Fisheries New Zealand

Tini a Tangaroa

Intertidal shellfish monitoring in the northern North Island region, 2017–18

New Zealand Fisheries Assessment Report 2018/28

K. Berkenbusch
P. Neubauer

ISSN 1179-5352 (online)
ISBN 978-1-77665-919-7 (online)

July 2018

New Zealand Government

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-and-resources/publications
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Berkenbusch, K.; Neubauer, P. (2018). Intertidal shellfish monitoring in the northern North Island region, 2017–18.

***New Zealand Fisheries Assessment Report 2018/28.* 99 p.**

New Zealand's coastal marine communities include species that are targeted in recreational and customary fisheries, including shellfish collections of intertidal bivalves. Two of the main target species in these fisheries in northern North Island are cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*). Both species support non-commercial fisheries across a range of coastal environments, such as beaches, harbours and sheltered bays and estuaries.

Their populations are monitored by regular surveys commissioned by Fisheries New Zealand (and its predecessors), which focus on different northern sites across the wider Auckland region, Northland, Waikato, and Bay of Plenty. These surveys collect data on the population status of cockle and pipi populations and allow temporal comparisons of population trends across the northern North Island region.

The present assessment presents the most recent data in the northern survey series, including the 2017–18 fishing year. The current survey included the following northern sites (in alphabetical order): Bowentown Beach, Cockle Bay, Little Waihi Estuary, Marsden Bank, Mill Bay, Okoromai Bay, Pataua Estuary, Raglan Harbour, Tairua Harbour, Umupuia Beach, Whangateau Harbour and Whitianga Harbour.

Cockle populations were present at 11 of the 2017–18 sites, excluding Marsden Bank. Their total population sizes ranged from a low 7.78 million (CV: 25.18%) cockles at Mill Bay to the highest estimate of 852.27 million (CV: 9.28%) cockles at Whangateau Harbour. Other northern sites with comparatively large cockle populations were Pataua Estuary with 406.39 million (CV: 11.78%) individuals and Raglan Harbour with 109.16 million (CV: 7.11%) cockles.

Corresponding cockle densities were high at a number of sites, with a maximum density of 2008 (CV: 6.25%) cockles per m^2 at Bowentown Beach, followed by Raglan Harbour and Pataua Estuary, where their densities were 1508 (CV: 7.11%) and 1467 (CV: 11.78%) cockles per m^2, respectively. Except for Mill Bay and Little Waihi Estuary, cockles also occurred at relatively high densities at other sites, ranging between 263 (CV: 15.24%) cockles per m^2 at Okoromai Bay to an estimated density of 922 (CV: 9.62%) cockles per m^2 at Tairua Harbour.

There was a general scarcity of large cockles ($\geq$30 mm shell length) in northern populations, and this size class was only present at low densities at most sites; only Umupuia Beach and Cockle Bay had population densities that exceeded 100 large individuals per m^2. Large cockles were absent at Whitianga Harbour, and varied in density between two and 44 large cockles per m^2 at the remaining sites.

Pipi were present at nine of the survey sites, where their estimated abundance varied from 0.48 million (CV: 32.31%) pipi at Bowentown Beach to 95.12 million (CV: 12.93%) pipi at Whitianga Harbour. Their total population densities varied across sites from low estimates of seven (CV: 35.38%) pipi per m^2 at Pataua Estuary to 1637 (CV: 12.93%) pipi per m^2 at Whitianga Harbour.

Few of the pipi populations included large individuals ($\geq$50 mm shell length), and their abundance and density estimates were generally low where they were present. Abundance estimates for this size class varied from 0.10 million (CV: 24.15%) large pipi at Raglan Harbour to 5.44 million (CV: 64.08%) individuals in this size class at Little Waihi Estuary. Their highest densities were at Little Waihi Estuary, Whitianga and Tairua harbours, with estimates between 30 (CV: 64.08%) large pipi per m^2 and 54 (CV: 21.56%) large pipi per m^2 at these sites; it was one individual (or less) per m^2 at the remaining sites.

Although there was some variation in sediment properties across the northern sites, areas inhabited by cockles were generally low in organic content and in the proportion of sediment fines (silt and clay; $<$63 µm grain size). Most sites were characterised by fine and medium sands (grain sizes $>$125 to $>$250 µm), but also contained some sediment in coarser fractions including gravel ($>$2000 µm).

1. INTRODUCTION

Coastal environments worldwide support a range of marine species that are increasingly being targeted in non-commercial fisheries. In intertidal and shallow subtidal habitats, these target species include infaunal bivalves, particularly species that are easily accessible and occur at high densities. Infaunal bivalves that support important recreational and customary fisheries in New Zealand include cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*) (Hauraki Māori Trust Board 2003, Hartill et al. 2005). Both species are widely distributed along New Zealand's coastline, where they occur in a variety of sedimentary environments. In suitable habitats, their populations form high-density beds, with observed densities exceeding 1000 individuals per m^2 (Morton & Miller 1973, Hooker 1995).

Although cockles and pipi occur sympatrically across a diverse range of coastal environments, they have distinctly different habitat preferences. Cockles are often widely distributed across intertidal sand- and mudflats, encompassing a range of sediment types. In contrast, pipi are more restricted in their distribution, which is often confined to coarse sands in the proximity of tidal channels or high-flow areas, and may extend into shallow, subtidal waters. Factors influencing the distribution and abundance of cockles and pipi include sediment characteristics, such as changes in the amount of sediment fines (silt and clay, $<$63 µm grain size). Although cockles seem to have a higher tolerance than pipi, both species are sensitive to increases in sediment fines.

Other factors that impact on cockle and pipi populations include exposure to pollutants, high levels of nutrients, diseases, parasites and fishing (e.g., see review by Grant & Hay 2003). Both species have featured in recent mass mortality events, including in northern New Zealand, where some of the observed population declines were related to bacterial infections and parasites (Ministry for Primary Industries 2015).

In some areas, northern shellfish populations are also exposed to considerable fishing pressure, raising concerns about the sustainability of cockle and pipi populations. These concerns have prompted a number of efforts to monitor northern bivalve populations, including a regular monitoring programme by Fisheries New Zealand Fisheries (and its predecessors) and community-led initiatives. The latter include surveys by community groups, schools, and local iwi on intertidal beaches in the Hauraki Gulf Marine Park that are co-ordinated by the Hauraki Gulf Forum (e.g., Auckland Council 2013).

The surveys commissioned by Fisheries New Zealand and its predecessors started in 1992, and were initially concentrated in the wider Auckland area. Since then, their geographical spread was extended to two northern fisheries management areas (FMA 1 and FMA 9), with a consistent methodology since 1999–2000 and a focus on northern cockle and pipi populations (see information about the surveys in Appendix A).

The main focus of the surveys is on particular bivalve beds that are considered to be targeted in non-commercial fishing activities. This focus means that survey data do not necessarily reflect the entire population of cockles and pipi that inhabit a site (Pawley & Ford 2007). Furthermore, as the distribution of pipi frequently extends into shallow subtidal waters, the intertidal sampling of the monitoring surveys may not capture this deeper component of some pipi populations.

Population data collected in the field sampling provides information of the abundance, density and size structure of cockle and pipi populations. In addition to ascertaining the present-day status of these bivalve populations, the survey series also allows comparisons of population trends over time. This information supports the management of northern bivalve populations, including measures to ensure their sustainability. Management measures have included fishing restrictions, such as seasonal and permanent closures, and reductions in bag limits at some sites.

In view of the importance of sediment variables, recent field surveys have also collected sediment samples to assess the sediment organic content and grain size composition in cockle beds (see Berkenbusch & Neubauer 2016, 2017). The sediment data provide baseline information that allow investigations into the predictability of cockle populations in relation to sediment variables at the survey sites (Neubauer et al. 2015).

This report presents the most recent survey in the northern monitoring programme. It focused on the abundance and population structure of bivalves at selected northern North Island sites. The overall objective of this study was "to determine the distribution, abundance and size frequency of selected intertidal shellfish" (i.e., cockles and pipi) for the 2017–18 fishing year. Northern sites included in the current survey were (in alphabetical order): Bowentown Beach, Cockle Bay, Little Waihi Estuary, Marsden Bank, Mill Bay, Okoromai Bay, Pataua Estuary, Raglan Harbour, Tairua Harbour, Umupuia Beach, Whangateau Harbour and Whitianga Harbour (Figure 1).

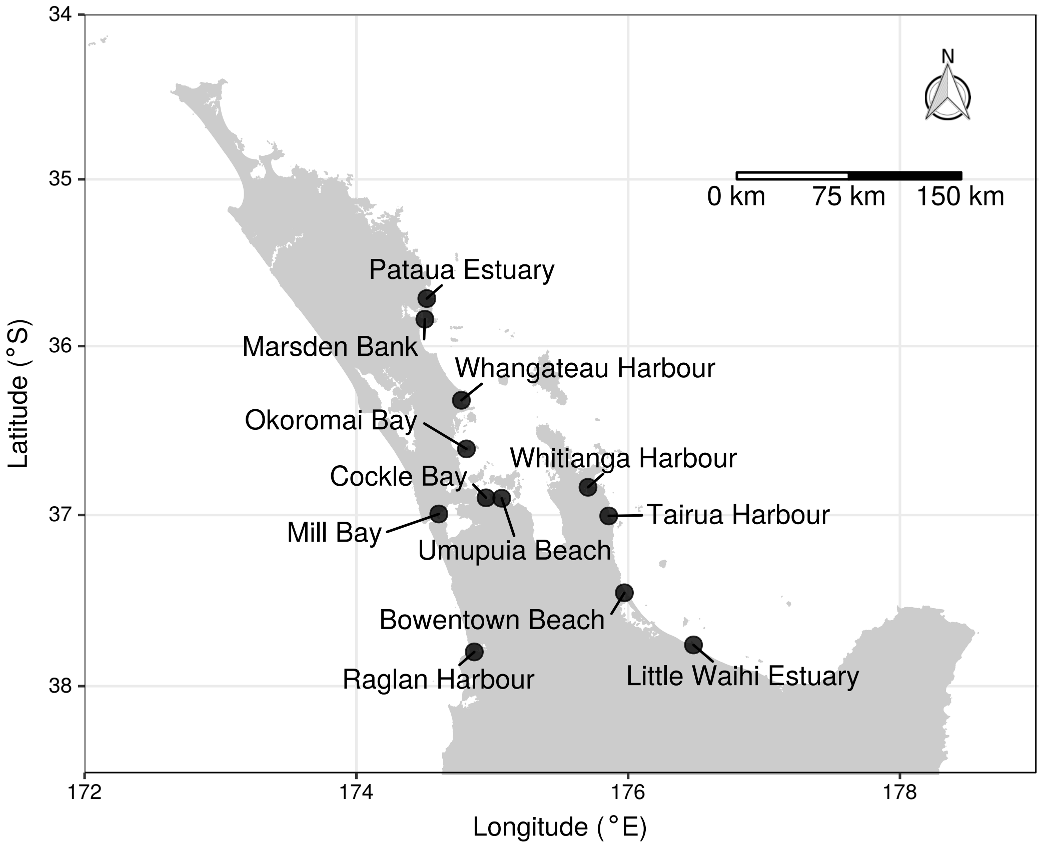


Figure 1: Sites included in the northern North Island intertidal bivalve surveys in 2017–18.

2. METHODS

The present study followed a similar methodology used in previous bivalve assessments allowing temporal comparisons across the northern survey series. Since 1996, the general sampling protocol of the northern North Island bivalve surveys has been based on a combination of a systematic design and a two-phase stratified random design (Pawley & Ford 2007).

The methods used in recent surveys are described in detail by Berkenbusch & Neubauer (2016, 2017). They are included here for completeness, following their update to reflect the 2017–18 survey.

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 density data from previous surveys (2013–14 to 2016–17) 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 cockle population sizes and densities. For this reason, the high-resolution spatial data (GPS-referenced samples) from previous surveys were used to re-define cockle strata based on the spatial distribution and variability of previous samples (see Berkenbusch & Neubauer 2016).

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 strata with odd shapes, the number of grid cells did not necessarily reflect the number of desired samples; if there were more grid cells than sampling points, not all cells had sampling points allocated to them. In this case, sampling points were allocated across all cells with a probability proportional to the area of the cells.

The position of the point within a cell was randomly allocated. 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 four sites in 2017–18). The number of required phase-2 samples was calculated using the method by Francis (1984).

Owing to the importance of sediment properties for infaunal bivalves, recent previous surveys included a sediment sampling programme to determine the sediment organic content and grain size at each site (see Berkenbusch et al. 2015, Berkenbusch & Neubauer 2015). The sediment sampling provided general baseline 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 2015–16 to allow the analysis of spatial patterns in sediment variables, and to assess gradients in cockle abundance in relation to sediment properties (Neubauer et al. 2015, Berkenbusch & Neubauer 2016).

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. Following the re-stratification of sites, a total of 24 sediment sampling points was allocated at each site. The sediment sampling point allocation was based on a subset of at least six sediment sampling points that was randomly allocated within each cockle stratum, corresponding with a randomly-allocated cockle sampling point. Data from the sediment sampling were used to provide baseline information of current sediment properties, and to build a data set that allows spatial and temporal comparisons in future analyses.

2.2 Field sampling–bivalves

The field survey of the northern North Island sites was conducted in January and February 2018. Over this time, bivalve populations at each site were sampled during periods of low tide (see sampling dates for the present and previous surveys in Appendix A, Tables A-1, A-2).

Bivalves were sampled using the same sampling unit as in previous surveys, consisting of a pair of benthic cores that were 15 cm diameter each; the combined cores sampled a surface area of 0.035 m^2. The cores were sampled to 15 cm sediment depth, and this sampling depth included the maximum burrowing depths of cockles and pipi, 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 placed directly adjacent to each other and pushed 15 cm into the sediment. 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 fewer 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.

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 using 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 $\pm$ 0.0001 g).

The sediment organic content of each sample was determined by loss on ignition (4 hours at 500°C) after drying the sample to constant weight at 60°C (Eleftheriou & McIntyre 2005).

Descriptive sediment data from these analyses include the percentage organic content and proportions of sediment in different grain size fractions for each sample (see detailed information in Appendix B).

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. Results from the present survey were compared with previous surveys using the Fisheries New Zealand 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.

The data analysis followed the previous approach (e.g., Berkenbusch et al. 2015). Consistent with previous surveys, the two cores within each grid cell were considered 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 ≥30 mm shell length for cockles, and ≥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 ≤15 mm and pipi that were ≤20 mm in shell length.

2.5 Sediment data

For each site, summaries of sediment data are provided, including organic content and grain size composition. Sediment organic content is presented as percentage of the total, in addition to percentages of the individual sediment grain size fractions.

3. RESULTS

3.1 Bowentown Beach

Bowentown Beach is in the northern part of Tauranga Harbour, in Bay of Plenty, with the sampling area situated on the intertidal sandflat in the vicinity of the main channel. The present survey was the fifth assessment of cockles and pipi at this site, with the preceding survey conducted in 2015–16 (see Appendix A, Tables A-1, A-2). Field sampling at this site has been consistent across the same sampling extent, including three different strata (Table 1). Across these strata, there was a total of 90 sampling points in the 2017–18 survey.

Sediment samples at this site revealed a low organic content across the cockle strata, with a maximum of 3.2% (Figure 2, and see details in Appendix B, Table B-3). The proportion of sediment fines (<63 µm grain size) was just over 9%, whereas fine and medium sands (>125 µm and >250 µm grain size) dominated the sediment grain size composition. There was some gravel (>2000 µm grain size) in the samples, with a maximum of 14.4% of sediment in this coarse fraction.

Cockles were abundant across the entire sampling extent at Bowentown Beach, with stratum C supporting the highest number and density of this species (Figure 3, Table 1). The total population abundance in 2017–18 was estimated at 30.07 million (CV: 6.25%) cockles, with an estimated mean population density of 2008 cockles per m^2 (Table 2). Both these estimates were the highest values in the survey series, and signified a continued increase in the population over time.

Similarly, the abundance of large cockles (≥30 mm shell length) showed an increase in 2017–18 to an estimated 0.16 million (CV: 20.55%) individuals, after continuous decreases in this size class since 2001–02. Their density increased to 10 large cockles per m^2 in 2017–18 compared with 2 large individuals per m^2 in the previous survey in 2015–16. Nevertheless, large cockles only made up a small proportion of the total population, with 0.52% of cockles in this size class in 2017–18 (Table 3). In comparison, recruits (≤15 mm shell length) constituted about 20% of the total population in the three most recent surveys, with 23.06% of these small-sized cockles in the current population. Overall, medium-sized cockles determined the population size structure over this period, with mean and modal shell lengths at about 19 mm and 20 mm, respectively (Figure 4).

The pipi population at Bowentown Beach was surveyed across the same sampling points as cockles, although only relatively few pipi (149 individuals) were sampled (Figure 5, Table 4). Based on the survey data, the total population estimate in 2017–18 was 0.48 million (CV: 32.31%) pipi, with a corresponding mean density of 32 pipi per m^2 (Table 5). The uncertainty of these estimates was relatively high (i.e., the CV exceeded 20%), similar to the uncertainty in most of the previous surveys, which indicate a fluctuating pipi population.

There were no large pipi (≥50 mm shell length) within the population, and this size class has been mostly absent throughout the survey series; it made up 0.53% of the total population in 2017–18 (but this estimate was based on a single large individual, resulting in large uncertainty) (Table 6). In contrast, there was a marked increase in the proportion of recruits (≤20 mm shell length), from 11.40% of the total population in the preceding survey in 2015–16 to 38.78% in the current study.

The increased contribution of recruits was reflected in the reduction in pipi sizes, with the current mean shell length of 23.96 mm and a modal size of 15 mm (Table 6). The influx of recruits was also reflected in the population size structure, which changed from a unimodal to a bimodal population, with the addition of this cohort (Figure 6). There were few medium-sized pipi at this site.

The findings from the 2017–18 survey document the small population size of pipi at Bowentown Beach, and confirm that changes in the abundance and density of this population are determined by recruitment events.

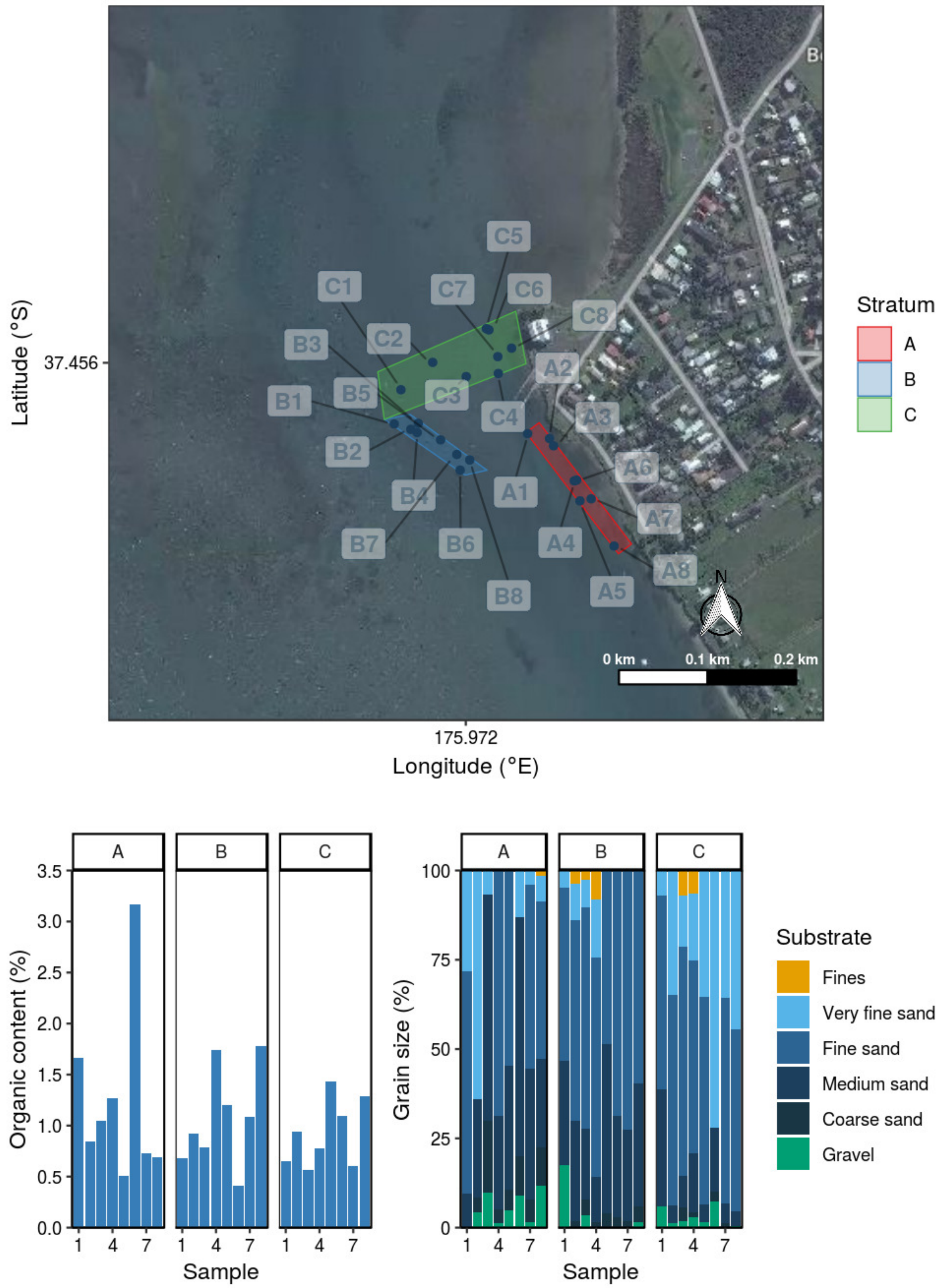


Figure 2: Sediment sample locations and characteristics at Bowentown Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.1.1 Cockles at Bowentown Beach

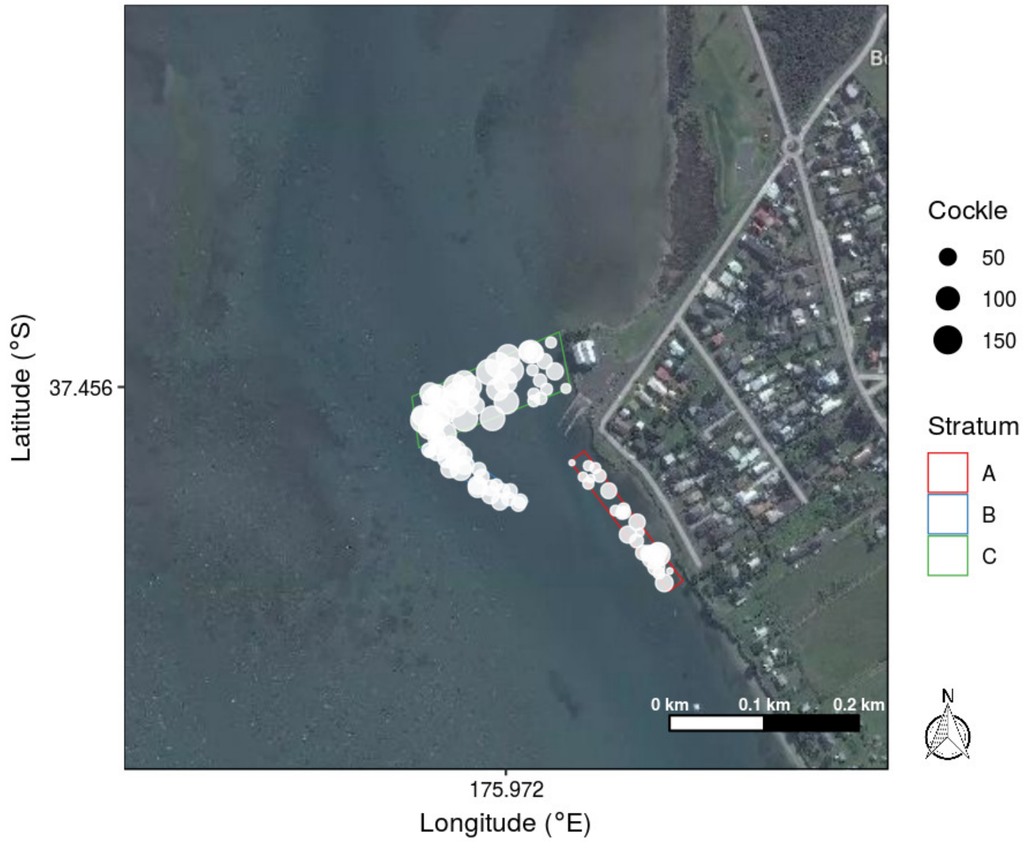


Figure 3: Map of sample strata and individual sample locations for cockles at Bowentown Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Bowentown Beach, by stratum, for 2017–18. 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	25	888	3.23	1 015	15.06
B	0.2	25	1 310	3.31	1 497	8.13
C	1.0	40	3 438	23.53	2 456	7.63

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
2017–18	1.5	30.07	2 008	6.25	0.16	10	20.55

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 ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	18.60	20	3–32	23.91	0.27
2015–16	18.95	20	6–31	19.83	0.12
2017–18	18.99	20	5–35	23.06	0.52

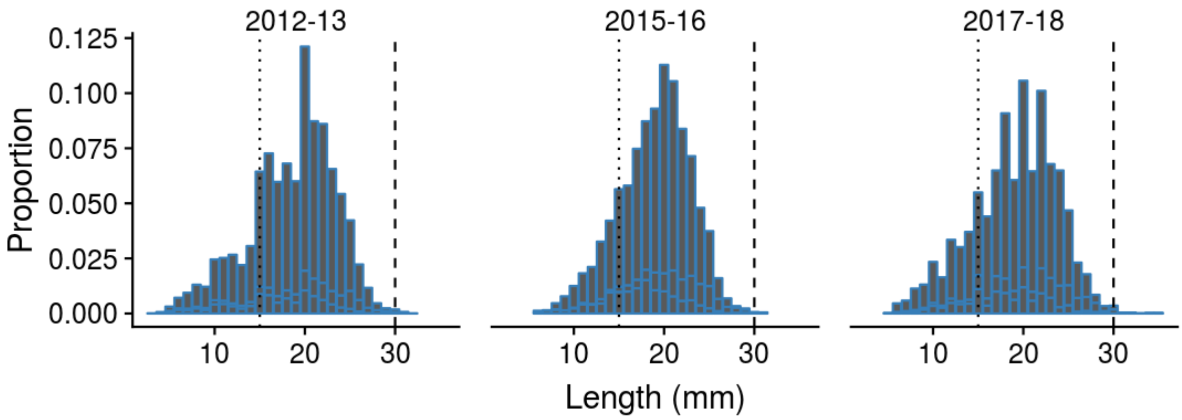


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.1.2 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 2017–18. 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	25	55	0.20	63	74.46
B	0.2	25	84	0.21	96	14.26
C	1.0	40	10	0.07	7	46.96

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
2017–18	1.5	0.48	32	32.31	0.00	<1	>100

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 (%)
2012–13	29.59	27	11–48	6.74	0.00
2015–16	29.53	22	9–57	11.40	6.21
2017–18	23.96	15	12–50	38.78	0.53

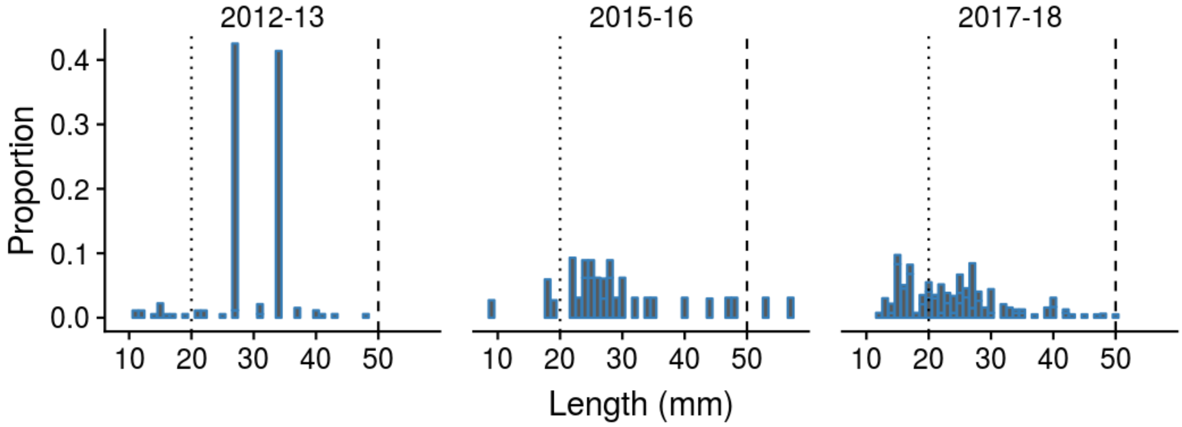


Figure 6: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.2 Cockle Bay

Cockle Bay is a small Auckland beach that is located in one of the eastern suburbs. Shellfish collections at this beach have been restricted since 2008, with a seasonal closure over summer (from 1 October to 30 April) and a maximum daily bag limit of 50 cockles per gatherer per day at other times.

This site was included in the northern survey series in 2009–10, with five surveys preceding the current assessment; the most recent previous survey was in 2015–16 (see Appendix A, Tables A-1, A-2). Throughout the survey series, the sampling extent has remained consistent across the intertidal sandflat, with the current assessment sampling a total of 60 points across two re-stratified strata (Figure 7, Table 7). There were only two pipi sampled at this site, so that the current assessment only focused on the cockle population at this site.

