines}} > 0) = 0.93$) for large cockles with the proportion of sediment fines, with β_{fines} = 1.04 (HPD interval: –0.50, 2.22).

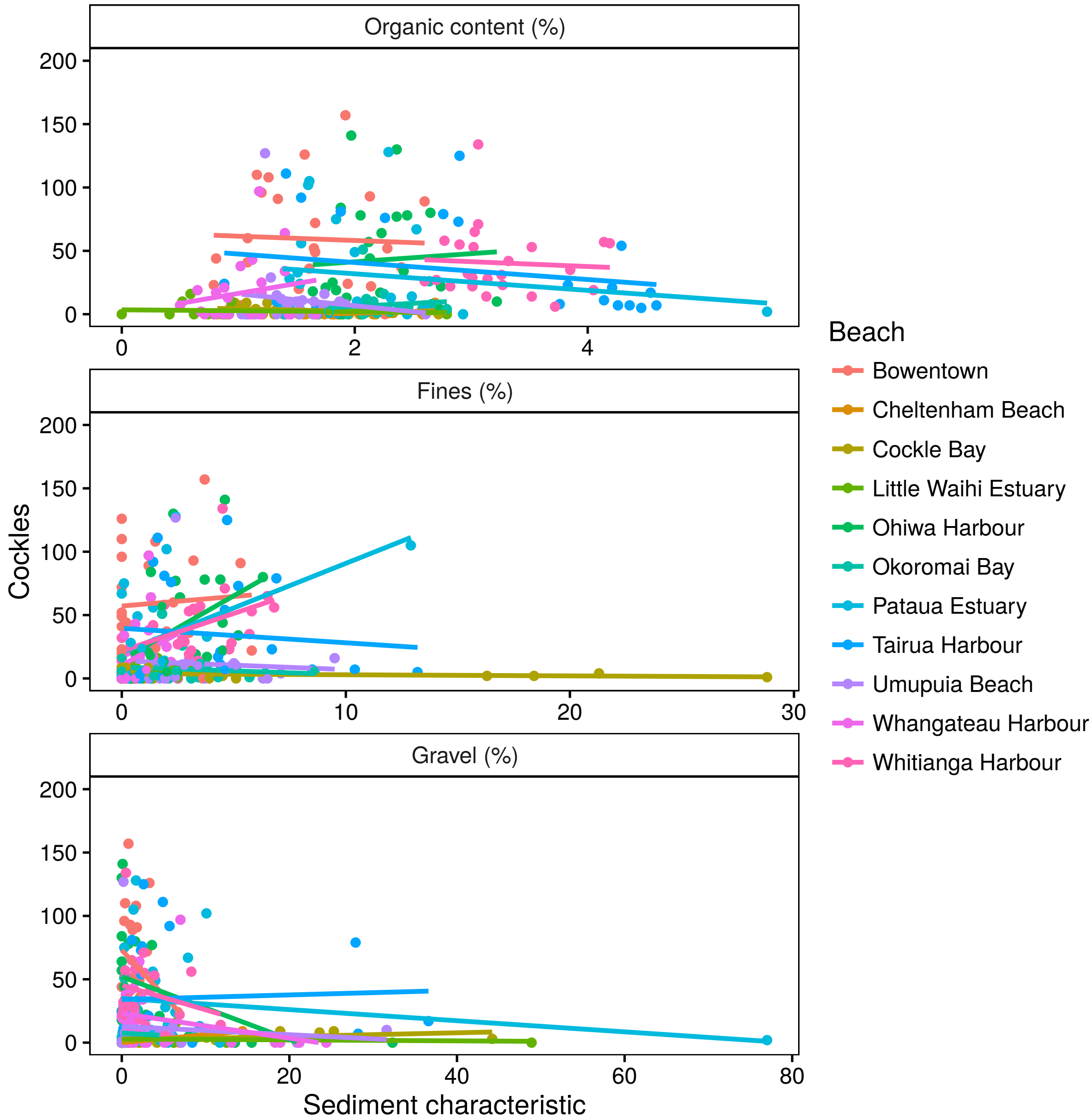


Figure 51: Sediment characteristics (organic content, proportion of fines, and proportion of gravel) and number of cockles in each sample. Regression lines relate to the two variables at each of the 2015–16 survey sites.

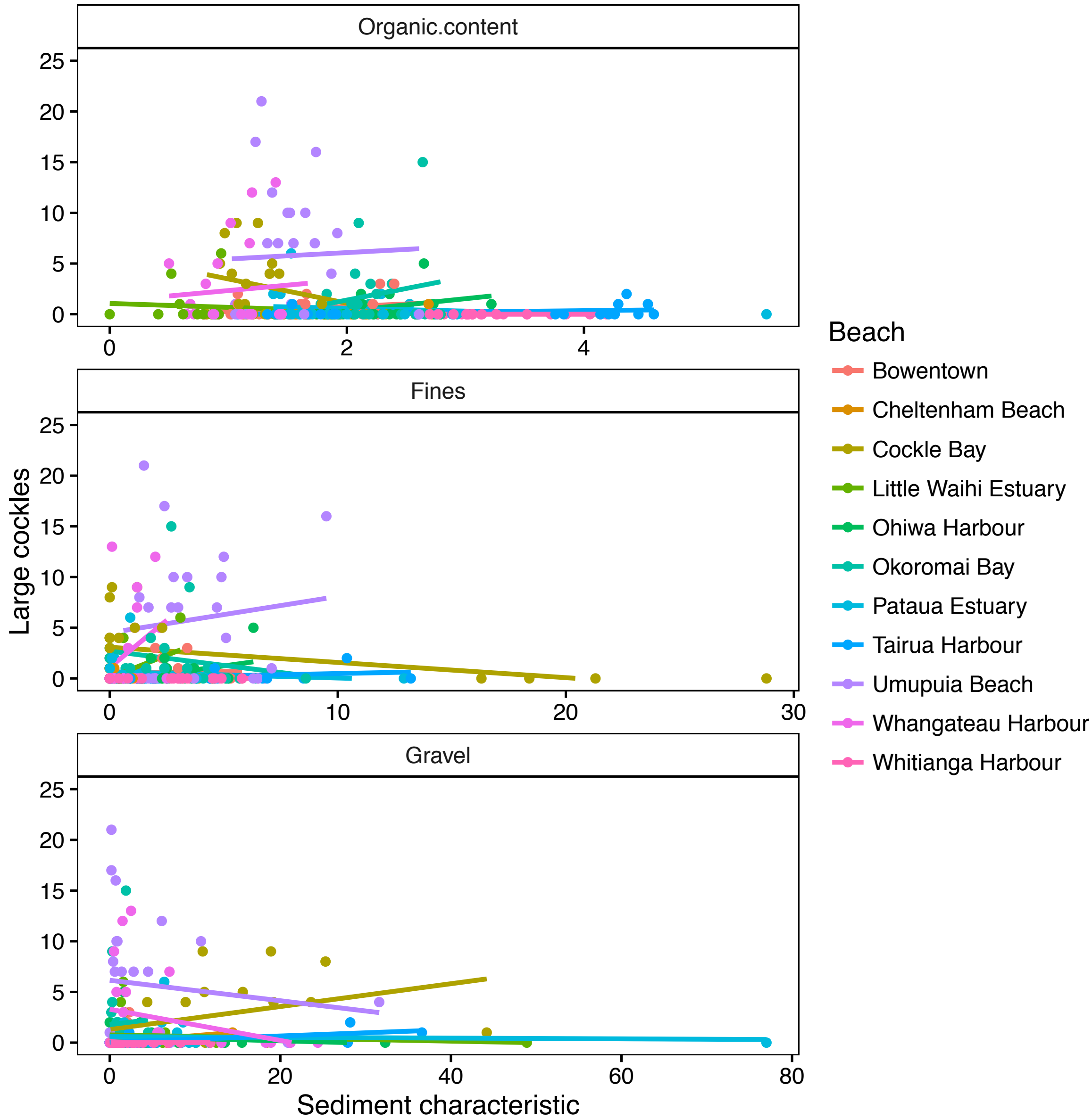


Figure 52: Sediment characteristics (organic content, proportion of fines, and proportion of gravel) and number of large ($\geq$ 30 mm shell length) cockles in each sample. Regression lines relate to the two variables at each of the 2015–16 survey sites.

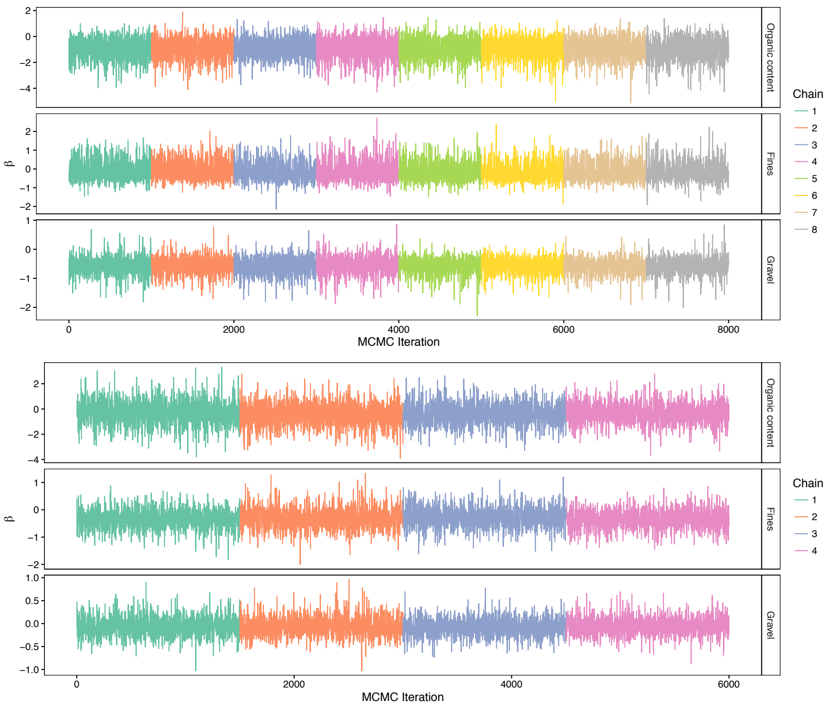


Figure 53: Markov Chain Monte Carlo (MCMC) iterations for the β parameter for total cockles (top) and for large (≥30 mm shell length) cockles (bottom) from independent MCMC chains.

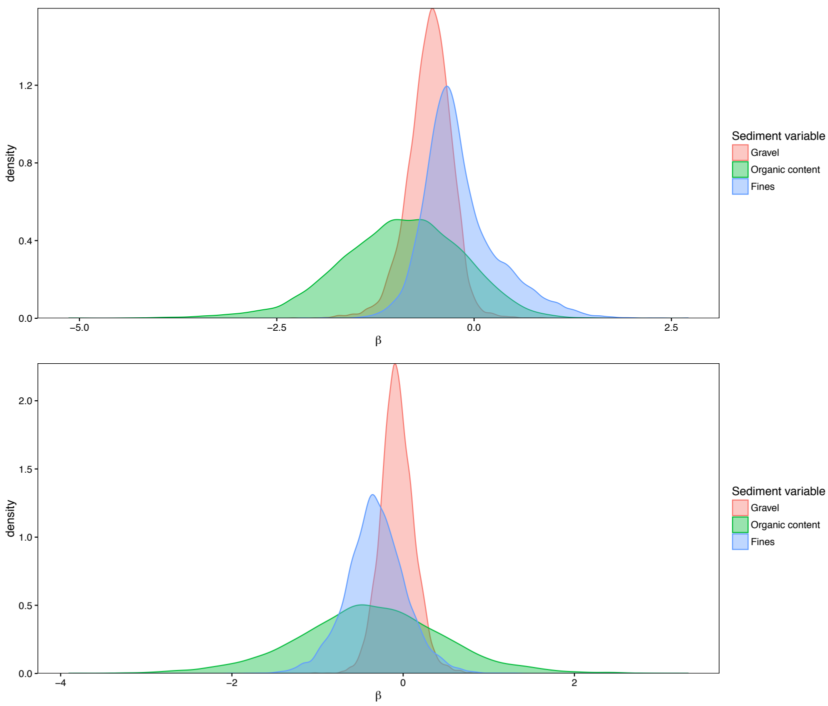


Figure 54: Estimates of posterior densities for the regression relationship with coefficient β between estimated mean sediment variables (proportion of fines (silt and clay <63 µm), organic content, and proportion of gravel (>2000 µm) and expected number of total cockles (top) and large (≥30 mm shell length) cockles (bottom) per sample.

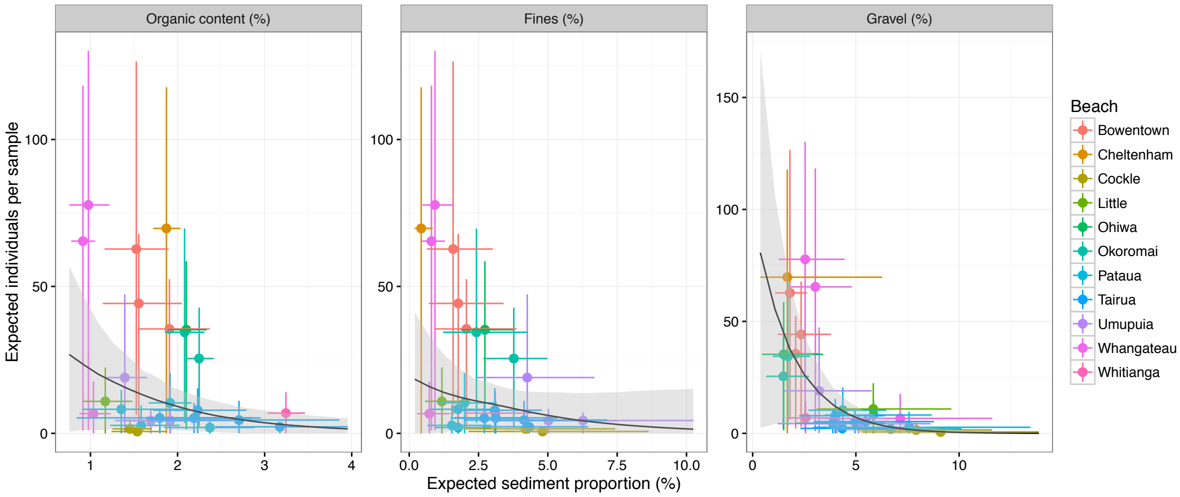


Figure 55: Estimates of the expected number of cockles per sample (adjusted to remove site-differences not due to sediment, i.e., site level random effects) in relation to proportion of fines (silt and clay, <63 µm), organic content, and gravel (>2000 µm) per stratum at the 2015–16 survey sites. The black line shows the posterior median of the linear predictor (model fit) and grey shading the interquartile range of the posterior distribution.