Sediment at this site had a low organic content (maximum of 1.7%), and the sediment grain size distribution was largely determined by fine sand (grain size $>$125 µm) (Figure 7, and see details in Appendix B, Table B-3). There was a varying proportion of fines (grain size $<$63 µm) across samples, with a maximum of 35.6% of sediment in this grain size fraction. Similarly, the proportion of gravel ($>$2000 µm) was relatively high in a number of samples, with most samples containing some gravel, and a maximum of 32.8% of sediment in this coarse fraction.

The cockle population at Cockle Bay was distributed across most of the sampling extent, but predominantly in stratum A (Figure 8, Table 7). The current population estimate for this site was a total of 43.37 million (CV: 11.62%) cockles in 2017–18, which occurred at a mean density of 275 individuals per m^2 (Table 8). The current estimates signified two-fold increases from preceding abundance and density estimates in 2015–16, following earlier declines from relatively high estimates in 2010–11.

Included in the 2017–18 population was a relatively high number of large cockles ($\geq$30 mm shell length), with an estimated 17.48 million (CV: 13.87%) individuals in this size class. Their mean density was 111 large cockles per m^2. Although these estimates reflect a small increase, this size class contributed markedly fewer individuals to the current population than previously, with 40.30% of large cockles in 2017–18, compared with 71.65% in 2015–16.

At the same time, the proportion of recruits ($\leq$15 mm shell length) increased from 5.66% of all cockles in 2015–16 to 13.25% of recruits in the current assessment. Their influence on the 2017–18 population was evident in observed decreases in cockle sizes to mean and modal shell lengths of 25.85 mm and 20 mm, respectively (Table 9, Figure 9). In addition, the population size structure changed from a generally unimodal to a bimodal population in 2017–18.

These findings indicate that the observed increase in cockle abundance at this site was mainly caused by the influx of recruits and small-sized individuals.

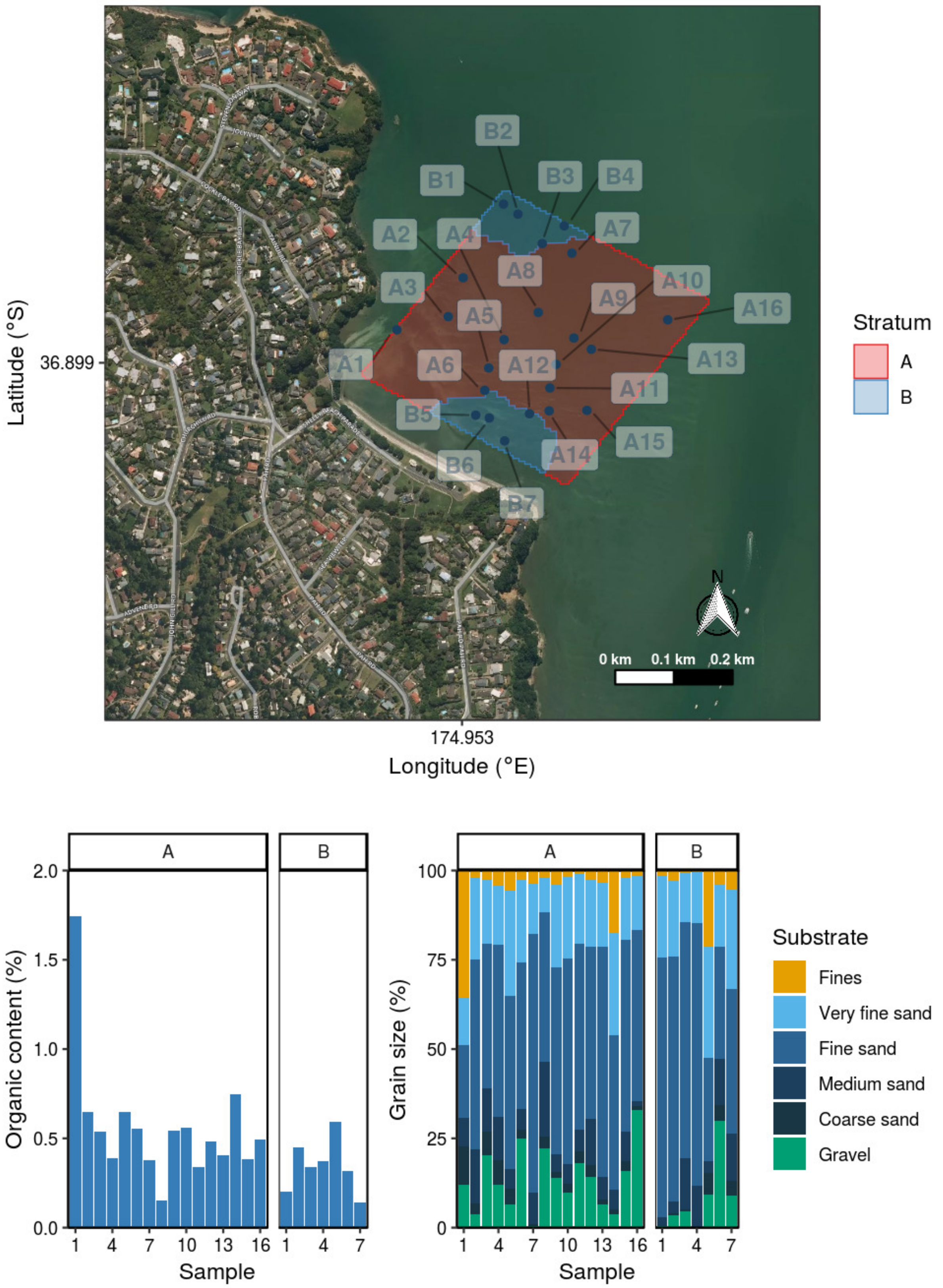


Figure 7: Sediment sample locations and characteristics at Cockle Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.2.1 Cockles at Cockle Bay

Figure 8: 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 7: Estimates of cockle abundance at Cockle Bay, by stratum, for 2017–18. 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	50	544	41.12	311	12.07
B	2.5	10	31	2.25	89	38.90

Table 8: 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
2017–18	15.8	43.37	275	11.62	17.48	111	13.87

Table 9: 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 (%)
2013–14	29.99	34	6–45	6.09	62.41
2015–16	31.82	37	7–50	5.66	71.65
2017–18	25.85	20	7–48	13.25	40.30

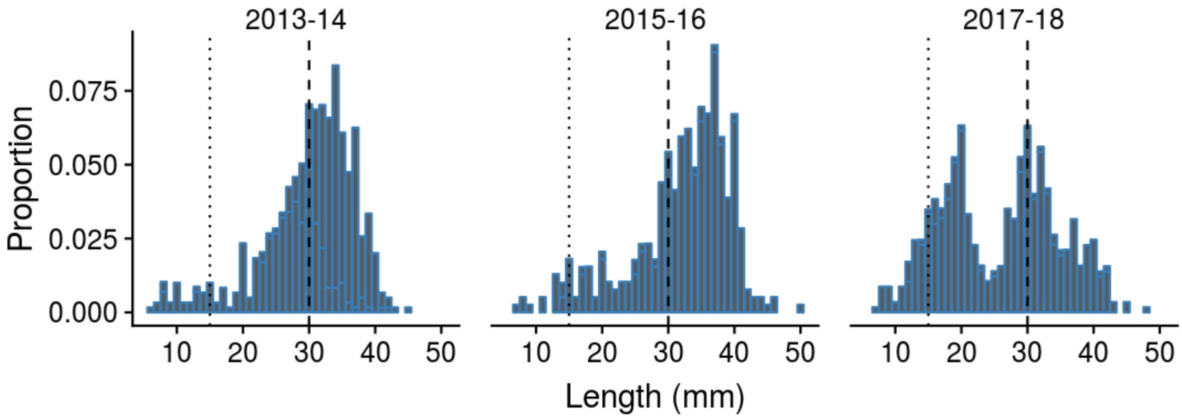


Figure 9: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Cockle Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3 Little Waihi Estuary

Little Waihi Estuary is in Bay of Plenty, east of Tauranga. This small estuary was included in ten previous bivalve assessments, with a survey in 2015–16 preceding the present study (see Appendix A, Tables A-1, A-2). Since 2009–10, the surveys have sampled a similar sampling extent, encompassing the entire lower estuary (Figure 10, Table 10). This area was re-stratified for the current study, resulting in a total of 138 sampling points across two strata, including 70 points for phase-2 sampling.

Sediment characteristics at Little Waihi Estuary included a low organic content (less than 2%) and a variable proportion of sediment fines (grain size <63 µm), ranging between none and 10.1% (Figure 10, and see details in Appendix B, Table B-3). The principal grain size fractions were fine and medium sands (grain sizes >125 µm and >250 µm), with varying proportions of coarser grain size fractions, including gravel (grain size >2000 µm). The highest proportion of gravel was 20%, but the majority of samples contained little or no gravel.

Cockles at Little Waihi Estuary were exclusively in stratum A, except for one individual (Figure 11, Table 10). Their distribution within stratum A was patchy and largely confined to intertidal mudflat areas. The total cockle population consisted of an estimated 15.50 million (CV: 26.09%) individuals. Their average density in 2017–18 was 84 cockles per m^2 (Table 11). The current estimates reflected a substantial decline (almost half) of the cockle population in the estuary; however, the uncertainty of the estimates was high, as the CV exceeded 20% in spite of the additional phase-2 sampling effort.

The population included few large cockles (≥30 mm shell length), and both their abundance and density were similar to values in recent previous surveys; in 2017–18, the population included 0.36 million (CV: >100%) large individuals, at a mean density of 2 large cockles per m^2. Their proportion within the population was minor, but showed a small increase to 2.33% of individuals in 2017–18.

In contrast, there was a considerable proportion of recruits (≤15 mm shell length), and this size class contributed a quarter of the total population (25.17%) in 2017–18. This percentage was similar to that in the two previous surveys, when over one third of the cockle population was in this size class. Both mean and modal sizes were small at 19.03 mm and 20 mm shell length, and length-frequency distributions documented a unimodal population size structure with a strong cohort around the modal length (Table 12, Figure 12). Across recent surveys, the current size structure indicated a small change with previously small cockles growing to medium sizes.

The distribution of pipi in the estuary was largely confined to channel areas of both strata (Figure 13, Table 13). The total size of the pipi population was an estimated 79.10 million (CV: 26.04%) pipi in 2017–18, and their mean density was 430 individuals per m^2 (Table 14). There was considerable uncertainty in these estimates, indicated by the CV exceeding 20%, even though the sampling included a second phase.

Included in the total population estimates was a small number of large pipi (≥50 mm shell length). Their estimated abundance was 5.44 million (CV: 64.08%) individuals and their mean density was 30 large pipi per m^2. Following the marked decreases in the pipi population in 2015–16, the current estimates indicated a stable population, including a small increase in the number of large individuals.

Although their proportion within the total population was generally small in recent surveys, it increased to 6.88% in 2017–18 (Table 15). Both the large size class and recruits (≤20 mm shell length) only represented small parts of the population: the proportion of recruits was 14.53%, which was similar to their contribution in the two previous surveys. Instead, medium-sized pipi consistently dominated the unimodal population, and their prevalence was reflected in length-frequency distributions in recent assessments that showed relatively little change (Figure 14). Nevertheless, the shift towards larger sizes within the single cohort in 2017–18 was reflected in mean and modal sizes, which increased to 35.48 mm and 40 mm shell length in the present assessment.

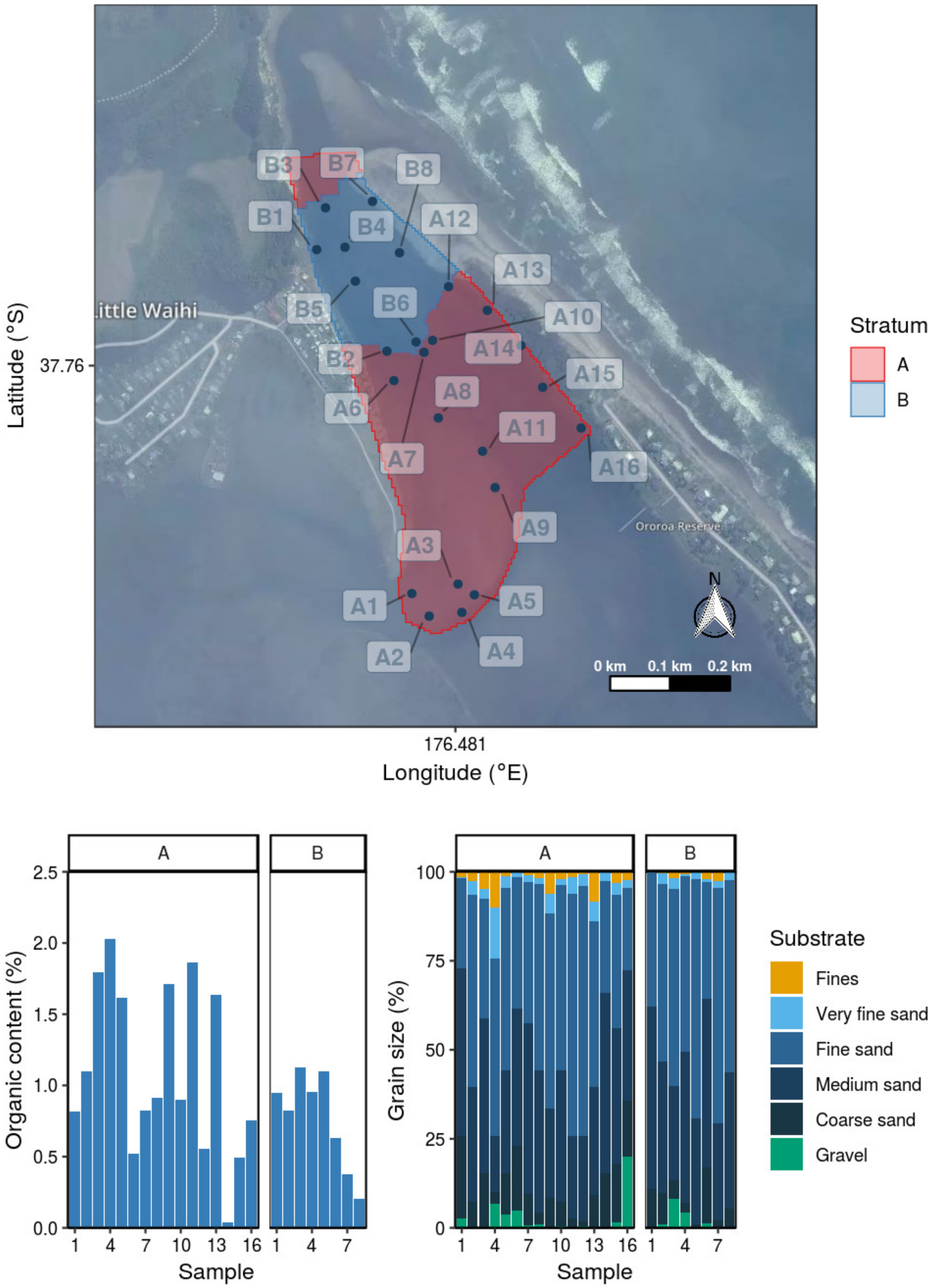


Figure 10: Sediment sample locations and characteristics at Little Waihi Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.3.1 Cockles at Little Waihi Estuary

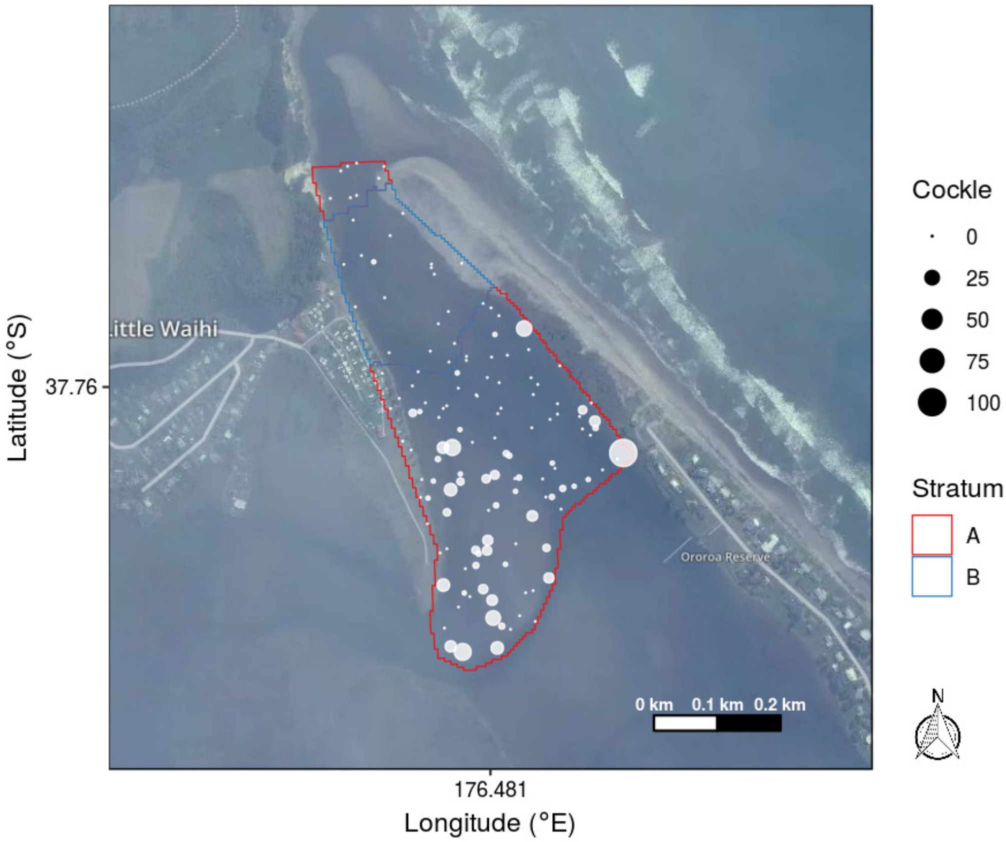


Figure 11: Map of sample strata and individual sample locations for cockles at Little Waihi Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 10: Estimates of cockle abundance at Little Waihi Estuary, by stratum, for 2017–18. 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	119	472	15.42	113	26.21
B	4.8	19	1	0.07	2	>100

Table 11: 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
2017–18	18.4	15.50	84	26.09	0.36	2	>100

Table 12: 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 ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2013–14	17.77	22	6–33	35.50	1.27
2015–16	17.68	15	4–35	36.45	0.86
2017–18	19.03	20	6–32	25.17	2.33

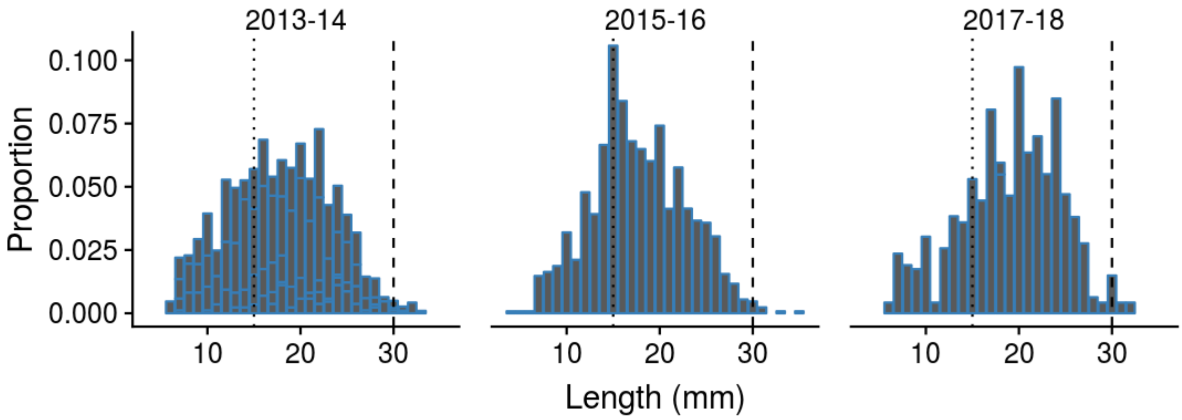


Figure 12: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3.2 Pipi at Little Waihi Estuary

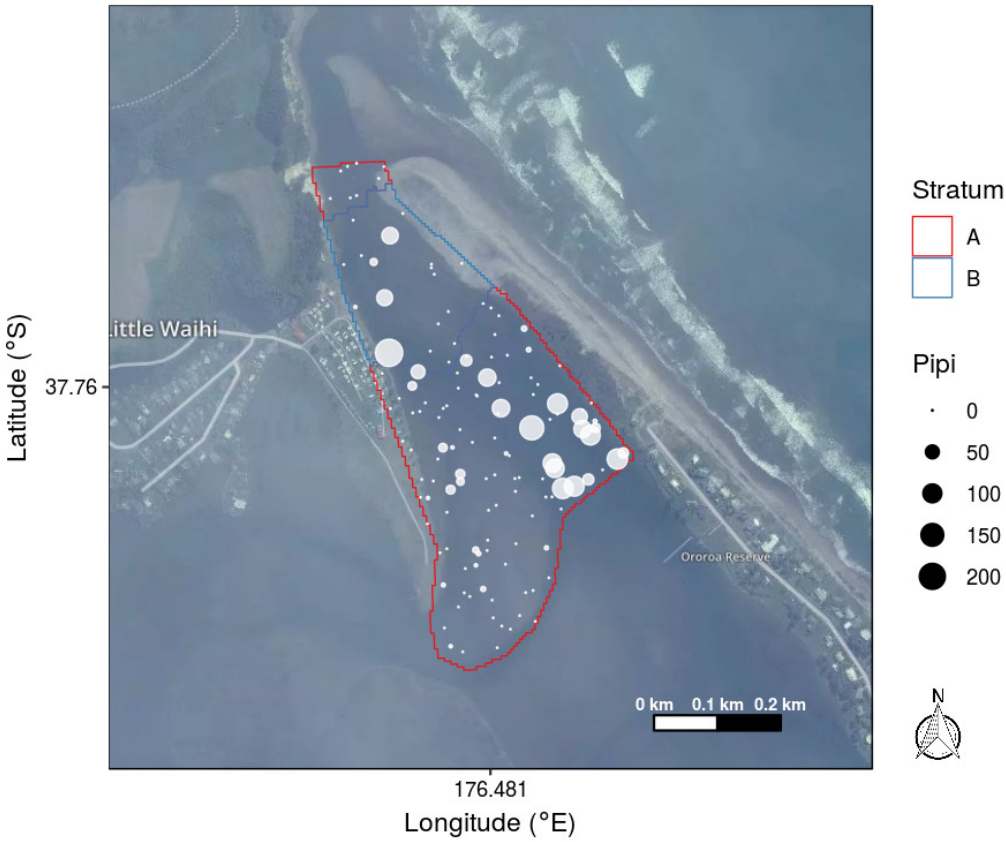


Figure 13: Map of sample strata and individual sample locations for pipi at Little Waihi Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of pipi abundance at Little Waihi Estuary, by stratum, for 2017–18. 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	119	1 479	48.33	355	24.10
B	4.8	19	429	30.77	645	55.20

Table 14: 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
2017–18	18.4	79.10	430	26.04	5.44	30	64.08

Table 15: 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 ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2013–14	31.49	42	8–57	17.71	2.68
2015–16	31.88	32	5–57	16.01	2.81
2017–18	35.48	40	7–58	14.53	6.88

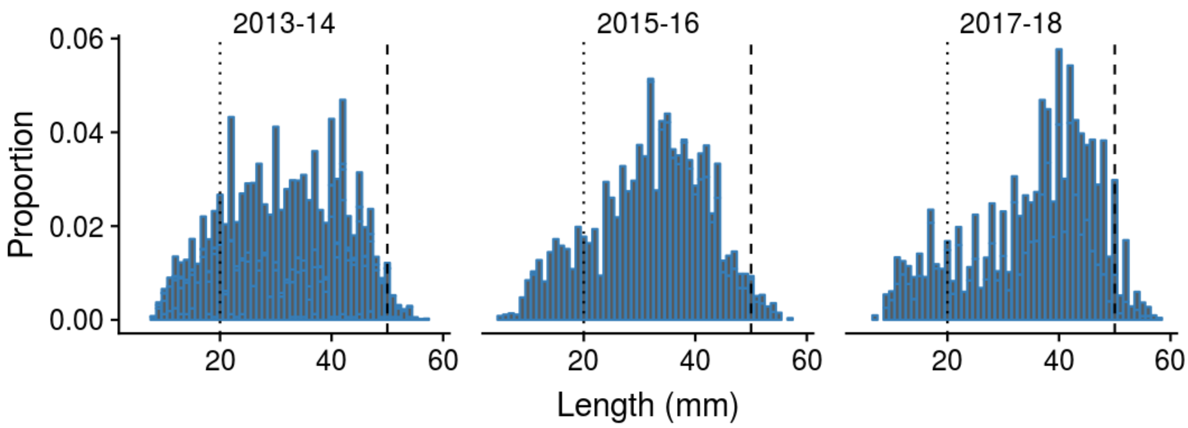


Figure 14: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4 Marsden Bank

Marsden Bank is in Northland, and situated just south of Whangarei. Its northern boundary is the main channel at the entrance of Whangarei Harbour. This site was closed to the collection of pipi in February 2011, with the subsequent closure of adjacent Mair Bank in October 2014. Marsden Bank was included in the monitoring programme in 2010–11, and has been surveyed four times since then, including the current study and the preceding survey in 2013–14 (see Appendix A, Tables A-1, A-2). Pipi at this site have also been assessed in other recent surveys, including a community-based monitoring programme led by Patuharakeke iwi (Williams et al. 2017).

Following the marked decline in the Marsden Bank pipi population in 2013–14, the sampling extent was re-defined for the current field sampling, using extensive on-site reconnaissance to ascertain the boundaries of the pipi bed prior to sampling. The reconnaissance was informed by data from recent pipi surveys conducted in 2016 and 2017 (Williams et al. 2017). The resulting sampling extent was markedly smaller than in previous surveys, and encompassed a small pipi bed on the sandbank adjacent to the Marsden Point Oil Refinery. Across this sampling extent, pipi were surveyed in a total of 120 sampling points, including 60 points in phase 2 (Figure 15, Table 16). Sampling at this site has solely focused on pipi throughout the survey series, and the lack of cockles in the 2017–18 survey confirmed the absence of this species at Marsden Bank.

The pipi population at Marsden Bank showed a patchy distribution across the sampling extent, with high densities in localised areas, especially the northern part next to the main channel. The total population estimate for this species was 10.93 million (CV: 19.17%) individuals in 2017–18 (Table 17). This estimate was a marked increase from their previous abundance estimate of 3.88 million (CV: 51.70%) in 2013–14, especially in view of the smaller sampling extent of the current survey (Table 17). Their current population density was an average 1284 pipi m^{-2}.

The population contained no large individuals ($\geq$ 50 mm shell length), and this size class disappeared from Marsden Bank in 2012–13, when the total pipi population underwent a significant decline. Although the current population consisted largely of small and medium-sized pipi, it also contained a small proportion of recruits ($\leq$ 20 mm shell length). This size class dominated the pipi population in the two preceding surveys with 57.86% and 69.10% of recruits, but their proportion in the current population was only 22.52% (Table 18, Figure 16).

In view of the population decline recorded in 2013–14, current survey data indicate some recovery of the pipi population at this site, including the presence of recruits. Nevertheless, changes in the morphology of the sandbank seemed to impact on pipi inhabiting this areas: between the reconnaissance in early December 2017 and the subsequent field sampling, the deposition of considerable amounts of sediment resulted in elevated sandbanks and deep depressions in an area that was previously relatively uniform (see Appendix C). This area was devoid of pipi during the field sampling.

Furthermore, at the time of sampling, there were localised patches of moribund and decaying bivalves, including pipi and oblong venus clam (*Venerupis largillierti*) in parts of the pipi bed (see Appendix C). The reasons for the observed mortalities are unknown, but subsequent investigations by Northland Regional Council and Fisheries New Zealand may elucidate the possible causes.

3.4.1 Pipi at Marsden Bank

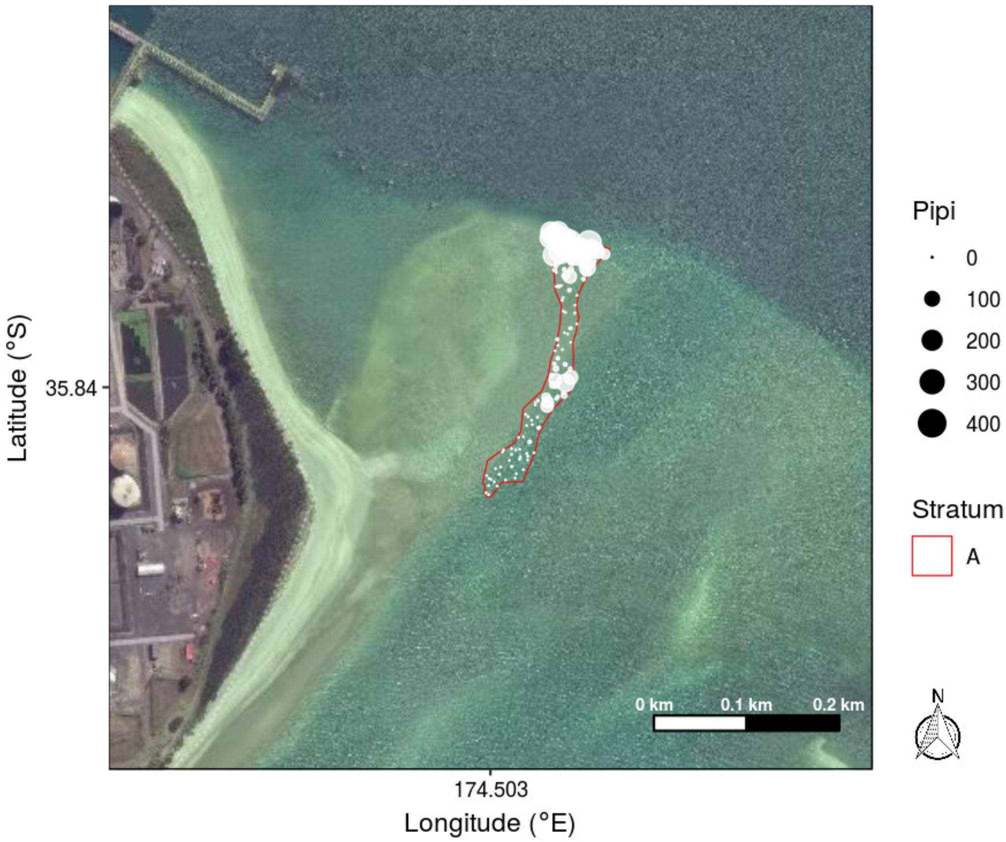


Figure 15: Map of sample strata and individual sample locations for pipi at Marsden Bank, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 16: Estimates of pipi abundance at Marsden Bank, by stratum, for 2017–18. 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	0.9	120	5 391	10.93	1 284	19.17

Table 17: Estimates of pipi abundance at Marsden Bank 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 (%)
2009–10	11.5	210.88	1 833	20.28	8.00	86	41.49
2012–13	6.3	60.53	959	19.79	0.00	0	
2013–14	15.4	3.88	25	51.70	0.00	0	
2017–18	0.9	10.93	1 284	19.17	0.00	0	

Table 18: Summary statistics of the length-frequency (LF) distribution of pipi at Marsden Bank. 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	20.60	20	1–48	57.86	0.00
2013–14	16.18	9	6–40	69.10	0.00
2017–18	26.47	32	8–47	22.52	0.00

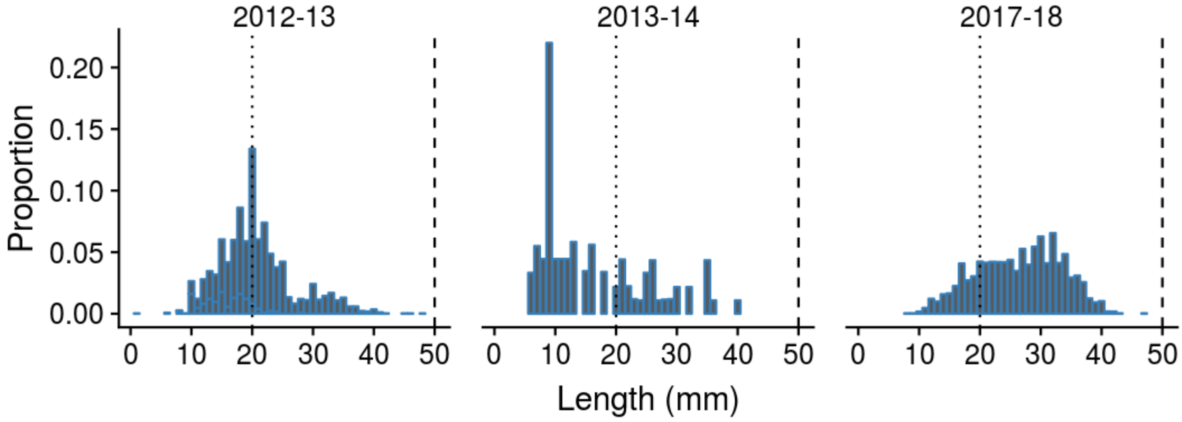


Figure 16: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Marsden Bank. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5 Mill Bay

Mill Bay is a small intertidal sandflat in northwestern Manukau Harbour, within the wider Auckland region. Bivalves at this site have been monitored in eight previous surveys, with the most recent preceding assessment in 2014–15 (see Appendix A, Tables A-1, A-2). The sampling extent at this site has been consistent throughout the survey series, although the current assessment was based on three different strata following re-stratification, compared with earlier surveys that were based on a single stratum. Across the three strata, there was a total of 145 points in 2017–18, including 83 sampling points each in phases 1 and 2 (Table 19).

Sediment samples revealed a low organic content of between 1.7 and 5.3% (Figure 17, and see details in Appendix B, Table B-3). At the same time, sediment grain size was largely determined by a relatively even distribution across three main sand fractions, ranging from fine (>125 µm grain size) to coarse (>500 µm grain size) sands. All of the sediment samples contained some fines (<63 µm grain size), with a maximum of 11.1% in this grain size fraction. The proportion of gravel (>2000 µm grain size) was generally low, although several samples contained over 20% of this coarse sediment.

The cockle population at Mill Bay was predominantly in the lower part of stratum C, with fewer cockles in other areas, particularly stratum A (Figure 18, Table 19). Based on the two-phase sampling, the population estimates for this species included a total of 7.78 million (CV: 25.18%) cockles and a mean density of 160 individuals per m^2 (Table 20). The current estimates documented a marked drop in the cockle population, with current abundance and density estimates of less than half the values of estimates in 2014–15. Nevertheless, the uncertainty of the estimates was high as the CV remained above 20%, in spite of the increased effort through phase-2 sampling.

There was a small number of large cockles (≥30 mm shell length) at Mill Bay, and their estimated abundance was 0.21 million (CV: 41.00%) individuals with a corresponding mean density of 4 large cockles per m^2, but the uncertainty of these estimates was also high. Cockles in the large size class have been consistently scarce at Mill Bay, even though their proportion increased to 2.67% in 2017–18 (Table 21).

In contrast, recruits (≤15 mm shell length) made up a considerable part within recent populations, contributing 31.00% of individuals in 2017–18. The prevalence of small and medium-sized cockles in the population was reflected in the mean and modal shell lengths at 18.02 mm and 17 mm, respectively (Figure 19). Cockles at these sizes dominated the unimodal population structure, with the growth of recruits and small-sized cockles over time contributing to the single cohort observed in 2017–18 resulting in the change from the previously bimodal population.

It is worth noting that the field sampling frequently encountered dying and recently-dead cockles across the entire sampling extent. Moribund cockles were usually found in small, water-logged depressions on the sandflat, with decaying tissue material adjacent to the bivalves (see Appendix D). The cause for the mortalities is unknown, but similar mortality events in New Zealand over the same period have been tentatively linked to sustained and unusually hot summer weather.

Pipi at Mill Bay were distributed throughout the western part of the sampling extent in strata B and C, with few pipi in stratum A (Figure 20, Table 22). The population estimates for this species were based on the same number of sampling points as for cockles, resulting in a total estimate of 0.77 million (CV: 18.86%) pipi and a mean density of 16 pipi per m^2 (Table 23). The current estimates were markedly lower than values in the two preceding surveys, but similar to the 2005–06 estimates.

There were no large pipi (≥50 mm shell length) in the current population, and individuals in this size class have consistently been absent at this site. Instead, the population consisted primarily of recruits (≤20 mm shell length) and small-sized pipi, with the former size class contributing 32.61% of individuals to the current population. The decrease in medium-sized pipi since the previous survey resulted in smaller mean and modal sizes of 22.58 mm and 25 mm shell length (Table 24, Figure 21). The previously bimodal population changed to a unimodal size structure with the strongest cohort around this modal length.

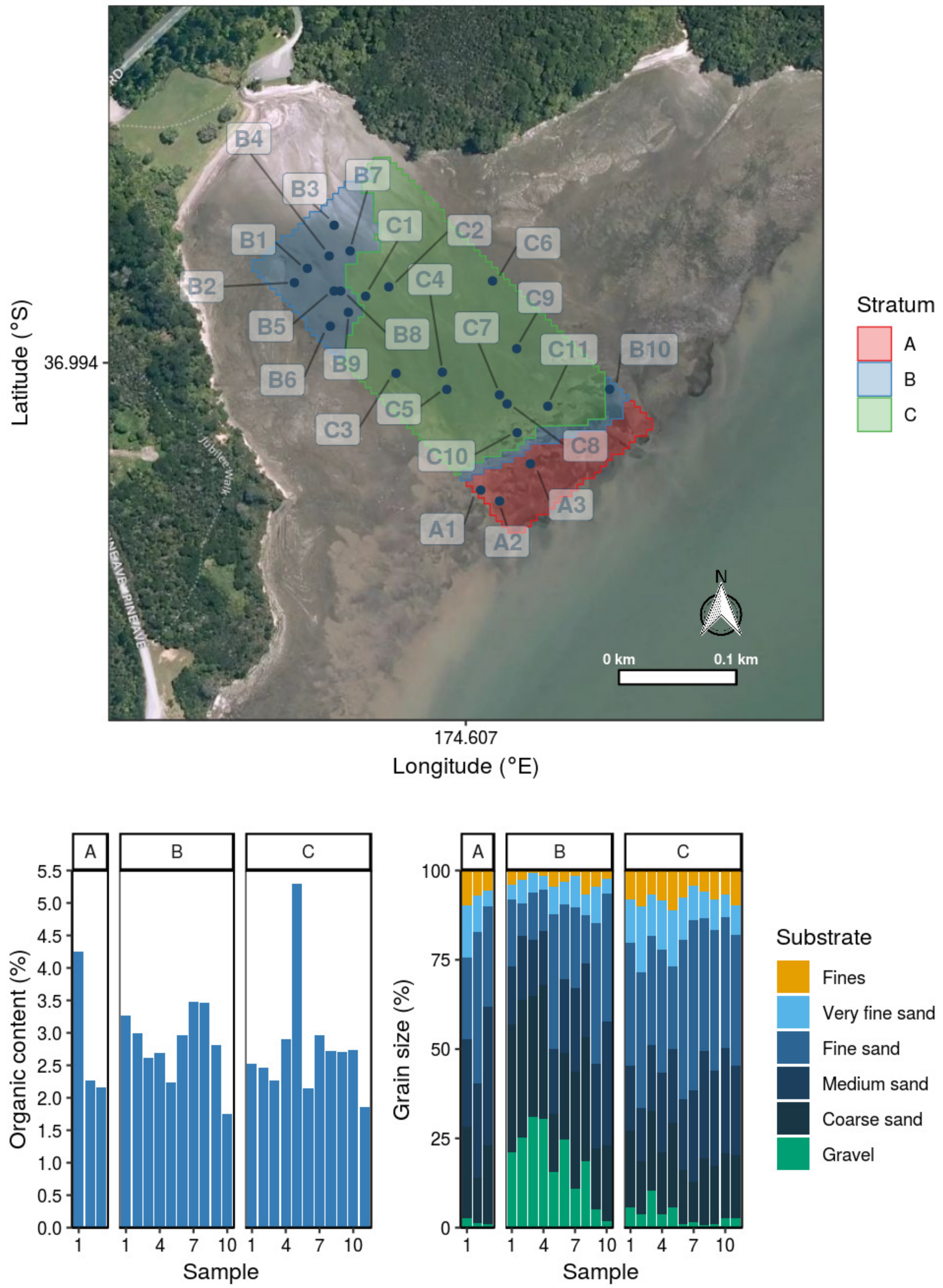


Figure 17: Sediment sample locations and characteristics at Mill Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.5.1 Cockles at Mill Bay

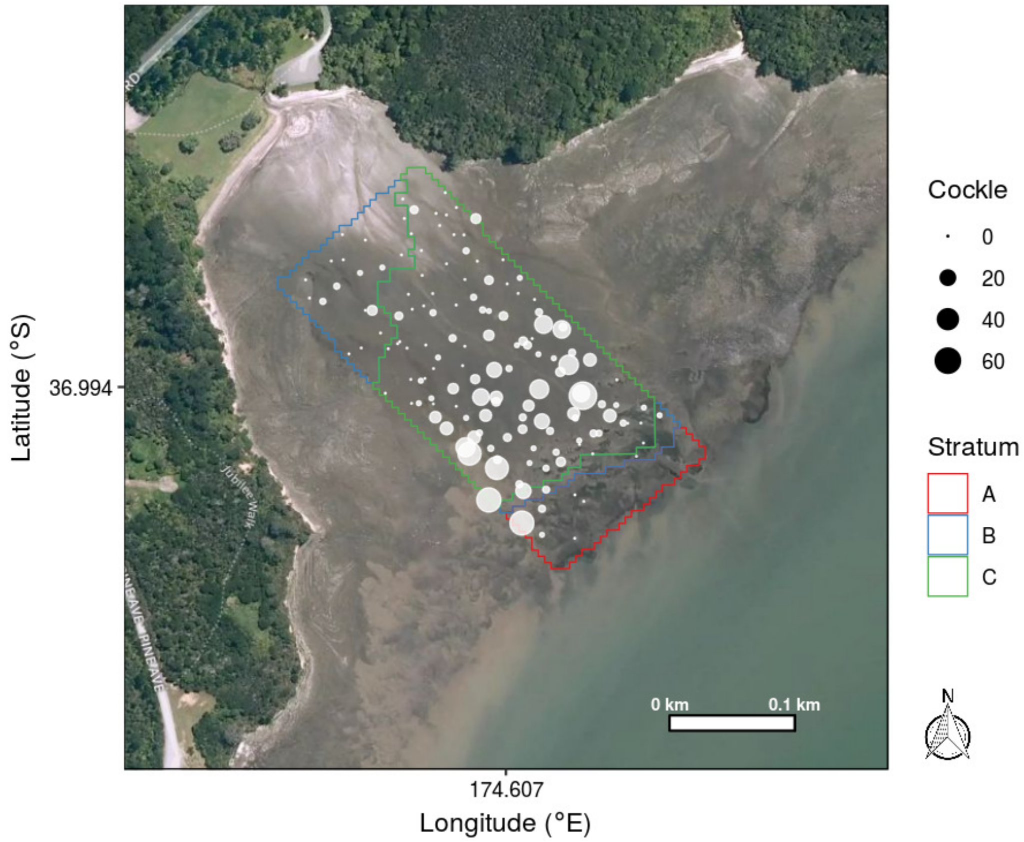


Figure 18: Map of sample strata and individual sample locations for cockles at Mill Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of cockle abundance at Mill Bay, by stratum, for 2017–18. 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	0.7	6	58	1.82	276	91.86
B	1.0	20	17	0.25	24	44.57
C	3.2	119	745	5.72	179	17.80

Table 20: Estimates of cockle abundance at Mill 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	4.6	4.91	107	7.87	0.74	16	12.06
2000–01	4.8	10.24	213	6.32	1.23	26	9.50
2001–02	4.5	5.21	116	6.89	0.38	8	13.26
2003–04	4.5	5.33	118	7.69	0.32	7	14.64
2004–05	4.5	4.23	94	7.30	0.30	7	14.45
2005–06	4.5	6.72	149	6.66	0.39	9	11.89
2009–10	5.0	11.31	229	8.92	0.18	4	31.80
2014–15	4.9	16.66	342	9.56	0.07	1	42.43
2017–18	4.9	7.78	160	25.18	0.21	4	41.00

Table 21: Summary statistics of the length-frequency (LF) distribution of cockles at Mill 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 (%)
2009–10	14.41	10	4–34	62.92	1.59
2014–15	19.42	22	4–32	24.37	0.43
2017–18	18.02	17	6–33	31.00	2.67

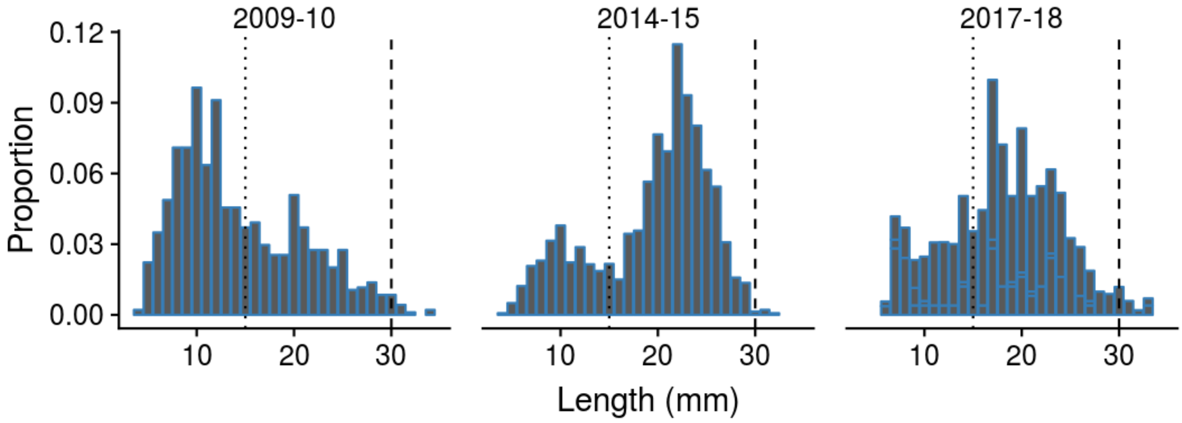


Figure 19: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mill Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5.2 Pipi at Mill Bay

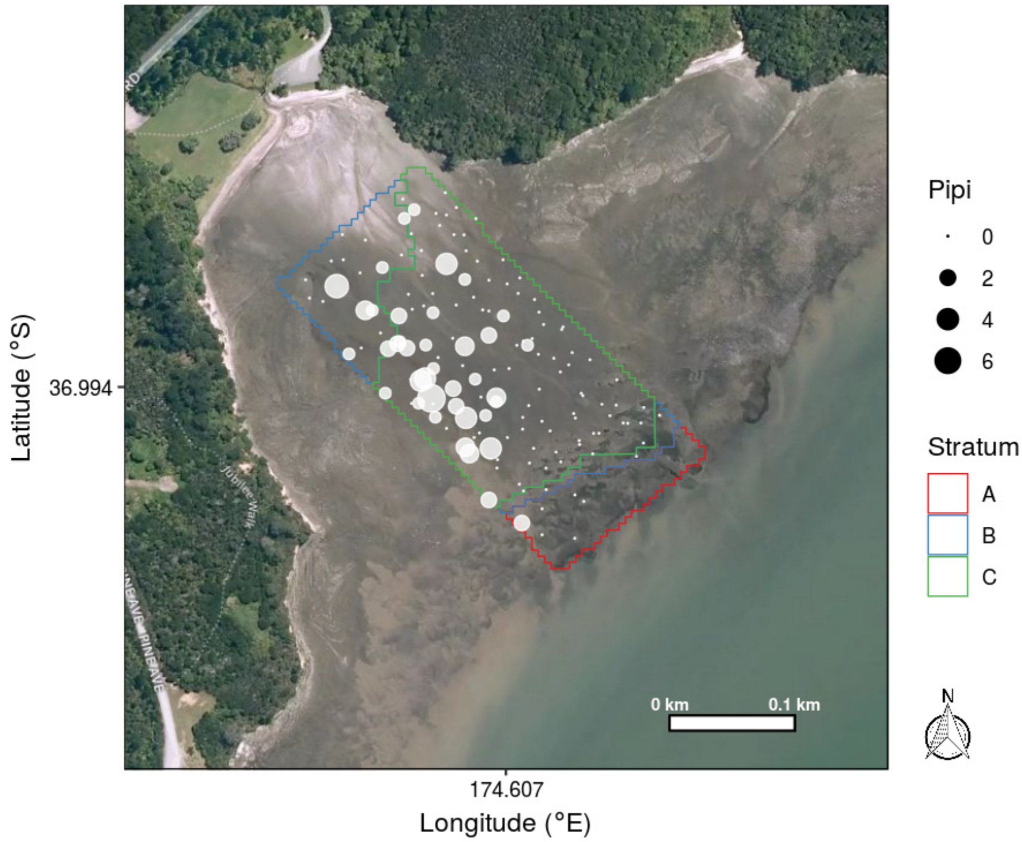


Figure 20: Map of sample strata and individual sample locations for pipi at Mill Bay, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 22: Estimates of pipi abundance at Mill Bay, by stratum, for 2017–18. 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	0.7	6	2	0.06	10	>100
B	1.0	20	12	0.17	17	47.45
C	3.2	119	69	0.53	17	19.03

Table 23: Estimates of pipi abundance at Mill Bay 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	4.6	0.49	11	13.59	0.01	<1	>100
2000–01	4.8	6.37	133	11.26	0.03	<1	37.87
2001–02	4.5	1.76	39	9.63	0.01	<1	91.42
2003–04	4.5	0.49	11	11.50	0.00	0	
2004–05	4.5	1.41	31	12.06	0.00	<1	>100
2005–06	4.5	0.79	18	13.50	0.00	<1	>100
2009–10	5.0	5.65	114	17.37	0.00	0	
2014–15	4.9	4.41	90	14.32	0.00	0	
2017–18	4.9	0.77	16	18.86	0.00	0	

Table 24: Summary statistics of the length-frequency (LF) distribution of pipi at Mill 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 ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	17.59	12	5–49	68.79	0.00
2014–15	24.78	29	7–42	32.06	0.00
2017–18	22.58	25	8–38	32.61	0.00

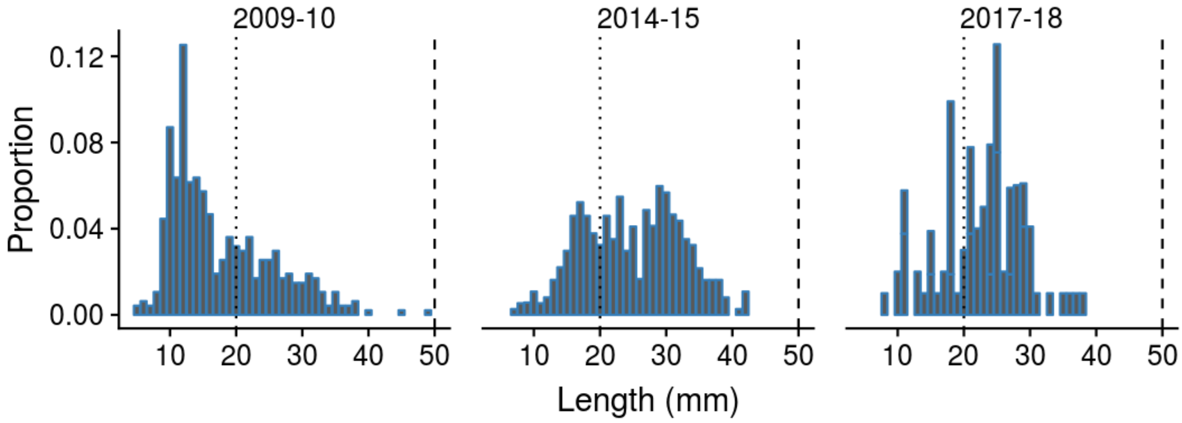


Figure 21: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Mill Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Okoromai Bay

Okoromai Bay is an intertidal site on the south side of Whangaparoa Peninsula, just north of Auckland. The bay has been included in ten surveys since 1999–2000, with the most recent survey in 2015–16 (see Appendix A, Tables A-1, A-2). At this site, the sampling extent has remained largely unchanged, and the current study sampled two re-stratified strata across this sampling extent (Table 25). The field sampling included a total of 80 sampling points in 2017–18. There were no pipi sampled at this site in 2017–18.

The sediment at Okoromai Bay was low in organic matter, containing less than 3.1% across all samples (Figure 22, and see details in Appendix B, Table B-3). The most prevalent grain size fraction was very fine sand (grain size >65 µm), followed by fine sand (grain size >125 µm), and most samples contained a small proportion of fines (grain size <63 µm), ranging from less than 1 to 10.6%. The majority of samples included only a small percentage of gravel (>2000 µm grain size), although this grain size fraction made up over 31% in one sample.

The cockle population at Okoromai Bay was spread across the lower part of the sampling extent, with high numbers and densities in stratum A (Figure 23). Based on the field data, the abundance of the total population was estimated at 52.25 million (CV: 15.24%) cockles in 2017–18, with a population density of 263 cockles per m^2 (Table 26). These estimates were the highest values since 2001–02, confirming a continued increase of the cockle population. Nevertheless, there was concomitant decrease in the number and density of large cockles (≥30 mm shell length): although this size class exhibited some fluctuation throughout the survey series, their abundance and density have remained low in recent assessments. The current values were the lowest estimates in the survey series, with an estimated abundance of 4.29 million (CV: 19.79%) large cockles and a mean density of 22 large individuals per m^2.

The marked decline in large cockles was reflected in the population structure (Table 27, Figure 24), which showed a recent decrease in the proportion of large cockles to 8.21%, after this size class made up almost a quarter of the population (24.37%) in 2015–16. The decrease in large cockles in 2017–18 was accompanied by a significant increase in the proportion of recruits (≤15 mm shell length) to 29.64%. Changes in mean and modal cockle sizes corresponded with this increase in recruits, with reductions in shell lengths to 15.54 mm, and 16 mm, respectively. In addition, recruits made up the strongest cohort in the bimodal population in 2017–18 .

These findings highlight that observed population increases at Okoromai Bay were largely determined by a recruitment event. Although the total population size increased in 2017–18, the dominance of recruits and decrease in large cockles resulted in a notable shift in the population towards small-sized individuals.

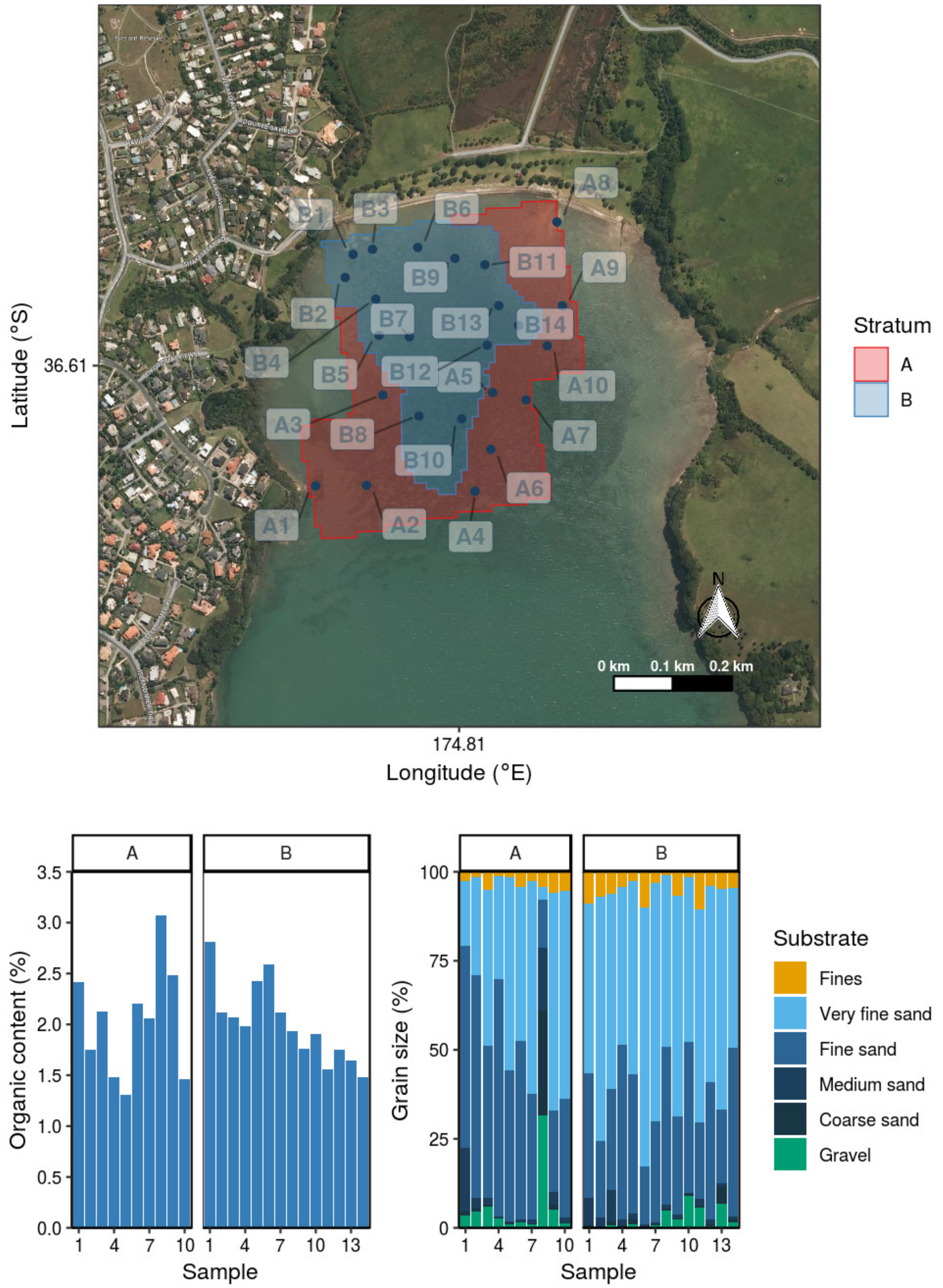


Figure 22: Sediment sample locations and characteristics at Okoromai Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.6.1 Cockles at Okoromai Bay