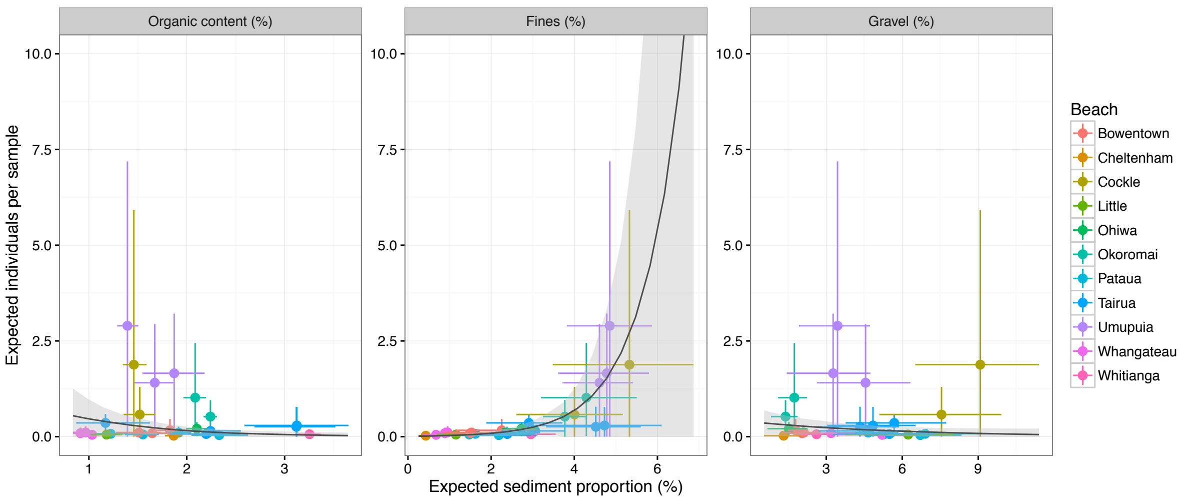


Figure 56: Estimates of the expected number of large (≥ 30 mm shell length) cockles per sample (adjusted to remove site-differences not due to sediment, i.e., site-level random effects) in relation to proportion of fines (silt and clay <63 µm), organic content, and gravel (>2000 µm) per stratum at the 2015–16 survey sites. The black line shows the posterior median of the linear predictor (model fit) and grey shading the interquartile range of the posterior distribution.

5. SUMMARIES

5.1 Cockle populations

Ten of the 2015–16 survey sites supported cockle populations, whereas Cheltenham Beach and Marokopa Estuary only contained low numbers of cockles, preventing reliable population estimates (i.e., the CV values exceeded 60%). At the remaining sites, cockle population estimates were robust, indicated by CV values generally well below 20%. Across these sites, total cockle population sizes ranged from an estimated 23.01 million (CV: 14.33%) individuals at Ohiwa Harbour to the highest population estimate of 742.44 million (CV: 7.02%) cockles at Whangateau Harbour (Table 59). Population estimates were also comparatively high at Pataua Estuary with an estimated 380.13 million (CV: 7.58%) cockles, and at Umupuia Beach, where total abundance was estimated at 98.88 million (CV: 15.93%) cockles in 2015–16.

Although it is difficult to compare population parameters across sites owing to differences in habitat characteristics and sampling areas, population densities provide some indication of the size of the bivalve beds targeted by non-commercial fishing. Cockle densities were high at two sites, Bowentown Beach and Pataua Estuary with 1799 cockles per m^2 and 1368 cockles per m^2, respectively. All other sites with cockle populations (i.e., excluding Cheltenham Beach and Marokopa Estuary) supported lower densities, ranging from 136 cockles per m^2 (Cockle Bay) to 852 cockles per m^2 (Whitianga Harbour).

Most populations contained some large cockles ($\geq$30 mm shell length), and their numbers were relatively high at five sites, ranging from 4.89 million (CV: 29.68%) individuals at Pataua Estuary to the largest population of 45.43 million (CV: 18.77%) large cockles at Whangateau Harbour. Their corresponding densities were highest at Umupuia Beach and Cockle Bay (128 and 98 individuals per m^2, respectively), with markedly lower densities at the other sites (2 to 51 cockles per m^2). At both Umupuia Beach and Cockle Bay, the large size class made up a substantial part of the total population, whereas it contributed relatively few individuals at other sites.

Cockle density estimates for individual strata documented a consistent pattern across recent surveys, including the present study (Figure 57). Frequency distributions of estimated cockle densities within strata were generally unimodal throughout the survey series, determined by strata with less than 500 individuals per m^2. Strata that supported higher cockle densities were considerably less frequent, and lacking in some years. Since 2010–11, there has been an increase in the proportion of strata with higher densities, including densities of 2000 (and more) cockles per m^2 such as in 2015–16.

Length-frequency distributions of cockle populations at the survey sites included in this study showed a decrease in the number of large cockles over time (Figure 58). Throughout the survey series, length frequency distributions were unimodal, dominated by medium-sized cockles, while recruits ($\leq$15 mm shell length) and large cockles ($\geq$30 mm shell length) were also present in the population. Since 2005–06, there has been a decline in the latter size class, with considerably fewer large individuals in subsequent surveys. This finding indicates that the strong cohort of medium-sized cockles did not contribute large individuals to the population. Instead, there was a general shift towards smaller-sized cockles in recent surveys, with an increase in the number of recruits.

Time-series comparisons of large cockle densities highlighted differences across sites, and also confirmed the overall decrease in large individuals over time (Figure 59). Although this size class showed some fluctuation throughout the survey series, there was a decline in the density of large cockles at each site, at least once in the reporting period. This decline was most pronounced at sites that initially supported high densities of large individuals. For example, at Tairua Harbour, the large size class underwent a decrease from over 400 individuals per m^2 in 1999–2000 to about 100 individuals per m^2 in 2001–02, and the decline of large cockles continued to a density of 4 individuals per m^2 in 2015–16. Other sites with low densities of large cockles (i.e., less than 20 individuals per m^2) in 2015–16 included Bowentown Beach, Little Waihi Estuary, Ohiwa Harbour, and Pataua Estuary. Large cockle densities at these sites remained similarly low as the preceding estimates, except for Ohiwa Harbour, where the current estimate was an increase from the two preceding assessments.

There were two other sites with small increases in the estimated densities of large cockles, Okoromai Bay and Whangateau Harbour. Although the increases were not significant, they potentially indicate some sign of recovery, particularly at Whangateau Harbour, where the current estimate reflected a continuing trend. In contrast, at Cockle Bay and Umupuia Beach the estimated densities of large cockles decreased in 2015–16, and for the former site, this trend was a continuation from the previous assessment. Both Cockle Bay and Umupuia Beach have had substantial increases in large cockle densities since 2009–10, but this increase was followed by declining estimates at Cockle Bay, whereas estimates have remained similar at Umupuia Beach in recent surveys.

Table 59: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2015–16 survey. For each site, the table includes the estimated mean number, the mean density, and coefficient of variation (CV) for all cockles (Total) and for large cockles (≥30 mm shell length).

Survey site	Population estimate			Population ≥30 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Bowentown Beach	26.95	1 799	5.17	0.03	2	34.77
Cheltenham Beach	1.60	5	66.48	0.23	<1	>100
Cockle Bay	21.46	136	8.48	15.37	98	10.77
Little Waihi Estuary	30.40	165	12.74	0.26	2	51.69
Marokopa Estuary	0.07	3	62.90	0.00	0	
Ohiwa Harbour	23.01	683	14.33	0.26	10	30.87
Okoromai Bay	34.78	175	19.45	8.48	43	19.44
Pataua Estuary	380.13	1 368	7.58	4.89	18	29.68
Tairua Harbour	57.22	700	10.46	0.37	4	43.97
Umupuia Beach	98.88	292	15.93	39.12	128	10.61
Whangateau Harbour	742.44	671	7.02	45.43	51	18.77
Whitianga Harbour	51.98	852	9.16	0.00	0	

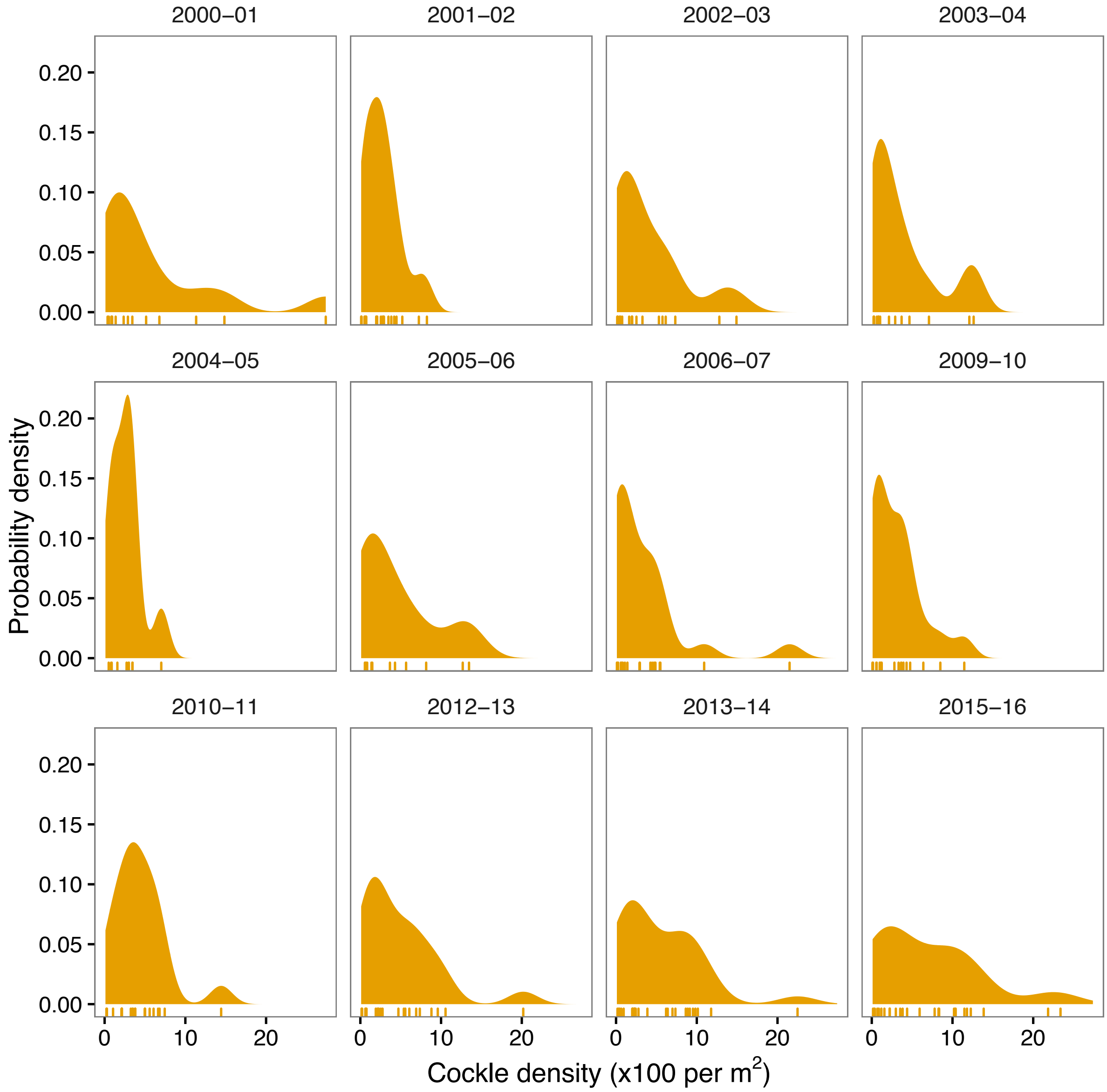


Figure 57: Cockle densities over time at sites included in the 2015–16 survey, estimated independently for all strata. Only strata with more than ten cockles per m^2 were included, the shading shows densities of individual strata. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

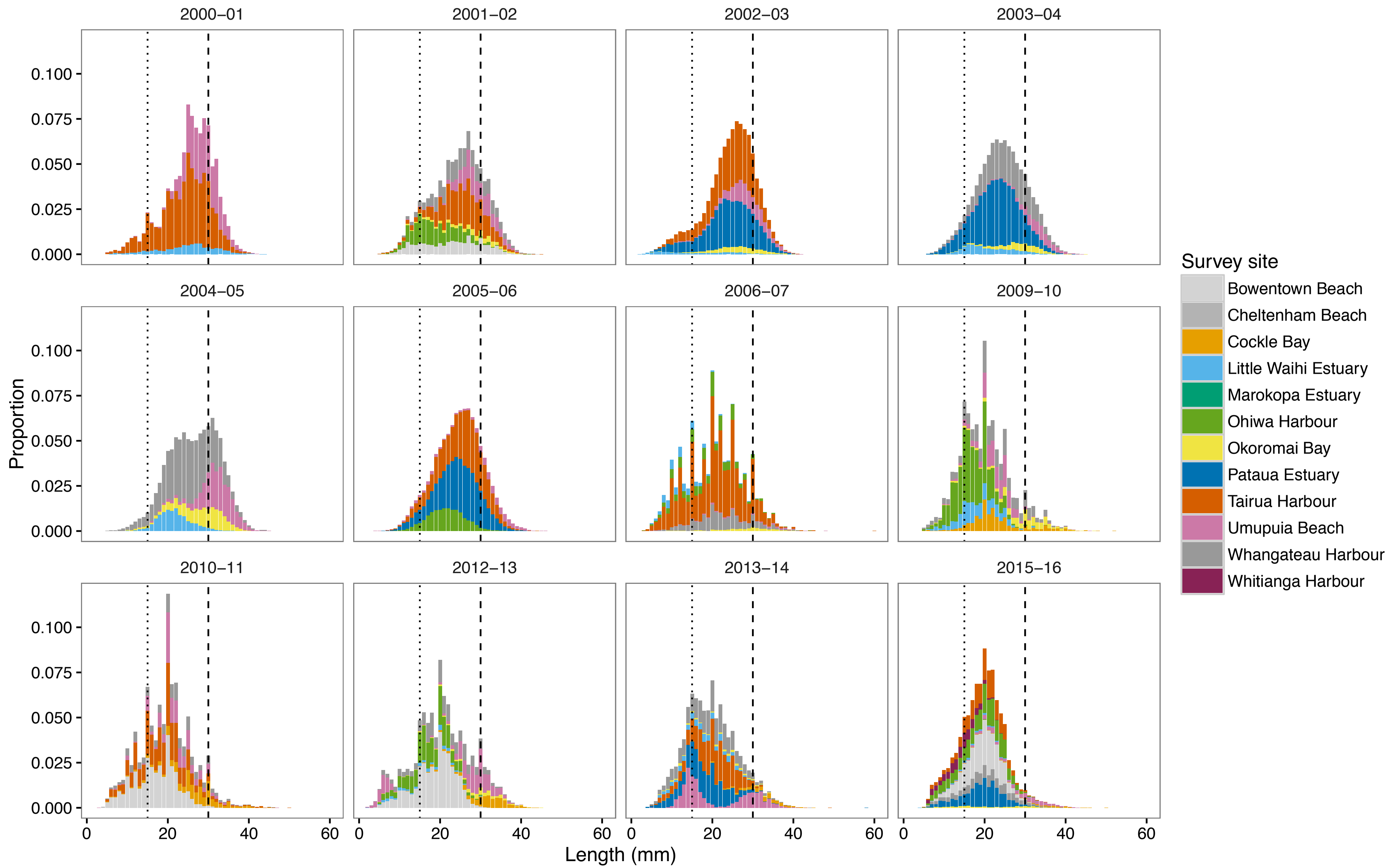


Figure 58: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2015–16 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

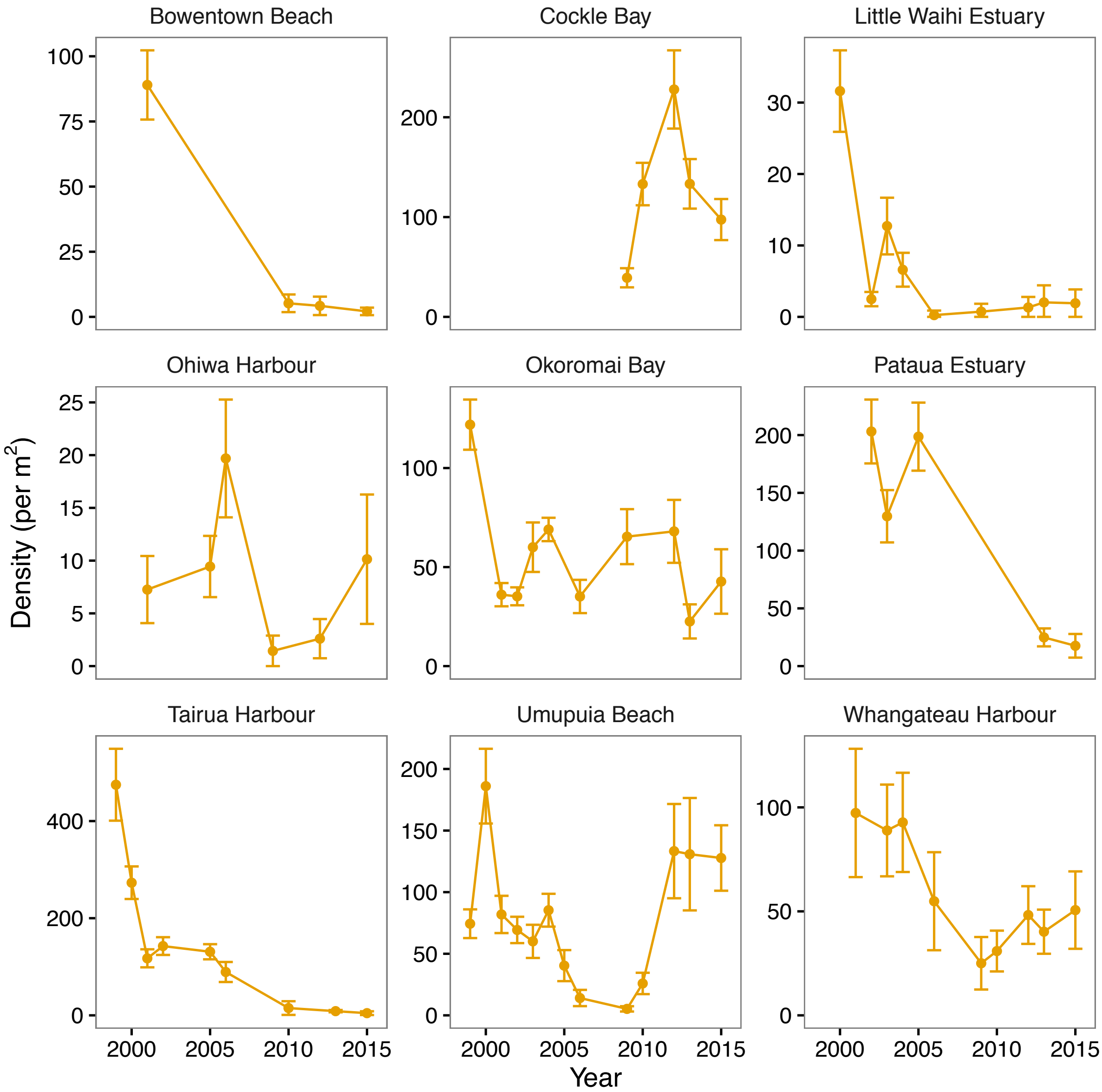


Figure 59: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. For each site, the figure shows the mean estimated density of large cockles across years within each year's survey strata, bars indicate 95% credible interval.(Note different scales on the y-axes.)

5.2 Pipi populations

Pipi populations were present at eight of the 2015–16 survey sites, and estimates for all but one population had CV values below 20% (Table 60). The exception was at Whangateau Harbour, where the patchy occurrence of pipi on the intertidal mudflat led to a higher CV for the pipi population estimates. A number of sites supported relatively large pipi populations, and abundance estimates ranged from a total population size of 0.15 million (CV: 16.6%) pipi at Bowentown Beach to the largest population estimate of 83.84 million (CV: 16.62%) pipi at Little Waihi Estuary.

The highest pipi population density was at Ohiwa Harbour with an estimated 1225 pipi per m^2 (CV: 12.1%). The next highest density estimate was at Little Waihi Estuary, with 456 pipi per m^2 (CV: 16.62%), and estimates at Marokopa Estuary and Tairua Harbour were slightly lower, with 333 pipi per m^2 (CV: 11.26%) and 327 pipi per m^2 (CV: 15.64%), respectively. Density estimates at the other sites were lower, with 104 pipi per m^2 at Whitianga Harbour, and less than 25 pipi per m^2 at the remaining sites, Bowentown Beach, Pataua Estuary, and Whangateau Harbour.

Except for pipi at Marokopa Estuary, all of the populations included some large individuals ($\geq$50 mm shell length), but estimates of this size class were generally low. The exception was Ohiwa Harbour, where the abundance estimate for large pipi was 3.70 million (CV: 18.37%) individuals. Their density at this site was also relatively high with 110 large pipi per m^2.

Population estimates for large pipi were also comparatively high at Little Waihi Estuary and Whitianga Harbour, with a total of 2.35 million (CV: 43.62%) individuals and 1.91 million (CV: 22.66%) individuals, respectively. Corresponding densities for large pipi at these sites were 13 large pipi per m^2 at Little Waihi Estuary, and 31 large pipi per m^2 at Whitianga Harbour. Densities at the other sites were low, ranging between <1 and 5 pipi per m^2. Overall, the large pipi size class contributed few individuals to the populations across sites, with the exception of Whitianga Harbour, where large pipi made up about a third of the resident population.

Estimated pipi densities within individual strata revealed similar frequency distributions across surveys, characterised by low pipi densities, not exceeding 500 individuals per m^2 (Figure 60). In addition to this prevalence of low-density strata, some assessments included strata with higher pipi densities, evident in the bimodal frequency distributions at those times (e.g., in 2006–07). Strata with higher pipi densities were consistently documented in the three most recent surveys, including the present study. The latter included strata with estimated pipi densities of over 7000 individuals per m^2, although a significant proportion of strata contained less than 2000 pipi per m^2.

The recent increases in strata with high density estimates were accompanied by a marked shift in the length-frequency distributions of the pipi populations towards smaller shell lengths (Figure 61). In early assessments, the pipi population structure at the survey sites was generally unimodal, determined by medium-sized to large pipi ($\geq$50 mm shell length) and a small number of recruits ($\leq$20 mm shell length). Large individuals were sufficiently frequent to be evident as a second cohort in a number of surveys. Since 2006–07, the number of recruits has increased, with a concomitant decrease in the number of large individuals. These changes resulted in pipi populations that contained smaller-sized individuals, including high numbers of recruits forming distinct cohorts in a bimodal population structure in 2012–13 and 2015–16. In 2015–16, this cohort was markedly stronger than the second cohort of medium-sized pipi, and there were few large individuals.

Five of the six sites that included large pipi at least once in the survey series showed a decline in their estimated densities over time (Figure 62). Time-series data highlighted considerable differences across sites, but all current density estimates of large pipi were low, except for the population at Ohiwa Harbour. This site also contained the only pipi population that showed a current increase in the estimated density of large pipi within strata. At Ohiwa Harbour, the density estimate of this size class increased notably from the previous survey, exceeding 100 large individuals per m^2 in 2015–16. Data from the two surveys at Whitianga Harbour showed similar density estimates between surveys of about 30 large pipi per m^2. At the other sites, large pipi were scarce, with estimated densities of <1 individuals per m^2 to 13 individuals per m^2. For both Little Waihi Estuary and Pataua Estuary, these low estimates reflected further declines from previous assessments, whereas density estimates continued to be low at Tairua and Whangateau harbours. At the latter site, there have been few large pipi since their significant decline in 2003–04, whereas the decrease in estimated densities of large pipi at Tairua Harbour has been more gradual, starting in 2005–06.

Table 60: Estimates of pipi abundance for all sites on which more than ten pipi were found in the 2015–16 survey. For each site, the table includes the estimated mean number, the mean density, and coefficient of variation (CV) for all pipi (Total) and for large pipi (≥50 mm shell length).

Survey site	Population estimate			Population ≥50 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Bowentown Beach	0.15	10	16.6	0.01	<1	72.82
Cockle Bay	0.11	<1	>100	0.00	0	
Little Waihi Estuary	83.84	456	16.62	2.35	13	43.62
Marokopa Estuary	8.62	333	11.26	0.00	0	
Ohiwa Harbour	41.26	1225	12.1	3.70	110	18.37
Pataua Estuary	6.45	23	14.67	0.19	<1	79.86
Tairua Harbour	26.71	327	15.64	0.38	5	39.85
Whangateau Harbour	15.00	14	23.2	0.40	<1	9.04
Whitianga Harbour	6.36	104	18.17	1.91	31	22.66

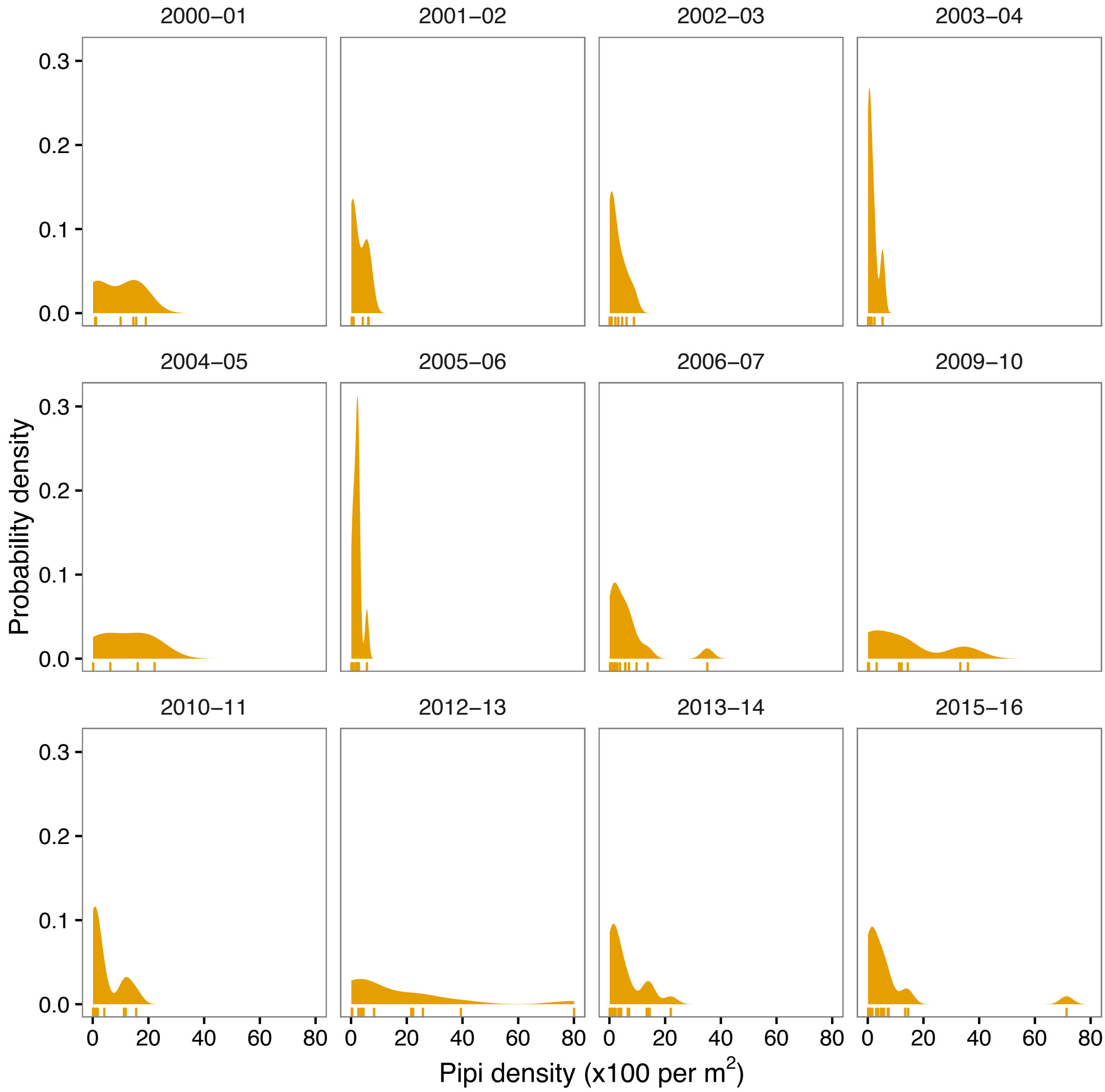


Figure 60: Pipi densities over time at sites included in the 2015–16 survey, estimated independently for all strata. Only strata with more than ten pipi per m^2 were included, the shading shows densities of individual strata. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

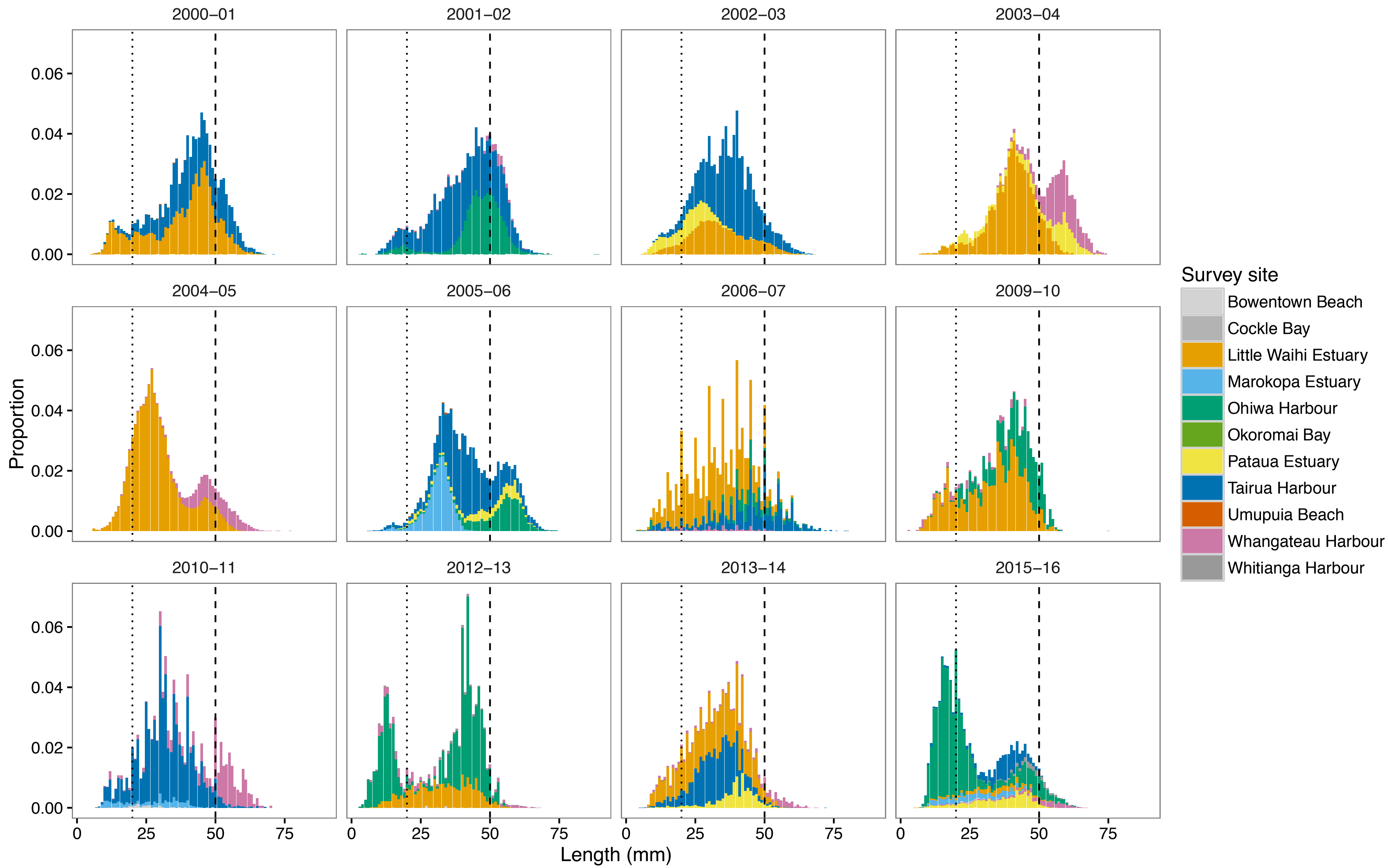


Figure 61: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2015–16 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