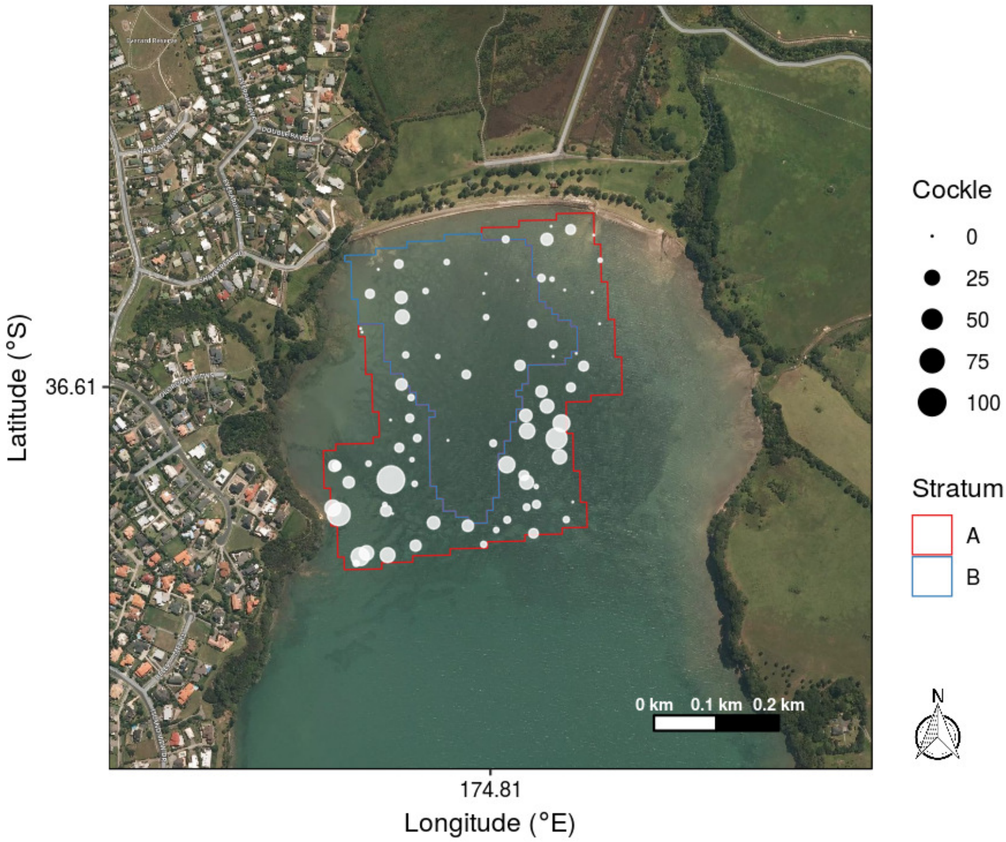


Figure 23: Map of sample strata and individual sample locations for cockles at Okoromai Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 25: Estimates of cockle abundance at Okoromai Bay, by stratum, for 2017–18. 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	10.6	60	780	39.51	371	18.03
B	9.2	20	97	12.74	139	27.92

Table 26: 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
2017–18	19.8	52.25	263	15.24	4.29	22	19.79

Table 27: 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 (%)
2013–14	21.38	12	7–39	28.09	15.91
2015–16	21.73	16	6–41	29.64	24.37
2017–18	15.54	10	3–43	60.38	8.21

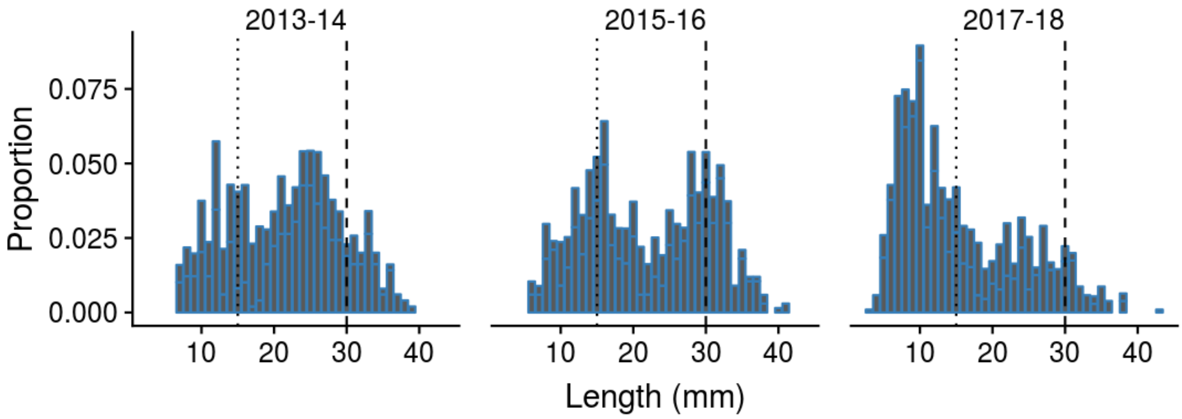


Figure 24: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Okoromai Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7 Pataua Estuary

Pataua Estuary is a small estuary in the Northland region, just north of Whangarei. Bivalves in this estuary have been sampled in a total of six surveys, including the current study (see Appendix A, Tables A-1, A-2). The most recent previous assessment was in 2015–16. The sampling area at this estuary was extended in 2013–14 to include all of the cockle beds on the intertidal sandflat in the main estuary (Figure 25, Table 28). The 2017–18 field survey was based on three strata, and included re-stratification of the two cockle strata, and a separate pipi stratum in the channel. Across these three strata, bivalves were targeted in a total of 119 sampling points, including 30 points for phase-2 sampling of the pipi stratum.

Sediment in the cockle strata at Pataua Estuary was characterised by a low organic content (0.6 to 2.3%) and a small proportion of fines (none to 3.9%; grain size <63 µm) (Figure 25, and see details in Appendix B, Table B-3). Fine sand (grain size >250 µm) largely defined the sediment grain size composition, with varying proportions of coarser grain size fractions. The proportion of gravel (grain size >2000 µm) was relatively high in some samples, particularly in stratum A, where the maximum value of gravel was 26.2%.

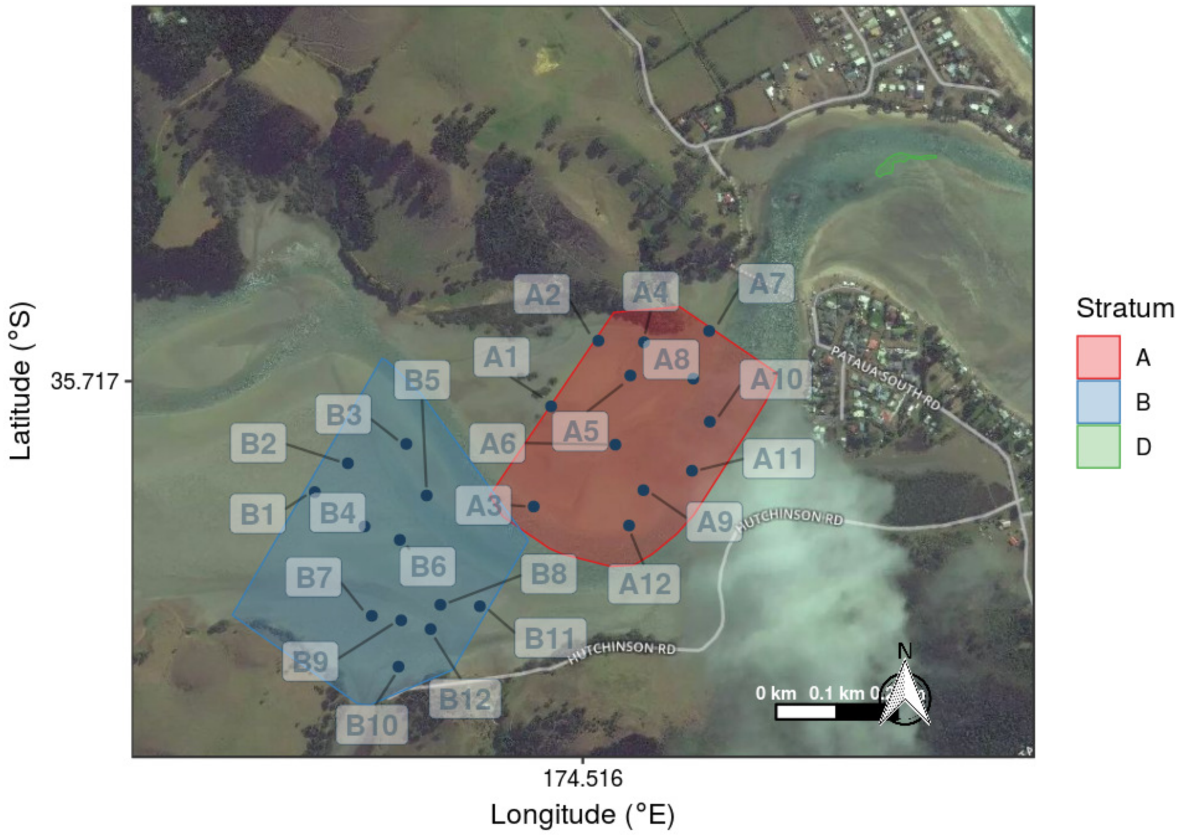
Cockles were predominantly in strata A and B, with only few individuals (i.e., five each) in the remaining strata (Figure 26, Table 28). The current abundance estimate for this population was 406.39 million (CV: 11.78%) individuals and the mean density was 1467 cockles per m^2 (Table 29). The current estimates indicated a stable population, with slight increases from the preceding survey. There was also little change in the abundance and density of large cockles (≥30 mm shell length), which were present in low numbers: there were an estimated 4.54 million (CV: 44.37%) individuals in this size class in 2017–18, and their density was 18 large cockles per m^2.

Large cockles have been consistently scarce in recent surveys at Pataua Estuary, where they have constituted just over 1% of the population since 2013–14 (Table 30). Instead, medium-sized individuals dominated the cockle population at this site, with recruits (≤15 mm shell length) contributing between 21.80% (in 2015–16) and 30.76% of individuals (current survey). The similar size-frequency distribution across recent surveys illustrates the persistence of a strong cohort of medium-sized cockles, with little growth to the larger size class over time (Figure 27). Mean and modal sizes remained similar throughout this period, and respective shell lengths in 2017–18 were 17.73 mm and 17 mm. These findings indicate a stable population of small and medium-sized cockles and regular recruitment events.

The pipi population at Pataua Estuary was concentrated in the main channel, in stratum D (Figure 28, Table 31). Their current abundance estimate was 2.04 million pipi (CV: 35.38%), which reflected a significant reduction from the preceding estimate of 6.45 million pipi (CV: 14.67%) in 2015–16 (Table 32). Their population density declined from 23 pipi per m^2 in the previous assessment to 7 individuals per m^2 in the present study. In addition, the uncertainty of the current estimates was high, with a CV exceeding 20%, even after additional phase-2 sampling. It was markedly lower (CV: 18.12%) when considering the estimates for the pipi stratum only, with a corresponding abundance estimate of 0.31 million pipi and a density of 291 pipi per m^2 in stratum D.

Large pipi (≥50 mm shell length) were present in low numbers; their abundance and density were estimated at 0.19 million (CV: >100%) individuals and <1 large pipi per m^2, respectively. This size class has consistently been small at Pataua Estuary, even though its proportion increased to 9.24% in 2017–18 (Table 33).

In comparison, recruits (≤20 mm shell length) continued to have a notable influence on the population size structure, with an increase in their proportion to 30.87% in the current study. This size class and small- to medium-sized pipi largely defined the bimodal population in recent assessments, although the cohorts were less uniform in 2017–18 (Figure 29). The modal size was largely determined by recruits, decreasing to 15 mm, about half the modal shell length recorded in 2015–16, although the mean shell length remained similar at 28.17 mm.



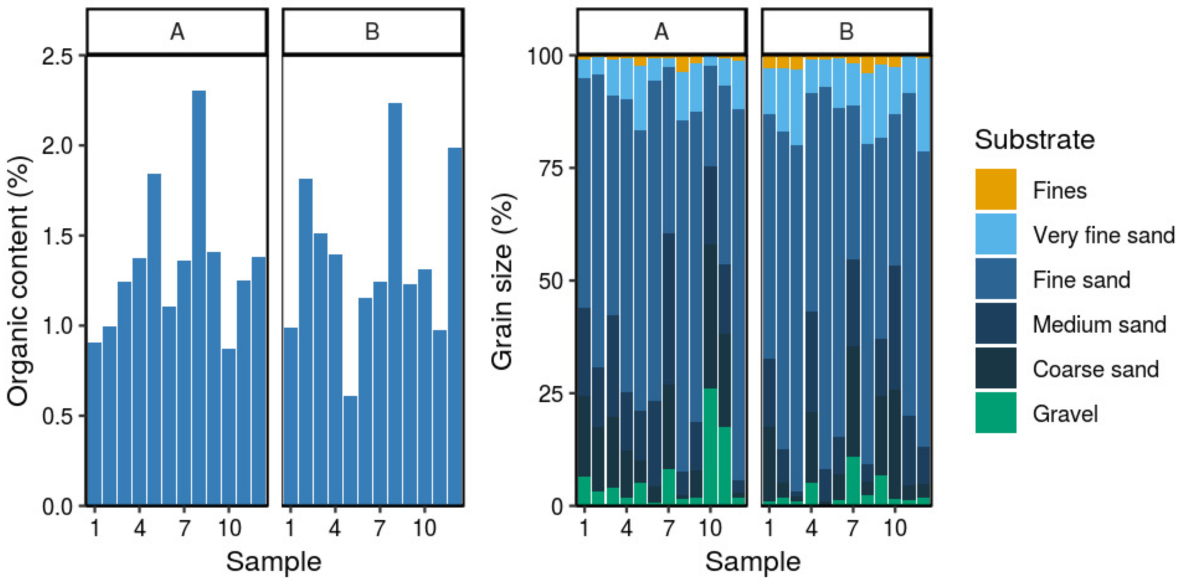


Figure 25: Sediment sample locations and characteristics at Pataua Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.7.1 Cockles at Pataua Estuary

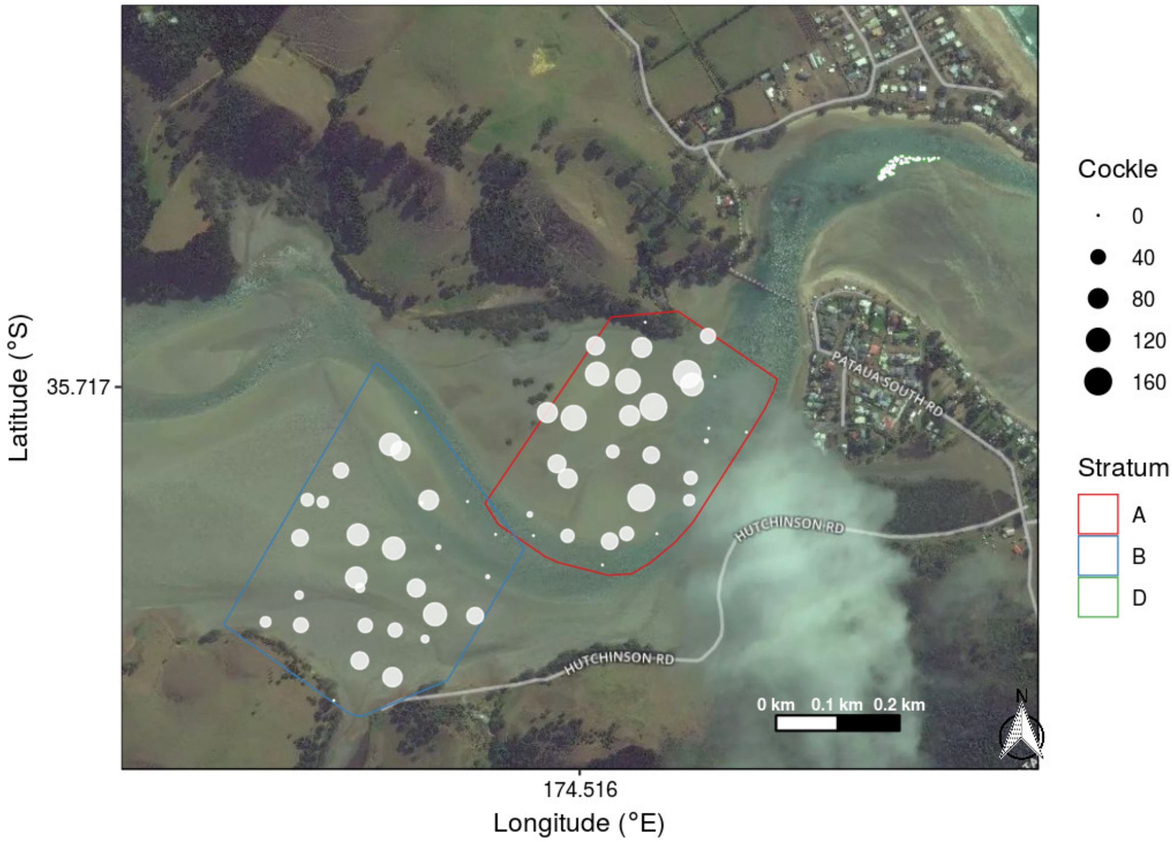


Figure 26: Map of sample strata and individual sample locations for cockles at Pataua Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 28: Estimates of cockle abundance at Pataua Estuary, by stratum, for 2017–18. 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	12.3	30	1 792	209.43	1 707	17.04
B	15.3	29	1 304	196.96	1 285	16.21
D	0.1	60	10	0.00	5	38.18

Table 29: 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).

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
2015–16	27.8	380.13	1 368	7.58	4.89	18	29.68
2017–18	27.7	406.39	1 467	11.78	4.54	16	44.37

Table 30: 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 (%)
2013–14	17.97	20	4–58	31.81	1.59
2015–16	19.11	20	5–36	21.80	1.29
2017–18	17.73	17	4–35	30.76	1.12

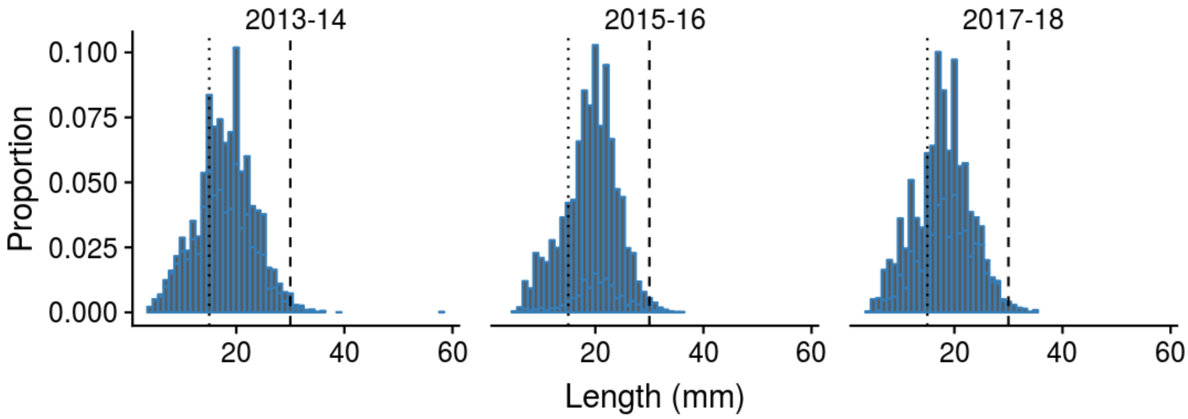


Figure 27: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7.2 Pipi at Pataua Estuary

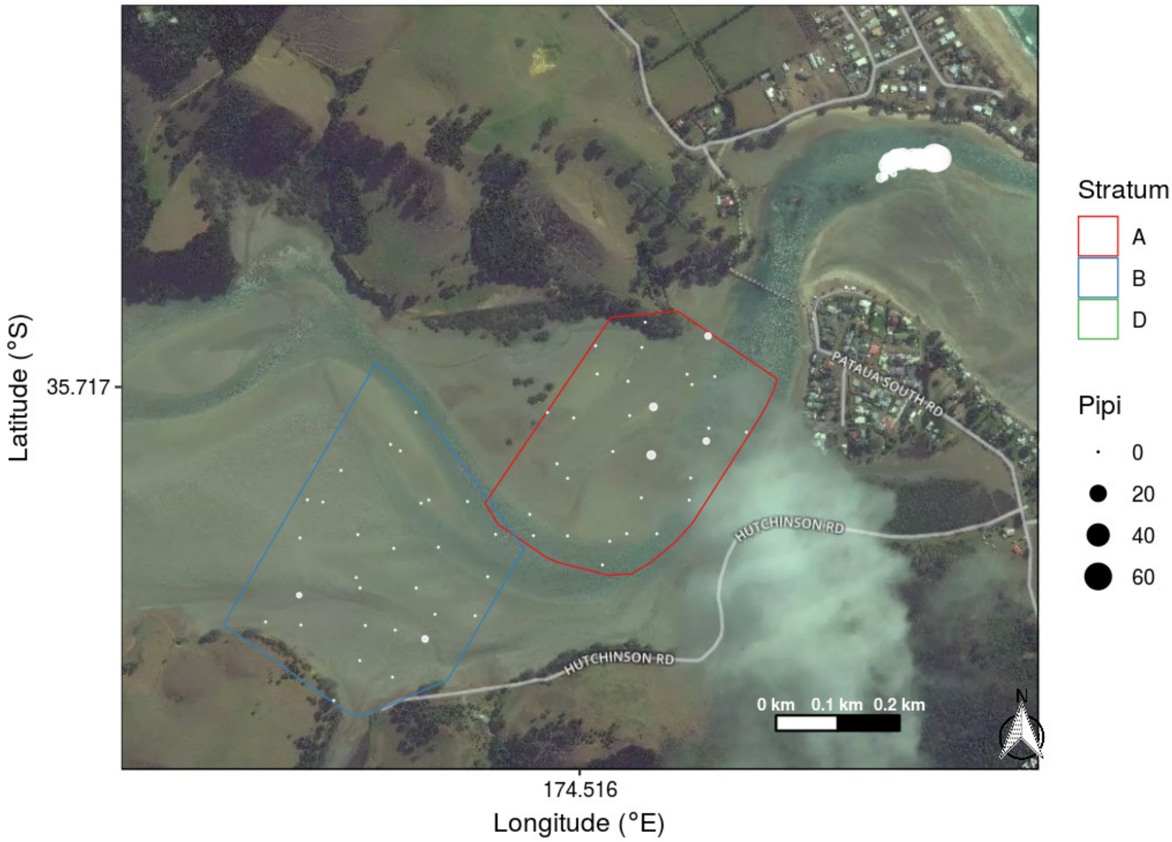


Figure 28: Map of sample strata and individual sample locations for pipi at Pataua Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of pipi abundance at Pataua Estuary, by stratum, for 2017–18. 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	12.3	30	11	1.29	10	49.76
B	15.3	29	3	0.45	3	73.46
D	0.1	60	612	0.31	291	18.12

Table 32: 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
2017–18	27.7	2.04	7	35.38	0.19	<1	>100

Table 33: 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 (%)
2013–14	31.28	19	7–58	29.82	6.27
2015–16	31.54	27	8–56	19.52	2.94
2017–18	28.17	15	11–59	30.87	9.24

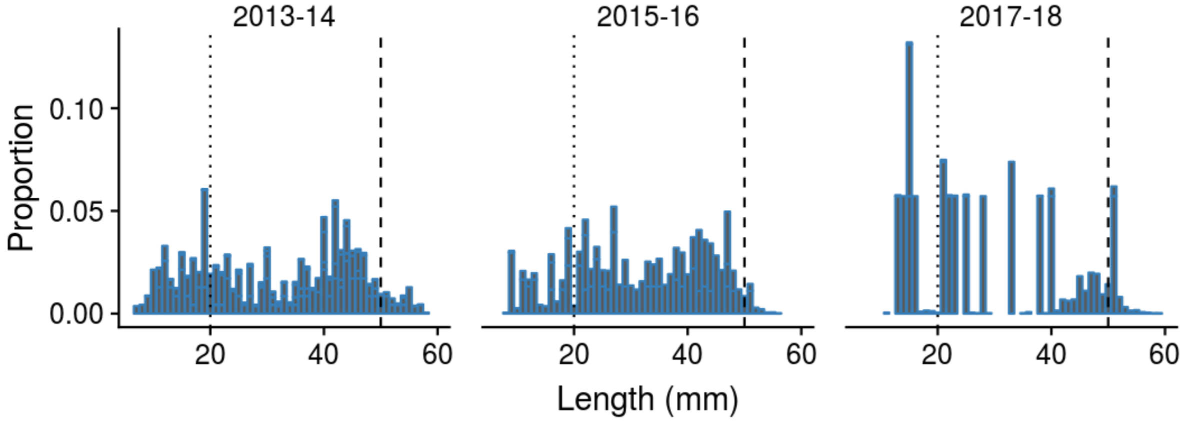


Figure 29: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Raglan Harbour

Raglan Harbour is a Waikato site that is situated on the west of the region. Bivalves at this site have been included in seven previous surveys since 1999–2000, most recently in 2014–15 (see Appendix A, Tables A-1, A-2). The current study surveyed the same sampling extent as previous recent surveys, focusing on two separate cockle strata in the main entrance of the harbour, and a pipi bed in a side channel close to the harbour entrance (Figure 30). Bivalves were sampled at 90 sampling points distributed across the three strata.

Sediment samples from the two separate cockle strata were relatively uniform and low in organic content, ranging between 0.4 and 2.4% (Figure 30, and see details in Appendix B, Table B-3). In contrast, the sediment composition was variable, with a relatively high proportion (over 10%) of fines ($<$63 µm grain size) in some of samples. Fine sand ($>$125 µm grain size) consistently made up most of the sediment, ranging between 48.8 and 80.2% in the samples. There were small proportions of coarse grain sizes, including gravel ($>$2000 µm grain size), with the exception of one sample that contained 17% of sediment in this grain size fraction.

The cockle population was distributed across both strata, with a small number of individuals also occurring in the pipi bed (Figure 31, Table 34). The total abundance of this population was estimated at 109.16 million (CV: 7.11%) individuals in 2017–18, a similar abundance to the preceding survey (Table 35). Their corresponding density was also similar to the previous estimate with an average density of 1508 cockles per m^2 in the current study.

The population included only a small number of large cockles ($\geq$30 mm shell length), and their abundance and density have been low throughout most of the survey series. There were an estimated 3.21 million (CV: 22.20%) large cockles in the population in 2017–18, and their density was 44 large individuals per m^2. These estimates were slight increases from values in the preceding survey, but remained well below earlier estimates for this size class.

The overall composition of the cockle population reflected the small proportion of large individuals, which made up 2.94% of the population. In comparison, recruits ($\leq$15 mm shell length) contributed 26.08% of individuals to the total population, reflecting an increase from previous estimates (Table 36). The observed increase in recruits resulted in smaller mean and modal sizes at shell lengths of 19.04 mm and 20 mm, respectively.

Furthermore, the influence of recruits on the population size structure was evident in the appearance of a second cohort in the previously unimodal population dominated by medium-sized cockles (Figure 32). Although recruitment strength was insufficient to form a strong second mode, it resulted in a shift towards smaller sizes within the cockle population.

Pipi were generally confined to the pipi bed, with only few individuals sampled in other strata (Figure 33, Table 37). Their total population size was an estimated 1.74 million (CV: 12.29%) pipi in 2017–18 (Table 38), and their average density was 24 pipi per m^2. Both these estimates signified a reduction in the total population.

Within the population, there was a small number of large pipi ($\geq$50 mm shell length); there were 0.10 million (CV: 24.15%) individuals in this size class at a low density of 1 large pipi per m^2. The low abundance of large pipi meant that this size class only constituted 5.81% of the total population in 2017–18, and this finding was consistent with the two preceding surveys (Table 39, Figure 34). Nevertheless, the proportion of recruits ($\leq$20 mm shell length) showed some variation across recent surveys, with a relatively large increase from 5.83% in 2014–15 to 16.55% in 2017–18.

Length frequency distributions across recent surveys illustrated the influence of recruitment events on the population size structure. As recruits constituted a second cohort in 2017–18, they changed the population size structure to a bimodal population. Although the population was still dominated by medium-sized pipi, there was a decrease in mean and modal sizes to 36.07 mm and 37 mm shell length.

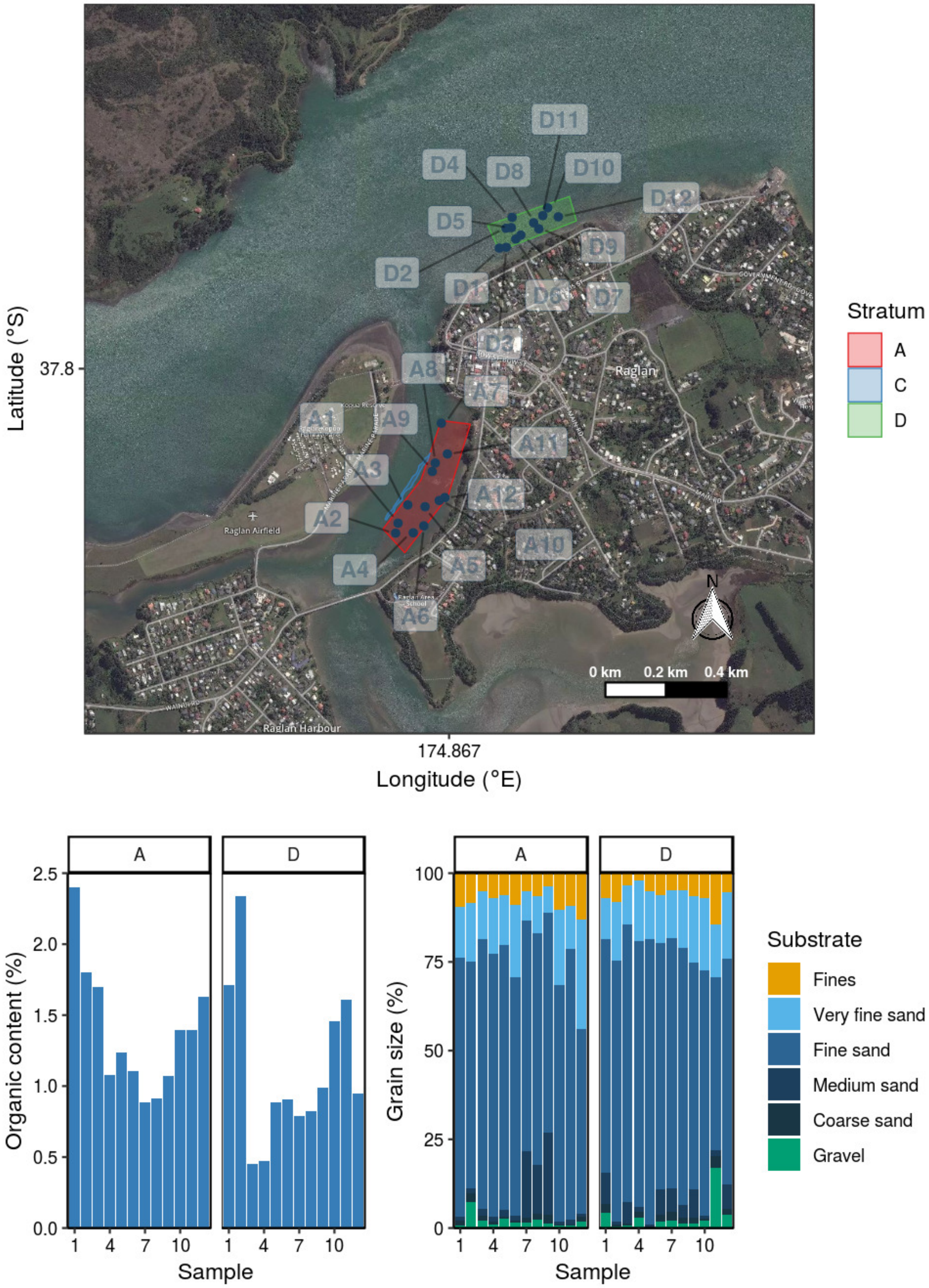


Figure 30: Sediment sample locations and characteristics at Raglan Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.8.1 Cockles at Raglan Harbour

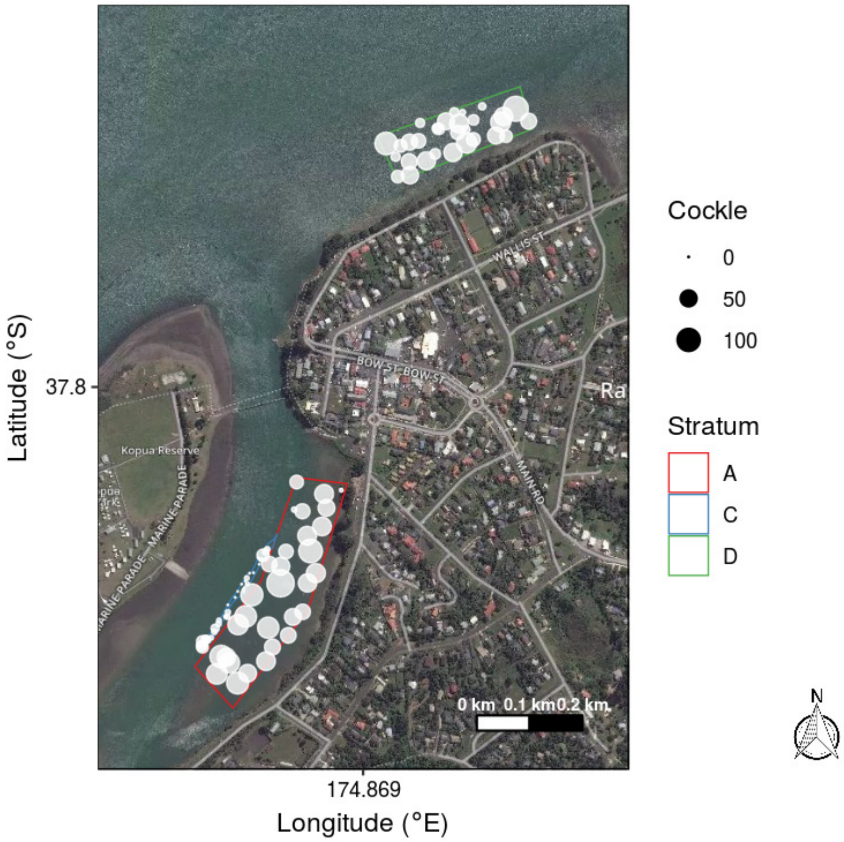


Figure 31: Map of sample strata and individual sample locations for cockles at Raglan Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of cockle abundance at Raglan Harbour, by stratum, for 2017–18. 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	4.6	30	1 858	80.56	1 770	8.54
C	0.2	30	136	0.28	130	27.90
D	2.5	30	1 206	28.32	1 149	12.70

Table 35: Estimates of cockle abundance at Raglan 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 (%)
1999–00	10.1	184.49	1 827	3.64	6.56	65	12.56
2000–01	10.0	220.43	2 195	3.34	17.28	172	6.50
2002–03	8.2	92.26	1 120	3.78	4.17	51	9.47
2003–04	8.2	89.79	1 090	3.50	3.76	46	7.49
2009–10	9.2	125.59	1 365	5.23	5.90	72	20.79
2012–13	8.2	129.04	1 566	6.84	6.08	74	19.74
2014–15	7.2	109.56	1 513	4.95	2.44	34	15.20
2017–18	7.2	109.16	1 508	7.11	3.21	44	22.20

Table 36: Summary statistics of the length-frequency (LF) distribution of cockles at Raglan 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	21.37	20	4–45	12.24	4.71
2014–15	21.61	22	6–39	9.87	2.22
2017–18	19.04	20	4–40	26.08	2.94

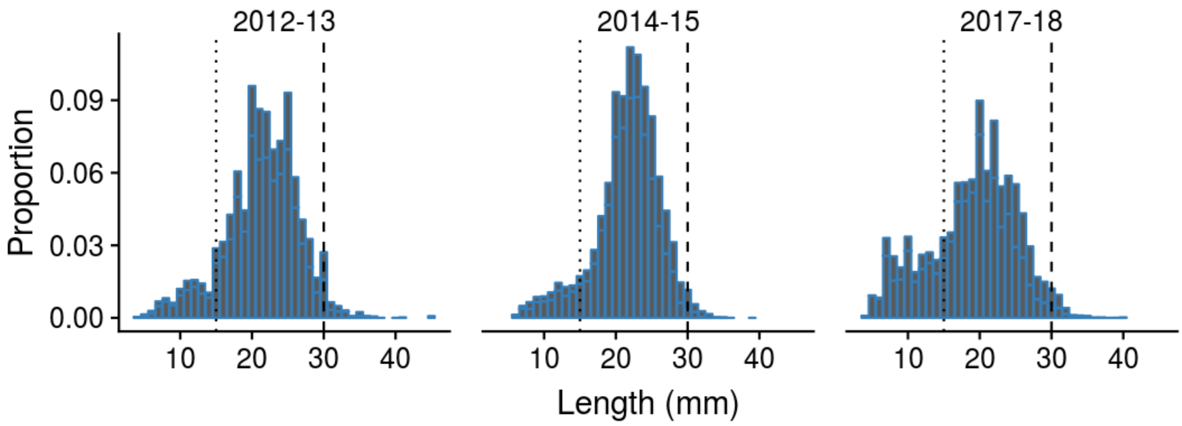


Figure 32: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Raglan Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8.2 Pipi at Raglan Harbour

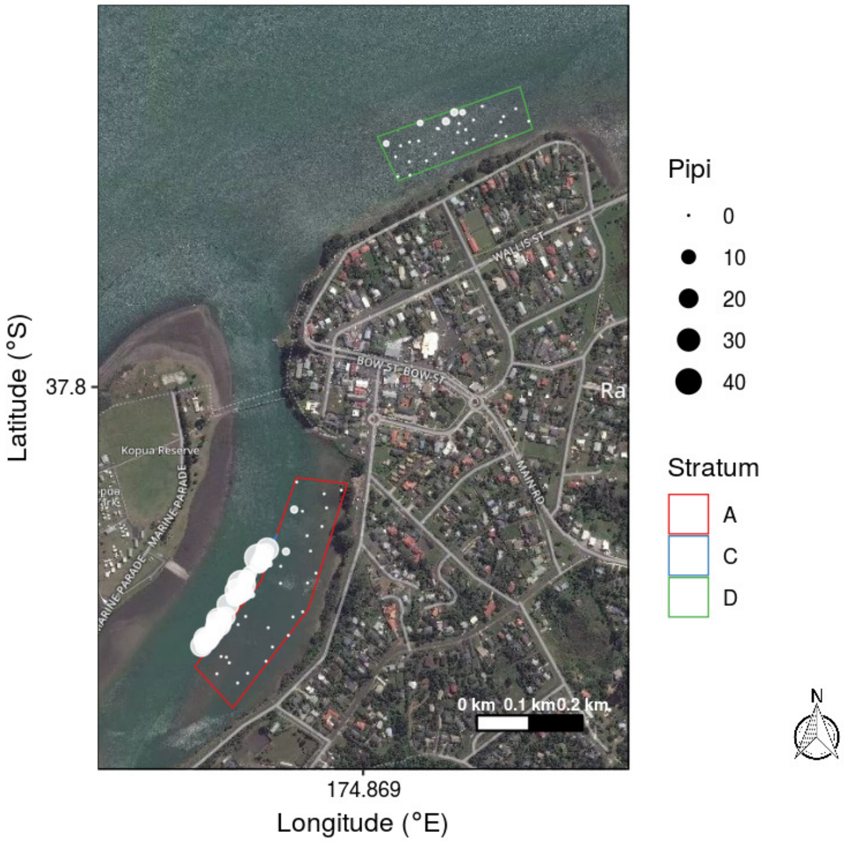


Figure 33: Map of sample strata and individual sample locations for pipi at Raglan Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 37: Estimates of pipi abundance at Raglan Harbour, by stratum, for 2017–18. 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	4.6	30	6	0.26	6	50.29
C	0.2	30	632	1.32	602	11.61
D	2.5	30	7	0.16	7	44.47

Table 38: Estimates of pipi abundance at Raglan 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	10.1	0.31	3	15.14	0.00	0	
2000–01	10.0	1.46	15	11.75	0.23	2	8.33
2002–03	8.2	0.47	6	13.18	0.08	<1	17.69
2003–04	8.2	0.43	5	13.70	0.02	<1	20.92
2009–10	9.2	0.60	7	19.17	0.15	2	12.61
2012–13	8.2	1.78	22	14.51	0.13	2	43.37
2014–15	7.2	2.35	32	15.53	0.14	2	40.45
2017–18	7.2	1.74	24	12.29	0.10	1	24.15

Table 39: Summary statistics of the length-frequency (LF) distribution of pipi at Raglan 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	33.45	35	3–61	12.06	7.46
2014–15	37.49	43	8–59	5.83	6.09
2017–18	36.07	37	8–56	16.55	5.81

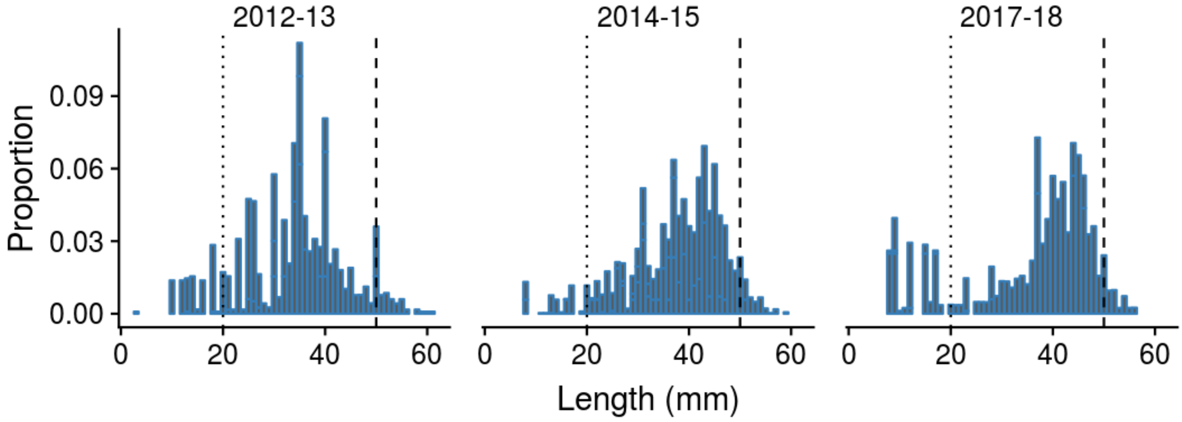


Figure 34: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Raglan Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9 Tairua Harbour

Tairua Harbour is in the Waikato region, and one of the Coromandel Peninsula sites. It was surveyed on seven previous occasions, including the most recent previous survey in 2015–16 (see Appendix A, Tables A-1, A-2). Throughout the survey series, the sampling extent has been adjusted to account for changes in the location and size of pipi beds over time. Some of these changes were related to the construction of a marina that deepened a side channel from the harbour entrance. This area contained one of two pipi beds included in the current study, in addition to three cockle strata following re-stratification. Across all strata, bivalves were sampled in a total of 160 sampling points in 2017–18 (Figure 35, Table 40).

The sediment sampling documented a low organic content but some differences across the three cockle strata, with a maximum values of over 4% in stratum A (Figure 35, and see details in Appendix B, Table B-3). At the same time, the proportion of fines (grain size <63 μm) was generally low, with only few samples containing more than 6% of fines. The main sediment grain size fractions were fine and medium sands (grain sizes >125 and >250 μm), with coarse sediment fractions in some of the samples.

The cockle sampling at Tairua Harbour focused on three strata on the intertidal mudflat, and cockles were also present in the pipi beds, although at low numbers in stratum D (Figure 36, Table 40). The estimated population abundance of this species in Tairua Harbour was 59.74 million (CV: 9.62%) cockles. While this estimate was similar to the preceding abundance estimate in 2015–16, it was based on a smaller sampling extent than previous recent surveys (Table 41). This difference was reflected in the density estimates, which showed an increase from 700 cockles per m^2 in the previous survey to 922 cockles per m^2 in the current assessment.

The population included a small number of large cockles ($\geq$30 mm shell length), which showed an increase in their population abundance and density, although there were generally few individuals in this size class. In 2017–18, there were 0.86 million (CV: 22.90%) large cockles, at a mean density of 13 large cockles per m^2. Their proportion within the total population has consistently been small across recent surveys, varying around 1%; it was 0.64% in 2017–18. Over the same period, the proportion of recruits ($\leq$15 mm shell length) also remained stable, at about 20% in recent assessments (21.50% in 2017–18) (Table 42).

The consistent population size structure and prevalence of small and medium-sized cockles was illustrated in length-frequency distributions across recent surveys (Figure 37). Mean and modal shell lengths in the unimodal population were 19.61 mm and 22 mm in the present study, and there was a single, strong cohort around these sizes. Although the population appeared stable, there was a consistent lack of large individuals in the cockle population.

Pipi at Tairua Harbour occurred in all strata, but were concentrated in pipi strata D and E (Figure 38, Table 43). The abundance estimate for pipi in 2017–18 was a total of 31.67 million (CV: 9.29%) individuals, which marked an increase from the 2015–16 survey, especially in view of the smaller sampling extent in the current study (Table 44). The average population density was 489 pipi per m^2.

There was a small number of large pipi ($\geq$50 mm shell length) at this site, with a population size of 3.52 million (CV: 21.56%) individuals and a corresponding density of 54 large pipi per m^2. Large pipi constituted 11.13% of the total population in 2017–18, which was a marked change from their negligible contributions of around 1% in the two preceding surveys (Table 45). The proportion of recruits ($\leq$20 mm shell length) also showed an increase from 6.72% in 2015–16 to 23.20% 2017–18.

The influx in recruits resulted in a second cohort, changing the population size structure from unimodal to bimodal (Figure 39). Mean and modal sizes were still determined by medium-sized pipi, but changed to 33.95 mm and 42 mm shell length, respectively. These changes indicated a less uniform cohort of medium-sized pipi, with an increase in the number of large individuals and the influence of recruits on the total population.

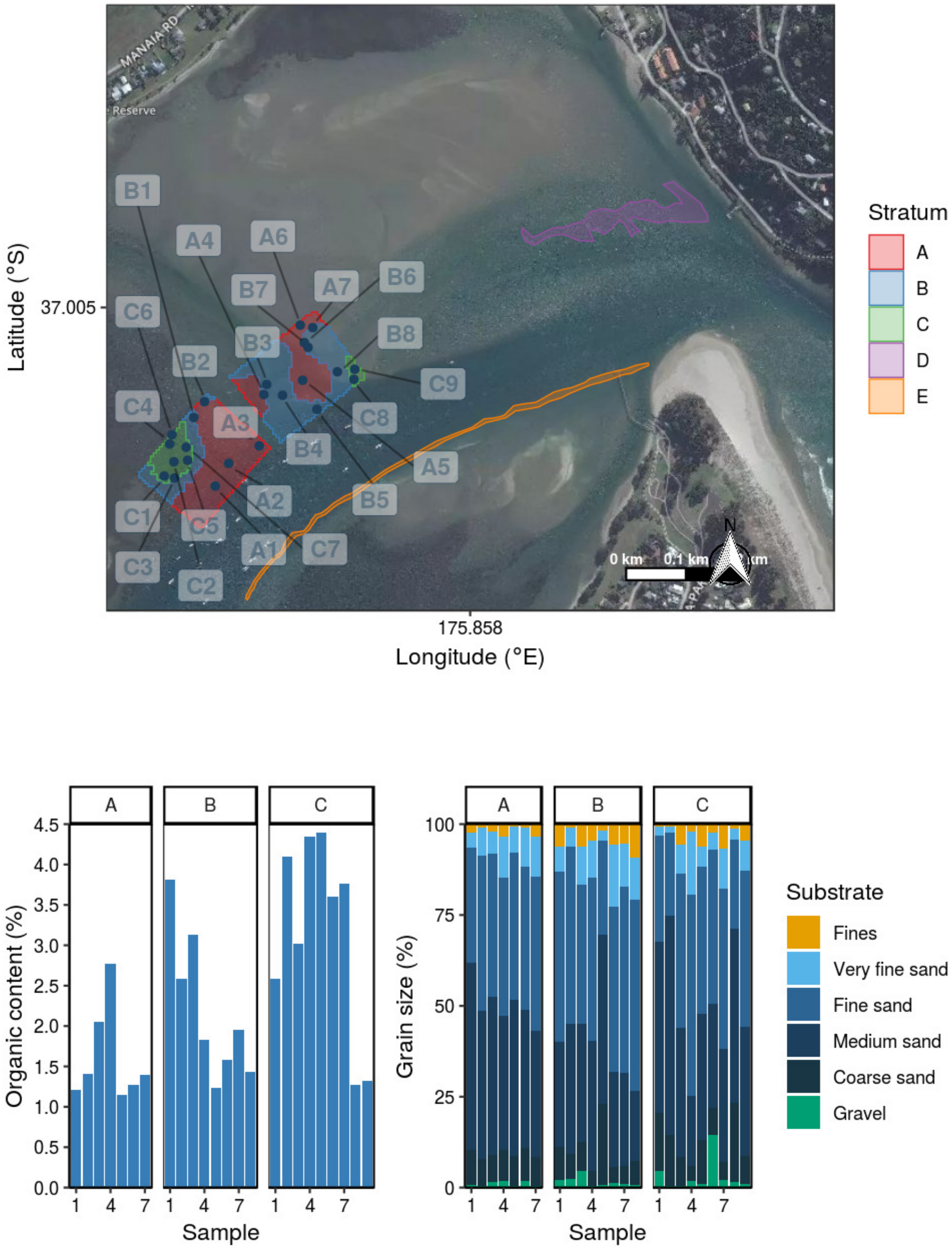


Figure 35: Sediment sample locations and characteristics at Tairua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.9.1 Cockles at Tairua Harbour

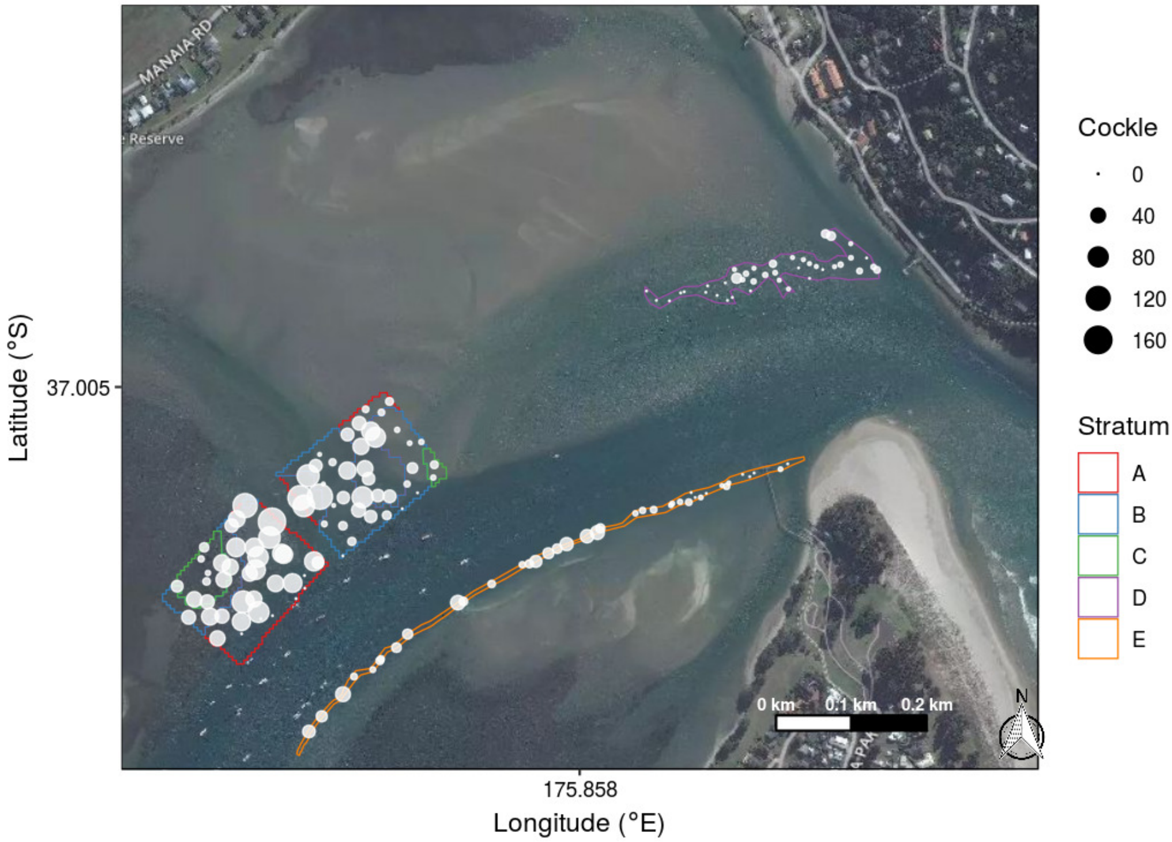


Figure 36: Map of sample strata and individual sample locations for cockles at Tairua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 40: Estimates of cockle abundance at Tairua Harbour, by stratum, for 2017–18. 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	40	2 151	39.11	1 536	12.06
B	2.0	30	800	15.03	762	20.70
C	0.5	10	228	3.40	651	29.24
D	0.9	40	87	0.57	62	26.33
E	0.5	40	434	1.64	310	17.86

Table 41: 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).

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
2015–16	8.2	57.22	700	10.46	0.37	4	43.97
2017–18	6.5	59.74	922	9.62	0.86	13	22.90

Table 42: 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 (%)
2013–14	19.12	20	5–49	21.98	1.16
2015–16	19.38	20	5–35	18.16	0.64
2017–18	19.61	22	5–35	21.50	1.44

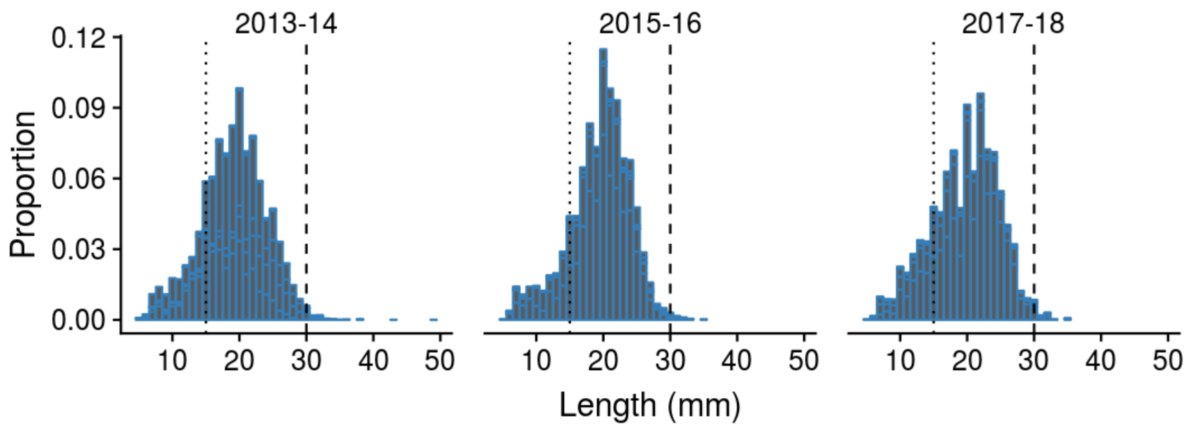


Figure 37: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9.2 Pipi at Tairua Harbour

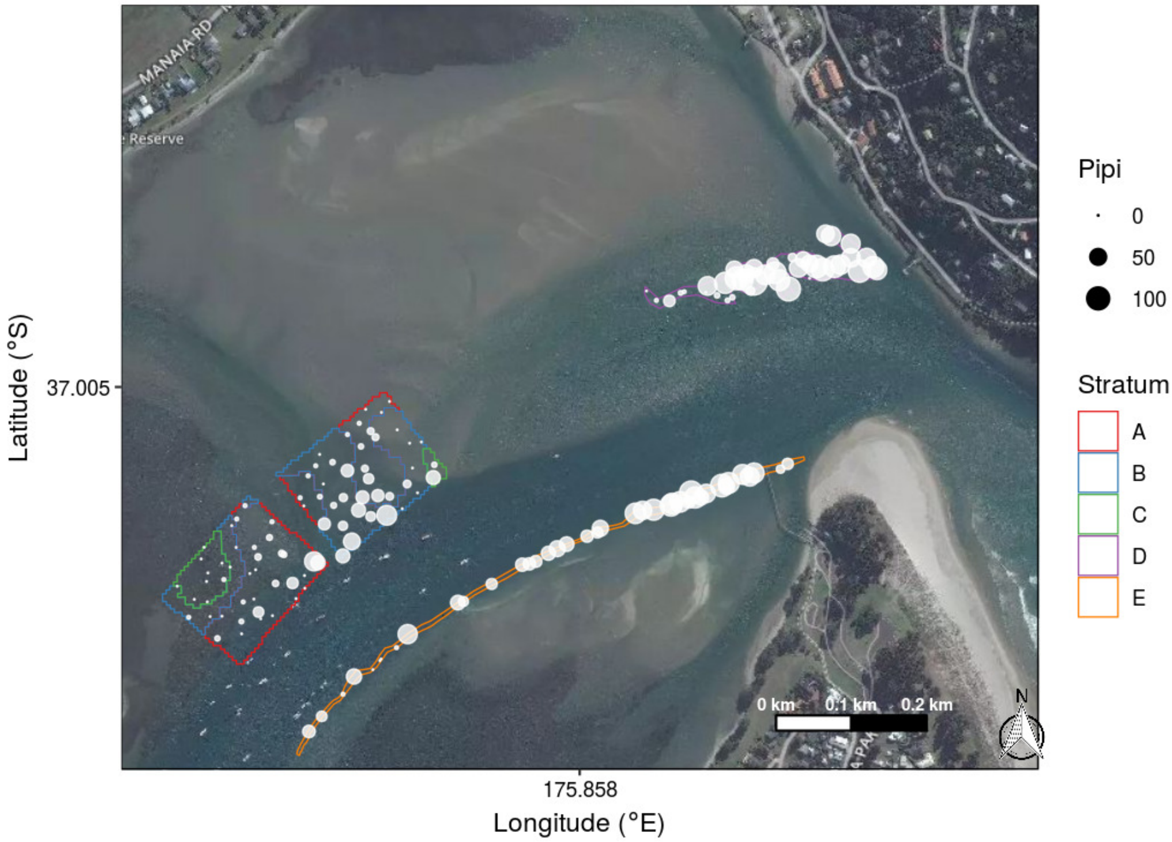


Figure 38: Map of sample strata and individual sample locations for pipi at Tairua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 43: Estimates of pipi abundance at Tairua Harbour, by stratum, for 2017–18. 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	40	261	4.75	186	31.10
B	2.0	30	303	5.69	289	31.38
C	0.5	10	37	0.55	106	88.37
D	0.9	40	2 157	14.03	1 541	11.31
E	0.5	40	1 756	6.65	1 254	10.97

Table 44: 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
2017–18	6.5	31.67	489	9.29	3.52	54	21.56

Table 45: 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 (%)
2013–14	31.39	35	5–72	9.39	0.88
2015–16	36.58	40	8–52	6.72	1.41
2017–18	33.95	42	7–65	23.20	11.13

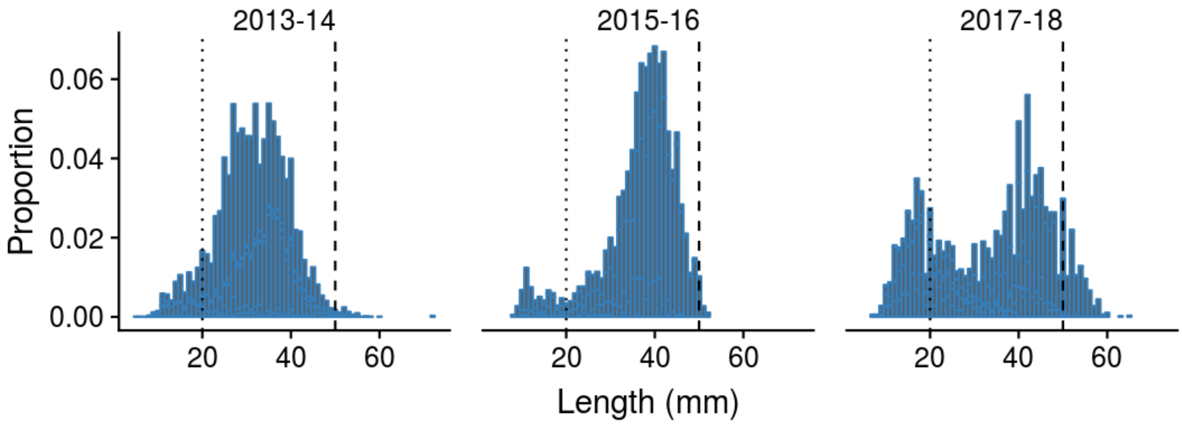


Figure 39: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10 Umupuia Beach

Umupuia Beach is situated within Hauraki Gulf in the wider Auckland area. It has been closed to the collection of cockles since October 2008 when a rāhui (total closure) was put in place. In addition to regular bivalve monitoring through the northern survey series, Umupuia Beach is also included in the Hauraki Gulf Forum community monitoring programme (Auckland Council 2013). The northern monitoring has surveyed this site in 13 previous bivalve assessments since 1999–2000, most recently in 2015–16 (see Appendix A, Tables A-1, A-2). Throughout the survey series, the sampling has consistently focused on the intertidal beach area within a similar sampling extent. The latter was re-stratified for the current field sampling, resulting in 75 sampling points across two strata (Figure 40, Table 46). There was only one pipi sampled in the current study, and this species is not further reported on here.