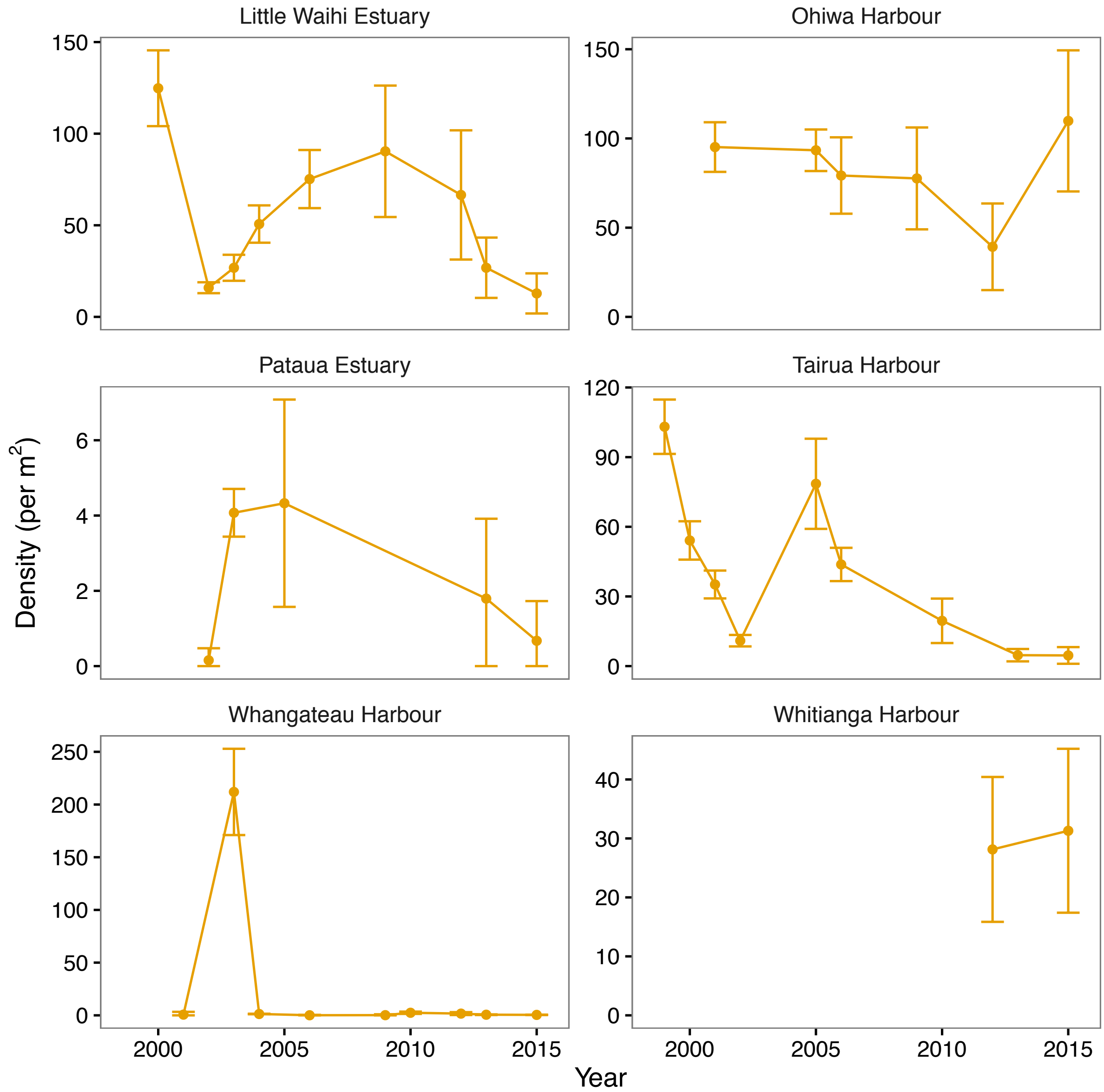


Figure 62: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. For each site, the figure shows the mean estimated density of large pipi across years within each year's survey strata, bars indicate 95% credible interval.

6. DISCUSSION

The sites included in the current assessment represented a range of coastal environments, such as open beaches, sheltered intertidal bays, and estuaries influenced by river input. All of the sites supported bivalve populations, and cockles were sampled at ten sites, while pipi were surveyed at eight sites. Most sites have been regularly monitored over the 17-year reporting period, including five surveys at Cockle Bay and Pataua Estuary, six surveys at Ohiwa Harbour, nine surveys at Little Waihi Estuary, Tairua and Whangamata harbours, ten surveys at Okoromai Bay, and 13 surveys at Umupuia Beach. Marokopa Estuary and Bowentown Beach were sampled less frequently, with three and four bivalve assessments, respectively. Whitianga Harbour was surveyed for the second time in 2015–16, after the initial survey in 2012–13. At Cheltenham Beach, the current study provided the first assessment in the survey series since 1998–99. At the other sites, previous assessments were more recent, either in 2012–13 or 2013–14, except for Marokopa Estuary, where the most recent, previous survey was conducted in 2010–11.

Throughout the survey series, the data collection at each site has focused on intertidal areas that have been identified as important for recreational and customary fisheries. Once these areas are identified, individual surveys generally rely on the same designated sampling areas used in previous assessments to allow comparisons over time. In the current study, on-site information identified changes in the spatial distribution of bivalve populations at some sites, leading to changes in the sampling extent in 2015–16.

For cockle population estimates, another change to the sampling extent involved re-stratification of areas that predominantly target cockles, at sites where high-resolution spatial information was available (see detailed information in Appendix B). Bivalve surveys since 2013–14 have included GPS positions for individual sampling points, and current sites that were part of these recent surveys were Cockle Bay, Little Waihi Estuary, Okoromai Bay, Pataua Estuary, Tairua Harbour, Umupuia Beach, and Whangateau Harbour (see, Berkenbusch et al. 2015). Based on detailed spatial information and corresponding cockle population data, the sampling extent at these sites was re-stratified in an attempt to optimise the sampling effort and improve population estimates (e.g., reducing CV values). This update meant that the overall size and location of the sampling extent remained unchanged, but individual strata within it were re-defined.

In general, the re-stratification succeeded in lowering the CV values of cockle population estimates at all but one site (Okoromai Bay). As the current re-stratification was based on only one year of data, it is likely that additional information from this study and subsequent surveys will further improve re-stratification efforts in the future. For example, high-resolution data for multiple years at a site will allow future stratification efforts to incorporate interannual variability in the cockle population data.

Other changes to the cockle sampling involved the upshore movement of one of the cockle strata at Ohiwa Harbour, and inclusion of a cockle stratum at Whitianga Harbour. At Ohiwa Harbour, the sideways shift of the cockle stratum was necessitated by the movement of the channel adjacent to it, which submerged the previous stratum area. The current sampling of the newly designated stratum in the directly adjacent area confirmed that cockles had moved to the intertidal part of the channel edge. At Whitianga Harbour, the cockle stratum included in the present study covered the same area regularly surveyed by the Hauraki Gulf Forum community monitoring programme, facilitating comparisons between the two different survey series.

For pipi population estimates, changes to the sampling extent mostly related to the position and size of the pipi beds, which usually occur in physically-dynamic areas, such as tidal channels and high-flow subtidal sediments. Physical changes to these habitats can lead to shifts in the spatial distribution of this species, requiring adjustments to strata targeting pipi. In addition, as their general habitat preference extends into subtidal waters, the intertidal sampling of this survey series may only access parts of the pipi populations, so that the total population size remains unknown.

Changes to the pipi strata in 2015–16 affected the data collection at Ohiwa Harbour, Pataua Estuary, Tairua Harbour, Whangateau Harbour and Whitianga Harbour. Most of the changes were comparatively small changes in the spatial extent of pipi beds, e.g., at Pataua Estuary and Whangateau Harbour. At other sites, some of the previously-sampled pipi beds had changed in their spatial extent or disappeared, including Ohiwa, Tairua, and Whitianga harbours. At Marokopa Estuary, the spatial distribution of pipi had remained largely unchanged since the preceding survey in 2010–11, with the pipi beds restricted to shallow subtidal waters in the main channel.

Considering the current estimates in the context of the survey series showed that estimated population parameters for both species were consistent with values recorded throughout the reporting period. Nevertheless, there were some marked changes in some of the cockle and pipi populations between the current study and the immediately preceding assessment. For cockles, these changes included marked increases in the population estimates at Ohiwa Harbour and Okoromai Bay between 2013–14 and 2015–16, including the estimates for large cockles. Over the same period, there were notable declines in the cockle populations at Cockle Bay, Umupuia Beach and Tairua Harbour. The population decreases at these sites were in part due to decreases in the populations of large cockles ($\geq$30 mm shell length).

For pipi, there was a notable increase in the population estimates at Marokopa Estuary since the preceding survey in 2010–11. In contrast, pipi populations underwent significant decreases at Little Waihi Estuary, Pataua Estuary, Tairua Harbour, Whangateau Harbour (between 2013–14 and 2015–16), and Whitianga Harbour (between 2012–13 and 2015–16). Declines in the numbers of large pipi ($\geq$50 mm shell length) contributed to the overall population declines at these sites.

The reason/s for the recent changes in cockle and pipi populations are unknown. Some of the recent population declines (including large cockles) occurred at sites that have fishery restrictions in place. For example, Cheltenham Beach has been closed to the collection of shellfish since 1992. Inspite of this closure, bivalve populations continued to decline, with no signs of recruitment or recovery throughout the 1990s (Morrison & Browne 1999, Morrison et al. 1999). In 2015–16, cockle and pipi populations (and other large bivalves) continued to be absent at this site. At Cockle Bay, Umupuia Beach and Whangateau Harbour, seasonal or permanent closures prohibit the collection of bivalves. At the two former sites, the introduction of fishery closures in 2008 led to initial increases in the cockle population estimates. For the cockle population at Cockle Bay, the recent decreases reflect a continuing decline since 2009–10. In contrast, there have been consistent increases in the cockle population size at Umupuia Beach, with the current estimates reflecting the smallest cockle population size since 2010–11.

The declines in large individuals at some sites tentatively suggest that fishing pressure may contribute to the observed decreases. Nevertheless, fishing is only one of the factors that potentially influence bivalve populations, which are also determined by population dynamics, environmental variables, and habitat properties. As there are no data available of the number and sizes of bivalves taken at any of the survey sites, the lack of information prevents an examination of the role of fishing for the cockle and pipi populations. In addition, for pipi, some of the population changes between surveys at Whangateau Harbour (and elsewhere) could be caused by changes in the spatial distribution of the pipi beds. Changes to the channels inhabited by pipi, and shifts into deeper water by this species may lead to changes in the proportion of the population that is available to the intertidal sampling, affecting the population estimates.

Most of the populations in 2015–16 contained some large individuals, although this size class only made up a small proportion of the population at most sites. The time-series data indicated that for most sites, strong cohorts of small and medium-sized individuals did not subsequently contribute to the large bivalve size class. Large individuals are considered to be preferentially targeted in fishing activities, and it is unknown if low numbers of large cockles and pipi lead to the collection of smaller-sized individuals, or if other factors (e.g., predation, limited food supply) prevent the smaller size classes from exceeding the large-size thresholds applied in this survey series.

The current study also involved sediment sampling within cockle strata to examine the relationship between cockle abundance and sediment properties, including organic matter content and the proportions of fines ($<$63 µm grain size) and gravel ($>$2000 µm grain size). Findings from the data modelling showed that cockle abundances decreased with increases in the three sediment variables at the stratum level, but these relationships were tentative only. The strongest correlation (i.e., with the lowest uncertainty) was between cockle abundance and the proportion of gravel. This size fraction showed considerable variation within and across sites, with a maximum proportion of this grain size fraction of 77.0% (at Pataua Estuary). In comparison, the proportion of sediment fines was low, although values were high at some sites, including a maximum proportion of 28.8% (at Cockle Bay). Sediment organic content showed less variation, and was generally low across all sampling points (i.e., below 5%). Overall the relationships between cockle abundance and the measured sediment variables were uncertain, which in part can be explained by the high variability in the sediment data combined with relatively limited data (i.e., only one-off sampling). As more data become available, the sediment modelling will be better informed, providing less uncertainty in the outcome, including the potential to explore other analysis approaches such as multivariate statistics, quantile regressions, and maximum-density models (e.g., Thrush et al. 2003). In view of the current findings and the effort involved in the sediment sampling, subsequent efforts may be targeted to establish a collection of baseline data to include all sites that are part of the northern North Island survey series. Once established, future sediment sampling may then focus on specific sites and times following specific events (such as sedimentation from urban development), and be used in Before-After-Control-Impact type assessments involving comparisons with baseline data.

7. ACKNOWLEDGMENTS

Many thanks to the field assistants who helped conduct the bivalve surveys across the northern region, including: Sophie Burgess, Charlotte Crummack, Mikhail Fokin, Lydia Hayward, Keith Jacob, Lily Kozmian-Ledward, Ana Markic, Clarisse Niemand, Carlos Olavarria, Alyx Pivac, and Angela Smith.

Thanks are also due to the local communities and iwi who shared their knowledge of the sites and provided guidance for the surveys.

Thanks to Beth McKinnel for help with the reconnaissance, and Sophie Fern for conducting the sediment analyses at the Portobello Marine Laboratory/University of Otago.

KG Kayaks provided kayaks for accessing sites at Ohiwa Harbour.

This research was funded by Ministry for Primary Industries project AKI2015/01.

8. REFERENCES

Anderson, M.J. (2008). Animal-sediment relationships re-visited: characterising species' distributions along an environmental gradient using canonical analysis and quantile regression splines. *Journal of Experimental Marine Biology and Ecology 366(1)*: 16–27.

Auckland Council. (2013). Hauraki Gulf Forum community monitoring programme annual report 2012–13. Unpublished report held by Auckland Council, Auckland. Retrieved 27 May 2016, from http://www.aucklandcouncil.govt.nz/en/aboutcouncil/representativesbodies/haurakigulfforum/Pages/home.aspx

Bates, D.; Mächler, M.; Bolker, B.; Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software 67(1)*: 1–48. doi:10.18637/jss.v067.i01

Berkenbusch, K.; Abraham, E.; Neubauer, P. (2015). Intertidal shellfish monitoring in the northern North Island region, 2013–14. *New Zealand Fisheries Assessment Report 2015/15*. 83 p.

Berkenbusch, K.; Neubauer, P. (2015). Intertidal shellfish monitoring in the northern North Island region, 2014–15. *New Zealand Fisheries Assessment Report 2015/59*. 110 p. Retrieved 3 October 2015, from https://www.mpi.govt.nz/document-vault/9800

Blangiardo, M.; Cameletti, M.; Baio, G.; avard Rue, H. (2013). Spatial and spatio-temporal models with R-INLA. *Spatial and Spatio-temporal Epidemiology 7*: 39–55.