Sediment samples taken across the two strata showed some variation in organic content and in sediment grain size composition (Figure 40, and see details in Appendix B, Table B-3). Sediment organic content was generally less than 1%, with some higher values and a maximum of about 7%. There was considerable variation in the proportion of fines (grain size $<$63 µm), ranging between 1 and 22% across samples. Varying proportions of very fine and fine sands (grain sizes $>$65 µm and $>$125 µm) made up the bulk of the sediment. Most samples also contained coarse sediment fractions, with gravel (grain size $>$2000 µm) making up a high proportion (40–55%) of sediment in some samples.

The cockle population at Umupuia Beach was distributed throughout the intertidal zone in stratum A, with no cockles in the lower corners of the sampling extent, in stratum B (Figure 41, Table 46). This population had an estimated total abundance of 92.15 million (CV: 19.27%) individuals, and a mean density of 276 cockles per m^2 (Table 47). The population consisted of a high number of large cockles ($\geq$30 mm shell length), which had an estimated abundance of 41.70 million (CV: 10.61%) individuals, and an average density of 128 large cockles per m^2.

Although the 2017–18 estimates for the total population were a slight reduction from the previous survey in 2015–16, they indicated a relatively stable population, especially in view of the marked population decline observed in earlier surveys. Furthermore, population estimates for this size class remained similar across recent assessments, and large individuals continued to constitute a substantial proportion of the total cockle population; in 2017–18, 45.25% of cockles were large individuals (Table 48, Figure 42).

At the same time, the proportion of recruits ($\leq$15 mm shell length) remained small at 4.85% in 2017–18. The low number of recruits in contrast to that of large individuals was also evident in increases in mean and modal shell lengths to 27.77 mm and 30 mm shell length, respectively. This increase in cockle sizes was reflected in the overall population structure, which changed from a bimodal population consisting of juveniles and a cohort of large individuals to an largely unimodal population dominated by the latter size group.

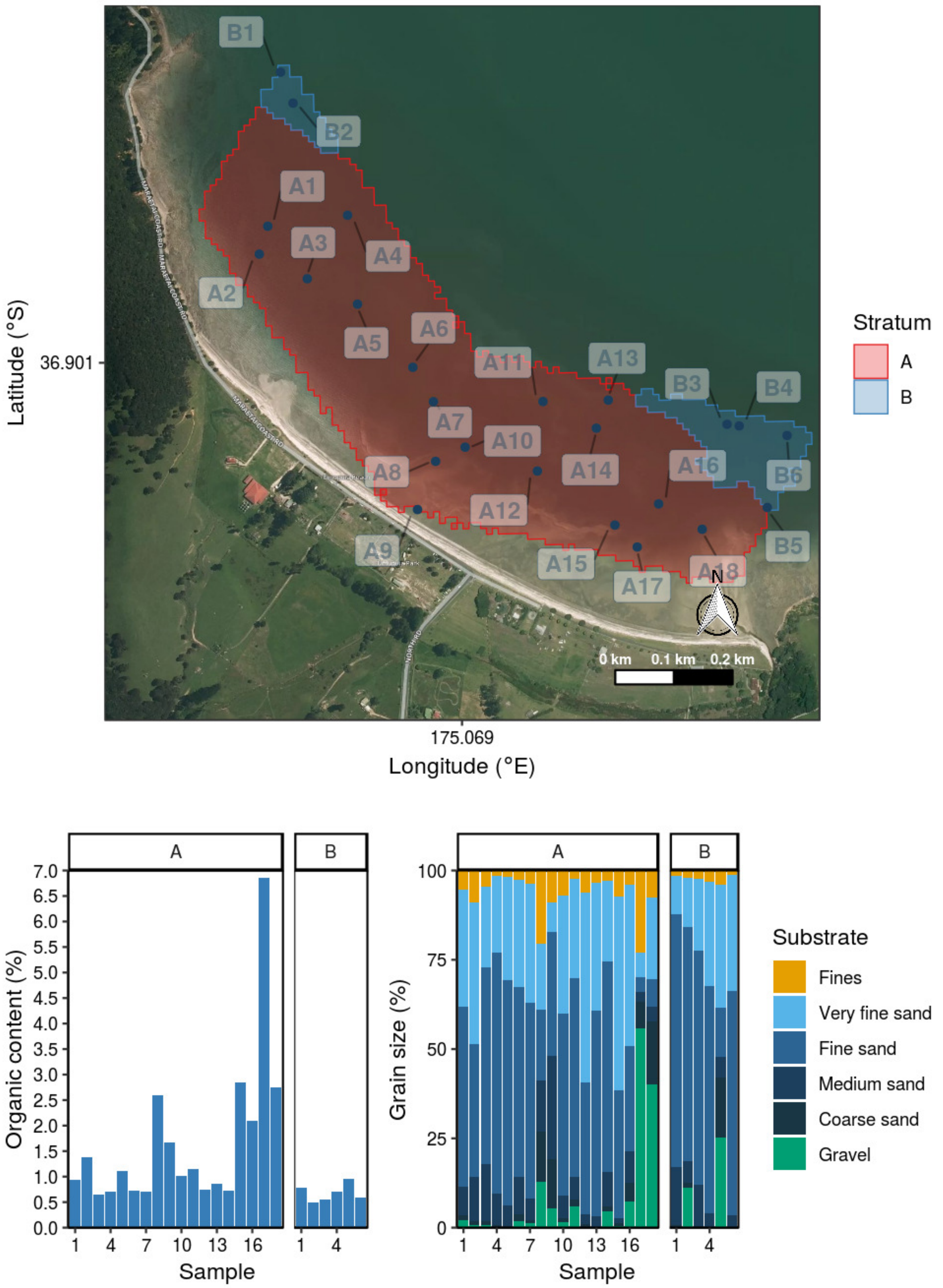


Figure 40: Sediment sample locations and characteristics at Umupuia Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.10.1 Cockles at Umupuia Beach

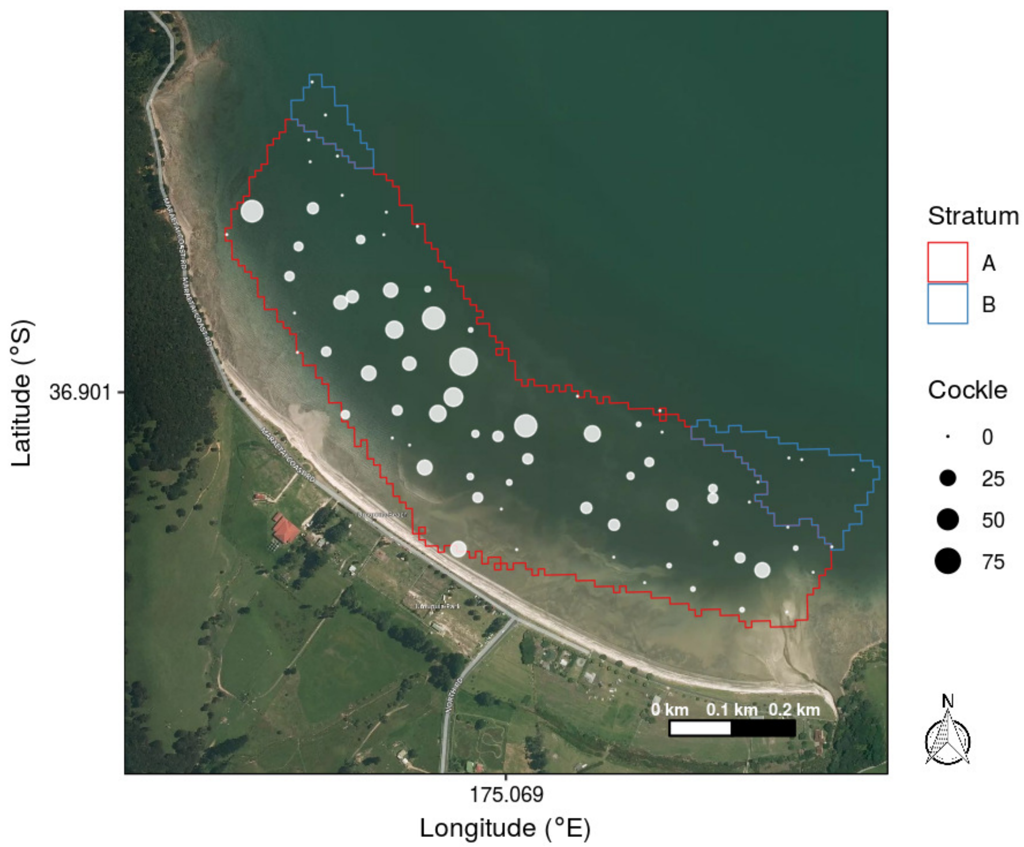


Figure 41: Map of sample strata and individual sample locations for cockles at Umupuia Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 46: Estimates of cockle abundance at Umupuia Beach, by stratum, for 2017–18. 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	30.0	69	743	92.15	308	19.27
B	3.5	6	0	0.00	0	

Table 47: **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
2017–18	33.4	92.15	276	19.27	41.70	139	22.25

Table 48: 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 (%)
2013–14	22.24	14	5–42	32.24	26.00
2015–16	26.80	22	8–43	2.04	39.56
2017–18	27.77	30	10–49	4.85	45.25

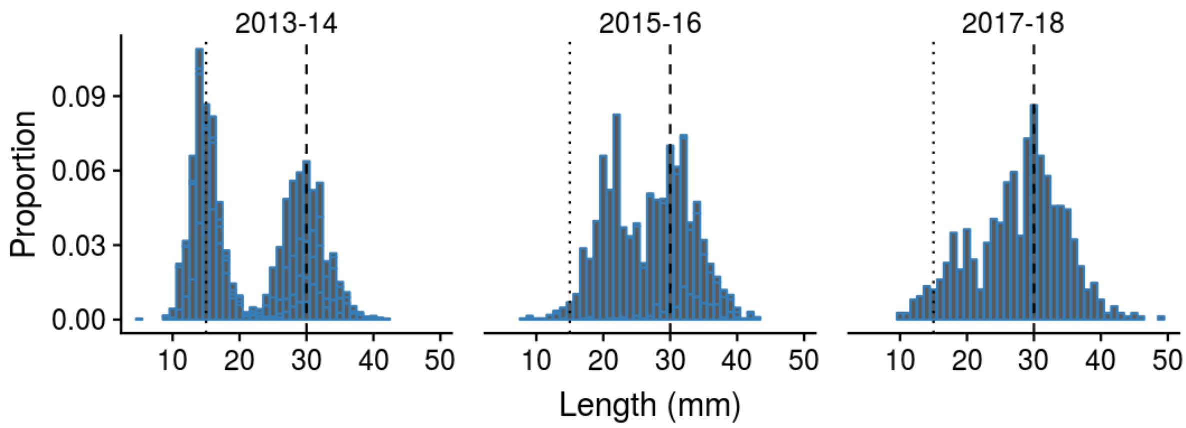


Figure 42: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Umupuia Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Whangateau Harbour

Whangateau Harbour is one of the sites in Hauraki Gulf, north of Auckland. This site has been closed to shellfish collections since March 2010. Bivalves in the harbour have been assessed in the northern monitoring programming since 1999–2000, and this site is also part of the Hauraki Gulf Forum community monitoring programme (Auckland Council 2013). There were nine previous surveys at Whangateau Harbour before the current study, with the immediately preceding assessment in 2015–16 (see Appendix A, Tables A-1, A-2). The sampling extent in 2017–18 was consistent with the two previous surveys, after the area was considerably extended in 2013–14. The current field sampling was based on five strata, including one designated pipi bed, following the re-stratification of the cockle strata. There was a total of 130 sampling points in 2017–18.

Sediment in the cockle strata was characterised by a low organic content that was generally less than 1.0% (Figure 43, and see details in Appendix B, Table B-3). Similarly, there was a low proportion of sediment fines (grain size <63 µm), including samples that contained no sediment in this grain size fraction. Samples in most strata were predominantly fine sand (grain size >125 µm) followed by a smaller proportion of medium sand (grain size >250 µm). The proportion of coarse sediment varied across samples, with a maximum value of 41.5% gravel (grain size >2000 µm) in one sample.

The cockle population at Whangateau Harbour was highly abundant in strata A and D, with similar numbers of cockles sampled in these two strata; in contrast, there were no cockles in strata B and C (Figure 44, Table 49). Based on the field sampling, the current population estimates for cockles were a total abundance of 852.27 million (CV: 9.28%) individuals and a mean density of 768 cockles per m^2 (Table 50).

Although both of these estimates reflected an increase in the total cockle population, the number and density of large cockles ($\geq$30 mm shell length) showed a decrease from estimates in 2013–14 and 2015–16: the current abundance of large cockles was 33.69 million (CV: 28.12%) individuals, with a corresponding density of 41 large cockles per m^2.

Corresponding with these estimates was a decrease in the proportion of large individuals and a concomitant increase in recruits ($\leq$15 mm shell length), which constituted 3.95% and 30.94% of the total population, respectively (Table 51, Figure 45). The increased contribution of recruits in 2017–18 was reflected in a reduction in mean shell length to 18.64 mm, although the modal size remained the same at 20 mm shell length. Across recent surveys, the cockle population size structure has remained consistent, with recruits and small- to medium-sized individuals defining a strong cohort in the unimodal population.

The pipi bed at Whangateau Harbour was in the main channel in stratum E, with a small number of individuals in stratum D, localised in one area (Figure 46, Table 52). The total population estimate for pipi was 20.13 million individuals, with a corresponding density of 18 pipi per m^2, but the uncertainty surrounding these estimates was high, with a CV of 42.77% (Table 53). When considering the pipi bed in stratum E only (i.e., omitting stratum D), the estimated total abundance was 3.89 million individuals at a density of 1149 pipi per m^2, with a low CV of 9.31%. In comparison, previous estimates for the pipi bed only were 0.71 million (CV: 8.28%) pipi at a density of 495 individuals per m^2 in 2015–16 (Berkenbusch & Neubauer 2016).

The pipi population contained only a small number of large pipi ($\geq$50 mm shell length), with an estimated 0.09 million (CV: 28.79%) individuals in this size class; their average density was <1 individual per m^2. This size class contributed few individuals (0.47%) to the total population in 2017–18, compared with 31.77% of recruits ($\leq$20 mm shell length) (Table 54, Figure 47). This finding was consistent with previous recent surveys that documented the scarcity of large individuals, while recruits primarily influenced the abundance and size structure of the pipi population at this site.

The prevalence of recruits and small-sized pipi was also reflected in mean and modal sizes, with respective shell lengths of 26.06 mm and 25 mm, indicating little change in the unimodal population size structure across recent surveys.

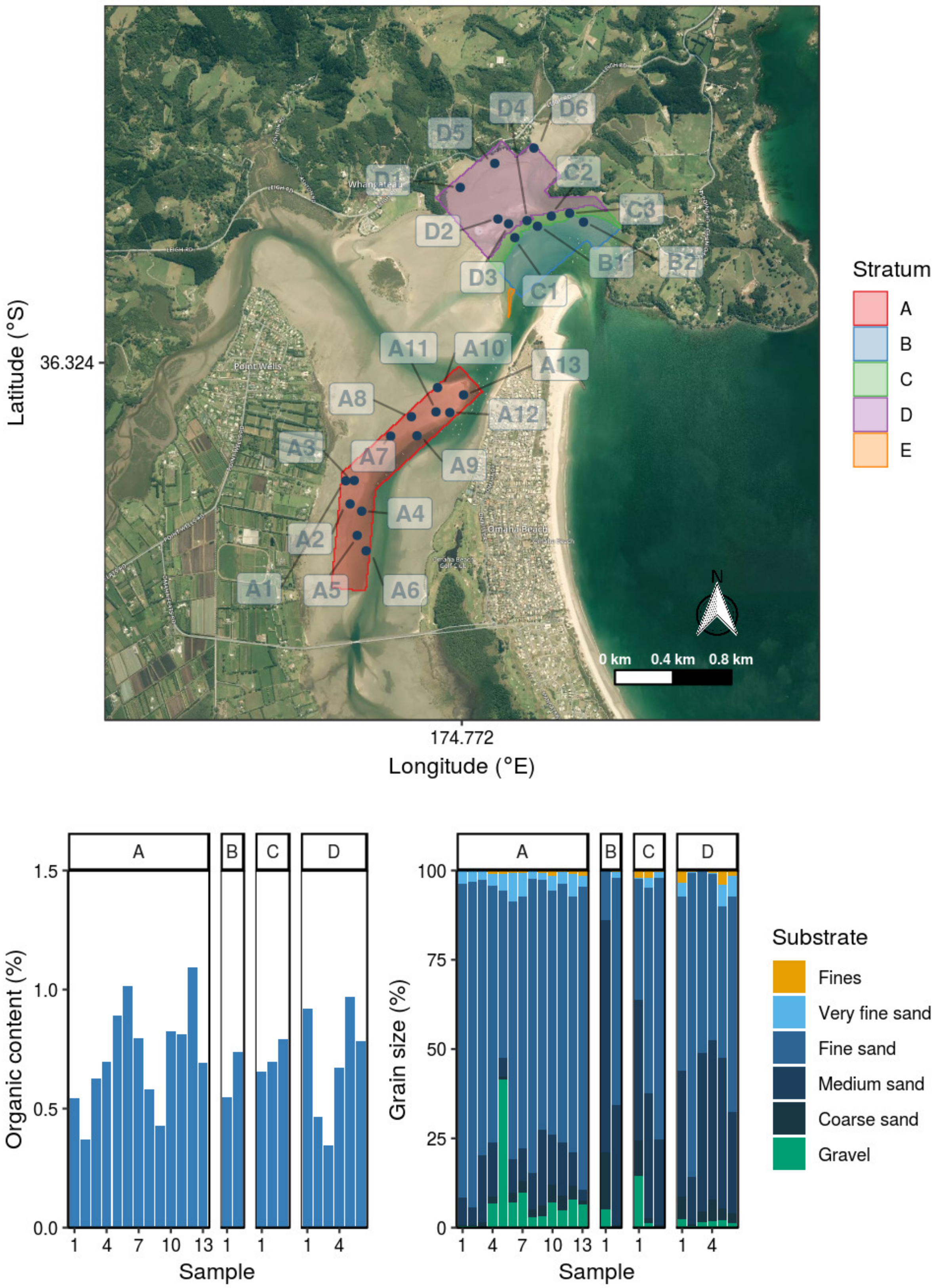


Figure 43: Sediment sample locations and characteristics at Whangateau Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.11.1 Cockles at Whangateau Harbour

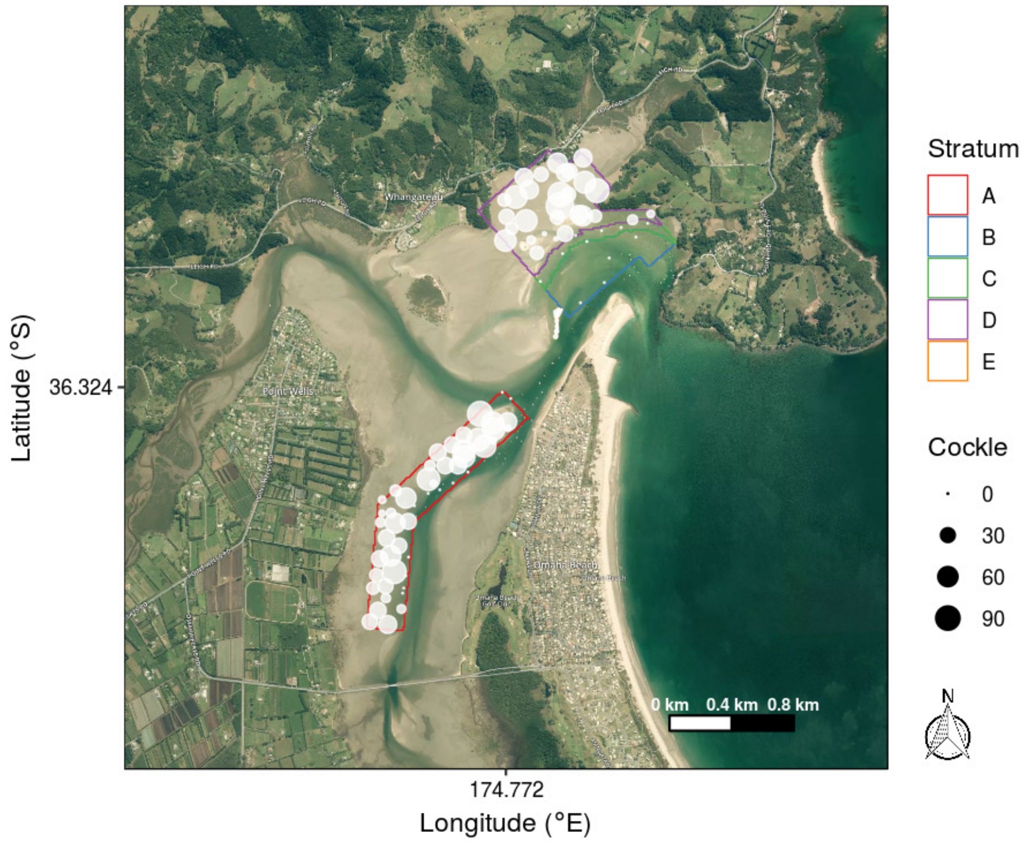


Figure 44: Map of sample strata and individual sample locations for cockles at Whangateau Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 49: Estimates of cockle abundance at Whangateau Harbour, by stratum, for 2017–18. 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	50	1 574	386.68	899	13.09
B	20.9	5	0	0.00	0	
C	7.1	5	0	0.00	0	
D	39.5	30	1 238	465.58	1 179	13.05
E	0.3	40	4	0.01	3	48.04

Table 50: 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).

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
2015–16	110.7	742.44	671	7.02	45.43	51	18.77
2017–18	110.9	852.27	768	9.28	33.69	41	28.12

Table 51: 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 (%)
2013–14	19.97	20	5–44	24.64	6.09
2015–16	19.88	20	4–44	23.81	6.12
2017–18	18.64	20	4–41	30.94	3.95

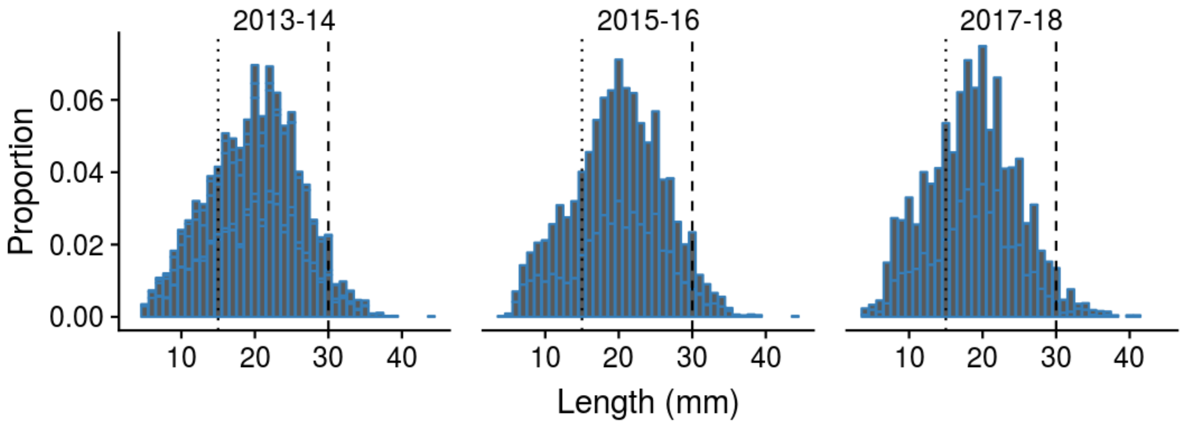


Figure 45: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11.2 Pipi at Whangateau Harbour

Figure 46: 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 52: Estimates of pipi abundance at Whangateau Harbour, by stratum, for 2017–18. 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	50	0	0.00	0	
B	20.9	5	0	0.00	0	
C	7.1	5	2	0.82	11	>100
D	39.5	30	41	15.42	39	55.52
E	0.3	40	1 608	3.89	1 149	9.31

Table 53: 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
2017–18	110.9	20.13	18	42.77	0.09	<1	28.79

Table 54: 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 (%)
2013–14	21.22	21	7–69	50.19	1.23
2015–16	26.26	26	9–67	32.19	2.68
2017–18	26.06	25	10–58	31.77	0.47

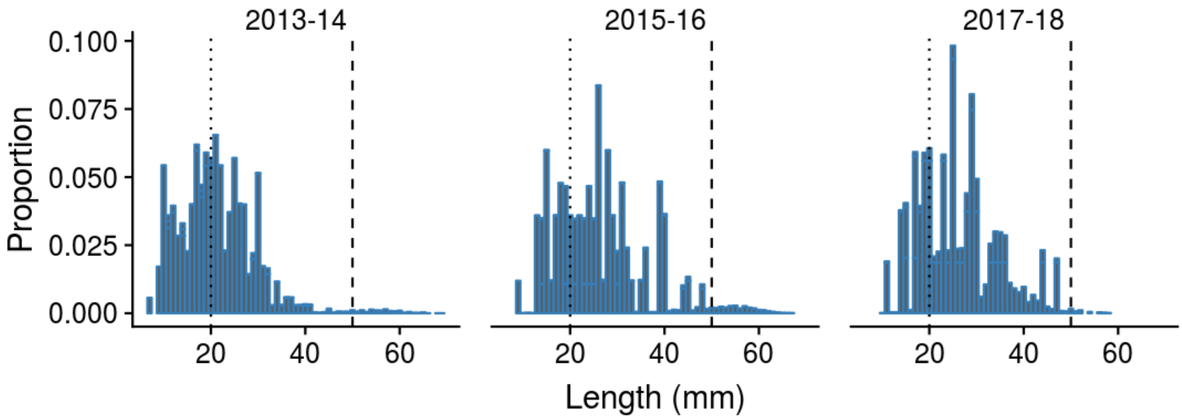


Figure 47: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12 Whitianga Harbour

Whitianga Harbour is in the Waikato region, on Coromandel Peninsula. This site was recently added to the survey programme, with the initial assessment in 2012–13 and a subsequent study in 2015–16 (see Appendix A, Tables A-1, A-2). The sampling extent at Whitianga Harbour encompassed two separate strata, with a pipi bed on the beach next to the harbour entrance and a cockle area on the intertidal mudflat within the harbour (Figure 48, Table 55). The latter was added in 2015–16 and is part of the Hauraki Gulf Forum community monitoring programme (e.g., Auckland Council 2013). The present survey was based on 80 sampling points across both strata.

Sediment samples from the cockle stratum were consistently low in organic content, i.e., containing less than 3% (Figure 48, and see details in Appendix B, Table B-3). The sediment composition was predominantly fine sand (grain size >250 µm), with a low proportion of fines (<63 µm), although this grain size fraction exceeded 13% in one sample. In addition, a number of samples contained relatively coarse sediment, including gravel (grain size >2000 µm grain size).

Cockles at Whitianga Harbour were exclusively in stratum B (Figure 49, Table 55). Their total abundance was estimated at 51.43 million (CV: 11.21%) cockles and their average density was 885 cockles per m^2 (Table 56). These estimates were close to values in the preceding survey in 2015–16.

The population contained no large individuals (≥30 mm shell length), but was dominated by recruits (≤15 mm shell length), which increased from 66.41% in 2015–16 to 81.25% of the total population in 2017–18 (Table 57, Figure 50). The marked increase in recruits was evident in the population size structure, which revealed a shift towards smaller-sized individuals, with a reduction in modal size from 15 mm in 2015–16 to 12 mm shell length in the current survey. Similarly, the mean shell length decreased from 13.76 mm to 12.46 mm in 2017–18.

The pipi population at Whitianga Harbour was distributed throughout stratum A (Figure 51, Table 58). Their estimated total population size was 95.12 million (CV: 12.93%) pipi in 2017–18, and their corresponding density was 1637 pipi per m^2 (Table 59). These estimates were substantial increases from the previous 2015–16 assessment, when the population consisted of 6.36 million (CV: 18.17%) pipi, occurring at a density of 104 individuals per m^2.

Nevertheless, there were only relatively small increases in the abundance and density of large pipi (≥50 mm shell length) with an estimated 2.37 million (CV: 14.68%) individuals in this size class and a corresponding density of 41 large pipi per m^2 in 2017–18. In view of the considerable population growth overall, this size class only made a small contribution to the total population; it decreased from 30.03% in 2015–16 to 2.49% in 2017–18 (Table 60).

Instead, the current pipi population was dominated by recruits (≤20 mm shell length), which showed a marked increase from 2.41% in the preceding survey to 54.82% in 2017–18. Their influx was reflected in notable decreases in pipi shell lengths, with both mean and modal sizes declining by about 50% from the previous survey to 21.16 mm and 22 mm shell length, respectively.

The population size structure revealed a corresponding shift from a unimodal population consisting of medium- and large-sized pipi in 2015–16 to recruits and small-sized individuals in 2017–18 (Figure 52). These findings highlight a strong recruitment event at Whitianga Harbour in 2017–18, but the persistence of these recruits remains unknown.

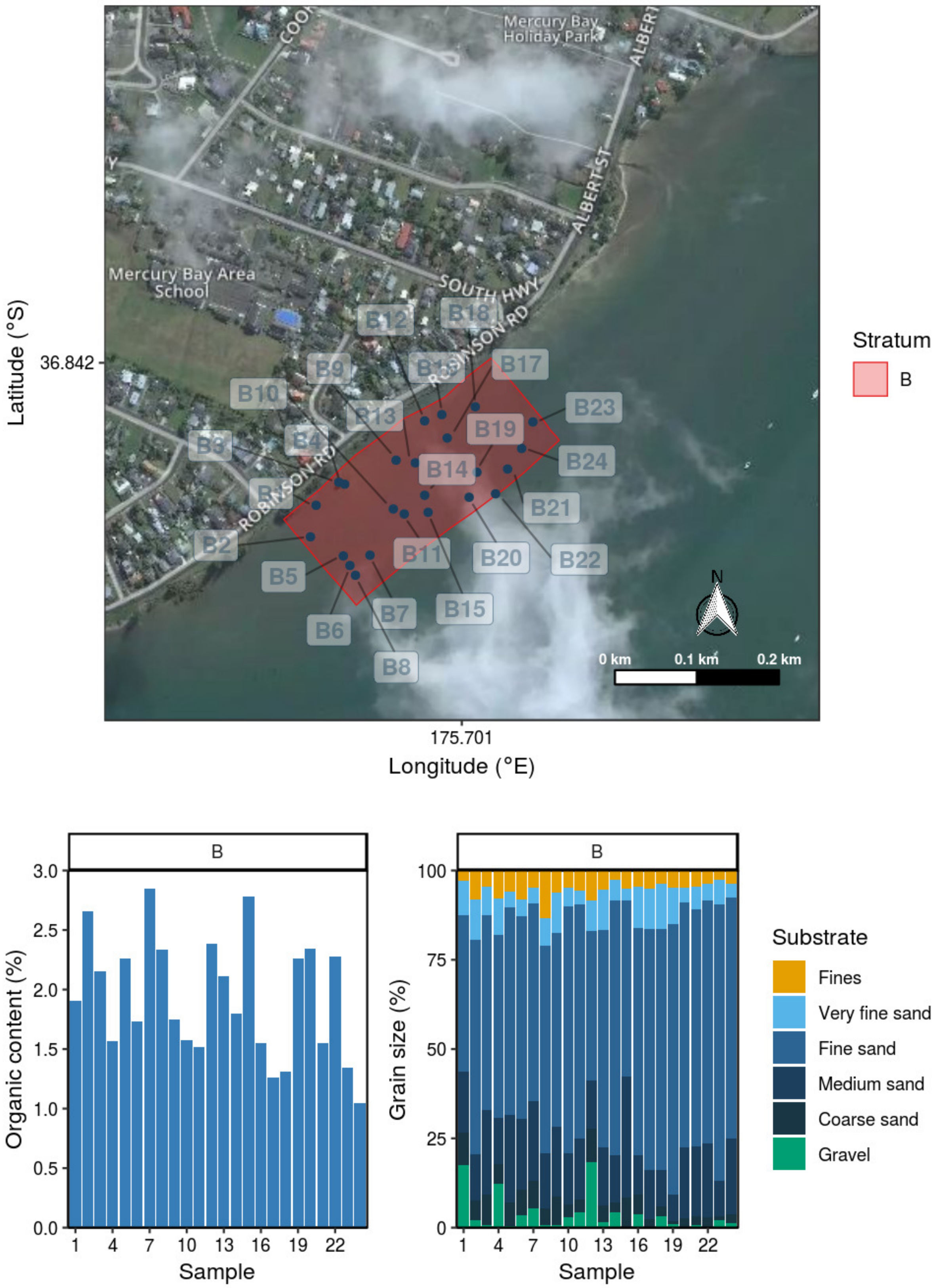


Figure 48: Sediment sample locations and characteristics at Whitianga Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.12.1 Cockles at Whitianga Harbour

Figure 49: 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 55: Estimates of cockle abundance at Whitianga Harbour, by stratum, for 2017–18. 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	1.4	40	0	0.00	0	
B	4.4	40	1 634	51.43	1 167	11.21

Table 56: 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	
2017–18	5.8	51.43	885	11.21	0.00	0	

Table 57: 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 ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2015–16	13.76	15	5–26	66.41	0.00
2017–18	12.46	12	5–26	81.25	0.00

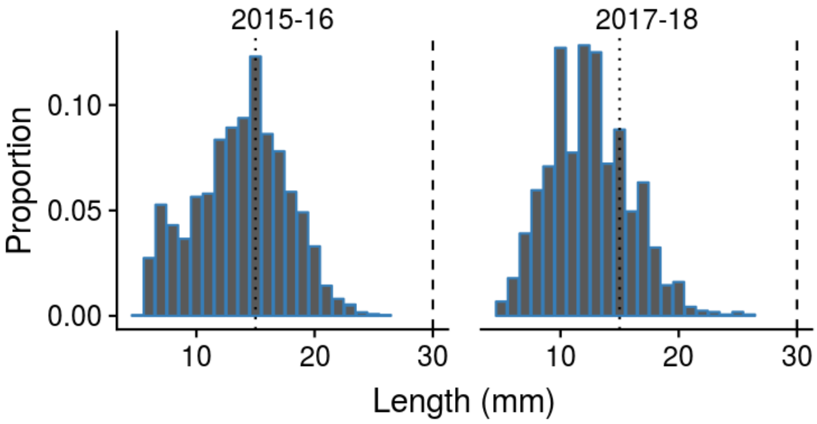


Figure 50: Weighted length-frequency (LF) distribution of cockles for the present survey at Whitianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12.2 Pipi at Whitianga Harbour

Figure 51: 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 58: Estimates of pipi abundance at Whitianga Harbour, by stratum, for 2017–18. 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	1.4	40	9 490	95.09	6779	12.93
B	4.4	40	1	0.03	<1	>100

Table 59: 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
2017–18	5.8	95.12	1 637	12.93	2.37	41	14.68

Table 60: 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
2017–18	21.16	22	6–65	54.82	2.49

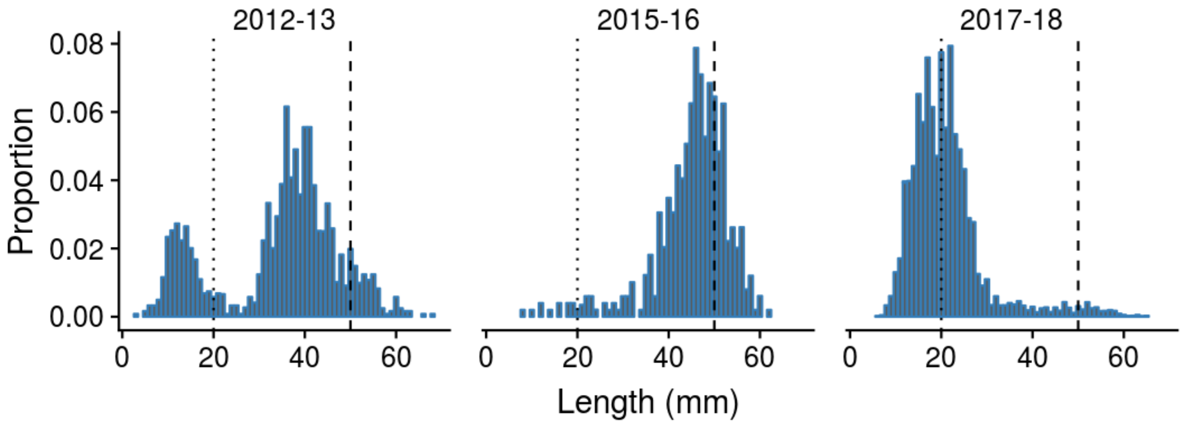


Figure 52: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whitianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

The 2017–18 survey assessed cockle populations at eleven different sites, which ranged from relatively small estuaries to harbours and sheltered bays (Table 61). There were no cockles at Marsden Point, and surveys at this site consistently documented the absence of this species at the Northland site. The field sampling allowed estimation of population parameters, including their associated uncertainty. The latter exceeded the target CV of 20% at two sites, Little Waihi Estuary and Mill Bay. At these sites, additional sampling effort through phase-2 sampling did not result in a marked lowering of the CV. At both sites, the cockle population had undergone a marked decline (about 50%) since the preceding survey, and remaining cockles showed a patchy distribution within the designated cockle strata, resulting in the high CV values.

Comparison of the cockle populations across sites reveal differences in population parameters, including abundance and density estimates. There were three 2017–18 sites that supported notable cockle populations, where cockle abundance exceeded 100 million individuals: Whangateau Harbour, Pataua Estuary and Tairua Harbour. Whangateau Harbour contained the largest cockle population in 2017–18 with an estimated total abundance of 852.27 million (CV: 9.28%) cockles. Abundance estimates at the remaining sites varied from 30.07 million (CV: 6.25%) cockles at Bowentown Beach to 92.15 million (CV: 19.27%) cockles at Umupuia Beach, apart from markedly lower estimates at Little Waihi Estuary and Mill Bay.

Population differences were also evident in the estimated cockle densities, and this parameter allowed some comparison between sites. Cockle densities were high at Bowentown Beach, Raglan Harbour and Pataua Estuary, where estimates exceeded 1000 cockles per m^2; at Bowentown Beach, the population density was 2008 cockles per m^2. Other sites with comparatively high cockle densities were Whangateau, Whitianga and Tairua harbours, where estimates were between 768 and 922 individuals per m^2. Excepting Little Waihi Estuary and Mill Bay, density estimates at other sites generally exceeded 200 cockles per m^2.

Considering the abundance and density of large cockles ($\geq$30 mm shell length) within the populations, there was a general pattern of low estimates for this size class across sites. Large cockles were absent at Whitianga Harbour, and were represented by few individuals at most sites; only Umupuia Beach and Cockle Bay had densities that exceeded 100 large individuals per m^2. At Little Waihi Estuary and Mill Bay, their densities were less than five individuals per m^2). At other sites, low density estimates for this size class varied from 10 large cockles per m^2 (CV: 20.55%) at Bowentown Beach to 44 individuals per m^2 (CV: 22.2%) at Raglan Harbour (excluding Little Waihi Estuary and Mill Bay, where their densities were less than five individuals per m^2). For most populations, the uncertainty of the estimates was relatively high (i.e., the CV exceeded 20%), owing to the low abundance of large individuals; however, they consistently indicated the overall scarcity of large cockles within northern populations.

Throughout the survey series, only two sites showed a discernible increase in the total cockle population, namely Bowentown Beach and Cockle Bay (Figure 53). At Bowentown Beach, the recent increase in total cockle density was small, but this beach was the only site where cockle densities continuously increased throughout the survey series. In addition, density estimates at Bowentown Beach have been high since 2010–11, when they first exceeded 1000 individuals per m^2. At Cockle Bay, total cockle densities increased considerably in the current survey, after a continued decline since 2010–11. In contrast, notable declines in cockle densities were evident at Little Waihi Estuary and Mill Bay, where total cockle populations have previously been stable or increasing. At the remaining sites, total cockle densities showed little change in the recent survey.

Length-frequency distributions of the survey sites over time documented changes in the population size structure of cockles (Figure 54). In general, populations were primarily defined by medium-sized cockles, with recruits and large individuals contributing varying proportions of individuals throughout the survey series. Changes in size-frequency distributions over time included a higher frequency of recruits and a concomitant reduction in large cockles in recent surveys. Theses changes resulted in an overall shift towards smaller-sized cockles, particularly recruits, over time.

The universal decline in large cockle densities was illustrated by time series data from the different survey sites (Figure 55). Throughout the survey series, densities of large individuals declined across all sites, resulting in the absence or low densities of large cockles at most sites in recent surveys. At Bowentown Beach and Umupuia Beach, there have been some signs of recovery, including a small increase in the densities of large cockles at the former site in 2017–18. At Umupuia Beach, densities of large cockles initially showed a marked increase between 2009–10 and 2012–13, but have since then showed little change. At two sites, Okoromai Bay and Whangateau Harbour, the current survey recorded a small decrease in large cockle densities in 2017–18.

Table 61: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2017–18 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	30.07	2 008	6.25	0.16	10	20.55
Cockle Bay	43.37	275	11.62	17.48	111	13.87
Little Waihi Estuary	15.50	84	26.09	0.36	2	>100
Mill Bay	7.78	160	25.18	0.21	4	41
Okoromai Bay	52.25	263	15.24	4.29	22	19.79
Pataua Estuary	406.39	1 467	11.78	4.54	16	44.37
Raglan Harbour	109.16	1 508	7.11	3.21	44	22.2
Tairua Harbour	59.74	922	9.62	0.86	13	22.9
Umupuia Beach	92.15	276	19.27	41.70	139	22.25
Whangateau Harbour	852.27	768	9.28	33.69	41	28.12
Whitianga Harbour	51.43	885	11.21	0.00	0	

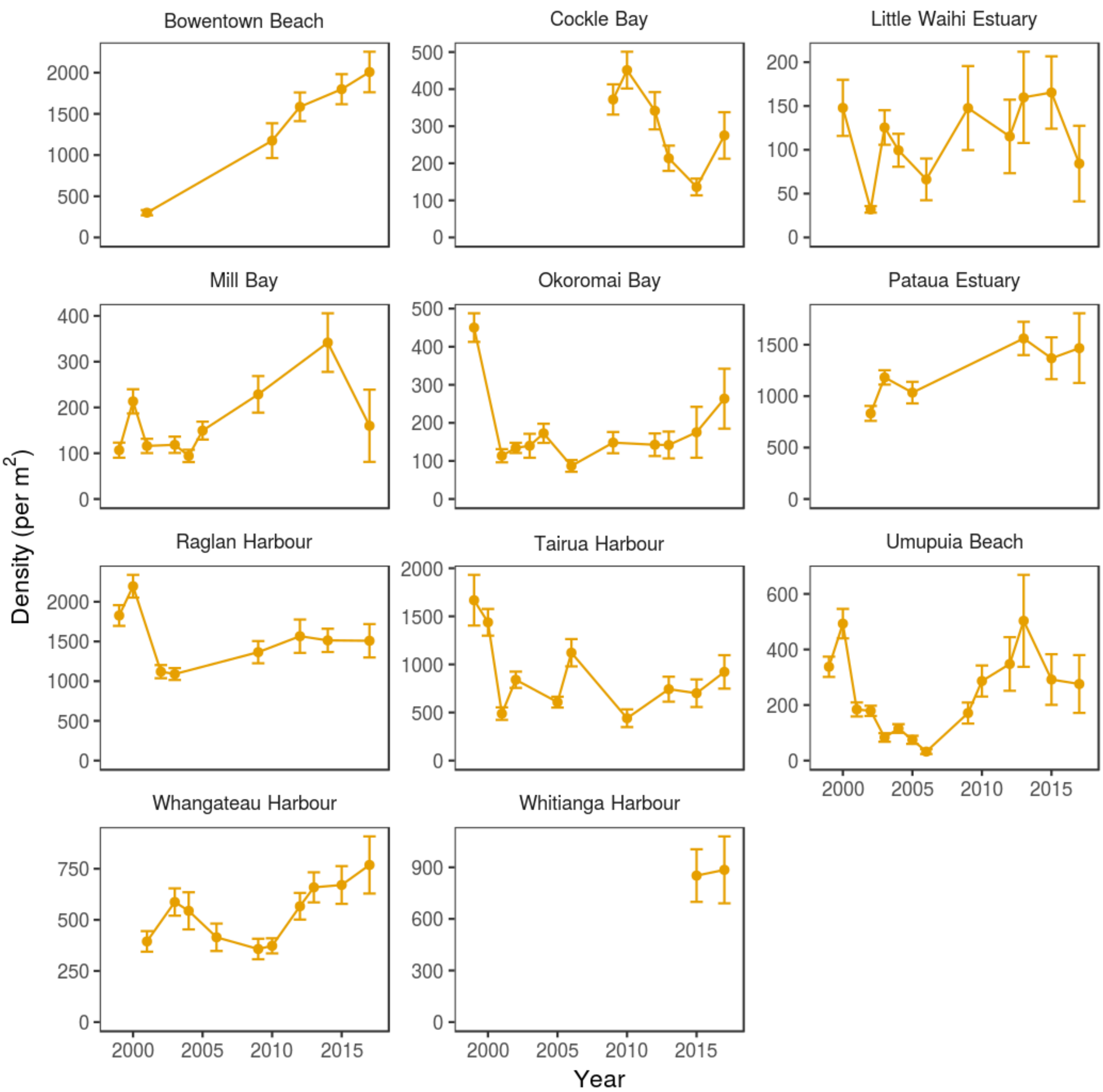


Figure 53: Estimated density of cockles for all sites included in the 2017–18 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

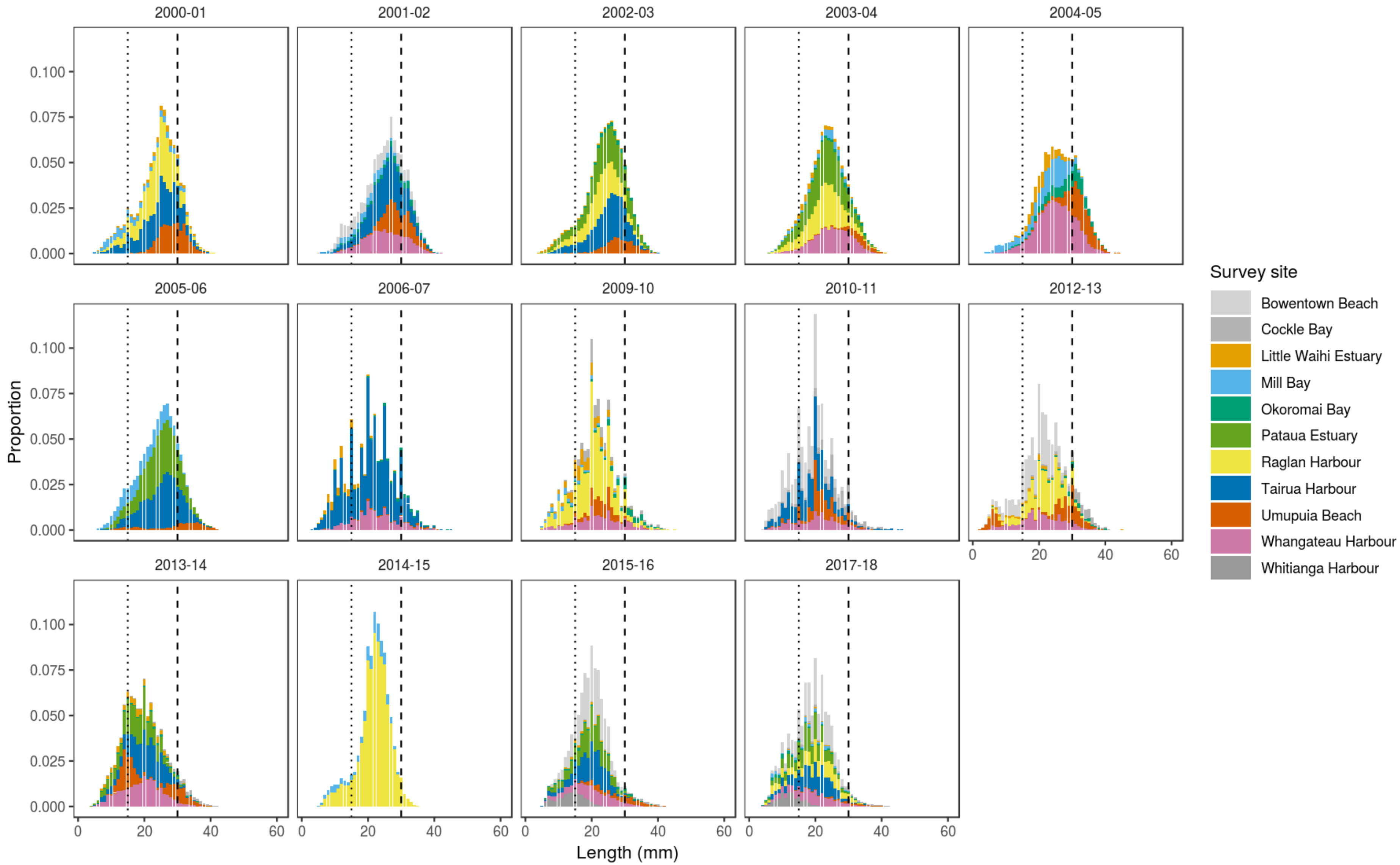


Figure 54: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2017–18 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note not all sites were surveyed each year, and the sampling extent may vary across years.)

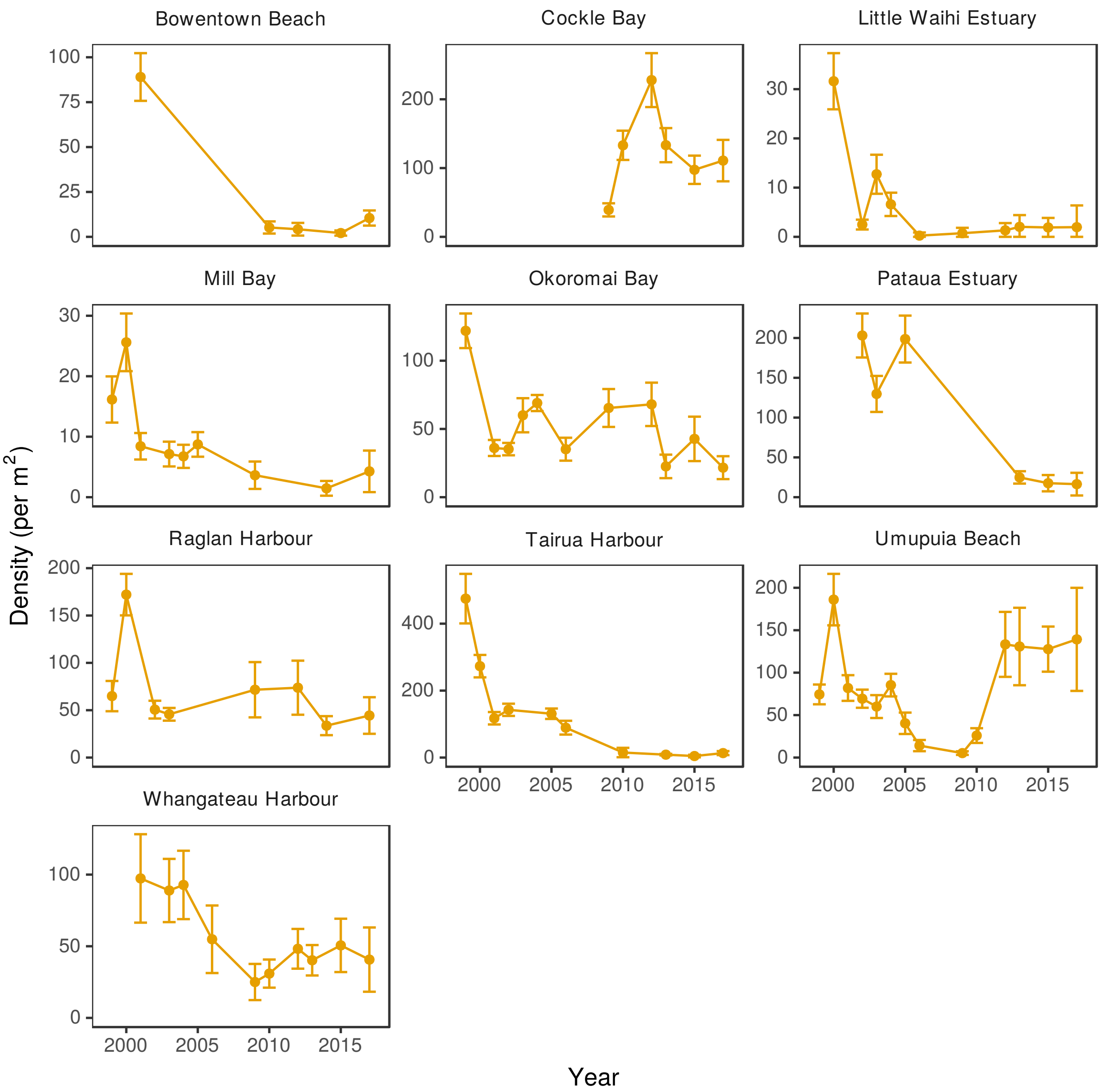


Figure 55: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.2 Pipi populations

Nine of the survey sites in 2017–18 contained pipi populations, with variable abundance and density estimates across sites (Table 62). The largest pipi population in 2017–18 was at Whitianga Harbour, where their total abundance was 95.12 million (CV: 12.93%) pipi. At four sites, Bowentown Beach, Little Waihi Estuary, Pataua Estuary and Whangateau Harbour, there was relatively high uncertainty associated with the estimates, indicated by CV values exceeding 20%. Part of the uncertainty was owing to the low density and patchy distribution of pipi at some of the sites, so that increased sampling effort through a second phase did not result in a sufficient lowering of the CV. Similarly, at Whangateau Harbour, the pipi bed was concentrated in one stratum, but individuals occurred in localised patches in the cockle strata also, affecting the population estimates overall.

In addition to having the largest pipi population in 2017–18, Whitianga Harbour also supported their highest estimated density, with an average of 1637 pipi per m^2, followed by 1284 individuals per m^2 at Marsden Bank. Population densities were also notable at Tairua Harbour and Little Waihi Estuary, where they exceeded 400 individuals per m^2. All other sites were characterised by low pipi densities (maximum of 32 pipi per m^2).

None of the pipi populations included a substantial number of large individuals ($\geq$50 mm shell length), and this size class was absent at several sites. Their uneven and low abundance frequently resulted in high CV values exceeding 20%. The highest abundance of large pipi was at Little Waihi Estuary, followed by Tairua and Whitianga Harbours, with estimates varying between 5.44 million (CV: 64.08%) pipi at the former site and 2.37 million (CV: 14.68%) pipi at Whitianga Harbour. At other sites where large pipi were present, abundance estimates were markedly lower. Furthermore, even at sites with a relatively high abundance of large individuals, this size class was only a minor part of the total population.

The low abundance of large pipi that characterised the 2017–18 survey sites was also evident in low densities of large individuals. There were only three sites where large pipi had notable densities, including Tairua and Whitanga harbours and Little Waihi Estuary. At the remaining sites containing large pipi, estimated densities were less than one large individual per m^2.

Time-series data from the monitoring surveys allowed comparisons of the different pipi populations over time (Figure 56). This assessment showed that all populations underwent some decline throughout the survey period, with the timing and magnitude of the decrease dependent on the site. At several sites, pipi populations showed no discernible, subsequent increases, and current pipi densities were low at Mill Bay, Pataua Estuary, Bowentown Beach, and Whangateau and Raglan harbours. At Marsden Bank and Whitianga Harbour, the recent survey recorded considerable increases in pipi populations, which were largely caused by significant recruitment events.

The increasing prevalence of recruits and small-sized pipi was also evident in the time-series of combined length-frequency distributions for the 2017–18 survey sites (Figure 57). While small and medium size classes became increasingly important, there was concomitant decrease in large pipi. In 2017–18, the influence of recruits characterised population size structure across sites, illustrated by the bimodal size structure in the current study.

Time-series data of density estimates of large pipi also show a general pattern of low densities and declines across sites (Figure 58). None of the 2017–18 populations that included large pipi contained high densities of this size class, and recent declines in large pipi were evident at Marsden Bank. Overall, these data reflect a general lack of large individuals in the current pipi populations.