Carpenter, B.; Gelman, A.; Hoffman, M.; Lee, D.; Goodrich, B.; Betancourt, M.; Brubaker, M.A.; Guo, J.; Li, P.; Riddell, A. (2015). Stan: a probabilistic programming language. *Journal of Statistical Software*. Retrieved from http://www.demonish.com/cracker/1431548798_9226234ebe/stan-resubmit-jss1293.pdf

De Gruijter, J.J.; Minasny, B.; Mcbratney, A.B. (2015). Optimizing stratification and allocation for design-based estimation of spatial means using predictions with error. *Journal of Survey Statistics and Methodology 3(1)*: 19–42.

Eleftheriou, A.; McIntyre, A. (2005). Methods for the study of marine benthos. Blackwell Science, Oxford, United Kingdom. 418 p.

Gelman, A.; Carlin, J.B.; Stern, H.S.; Rubin, D.B. (2004). Bayesian data analysis. (2nd edition). Chapman & Hall/CRC, Boca Raton. 668 p.

Grant, C.M.; Hay, B.E. (2003). A review of issues related to depletion of populations of selected infaunal bivalve species in the Hauraki Gulf Marine Park. A report prepared for the Hauraki Gulf Marine Park Forum by AquaBio Consultants Limited (Unpublished report held by Auckland Regional Council, Auckland).

Hartill, B.; Morrison, M.A.; Cryer, M. (2005). Estimates of biomass, sustainable yield and harvest: neither necessary nor sufficient for the management of amateur intertidal fisheries. *Fisheries Research 71*: 209–222.

Hauraki Māori Trust Board. (2003). Strategic plan for the customary fisheries of Hauraki. Retrieved 3 August 2013, from http://www.hauraki.iwi.nz/resources/publications_pdf

Hewitt, J.E.; Cummings, V.J. (2013). Context-dependent success of restoration of a key species, biodiversity and community composition. *Marine Ecology Progress Series 479*: 63–73.

Hooker, S.H. (1995). Life history and demography of the pipi - *Paphies australis* (Bivalvia: Mesodesmatidae) in northeastern New Zealand. Unpublished Ph.D. dissertation, University of Auckland, Auckland, New Zealand.

Lindgren, F.; Rue, H. (2015). Bayesian spatial modelling with R-INLA. *Journal of Statistical Software 63(19)*.

Morrison, M.A.; Browne, G.N. (1999). Intertidal shellfish population surveys in the Auckland region 1998–99 and associated yield estimates. New Zealand Fisheries Assessment Research Document 99/43 (Unpublished report held by the Ministry for Primary Industries, Wellington).

Morrison, M.A.; Pawley, M.D.M.; Browne, G.N. (1999). Intertidal surveys of shellfish populations in the Auckland region, 1997–98, and associated yield estimates. New Zealand Fisheries Assessment Research Document 99/25 (Unpublished report held by the Ministry for Primary Industries, Wellington).

Morton, J.E.; Miller, M.C. (1973). The New Zealand sea shore. Collins, London. 653 p.

Pawley, M.D.M. (2011). The distribution and abundance of pipis and cockles in the Northland, Auckland, and Bay of Plenty regions, 2010. *New Zealand Fisheries Assessment Report 2011/24*.

Pawley, M.D.M. (2012). The distribution and abundance of pipis and cockles in the Northland, Auckland and Bay of Plenty regions, 2012. *New Zealand Fisheries Assessment Report 2012/45*.

Pawley, M.D.M.; Ford, R. (2007). Report for AKI2006/01. Final Research Report for Ministry of Fisheries Project AKl2006/01 (Unpublished report held by the Ministry for Primary Industries, Wellington).

Pawley, M.D.M.; Smith, A.N.H. (2014). The distribution and abundance of pipis and cockles in the Northland, Auckland and Bay of Plenty regions, 2013. *New Zealand Fisheries Assessment Report 2014/29*.

R Core Team. (2015). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Vienna, Austria.

Thrush, S.F.; Hewitt, J.E.; Norkko, A.; Nicholls, P.E.; Funnell, G.A.; Ellis, J.I. (2003). Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. *Marine Ecology Progress Series 263*: 101–112.

APPENDIX A: Sampling dates and extent of northern North Island bivalve surveys

Table A-1: Sampling years (coloured blue) for sites included in the northern North Island bivalve surveys since 1999–00.

Survey site	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2009–10	2010–11	2012–13	2013–14	2014–15	2015–16
Aotea Harbour							■		■				■	
Bowentown Beach			■							■	■			■
Cheltenham Beach														■
Clarks Beach						■								
Cockle Bay									■	■	■	■		■
Cornwallis Wharf			■											
Eastern Beach	■		■										■	
Grahams Beach								■		■	■	■		
Howick Harbour							■							
Kawakawa Bay (West)						■		■					■	
Little Waihi Estuary		■		■	■	■		■	■		■	■		■
Mangawhai Harbour	■	■	■	■	■					■			■	
Marokopa Estuary							■			■				■
Marsden Bank									■		■	■		
Mill Bay	■	■	■		■	■	■		■				■	
Ngunguru Estuary					■	■				■			■	
Ohiwa Harbour			■				■	■	■		■			■
Okoromai Bay	■		■	■	■	■		■	■		■	■		■
Otumoetai Harbour		■		■			■	■	■				■	
Papamoa Beach	■													
Pataua Estuary				■	■		■					■		■
Raglan Harbour	■	■		■	■				■		■		■	
Ruakaka Estuary								■		■			■	
Tairua Harbour	■	■	■	■			■	■		■		■		■
Te Haumi Bay	■	■	■	■				■	■		■		■	
Umupuia Beach	■	■	■	■	■	■	■	■	■	■	■	■		■
Waikawau Beach	■	■				■	■					■		
Waiotahi Estuary				■	■	■	■		■			■		
Whangamata Beach	■	■	■	■	■	■		■		■			■	
Whangapoua Harbour				■	■	■	■			■			■	
Whangateau Harbour			■		■	■		■	■	■	■	■		■
Whitianga Harbour											■			■

Table A-2: Sampling dates and size of the sampling extent for sites included in the northern North Island bivalve surveys since 1999–00, including the present survey in 2015–16. Surveys are ordered by site and year.

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
Aotea Harbour	2005–06	17 Jan–18 Jan	9.60	AKI2005-01
	2009–10	26 Mar–13 Jul	28.10	AKI2009-01
	2014–15	19 Feb	19.46	AKI2014-01
Bowentown Beach	2001–02	26 Apr–25 May	1.58	AKI2001-01
	2010–11	18 Mar	1.58	AKI2010-01
	2012–13	8 Feb	1.58	AKI2012-01
	2015–16	20 Jan	1.50	AKI2015-01
Cheltenham Beach	2015–16	14 Jan	31.92	AKI2015-01
Clarks Beach	2004–05	3 Feb–24 Feb	144.71	AKI2004-01
Cockle Bay	2009–10	16 Feb	16.00	AKI2009-01
	2010–11	5 May	16.00	AKI2010-01
	2012–13	31 Jan	16.00	AKI2012-01
	2013–14	29 Mar	15.77	AKI2013-01
	2015–16	18 Jan	15.77	AKI2015-01
Cornwallis Wharf	2001–02	26 Mar–20 Apr	2.65	AKI2001-01
Eastern Beach	1999–00	15 May–30 Jun	48.00	AKI1999-01
	2001–02	14 Mar–16 Apr	43.38	AKI2001-01
	2014–15	27 Jan–18 Feb	41.42	AKI2014-01
Grahams Beach	2006–07	20 Apr	24.75	AKI2006-01
	2010–11	17 May	25.15	AKI2010-01
	2012–13	11 Mar	20.06	AKI2012-01
	2013–14	28 Mar	26.76	AKI2013-01
Howick Harbour	2005–06	23 Dec–24 Jan	6.90	AKI2005-01
Kawakawa Bay (West)	2004–05	5 Feb–8 Apr	60.37	AKI2004-01
	2006–07	19 Apr	62.94	AKI2006-01
	2014–15	17 Feb–25 Feb	60.90	AKI2014-01
Little Waihi Estuary	2000–01	21 Mar–31 Mar	3.00	AKI2000-01
	2002–03	30 Jan–1 Feb	3.00	AKI2002-01
	2003–04	7 Jan–19 Jan	3.12	AKI2003-01
	2004–05	14 Jan–15 Jan	3.75	AKI2004-01
	2006–07	15 Jun–28 Jun	3.16	AKI2006-01
	2009–10	2 Mar	13.92	AKI2009-01
	2012–13	10 Feb	15.42	AKI2012-01
	2013–14	19 Mar–20 Mar	17.09	AKI2013-01
	2015–16	8 Feb–11 Feb	18.38	AKI2015-01
Mangawhai Harbour	1999–00	23 Mar–30 Jun	9.40	AKI1999-01
	2000–01	29 Jan–31 Jan	8.40	AKI2000-01
	2001–02	15 Mar–14 Apr	8.40	AKI2001-01
	2002–03	1 Jan–31 Jan	8.40	AKI2002-01
	2003–04	1 Jan–31 Jan	8.40	AKI2003-01
	2010–11	24 Mar–15 Apr	9.00	AKI2010-01
	2014–15	21 Jan–22 Jan	8.55	AKI2014-01
Marokopa Estuary	2005–06	18 Feb–20 Feb	2.35	AKI2005-01
	2010–11	16 May	2.35	AKI2010-01
	2015–16	12 Feb–13 Feb	2.58	AKI2015-01

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
Marsden Bank	2009–10	13 Nov	11.51	IPA2009-12
	2012–13	12 Dec	6.31	AKI2012-01
	2013–14	2 Feb	15.43	AKI2013-01
Mill Bay	1999–00	4 May–30 Jun	4.60	AKI1999-01
	2000–01	20 Feb–23 Feb	4.80	AKI2000-01
	2001–02	20 Mar–22 Apr	4.50	AKI2001-01
	2003–04	26 Jan–28 Jan	4.50	AKI2003-01
	2004–05	24 Dec–24 Jan	4.50	AKI2004-01
	2005–06	20 Dec–24 Dec	4.50	AKI2005-01
	2009–10	13 May	4.95	AKI2009-01
	2014–15	26 Feb	4.88	AKI2014-01
Ngunguru Estuary	2003–04	6 Mar–7 Mar	1.70	AKI2003-01
	2004–05	6 Feb–7 Feb	1.80	AKI2004-01
	2010–11	23 Mar	1.80	AKI2010-01
	2014–15	23 Jan–24 Jan	5.46	AKI2014-01
Ohiwa Harbour	2001–02	9 Apr–11 Apr	2.25	AKI2001-01
	2005–06	25 Feb–26 Feb	2.70	AKI2005-01
	2006–07	13 Jun–29 Jun	5.70	AKI2006-01
	2009–10	3 Mar	2.10	AKI2009-01
	2012–13	9 Feb–15 Mar	2.63	AKI2012-01
	2015–16	9 Feb–10 Feb	3.37	AKI2015-01
Okoromai Bay	1999–00	19 Apr–24 Apr	20.00	AKI1999-01
	2001–02	8 Apr–12 Apr	24.00	AKI2001-01
	2002–03	26 Dec–29 Dec	20.00	AKI2002-01
	2003–04	17 Mar–20 Mar	20.00	AKI2003-01
	2004–05	15 Jan–16 Jan	20.00	AKI2004-01
	2006–07	20 Mar	20.00	AKI2006-01
	2009–10	17 Feb	20.00	AKI2009-01
	2012–13	30 Jan	20.00	AKI2012-01
	2013–14	31 Mar	19.84	AKI2013-01
	2015–16	11 Jan	19.84	AKI2015-01
Otumoetai Harbour	2000–01	27 Mar–2 Apr	5.60	AKI2000-01
	2002–03	3 Mar–5 Mar	5.60	AKI2002-01
	2005–06	15 Feb–28 Feb	4.60	AKI2005-01
	2006–07	13 Jun–14 Jun	4.60	AKI2006-01
	2009–10	1 Mar–17 Mar	5.60	AKI2009-01
	2014–15	31 Jan–1 Feb	7.67	AKI2014-01
Papamoa Beach	1999–00	1 May–3 May	2.00	AKI1999-01
Pataua Estuary	2002–03	4 Mar–28 Mar	10.65	AKI2002-01
	2003–04	14 Feb–16 Feb	10.45	AKI2003-01
	2005–06	14 Feb–16 Feb	10.45	AKI2005-01
	2013–14	3 Feb–6 Feb	26.30	AKI2013-01
	2015–16	12 Jan–13 Jan	27.78	AKI2015-01
Raglan Harbour	1999–00	26 May–30 Jun	10.10	AKI1999-01
	2000–01	13 Feb–10 Mar	10.04	AKI2000-01
	2002–03	13 Jan–16 Jan	8.24	AKI2002-01
	2003–04	14 Jan–16 Jan	8.24	AKI2003-01

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2009–10	26 Apr	9.20	AKI2009-01
	2012–13	11 Jan	8.24	AKI2012-01
	2014–15	20 Feb–23 Feb	7.24	AKI2014-01
Ruakaka Estuary	2006–07	21 Mar	7.00	AKI2006-01
	2010–11	22 Mar	11.01	AKI2010-01
	2014–15	25 Jan–26 Jan	6.51	AKI2014-01
Tairua Harbour	1999–00	1 Apr–1 May	3.70	AKI1999-01
	2000–01	15 Feb–16 Feb	3.90	AKI2000-01
	2001–02	23 May–24 May	3.90	AKI2001-01
	2002–03	23 Feb–28 Mar	3.90	AKI2002-01
	2005–06	14 Jan–15 Jan	3.90	AKI2005-01
	2006–07	3 May–1 Aug	4.80	AKI2006-01
	2010–11	20 Apr	5.80	AKI2010-01
	2013–14	13 Mar–22 Mar	9.38	AKI2013-01
	2015–16	6 Feb–7 Feb	8.17	AKI2015-01
Te Haumi Bay	1999–00	7 Mar–30 Mar	10.00	AKI1999-01
	2000–01	12 Mar	13.53	AKI2000-01
	2000–01	15 Jan–26 Jan	9.90	AKI2000-01
	2001–02	15 Mar–15 Apr	9.90	AKI2001-01
	2002–03	21 Jan–22 Apr	9.90	AKI2002-01
	2006–07	22 Mar	9.81	AKI2006-01
	2009–10	18 Feb	12.06	AKI2009-01
	2012–13	13 Dec	12.06	AKI2012-01
	2014–15	24 Jan–26 Jan	12.78	AKI2014-01
Umupuia Beach	1999–00	1 Apr–12 Apr	25.00	AKI1999-01
	2000–01	15 Feb–16 Feb	36.00	AKI2000-01
	2001–02	28 Mar–12 Apr	36.00	AKI2001-01
	2002–03	28 Dec–2 Jan	36.00	AKI2002-01
	2003–04	25 Mar–28 Mar	36.00	AKI2003-01
	2004–05	22 Jan–23 Jan	36.00	AKI2004-01
	2005–06	28 Jan–29 Jan	36.00	AKI2005-01
	2006–07	18 Apr	36.00	AKI2006-01
	2009–10	15 Feb	36.00	AKI2009-01
	2010–11	4 May	36.00	AKI2010-01
	2012–13	13 Mar	36.00	AKI2012-01
	2013–14	30 Mar–1 Apr	33.86	AKI2013-01
	2015–16	18 Jan–19 Jan	33.90	AKI2015-01
Waikawau Beach	1999–00	20 May–30 Jun	2.90	AKI1999-01
	2000–01	24 Feb–15 May	2.70	AKI2000-01
	2004–05	18 Jan–10 Mar	3.10	AKI2004-01
	2005–06	15 Feb–27 Feb	3.10	AKI2005-01
	2013–14	21 Mar		AKI2013-01
Waiotahi Estuary	2002–03	7 Feb–10 Feb	8.50	AKI2002-01
	2003–04	21 Jan–24 Jan	8.50	AKI2003-01
	2004–05	21 Jan–25 Jan	9.50	AKI2004-01
	2005–06	10 Feb–12 Feb	9.50	AKI2005-01
	2009–10	4 Mar	9.50	AKI2009-01

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2013–14	17 Mar–20 Mar	11.23	AKI2013-01
Whangamata Beach	1999–00	20 May–29 May	5.48	AKI1999-01
	2000–01	15 Feb–16 Feb	5.48	AKI2000-01
	2001–02	9 May–26 May	5.48	AKI2001-01
	2002–03	9 Mar–28 Mar	5.48	AKI2002-01
	2003–04	1 Jan–31 Jan	5.48	AKI2003-01
	2004–05	6 Feb–8 Feb	5.48	AKI2004-01
	2006–07	2 May–2 Aug	24.61	AKI2006-01
	2010–11	19 Apr	5.89	AKI2010-01
	2014–15	28 Jan–30 Jan	7.62	AKI2014-01
Whangapoua Harbour	2002–03	30 Mar–6 Apr	1.66	AKI2002-01
	2003–04	1 Feb–3 Feb	5.20	AKI2003-01
	2004–05	8 Mar–10 Mar	5.20	AKI2004-01
	2005–06	8 Mar–10 Mar	5.20	AKI2005-01
	2010–11	21 Apr	5.20	AKI2010-01
	2014–15	24 Feb–25 Feb	6.32	AKI2014-01
Whangateau Harbour	2001–02	7 Apr–22 May	64.19	AKI2001-01
	2003–04	17 Dec–2 Mar	64.15	AKI2003-01
	2004–05	2 Feb–26 Mar	64.15	AKI2004-01
	2006–07	19 Mar–2 May	64.15	AKI2006-01
	2009–10	18 Mar–14 Jul	64.51	AKI2009-01
	2010–11	19 May–20 May	64.15	AKI2010-01
	2012–13	14 Dec–17 Dec	64.20	AKI2012-01
	2013–14	29 Jan–6 Feb	110.91	AKI2013-01
	2015–16	15 Jan–17 Jan	110.71	AKI2015-01
Whitianga Harbour	2012–13	7 Feb	7.08	AKI2012-01
	2015–16	5 Feb	6.10	AKI2015-01

APPENDIX B: Re-defining strata with geo-located samples

At sites with high-resolution spatial information, areas predominantly targeting cockles were re-stratified based on geo-referenced sampling data. The re-stratification at these sites with GPS-referenced samples followed a two-step procedure, adapted from De Gruijter et al. (2015). This procedure was based on a model-based prediction of cockle densities to avoid using the samples themselves for re-stratification. The procedure recognises that the samples from a survey are a draw from a random field. The prediction smoothes out sample variability, and delimits zones of similar densities (i.e., minimising within-stratum variance).

B.1 Predicting densities in space

First, existing data were used to generate a prediction map, based on a geo-statistical model for the number of cockles sampled. The model can be viewed as a generalised linear mixed model with a negative-binomial response and a spatial random effect term. The model can be written hierarchically as:

$$y_s \sim NB(\lambda_s, \alpha), \tag{B-1}$$
$$log(\lambda_s) = \mu + S_s, \tag{B-2}$$

for bivalve counts y at sampling location s, with an overdispersion parameter α and a scale parameter λ_s that is linked to a linear predictor through the log-link function; the parameter μ is the overall mean on the log-scale, and S is a Gaussian random field such that $S\ MVN(0, \Sigma)$, where Σ is a covariance matrix. The covariance between measurements y_s and y_t is determined by their distance in space via a stationary, isotropic Matern correlation function. Thus $Cov(y_s, y_t) = Matern(d(y_s, y_t)$, where d specifies the distance in space. The model was implemented in R-INLA (Blangiardo et al. 2013, Lindgren & Rue 2015), and estimates of the spatial field were obtained on a triangulated mesh representation of the sampling extent, allowing straightforward predictions to any point within the original sampling extent (Lindgren & Rue 2015).

B.2 From spatial density maps to new strata

The geo-statistical prediction and the estimated prediction variances at a fine grid were then used to define a distance measure $D_{i,j}$ that estimated pairwise dissimilarity between grid points. To account for the associated prediction variation of the predictions at each grid point, $D_{i,j}$ was defined as:

$$D_{i,j} = E[(\tilde{z}_i - \tilde{z}_j)^2] \tag{B-3}$$
$$= (\tilde{z}_i - \tilde{z}_j)^2 + Var(\tilde{z}_i) + Var(\tilde{z}_j) - Cov(\tilde{z}_i - \tilde{z}_j), \tag{B-4}$$

where $\tilde{z}_i$ is the prediction at point i. In practice, the prediction variance underestimates the true variance. For this reason, the first term in the equation above (Equation B-4) can be divided by the correlation coefficient to increase the prediction variance to that of the true z_i. The last term in the above equation was obtained from the estimated covariance model from the geo-statistical model fit.

It can be shown that, under some assumptions, minimising this distance measure across strata will lead to optimal stratification given a representative dataset over the sampling extent. Therefore, the aim here was to minimise the sum of within stratum variances, $\Delta = \sum_A \sum_i \sum_j D_{i,j}$, where the first sum is over strata, and the subsequent sums are over all grid points allocated to each stratum. Instead of an

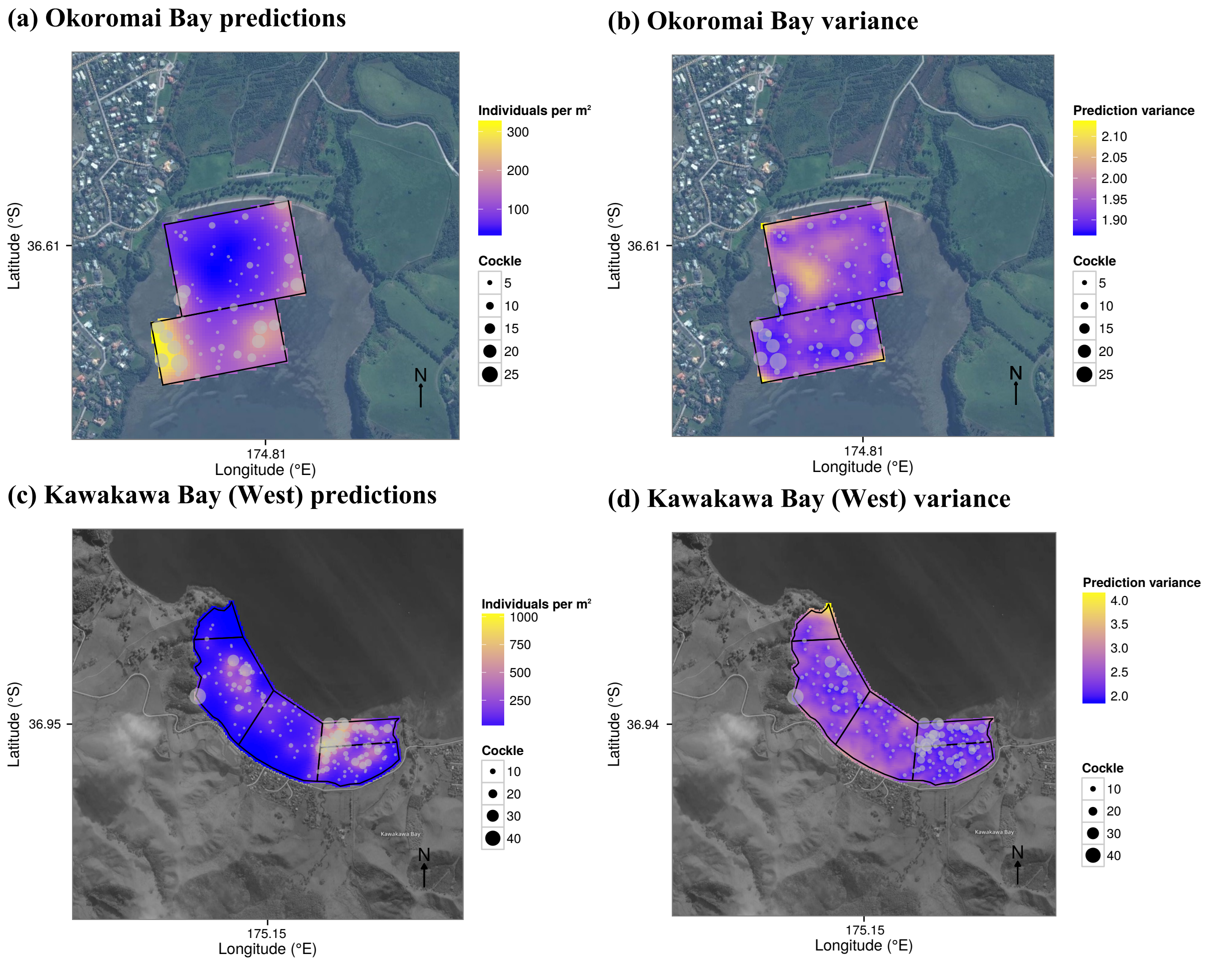


Figure B-1: Cockle abundance within existing stratification (black lines) at Okoromai Bay and Kawakawa Bay (West). Shown are sampling densities (size of the circles proportional to the number of cockles sampled per 0.035 m^2) with predicted densities (number of individuals per m^2) (left-hand column) and the prediction variance (right-hand column).

iterative allocation proposed by De Gruijter et al. (2015), which can be slow for large grids, the present re-stratification used simple hierarchical clustering of $D_{i,j}$. The hierarchical clustering tree was split into a fixed number of strata starting from the root, and the observed reduction in Δ was monitored as strata were added. The number of strata was then chosen at a point of inflection on a plot of the number of strata against Δ, i.e., at the point where adding additional strata did not lead to a significant reduction of Δ.

B.3 Illustrated examples of re-stratification

Examples for the re-stratification procedure were illustrated for two sites that were previously sampled using GPS-referenced samples (in 2013–14 and 2014–15), Okoromai Bay and Kawakawa Bay (West). At both sites, the existing stratification did not delimit areas of high or low cockle density, but strata seemed to be *ad hoc* subdivisions of the sampling extent (Figure B-1).

The new stratification used predicted densities and their variance (Figure B-1) to define $D_{i,j}$ between prediction points, and Δ_A, the sum of $D_{i,j}$ over all paired grid-points within stratum A. The sum of Δ_A will reduce with an increasing number of strata (Figure B-2; first row), but at some point the reduction in Δ will be mainly due to noise rather than signal. In these examples, we chose to retain two strata for Okoromai Bay and three strata for Kawakawa Bay (West), both of which corresponded to the inflection point on the plot of Δ against the number of strata.

Corresponding plots confirm qualitatively that at Okoromai Bay, adding strata beyond the two main strata divides the stratum with low abundance into a stratum with near absence of cockle and one with generally low abundance (Figure B-2). With a single year's sampling it is difficult to assess whether this pattern reflects a real signal or unexplained variation in the data, and we thus prefer the two stratum solution. At Kawakawa Bay (West), it was evident that two strata were insufficient to delimit the high-density beds from areas of intermediate density. For this reason, we retained three strata, dividing areas of low density (or absence), intermediate and high density (Figure B-2).

B.4 Re-stratification comparison

The performance of the re-stratification was site dependent (Table B-3): only one site (Okoromai Bay) had a higher CV with new strata (19.45 in 2015–16 with re-defined strata compared with 19.17 in 2013–14 with existing strata). This site had two new strata with one high- and one low-density stratum. Nevertheless, examination of the map of the present survey at this site (Figure 26) suggested that the low-density stratum included a number of sampling points with relatively high cockle densities. This observation indicates that the low-density area is variable in size among years.

The magnitude of improvements in the estimates (i.e., reductions in the CV) from the re-stratification was linked to the interannual variability and the adequacy of strata derived from the survey conducted two years prior to the current study. The largest improvement in the CV was at Pataua Estuary (7.58 in 2015–16 compared with 10.95 using 2013–14 strata). It was evident that the new strata A to C were still a relatively adequate reflection of high, medium and low densities (Figure 29). A similar improvement resulting from the alignment of strata with density patterns was evident at Whangateau Harbour (Figure 42). Other sites, such as Umupuia Beach did not show an improvement in CV, and mapping of current samples suggested that the density patterns have changed markedly from those in the preceding survey (Figure 39), suggesting that the derived strata were sub-optimal.

Table B-3: Estimates of cockle abundance for all sites that were re-stratified using geo-located data from the 2013–14 survey. Estimates using old strata used in 2013–14 are shown for comparison. For each site, the table includes the estimated mean number, the mean density, and coefficient of variation (CV) for new (2015–16) and old (2013–14) strata.

Survey site	New Strata			Old Strata		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Cockle Bay	21.46	136	8.48	21.71	138	9.25
Little Waihi Estuary	30.40	165	12.74	27.79	163	11.11
Okoromai Bay	34.78	175	19.45	35.48	179	19.17
Pataua Estuary	380.13	1 368	7.58	289.04	1 103	10.95
Tairua Harbour	57.22	700	10.46	64.80	797	10.57
Umupuia Beach	98.88	292	15.93	111.87	330	15.99
Whangateau Harbour	742.44	671	7.02	678.81	612	8.74

Over-all, stratification based on geo-located samples is likely to improve when multiple years of data are available, since the stratification can then account for interannual variability (e.g., by increasing the prediction variance to account for temporal variability). We thus suggest that the re-stratification method applied to the current survey could be used to continuously refine strata.

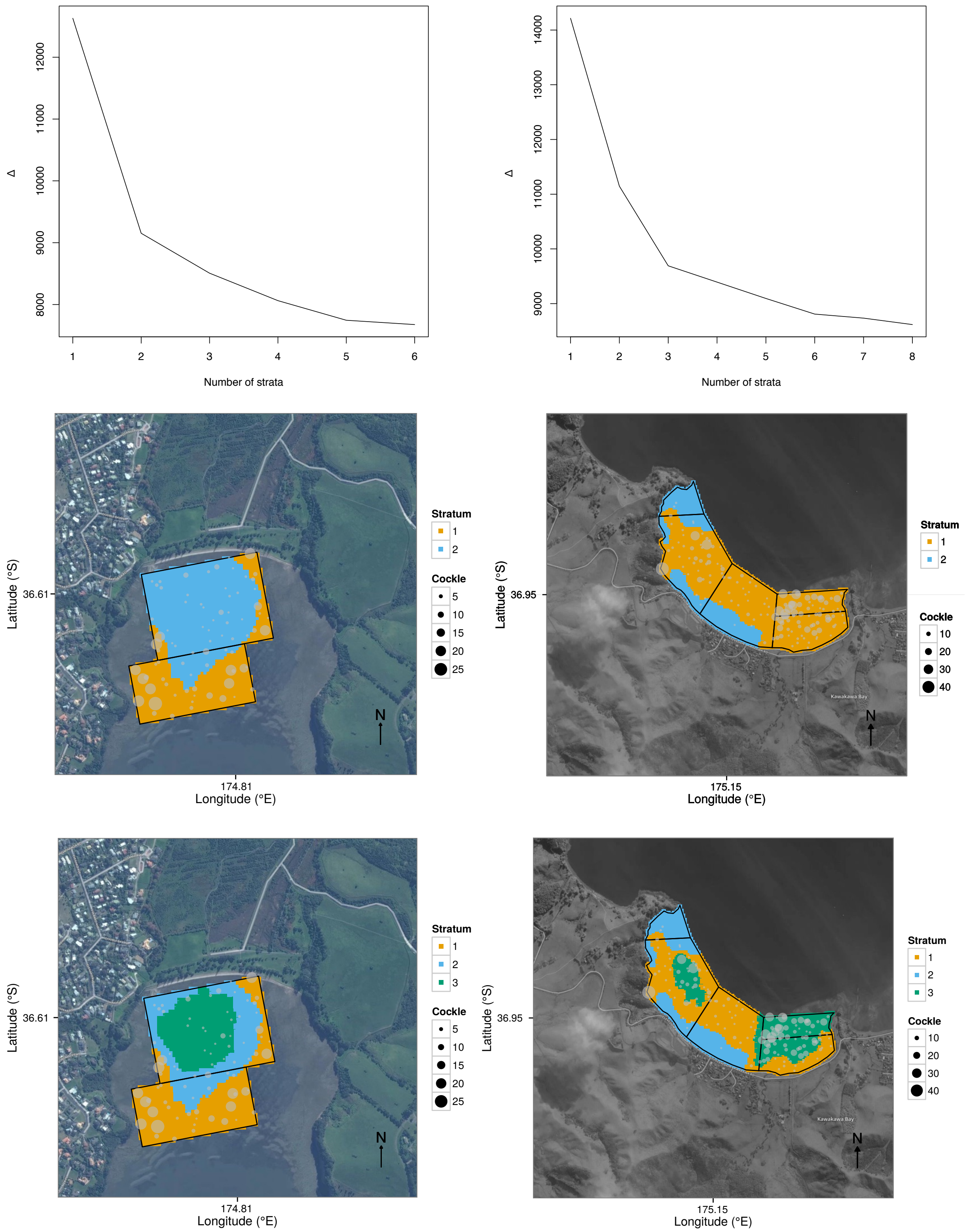


Figure B-2: Re-stratification of the sampling extent at Okoromai Bay (left column) and Kawakawa Bay (West)(right column), based on geo-referenced sampling data from previous surveys. Shown for each site are the number of added strata in relation to a reduction in the distance measure (delta, top graphs), and cockle sampling densities (size of the circles proportional to the number of cockles sampled per 0.035 m^2) with the re-stratification based on two (middle graphs) and three strata (bottom graphs). Black lines indicate previous stratification.

APPENDIX C: Sediment properties

Table C-4: Sediment organic content and sediment grain size distributions at sites surveyed in 2015–16 as part of the northern North Island bivalve surveys.Position of the sampling points is indicated in decimal degrees (World Geodetic System 1984). Sediments grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm. Missing cells indicate missing data.

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Bowentown Beach	A	1	-37.45639	175.97283	2.3	3.6	9.1	30.6	29.7	20.1	6.9
	A	2	-37.45657	175.97309	1.5	0.0	6.0	36.9	48.8	7.9	0.4
	A	3	-37.45694	175.97341	1.9	1.5	10.4	37.8	35.3	8.3	6.7
	A	4	-37.45709	175.97357	0.8	0.0	3.4	25.0	47.8	23.5	0.2
	A	5	-37.45716	175.97374	1.9	3.7	6.0	34.8	34.0	20.8	0.8
	A	6	-37.45733	175.97381	0.8	0.2	4.5	27.4	51.0	16.9	0.0
	A	7	-37.45729	175.97389	1.2	0.0	2.1	27.4	58.3	11.9	0.4
	A	8	-37.45756	175.97401	1.1	0.0	8.1	36.4	43.6	11.0	1.0
	B	1	-37.45623	175.97103	1.1	2.3	4.9	32.3	49.8	8.8	1.9
	B	2	-37.45627	175.97130	1.6	0.0	12.5	38.2	39.3	8.6	1.5
	B	3	-37.45631	175.97132	2.3	3.4	16.2	40.4	32.2	6.1	1.7
	B	4	-37.45642	175.97159	1.7	0.0	12.1	41.2	37.1	7.5	2.1
	B	5	-37.45641	175.97162	1.6	3.0	14.2	42.2	32.8	5.5	2.2
	B	6	-37.45655	175.97183	2.4	2.0	16.6	40.2	33.8	5.1	2.3
	B	7	-37.45665	175.97200	2.1	5.8	14.9	37.2	34.4	6.4	1.3
	B	8	-37.45666	175.97203	2.2	0.0	19.1	39.2	33.2	7.7	0.8
	C	1	-37.45565	175.97126	1.2	0.0	17.3	41.2	35.5	5.6	0.3
	C	2	-37.45611	175.97124	1.7	0.0	13.3	48.5	31.2	4.1	3.0
	C	3	-37.45556	175.97171	2.1	3.2	17.4	47.3	26.7	4.4	1.0
	C	4	-37.45592	175.97173	2.6	1.2	20.3	48.2	26.5	2.5	1.3
	C	5	-37.45547	175.97187	1.3	5.3	11.1	48.7	28.8	4.4	1.8
	C	6	-37.45566	175.97209	1.6	0.0	7.8	50.7	33.2	5.0	3.3
	C	7	-37.45581	175.97202	1.3	1.5	8.5	43.0	36.5	8.8	1.7
	C	8	-37.45573	175.97254	1.0	0.0	2.5	31.5	45.5	17.3	3.3

Continued on next page

Table C-4 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Cheltenham Beach	A	1	-36.81933	174.80734	1.7	0.4	5.7	46.3	46.5	1.1	0.0
	A	2	-36.81978	174.80747	2.6	0.0	5.5	35.3	57.5	1.8	0.0
	A	3	-36.81817	174.80824	1.9	0.0	47.1	44.2	7.7	1.0	0.0
	A	4	-36.81887	174.80831	1.9	0.4	53.1	37.9	7.8	0.8	0.0
	A	5	-36.82004	174.80798	1.6	0.0	16.2	30.2	52.3	1.4	0.0
	A	6	-36.81910	174.80893	1.7	0.7	52.0	45.2	2.0	0.2	0.0
	A	7	-36.81952	174.80855	2.2	1.0	62.9	31.1	4.7	0.4	0.0
	A	8	-36.81813	174.80923	1.6	0.0	18.1	77.0	4.6	0.3	0.0
	A	9	-36.81859	174.80956	1.7	0.0	23.2	75.0	1.6	0.1	0.1
	A	10	-36.82184	174.80944	2.2	0.2	61.5	34.3	3.1	0.5	0.5
	A	11	-36.82272	174.80941	2.3	0.3	45.9	48.3	5.0	0.4	0.0
	A	12	-36.81954	174.80985	1.4	0.0	30.1	67.2	2.1	0.3	0.4
	A	13	-36.82321	174.81018	2.0	0.5	57.5	39.0	2.8	0.2	0.0
	A	14	-36.81915	174.81062	1.7	0.0	4.3	88.7	6.8	0.1	0.0
	A	15	-36.81986	174.81090	1.7	0.4	9.5	82.9	6.5	0.6	0.0
	A	16	-36.82137	174.81123	1.8	0.0	25.3	71.9	2.6	0.2	0.0
	A	17	-36.82178	174.81082	1.8	0.0	45.4	53.9	0.6	0.0	0.0
	A	18	-36.82359	174.81112	1.9	1.4	56.4	39.6	2.3	0.2	0.0
	A	19	-36.82250	174.81149	1.9	0.9	32.1	62.5	4.1	0.4	0.0
	A	20	-36.82386	174.81146	2.0	0.4	55.5	42.3	1.7	0.0	0.0
	A	21	-36.82527	174.81174	2.7	0.2	15.6	14.6	39.1	16.1	14.4
	A	22	-36.82299	174.81215	1.1	0.0	26.6	70.3	3.0	0.1	0.0
	A	23	-36.82353	174.81360	1.6	0.0	19.8	79.3	0.8	0.1	0.0
	A	24	-36.82421	174.81366	1.8	0.0	16.5	82.4	1.0	0.1	0.0
Cockle Bay	A	1	-36.89934	174.95142	2.3	28.8	51.7	15.3	3.3	0.8	0.1
	A	2	-36.89877	174.95266	1.8	0.0	29.3	17.4	4.7	4.5	44.2
	A	3	-36.89926	174.95294	1.4	0.4	36.9	29.8	5.3	3.9	23.6

Continued on next page

Table C-4 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	4	-36.89787	174.95334	1.2	0.1	30.3	40.0	7.4	3.3	18.9
	A	5	-36.89965	174.95343	1.1	0.1	47.2	28.8	8.2	5.6	10.1
	A	6	-36.89875	174.95440	0.9	2.3	24.2	50.9	9.5	2.2	11.1
	A	7	-36.89852	174.95481	1.4	1.1	28.2	47.1	5.5	2.5	15.6
	A	8	-36.89928	174.95543	1.1	0.0	34.6	58.2	3.9	1.6	1.7
	A	9	-36.90016	174.95519	1.5	4.5	37.0	46.6	7.1	4.4	0.4
	A	10	-36.89901	174.95592	1.1	1.2	35.2	48.4	2.5	1.7	10.9
	A	11	-36.89977	174.95586	1.0	0.0	30.4	40.1	3.3	0.9	25.3
	A	12	-36.89891	174.95616	1.0	0.0	31.7	54.5	3.3	1.5	8.9
	A	13	-36.89936	174.95653	1.4	0.0	31.4	57.9	3.4	2.9	4.4
	B	1	-36.90004	174.95294	1.3	21.3	43.2	29.0	4.0	0.9	1.6
	B	2	-36.89745	174.95321	1.5	3.9	44.5	40.0	6.9	2.5	2.2
	B	3	-36.90015	174.95340	2.1	16.3	40.8	22.9	5.6	3.1	11.2
	B	4	-36.90030	174.95305	2.7	0.0	45.2	40.8	7.0	2.7	4.2
	B	5	-36.89697	174.95380	1.2	0.5	41.1	54.9	3.1	0.3	0.2
	B	6	-36.89733	174.95381	1.1	0.0	43.6	50.8	5.0	0.3	0.3
	B	7	-36.90024	174.95370	2.8	18.4	35.3	19.8	4.9	3.2	18.4
	B	8	-36.90028	174.95377	1.3	5.1	59.4	29.6	3.9	1.2	0.9
	B	9	-36.89741	174.95437	1.1	0.0	41.1	53.1	5.0	0.4	0.4
	B	10	-36.89766	174.95433	1.4	0.0	32.8	43.3	4.1	0.6	19.2
	B	11	-36.89733	174.95475	0.8	1.4	30.1	61.6	4.7	0.2	2.0
Little Waihi Estuary	A	1	-37.75674	176.47912	0.9	0.0	0.1	1.2	6.4	43.4	48.9
	A	2	-37.76330	176.48010	0.9	0.0	0.1	2.7	22.7	62.1	12.5
	A	3	-37.76168	176.48060	0.6	1.6	3.1	35.0	30.5	23.4	6.5
	A	4	-37.76276	176.48050	0.5	0.6	1.8	29.5	41.1	25.7	1.3
	A	5	-37.76042	176.48115	0.9	0.0	1.0	45.3	50.7	2.5	0.6
	A	6	-37.76225	176.48120	1.8	2.3	4.7	49.5	39.7	3.2	0.5

Continued on next page

Table C-4 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	A	7	-37.75913	176.48154	1.4	0.0	2.7	73.1	23.2	0.9	0.1
	A	8	-37.75981	176.48257	0.0	0.4	2.7	69.6	26.5	0.7	0.0
	A	9	-37.76013	176.48255	0.9	3.1	6.3	51.4	27.8	9.8	1.6
	A	10	-37.76140	176.48272	2.8	2.5	6.1	58.3	27.5	5.5	0.2
	A	11	-37.76294	176.48022	0.6	2.0	1.9	33.8	31.4	10.1	20.7
	A	12	-37.76157	176.48060	1.1	1.0	4.3	35.2	20.5	26.2	12.7
	A	13	-37.75936	176.48084	1.0	0.0	0.6	55.7	41.4	1.8	0.4
	A	14	-37.76038	176.48092	1.4	0.1	0.6	35.0	61.1	2.8	0.4
	A	15	-37.76174	176.48100	1.3	1.7	3.0	47.4	40.3	7.4	0.2
	A	16	-37.76289	176.48115	1.4	1.4	4.1	45.1	26.2	6.2	17.0
	A	17	-37.76134	176.48162	1.4	0.7	4.6	47.9	29.4	14.1	3.3
	A	18	-37.76276	176.48175	1.4	0.0	6.2	68.5	16.0	4.6	4.8
	B	1	-37.75753	176.47933	0.4	0.0	2.4	67.8	28.6	1.2	0.0
	B	2	-37.75794	176.47938	1.4	0.6	1.0	54.6	30.6	12.4	0.9
	B	3	-37.75877	176.47926	0.9	0.0	2.5	66.1	29.3	0.6	1.4
	B	4	-37.75866	176.48025	0.8	0.0	1.0	76.5	21.8	0.7	0.0
	B	5	-37.75909	176.48007	0.7	0.0	0.1	17.9	46.8	28.9	6.2
	B	6	-37.75834	176.48051	0.6	0.0	1.1	35.9	50.3	12.4	0.3
Ohiwa Harbour	A	1	-38.00669	177.13892	2.1	0.5	7.2	71.8	3.5	1.4	15.5
	A	2	-38.00720	177.13898	2.1	4.5	10.1	82.5	2.1	0.5	0.3
	A	3	-38.00756	177.13918	2.0	4.6	8.4	85.7	1.2	0.1	0.1
	A	4	-38.00687	177.13920	1.9	0.4	6.2	66.8	9.3	3.9	13.5
	A	5	-38.00816	177.13941	2.4	2.4	8.9	82.4	1.9	0.8	3.6
	A	6	-38.00881	177.13936	2.6	6.3	19.1	71.1	1.0	0.9	1.6
	A	7	-38.00943	177.13968	1.9	0.9	8.9	51.2	3.1	3.6	32.3
	A	8	-38.00960	177.13967	2.7	2.5	12.9	76.7	2.0	1.0	4.9
	A	9	-38.00973	177.13971	2.1	2.0	18.0	69.4	1.9	0.8	8.0

Continued on next page

Table C-4 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	10	-38.00984	177.13968	3.2	3.4	30.2	62.4	2.2	1.0	0.8
	B	1	-38.01395	177.13844	2.4	2.3	22.3	74.4	0.9	0.1	0.0
	B	2	-38.01412	177.13835	2.0	3.7	12.0	81.5	1.8	0.2	0.8
	B	3	-38.01478	177.13785	2.7	4.5	24.3	65.9	1.8	0.5	2.9
	B	4	-38.01357	177.13894	2.1	1.8	9.3	85.5	2.7	0.6	0.0
	B	5	-38.01399	177.13859	1.9	1.9	11.8	82.7	2.0	0.2	1.3
	B	6	-38.01422	177.13846	1.8	1.2	3.7	89.7	0.9	0.0	4.5
	B	7	-38.01427	177.13831	2.4	5.2	20.2	72.7	1.3	0.3	0.4
	B	8	-38.01436	177.13822	2.5	4.4	17.8	75.0	1.4	0.5	0.8
	B	9	-38.01449	177.13825	1.9	1.3	7.3	89.2	2.1	0.0	0.0
	B	10	-38.01463	177.13810	2.2	2.6	14.5	81.7	1.1	0.1	0.0
	B	11	-38.01401	177.13864	2.2	3.8	8.8	84.8	2.4	0.1	0.1
	B	12	-38.01433	177.13840	1.8	3.3	5.7	88.6	1.5	0.1	0.8
	B	13	-38.01452	177.13826	1.8	1.4	4.9	92.4	1.2	0.1	0.0
	B	14	-38.01461	177.13820	1.6	1.3	7.7	90.2	0.7	0.0	0.0
Okoromai Bay	A	1	-36.61170	174.80792	2.2	0.0	28.2	64.9	5.8	0.2	1.0
	A	2	-36.61258	174.80799	1.9	2.1	38.8	54.8	4.3	0.1	0.0
	A	3	-36.61121	174.80871	2.1	1.8	55.1	42.0	0.6	0.2	0.3
	A	4	-36.61180	174.80836	2.6	2.7	51.3	42.7	1.3	0.2	1.9
	A	5	-36.61074	174.80950	2.1	0.9	64.1	33.7	0.5	0.1	0.6
	A	6	-36.61162	174.81003	2.0	0.7	45.3	52.2	0.7	0.9	0.2
	A	7	-36.61074	174.81109	1.8	1.6	58.8	34.0	0.7	0.5	4.5
	A	8	-36.61129	174.81088	2.2	0.0	45.9	53.7	0.2	0.1	0.2
	A	9	-36.61072	174.81126	2.0	2.4	66.9	27.7	0.4	0.4	2.1
	A	10	-36.61139	174.81189	1.8	0.0	56.0	42.2	0.7	0.4	0.8
	A	11	-36.60901	174.81259	2.8	6.4	64.9	19.2	3.8	1.2	4.5
	B	1	-36.60832	174.80824	2.3	1.4	40.6	37.7	17.9	0.7	1.7

Continued on next page

Table C-4 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	2	-36.60808	174.80912	2.5	8.6	80.5	9.4	0.7	0.3	0.6
	B	3	-36.60972	174.80913	2.4	2.4	66.5	29.9	0.8	0.3	0.2
	B	4	-36.60818	174.80932	2.2	5.7	83.7	10.2	0.3	0.1	0.0
	B	5	-36.60849	174.80932	2.6	3.6	84.0	11.7	0.5	0.2	0.0
	B	6	-36.60932	174.80930	2.1	4.3	65.2	29.4	0.5	0.1	0.4
	B	7	-36.61010	174.80943	2.1	2.4	66.9	30.0	0.5	0.2	0.1
	B	8	-36.60786	174.80968	2.7	5.1	86.5	7.4	0.6	0.4	0.1
	B	9	-36.60939	174.80997	2.1	3.1	74.5	21.2	0.5	0.3	0.4
	B	10	-36.61016	174.80974	2.1	3.5	48.4	46.7	0.8	0.3	0.3
	B	11	-36.60918	174.81087	2.2	3.4	71.2	22.3	0.7	0.7	1.8
	B	12	-36.61004	174.81133	2.1	4.1	60.2	34.1	0.9	0.2	0.4
	B	13	-36.60856	174.81161	2.2	3.8	74.4	19.1	1.2	0.5	0.9
Pataua Estuary	A	1	-35.72048	174.51055	5.5	0.0	3.6	9.5	5.0	4.9	77.0
	A	2	-35.71830	174.51151	2.0	0.7	16.6	63.4	9.5	5.8	4.0
	A	3	-35.71977	174.51121	1.7	0.0	18.8	56.7	14.4	8.5	1.6
	A	4	-35.71806	174.51197	1.5	0.9	16.8	52.5	12.6	10.8	6.4
	A	5	-35.71962	174.51169	2.3	1.8	23.1	54.1	7.6	4.1	9.3
	A	6	-35.71848	174.51261	1.4	0.1	9.1	32.5	27.7	24.4	6.1
	A	7	-35.72022	174.51244	2.5	1.9	15.1	33.5	15.9	28.1	5.5
	A	8	-35.72031	174.51325	2.0	1.5	19.9	54.3	11.3	9.5	3.5
	A	9	-35.71829	174.51366	2.6	2.0	25.1	70.8	1.5	0.5	0.1
	A	10	-35.72104	174.51364	2.9	1.3	21.6	27.3	12.7	25.4	11.7
	B	1	-35.72030	174.51161	1.5	1.4	9.6	25.8	22.7	36.8	3.7
	B	2	-35.72091	174.51167	1.5	3.8	7.3	32.7	32.0	22.2	1.8
	B	3	-35.71716	174.51190	1.8	0.1	22.0	69.0	7.1	1.5	0.3
	B	4	-35.72098	174.51280	1.4	0.4	7.9	19.5	29.9	37.1	5.2
	B	5	-35.71831	174.51490	2.3	2.4	15.5	70.8	7.3	2.3	1.7

Continued on next page

Table C-4 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	6	-35.71764	174.51511	1.6	2.0	6.9	48.5	18.9	13.6	10.1
	B	7	-35.71854	174.51520	1.6	12.9	10.7	61.5	11.4	2.0	1.4
	B	8	-35.71873	174.51659	2.5	0.0	14.7	66.6	7.7	3.0	7.9
	B	9	-35.71695	174.51757	2.5	0.1	18.4	65.5	3.5	3.9	8.6
	C	1	-35.71900	174.51383	2.5	0.3	15.8	76.6	6.4	0.7	0.2
	C	2	-35.71909	174.51443	1.7	0.3	11.6	72.4	13.0	2.7	0.0
	C	3	-35.71739	174.51843	1.4	0.2	4.3	27.2	29.4	30.4	8.6
	C	4	-35.71781	174.51840	1.4	0.9	1.4	38.4	40.2	16.5	2.6
	C	5	-35.71710	174.51856	1.4	1.2	1.9	19.5	38.2	33.7	5.5
Tairua Harbour	A	1	-37.00750	175.85271	2.9	5.2	20.3	56.9	12.6	2.8	2.3
	A	2	-37.00766	175.85268	1.9	1.9	7.8	52.4	34.6	2.2	1.2
	A	3	-37.00646	175.85307	2.8	6.9	1.2	1.4	7.2	55.4	27.9
	A	4	-37.00699	175.85308	4.3	4.6	29.6	57.3	5.2	1.1	2.3
	A	5	-37.00632	175.85357	2.9	4.7	15.5	52.1	19.5	5.6	2.6
	A	6	-37.00668	175.85356	2.3	2.2	16.1	63.3	14.1	1.8	2.4
	A	7	-37.00488	175.85494	1.9	0.8	1.3	40.2	51.4	6.0	0.3
	A	8	-37.00482	175.85532	1.9	1.8	1.5	58.7	36.7	1.3	0.0
	B	1	-37.00713	175.85278	4.5	4.3	1.1	1.1	4.5	52.5	36.6
	B	2	-37.00681	175.85294	4.2	4.4	21.0	60.6	9.4	1.5	3.2
	B	3	-37.00540	175.85421	0.9	1.2	3.0	51.3	43.4	1.1	0.0
	B	4	-37.00522	175.85453	1.5	1.4	7.0	43.0	37.7	5.3	5.7
	B	5	-37.00546	175.85439	1.1	0.8	4.2	55.5	27.4	3.6	8.4
	B	6	-37.00638	175.85445	1.7	0.9	2.8	44.1	39.1	10.8	2.3
	B	7	-37.00554	175.85464	1.4	1.6	6.9	43.7	35.9	6.9	4.9
	B	8	-37.00501	175.85512	1.8	2.0	2.2	61.7	33.2	1.0	0.0
	C	1	-37.00670	175.85224	4.1	4.4	31.6	54.9	8.3	0.6	0.2
	C	2	-37.00680	175.85222	3.8	6.7	25.2	52.2	13.3	2.1	0.5

Continued on next page

Table C-4 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	C	3	-37.00681	175.85244	4.5	13.2	36.1	45.0	0.4	5.1	0.2
	C	4	-37.00710	175.85246	4.4	10.4	0.4	0.6	7.1	53.3	28.2
	C	5	-37.00643	175.85259	4.6	8.5	33.5	52.0	4.6	0.7	0.7
	C	6	-37.00652	175.85259	3.8	2.5	35.7	52.9	5.7	0.6	2.6
	C	7	-37.00677	175.85259	4.3	4.6	33.0	54.3	6.7	0.6	0.7
	C	8	-37.00563	175.85608	1.3	0.1	0.3	16.5	73.1	9.1	0.9
Umupuia Beach	A	1	-36.90291	175.07199	1.5	3.4	59.1	34.4	1.6	0.6	0.9
	A	2	-36.90309	175.07196	1.7	9.5	70.0	18.7	0.8	0.4	0.7
	A	3	-36.90269	175.07206	1.5	2.8	54.5	39.7	1.6	0.5	0.8
	A	4	-36.90254	175.07273	1.4	5.0	42.9	42.3	1.7	1.9	6.1
	A	5	-36.90415	175.07326	1.9	5.1	8.2	10.6	17.6	26.9	31.6
	A	6	-36.90341	175.07476	2.6	6.5	58.6	8.2	2.1	3.6	20.9
	B	1	-36.89923	175.06607	1.3	1.5	31.3	57.3	9.4	0.4	0.2
	B	2	-36.90086	175.06755	1.6	2.7	37.1	46.8	9.2	1.5	2.8
	B	3	-36.90138	175.06863	1.3	3.0	51.9	34.0	7.5	2.2	1.4
	B	4	-36.90222	175.06856	1.5	7.1	48.7	25.5	8.7	4.1	5.9
	B	5	-36.90137	175.06912	1.2	2.4	52.0	40.3	4.6	0.6	0.2
	B	6	-36.90229	175.07107	1.6	4.9	50.7	29.2	3.4	1.1	10.7
	C	1	-36.89751	175.06500	1.4	2.0	40.0	54.1	3.3	0.4	0.3
	C	2	-36.89712	175.06543	1.1	6.3	32.2	55.6	4.7	0.7	0.5
	C	3	-36.89686	175.06591	1.1	3.7	19.5	64.7	4.3	0.7	7.1
	C	4	-36.89724	175.06614	1.1	1.9	19.4	75.3	3.2	0.2	0.0
	C	5	-36.89780	175.06649	1.0	0.6	21.9	71.3	6.0	0.2	0.0
	C	6	-36.90233	175.07424	1.3	1.7	43.8	49.6	4.5	0.4	0.0
	C	7	-36.90275	175.07541	1.6	1.2	75.9	19.4	2.9	0.5	0.1
	D	1	-36.89806	175.06504	1.9	1.3	46.5	44.6	6.4	0.9	0.4
	D	2	-36.89809	175.06522	1.7	4.7	43.0	45.2	5.6	0.8	0.6

Continued on next page

Table C-4 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	D	3	-36.89797	175.06596	1.5	2.0	33.9	59.9	3.7	0.4	0.0
	D	4	-36.89824	175.06578	1.4	1.7	20.4	64.6	6.6	2.1	4.5
	D	5	-36.89851	175.06635	1.1	2.4	23.1	62.3	11.4	0.8	0.0
Whangateau Harbour	A	1	-36.33215	174.76353	0.7	0.6	3.8	84.9	10.5	0.2	0.1
	A	2	-36.33629	174.76348	1.2	0.0	6.8	72.3	19.3	0.7	0.8
	A	3	-36.33168	174.76397	0.9	0.2	2.5	83.3	13.7	0.3	0.0
	A	4	-36.33146	174.76560	0.9	2.2	2.6	70.7	22.0	1.7	0.8
	A	5	-36.33316	174.76503	0.8	0.6	3.2	63.6	27.9	2.0	2.7
	A	6	-36.33058	174.76575	1.0	1.2	5.7	76.4	15.4	0.9	0.5
	A	7	-36.32491	174.77274	1.2	1.2	2.8	76.2	9.4	3.4	7.0
	B	1	-36.31806	174.77577	1.1	0.0	0.3	29.4	48.8	8.5	13.1
	B	2	-36.31843	174.77696	1.7	0.2	0.3	31.8	38.8	10.6	18.3
	C	1	-36.31612	174.77582	1.4	0.0	0.9	26.5	43.1	10.6	18.9
	C	2	-36.31727	174.77569	0.9	0.0	0.2	18.1	62.9	13.7	5.1
	C	3	-36.31609	174.77603	1.2	0.0	0.4	23.8	38.9	15.7	21.2
	C	4	-36.31555	174.77706	1.2	0.0	0.2	15.5	41.4	18.6	24.4
	C	5	-36.31516	174.77784	0.7	0.1	0.1	24.9	61.4	7.9	5.6
	C	6	-36.31486	174.77905	0.7	0.1	0.3	51.4	44.5	2.4	1.4
	C	7	-36.31492	174.78026	0.9	0.0	1.2	77.8	19.4	0.6	1.0
	C	8	-36.31470	174.78359	1.4	2.5	11.1	69.1	12.1	2.1	3.0
	D	1	-36.31714	174.77464	0.5	1.1	0.3	31.9	59.7	5.2	1.9
	D	2	-36.31155	174.77522	1.2	1.4	9.6	45.7	39.3	3.3	0.8
	D	3	-36.31193	174.77532	1.1	0.6	6.5	63.0	25.1	3.4	1.4
	D	4	-36.31504	174.77570	0.8	0.8	0.5	58.5	35.2	3.4	1.6
	D	5	-36.31321	174.77760	1.4	0.1	4.5	62.4	26.1	4.3	2.5
	D	6	-36.31116	174.77805	1.4	1.3	17.0	48.3	29.3	2.1	2.1
	D	7	-36.31418	174.78096	1.2	2.0	7.2	51.4	37.3	0.6	1.5

Continued on next page

Table C-4 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Whitianga Harbour	A	1	-36.84407	175.69828	3.7	1.1	9.5	56.4	15.0	2.2	5.2
	A	2	-36.84406	175.69857	3.3	2.7	13.0	58.3	20.0	5.2	0.9
	A	3	-36.84443	175.69885	3.0	5.8	9.2	66.0	11.5	3.6	3.9
	A	4	-36.84398	175.69888	3.0	3.1	15.3	55.8	12.7	6.1	6.9
	A	5	-36.84441	175.69905	3.3	1.4	13.5	55.6	18.6	7.6	3.4
	A	6	-36.84392	175.69926	3.9	5.7	8.8	70.7	11.7	2.3	0.7
	A	7	-36.84415	175.69931	2.8	1.9	9.6	68.8	13.9	4.2	1.6
	A	8	-36.84434	175.69924	3.1	4.9	7.8	71.0	12.4	2.4	1.5
	A	9	-36.84484	175.69935	3.1	4.6	6.7	60.4	21.8	3.9	2.6
	A	10	-36.84449	175.69958	3.1	4.5	4.6	45.5	35.9	9.0	0.5
	A	11	-36.84313	175.69977	3.5	3.4	13.6	46.2	17.6	7.4	11.8
	A	12	-36.84371	175.69992	2.7	2.5	9.3	60.1	20.4	6.3	1.4
	A	13	-36.84405	175.69997	4.2	6.8	8.9	64.1	9.3	2.6	8.3
	A	14	-36.84407	175.70033	3.0	6.5	6.3	61.0	22.2	2.8	1.2
	A	15	-36.84281	175.70054	4.0	3.0	10.8	53.6	24.3	6.1	2.1
	A	16	-36.84321	175.70058	2.8	0.8	14.9	70.7	11.9	1.5	0.2
	A	17	-36.84352	175.70057	3.3	4.8	17.9	71.2	5.4	0.6	0.1
	A	18	-36.84380	175.70069	3.1	0.0	10.6	71.7	14.0	0.9	2.8
	A	19	-36.84380	175.70074	3.0	2.8	11.0	71.1	13.5	1.2	0.4
	A	20	-36.84294	175.70124	3.5	3.0	13.8	64.7	15.8	2.2	0.5
	A	21	-36.84376	175.70122	2.9	3.2	5.5	62.1	23.2	3.5	2.7
	A	22	-36.84309	175.70134	4.1	3.5	17.3	71.7	6.3	0.8	0.4
	A	23	-36.84337	175.70151	2.6	0.4	6.9	71.0	19.6	2.0	0.2
	A	24	-36.84345	175.70165	3.0	0.0	5.8	70.9	21.1	2.0	0.2