Table 62: Estimates of pipi abundance for all sites where more than ten pipi were sampled in the 2017–18 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	0.48	32	32.31	0.00	<1	>100
Little Waihi Estuary	79.10	430	26.04	5.44	30	64.08
Marsden Bank	10.93	1 284	19.17	0.00	0	
Mill Bay	0.77	16	18.86	0.00	0	
Pataua Estuary	2.04	7	35.38	0.19	<1	>100
Raglan Harbour	1.74	24	12.29	0.10	1	24.15
Tairua Harbour	31.67	489	9.29	3.52	54	21.56
Whangateau Harbour	20.13	18	42.77	0.09	<1	28.79
Whitianga Harbour	95.12	1 637	12.93	2.37	41	14.68

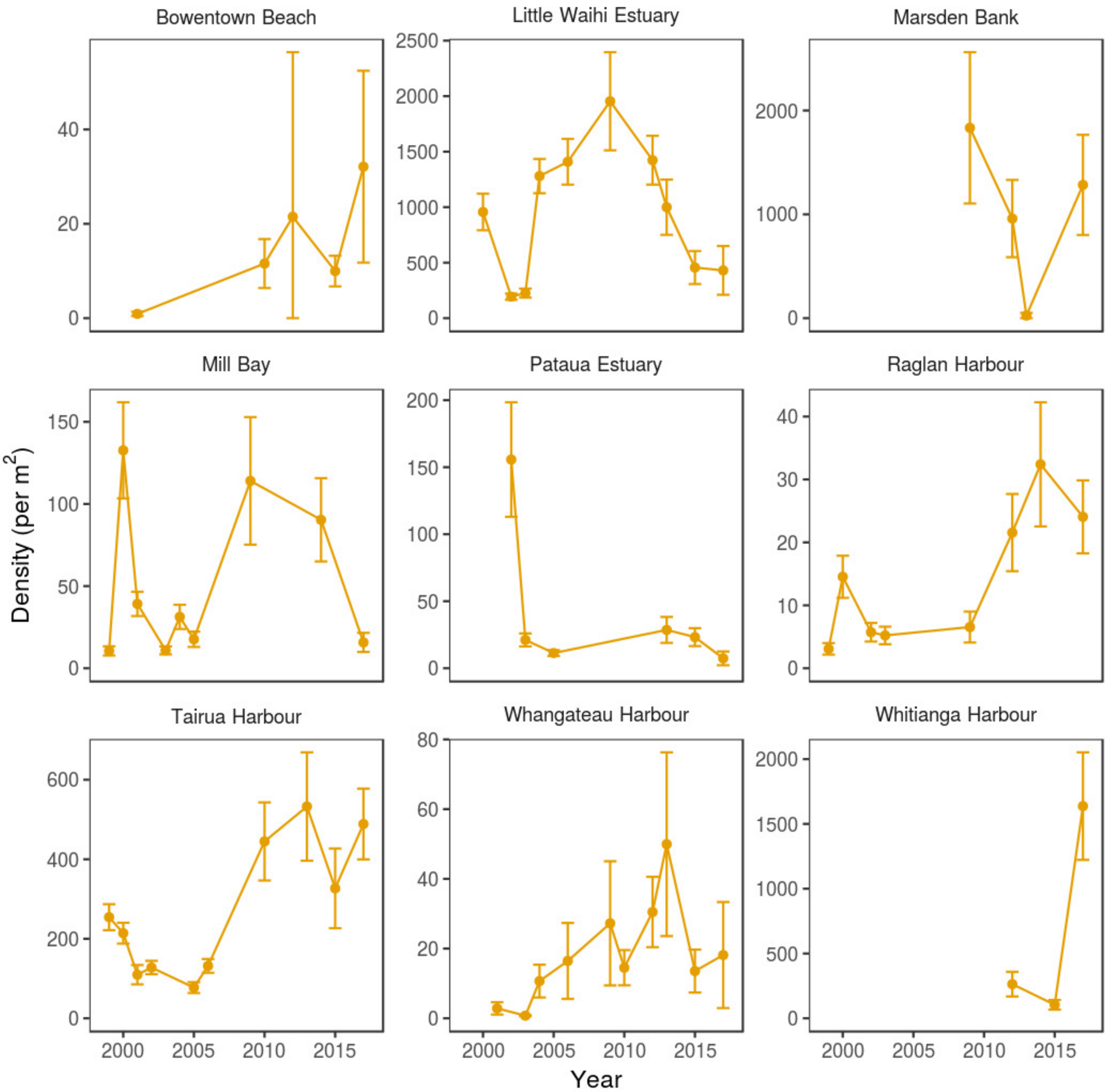


Figure 56: Estimated density of pipi for all sites included in the 2017–18 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

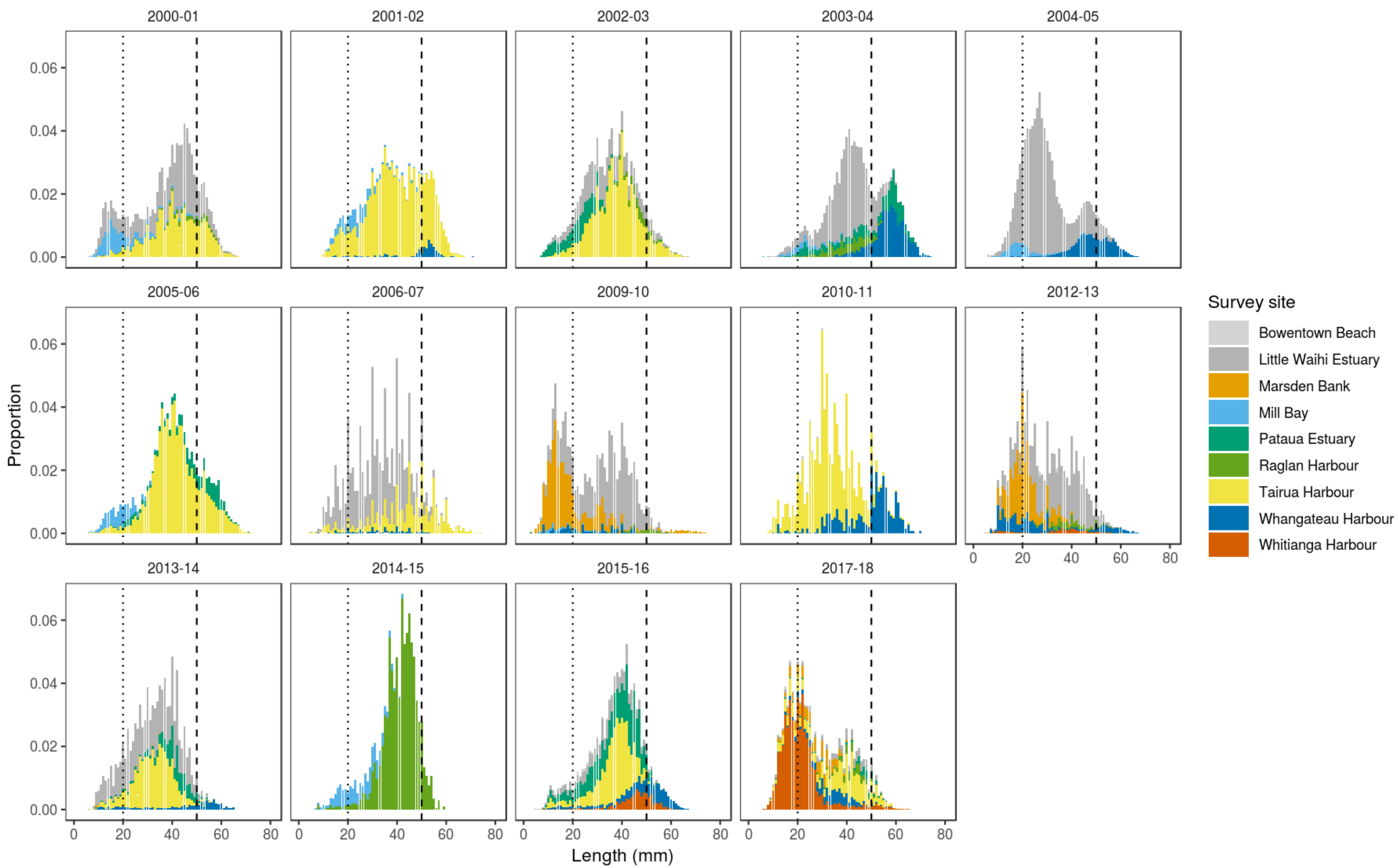


Figure 57: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2017–18 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

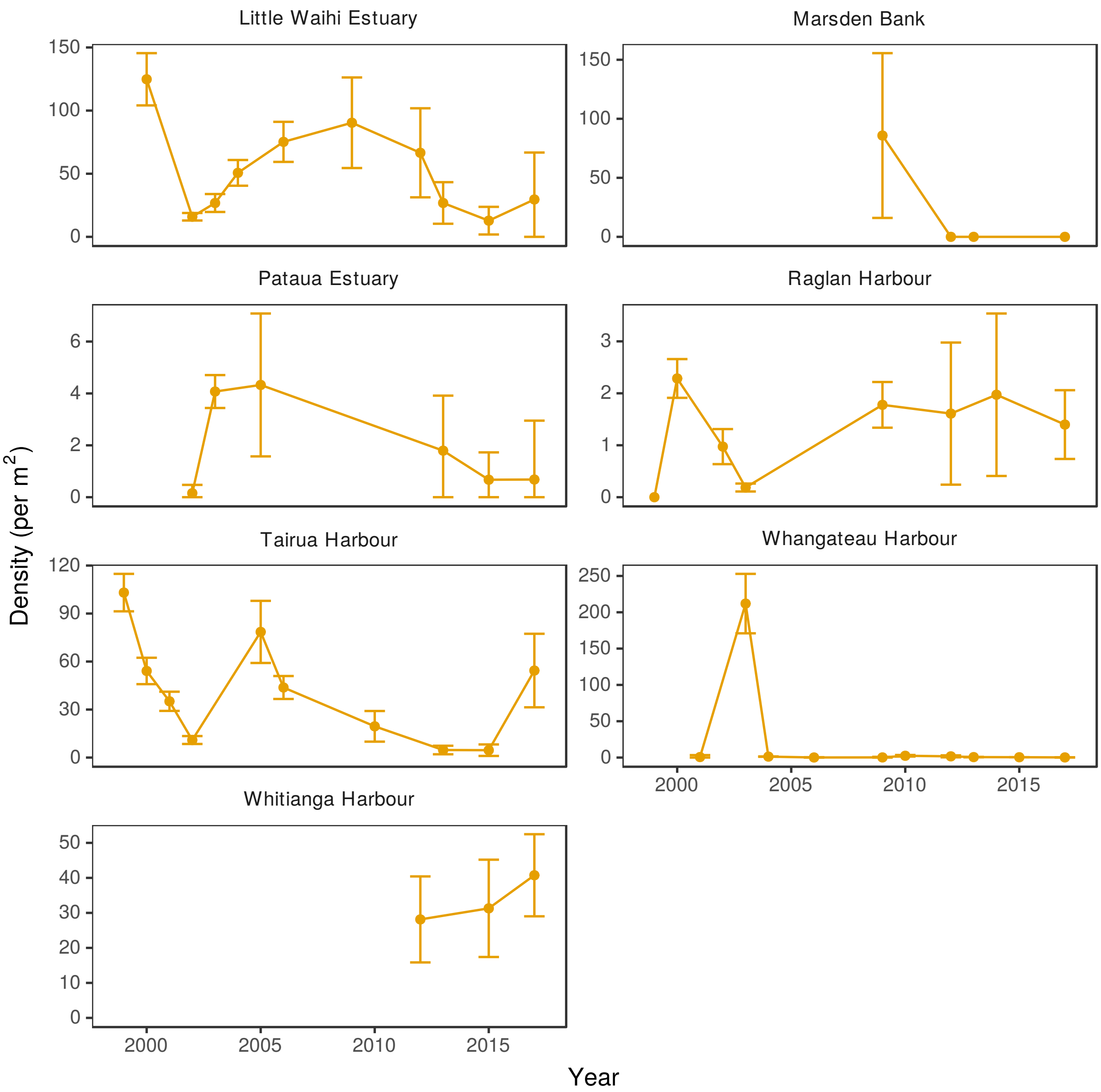


Figure 58: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

5. DISCUSSION

This report documents the most recent northern North Island shellfish survey in the northern monitoring series, conducted in the 2017–18 fishing year. Survey sites included a variety of beaches, harbours, bays and estuaries in the northern North Island region. Several of the 2017–18 sites have been regularly surveyed as part of the northern monitoring programme, with the sampling frequency ranging from three (Whitianga Harbour) to 14 (Umupuia Beach) surveys since 1999–2000. Throughout this period, there have been some changes to the sampling extent at a number of sites, with recent changes (i.e., since 2013–14) mostly relating to the location and size of pipi beds.

Cockle populations were present at 11 of the 12 northern sites, and their densities were generally high: at Bowentown Beach, Raglan Harbour and Pataua Estuary, density estimates exceeded 1400 individuals per m^2; at three other sites, they exceeded 750 individuals per m^2. Notable exceptions were Mill Bay and Little Waihi Estuary, where cockles exhibited substantial declines since the preceding surveys in 2014–15 and 2015–16, respectively, leading to comparatively low estimates in the current study.

At Mill Bay, the decline followed a period of steady population increases since 2004–05, and coincided with extended periods of particularly high temperatures during the summer sampling period. Furthermore, the presence of high numbers of moribund and decaying cockles at the time of the survey suggested that the decline was continuing. At Little Waihi Estuary, the current decrease in cockle densities was consistent with population fluctuations throughout the survey period, which seem to characterise the cockle population at this site.

At most of the remaining survey sites, cockle densities exhibited little change in recent assessments, indicating stable populations. Any observed population increases in 2017–18 were small, except for Cockle Bay, where a marked increase followed a steady population decline since 2012–13. Shellfish collections at this site are restricted by a seasonal closure over summer and a bag limit of 50 cockles at other times; however, the introduction of these fishing restrictions in 2008 were only initially followed by a population increase, and then decreased to the lowest density estimate in 2014–15.

Current fishing restrictions are also in place at Umupuia Beach and Whangateau Harbour, where recent cockle population estimates were relatively unchanged.

These three sites with fishing restrictions in place were also the only sites where large cockles were present at relatively high densities. Although the lack of fishing data prevents a direct assessment of fishing impacts on local bivalve populations, the current findings suggest that these restrictions help to sustain cockles in the large size class.

This notion is supported by time-series data that highlighted a universal decline in large cockles across the northern survey sites, generally in the early period of the monitoring programme. Across most sites, this size class showed few signs of recovery since its decline, and populations were generally characterised by a continuing scarcity of large individuals that was evident in the present study.

This finding was similar for pipi populations at the 2017–18 survey sites. Nine of the current sites contained pipi populations, but few of the populations included large individuals. Furthermore, total population densities were low at several of the 2017–18 sites, following considerable fluctuations over time. Only two sites, Whitianga Harbour and Marsden Bank, had current population densities exceeding 1000 pipi per m^2, and the high densities at these two sites were largely determined by recruits and small-sized pipi.

Some of the observed pipi population trends at the current survey sites may have been owing to the spatial distribution of pipi. This species extends into subtidal areas which are inaccessible to the intertidal sampling of the current survey series. At the same time, small, highly-localised patches of pipi also occur in other intertidal areas, including cockle strata. This patchy distribution can affect the overall population estimates, as was evident at Whangateau Harbour where the total population estimates had high uncertainty compared with estimates relating to the pipi stratum only.

At two of the sites, Pataua Estuary and Marsden Bank, the pipi beds became less uniform over the two- to three-month period between the reconnaissance and the time of the field sampling. At Marsden Bank, this change was accompanied by a significant change in beach morphology along the eastern side of the pipi bed. Changes in this relatively exposed area included the deposition of a considerable amount of sediment since early December 2017, resulting in elevated sandbanks and deep depressions. Previously, this area was characterised by a relatively uniform beach slope that extended along the eastern side, providing the demarcation of the pipi bed boundary in its mid-tidal zone. This area was devoid of pipi in the subsequent field sampling.

In general, northern North Island cockle and pipi populations included in the 2017–18 survey were characterised by the decline of large individuals. This finding was consistent with previous assessments that focused on northern populations and highlighted the general decrease of this size class at other sites (e.g., Berkenbusch & Neubauer 2017). Causes for the general decline of large individuals remain largely unknown. It is possible that this size group is preferentially targeted in fishing activities, in addition to factors that prevent small and medium-sized individuals to contribute to the large size class. While the findings from the current study clearly document the presence of recruits at a number of sites, it is unclear whether these small-sized individuals will persist over time and contribute to the adult population in the future.

The lack of fishing data prevents an assessment of the impact of fishing activities on local bivalve populations. In addition, a number of other human activities and environmental factors can affect the distribution and abundance of cockle and pipi populations, through changes to the habitat and direct impacts. Aspects pertaining to habitat suitability are considered in the sediment sampling that has become a part of recent northern surveys. As both sediment organic content and grain size composition influence cockle populations, sediment data from the surveys provide baseline information for future analyses of spatial and temporal changes in cockle populations.

6. ACKNOWLEDGMENTS

Many thanks to the field assistants who helped conduct the northern bivalve surveys, including Amy Archer, Emma Crawford, Matthew House, Lily Kozmian-Ledward, Calum Macleod, Beth McKinnel and Tom Miles. Ari Carrington and Summa Simperingham assisted with the survey at Marsden Bank.

Thanks are also due to 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 logistics, and Josie Crawshaw and Bev Dickson for conducting the sediment analyses.

This project was funded by Ministry for Primary Industries project AKI2017/01.

7. REFERENCES

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

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 from https://www.mpi.govt.nz/document-vault/9800.

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. Retrieved from http://mpi.govt.nz/document-vault/14329.

Berkenbusch, K.; Neubauer, P. (2017). Intertidal shellfish monitoring in the northern North Island region, 2016–17. *New Zealand Fisheries Assessment Report 2017/51*. 103 p. Retrieved from https://mpigovtnz.cwp.govt.nz/dmsdocument/21239.

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

Francis, R.I.C.C. (1984). An adaptive strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research 18*: 59–71.

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 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. Doctoral dissertation, University of Auckland, Auckland, New Zealand.

Ministry for Primary Industries (2015). Proposed closures to the recreational harvesting of cockle and pipi at Ngunguru and Whangateau. 21 p. Ministry for Primary Industries, Wellington. Retrieved from https://www.mpi.govt.nz/document-vault/10070.

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

Neubauer, P.; Abraham, E.R.; Berkenbusch, K. (2015). Predictability of cockle (*Austrovenus stutchburyi*) population trends in New Zealand's northern North Island. *PeerJ PrePrints 3*: e1772. doi:10.7287/peerj.preprints.1422v1.

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.; 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).

Williams, J.; Roberts, C.; Chetham, J. (2017). Initiation of a community-based pipi monitoring programme. Unpublished report prepared for Patuharakeke Te Iwi Trust Board by the National Institute of Water and Atmospheric Research, NIWA Client Report 2017255AK. 47 p.

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	2016–17	2017–18
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 Beach	■	■	■	■				■	■		■		■		■	
Umupuia Beach	■	■	■	■	■	■	■	■	■	■	■	■		■		■
Waikawau Beach	■	■				■	■					■				
Waiotahe Estuary				■	■	■	■		■			■			■	
Whangamata Beach	■	■	■	■	■	■		■		■			■		■	
Whangapoua Estuary				■	■	■	■			■			■		■	
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 2017–18. 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
	2016–17	9 Feb	19.46	AKI2016-01
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
	2017–18	29 Mar	1.50	AKI2017-01
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
	2017–18	29 Mar	15.77	AKI2017-01
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
	2016–17	16 Feb	22.58	AKI2016-01
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
	2016–17	10 Feb–28 Feb	26.78	AKI2016-01
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
	2016–17	27 Feb	60.89	AKI2016-01
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
	2017–18	29 Mar	18.38	AKI2017-01
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

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	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
	2016–17	11 Feb–16 Feb	8.59	AKI2016-01
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
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
	2017–18	29 Mar	0.85	AKI2017-01
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
	2017–18	29 Mar	4.86	AKI2017-01
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
	2016–17	13 Feb–15 Feb	6.28	AKI2016-01
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	4.58	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
	2017–18	29 Mar	19.83	AKI2017-01
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

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2009–10	1 Mar–17 Mar	5.60	AKI2009-01
	2014–15	31 Jan–1 Feb	7.67	AKI2014-01
	2016–17	20 Feb–21 Feb	8.09	AKI2016-01
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	27.89	AKI2015-01
	2017–18	29 Mar	27.71	AKI2017-01
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
	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
	2017–18	29 Mar	7.24	AKI2017-01
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
	2016–17	14 Feb	5.61	AKI2016-01
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
	2017–18	29 Mar	6.48	AKI2017-01
Te Haumi Beach	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
	2016–17	12 Feb	12.77	AKI2016-01
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

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	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
	2017–18	29 Mar	33.43	AKI2017-01
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
Waiotahe 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
	2013–14	17 Mar–20 Mar	11.23	AKI2013-01
	2016–17	22 Feb	11.98	AKI2016-01
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
	2016–17	24 Feb–26 Feb	7.71	AKI2016-01
Whangapoua Estuary	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
	2016–17	25 Feb–26 Feb	6.32	AKI2016-01
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

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2017–18	29 Mar	110.91	AKI2017-01
Whitianga Harbour	2012–13	7 Feb	7.08	AKI2012-01
	2015–16	5 Feb	6.10	AKI2015-01
	2017–18	29 Mar	5.81	AKI2017-01

APPENDIX B: Sediment properties

Table B-3: Sediment organic content and sediment grain size distributions at sites surveyed in 2017–18 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	8	-37.45752	175.97391	0.7	1.6	7.0	44.0	25.0	10.8	11.6
	A	1	-37.45638	175.97280	1.7	0.0	28.1	62.3	9.2	0.0	0.3
	A	2	-37.45643	175.97308	0.8	0.1	64.1	0.0	27.5	4.0	4.4
	A	3	-37.45650	175.97313	1.0	0.0	6.7	0.0	63.3	20.2	9.8
	A	6	-37.45685	175.97343	3.2	0.0	13.1	0.0	67.0	11.0	9.0
	A	4	-37.45686	175.97340	1.3	0.0	0.0	68.7	26.2	3.8	1.3
	A	5	-37.45706	175.97347	0.5	0.0	0.0	54.7	34.5	5.9	4.9
	A	7	-37.45704	175.97362	0.7	0.0	3.9	51.5	36.7	6.3	1.6
	B	2	-37.45633	175.97131	0.9	3.8	10.1	56.2	28.0	1.8	0.0
	B	3	-37.45627	175.97140	0.8	2.6	7.7	61.9	20.0	4.5	3.3
	B	4	-37.45637	175.97139	1.7	8.1	16.4	61.4	12.7	1.3	0.1
	B	1	-37.45628	175.97109	0.7	0.0	4.7	48.6	29.2	0.0	17.5
	B	5	-37.45644	175.97169	1.2	0.0	0.0	48.7	47.3	3.7	0.3
	B	8	-37.45665	175.97206	1.8	0.0	0.0	59.6	34.6	4.4	1.4
	B	6	-37.45675	175.97194	0.4	0.0	0.0	68.7	28.5	2.8	0.0
	B	7	-37.45659	175.97190	1.1	0.0	0.0	72.4	25.8	1.7	0.0
	C	3	-37.45580	175.97202	0.6	7.0	14.4	63.9	9.0	3.8	1.8
	C	4	-37.45577	175.97243	0.8	6.5	18.8	53.9	16.4	1.4	3.0
	C	7	-37.45560	175.97242	0.6	0.1	35.6	57.5	5.5	1.2	0.2
	C	8	-37.45551	175.97260	1.3	0.0	44.5	50.9	4.1	0.0	0.5
	C	1	-37.45593	175.97118	0.7	0.0	7.1	54.2	32.8	0.0	5.9
	C	2	-37.45565	175.97159	0.9	0.0	34.7	59.0	4.9	0.0	1.4
	C	5	-37.45531	175.97227	1.4	0.0	35.3	58.1	5.0	0.0	1.6
	C	6	-37.45532	175.97231	1.1	0.1	72.0	0.0	17.9	2.8	7.3

Continued on next page

Table B-3 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
Cockle Bay	A	7	-36.89778	174.95502	0.4	3.6	14.2	72.4	8.8	0.6	0.4
	A	3	-36.89875	174.95264	0.5	2.7	17.7	40.5	12.3	6.6	20.2
	A	2	-36.89816	174.95293	0.7	2.1	22.8	53.1	15.2	2.9	3.9
	A	1	-36.89896	174.95166	1.7	35.6	13.3	20.3	8.0	10.8	12.0
	A	8	-36.89869	174.95437	0.2	2.0	9.6	41.9	20.9	3.3	22.2
	A	4	-36.89911	174.95371	0.4	4.3	16.4	48.1	12.3	6.9	11.9
	A	5	-36.89954	174.95342	0.6	5.7	29.3	48.6	5.5	4.3	6.5
	A	6	-36.89989	174.95334	0.6	2.5	23.2	41.2	5.6	2.5	25.0
	A	14	-36.90020	174.95458	0.7	17.5	28.5	43.4	5.5	1.5	3.7
	A	12	-36.90025	174.95420	0.5	2.5	18.8	48.3	12.8	3.5	14.1
	A	11	-36.89985	174.95459	0.3	0.9	19.7	51.9	6.1	3.4	18.0
	A	16	-36.89880	174.95686	0.5	1.6	14.9	48.0	1.4	1.2	32.8
	A	15	-36.90020	174.95530	0.4	1.9	17.4	53.7	8.2	3.0	15.7
	A	13	-36.89926	174.95539	0.4	3.4	17.8	64.5	6.5	1.2	6.6
	A	9	-36.89908	174.95505	0.5	3.9	23.4	52.2	5.1	1.6	13.8
	A	10	-36.89949	174.95471	0.6	1.9	22.7	57.5	5.7	2.5	9.7
	B	4	-36.89736	174.95487	0.4	0.5	14.1	73.6	11.7	0.1	0.0
	B	3	-36.89763	174.95445	0.3	0.7	13.7	66.0	14.3	0.5	4.7
	B	6	-36.90031	174.95343	0.3	4.0	17.2	31.5	12.9	4.4	30.0
	B	2	-36.89718	174.95398	0.5	2.9	21.2	68.6	3.3	0.6	3.5
	B	5	-36.90027	174.95317	0.6	21.2	31.1	28.9	3.5	5.8	9.4
	B	7	-36.90066	174.95372	0.1	5.4	27.8	40.4	13.3	4.3	8.8
	B	1	-36.89703	174.95370	0.2	1.6	22.8	72.6	2.5	0.2	0.3
Little Waihi Estuary	A	1	-37.76333	176.48028	0.8	1.5	0.3	25.3	47.2	23.2	2.6
	A	2	-37.76367	176.48061	1.1	2.7	3.7	54.0	32.2	7.1	0.2
	A	4	-37.76362	176.48123	2.0	10.1	14.2	50.0	15.7	3.4	6.7
	A	5	-37.76335	176.48147	1.6	1.2	3.3	51.2	28.8	11.7	3.7

Continued on next page

Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	3	-37.76319	176.48116	1.8	4.8	2.8	33.7	43.5	15.0	0.2
	A	9	-37.76174	176.48186	1.7	6.3	5.5	54.7	25.2	8.3	0.0
	A	7	-37.75971	176.48051	0.8	0.9	2.0	39.6	48.0	8.9	0.6
	A	10	-37.75953	176.48068	0.9	2.1	1.7	52.1	36.8	7.0	0.3
	A	13	-37.75908	176.48172	1.6	8.5	5.4	46.5	30.3	9.2	0.0
	A	14	-37.75961	176.48236	0.0	0.0	2.7	31.2	50.7	15.1	0.2
	A	15	-37.76023	176.48277	0.5	3.0	3.3	37.5	38.0	16.6	1.6
	A	16	-37.76085	176.48350	0.8	2.2	2.4	23.2	36.6	15.7	19.9
	A	6	-37.76013	176.47994	0.5	0.2	1.3	36.9	38.6	18.0	4.9
	A	12	-37.75872	176.48098	0.6	0.6	3.2	70.3	24.1	1.4	0.3
	A	8	-37.76069	176.48079	0.9	1.7	1.8	52.4	39.8	3.4	0.9
	A	11	-37.76120	176.48163	1.9	1.5	4.7	68.0	23.2	2.6	0.1
	B	6	-37.75955	176.48036	0.6	2.0	0.8	33.0	47.3	15.5	1.4
	B	2	-37.75969	176.47981	0.8	0.3	3.3	49.7	37.0	8.7	1.1
	B	5	-37.75864	176.47921	1.1	0.0	2.0	67.4	29.6	0.8	0.1
	B	4	-37.75813	176.47901	1.0	0.7	0.4	49.4	42.4	2.8	4.3
	B	1	-37.75816	176.47847	0.9	0.0	0.4	37.4	51.3	10.9	0.0
	B	3	-37.75754	176.47864	1.1	1.7	3.0	55.5	26.5	5.2	8.1
	B	7	-37.75744	176.47953	0.4	2.6	1.9	66.0	27.4	2.1	0.0
	B	8	-37.75821	176.48005	0.2	0.0	2.4	53.9	38.2	5.5	0.1
Mill Bay	A	2	-36.99532	174.60703	2.3	7.0	10.2	42.5	26.2	12.7	1.4
	A	1	-36.99523	174.60685	4.2	9.8	14.6	22.8	24.5	25.5	2.8
	A	3	-36.99503	174.60733	2.2	5.7	4.2	28.1	39.0	21.8	1.1
	B	10	-36.99446	174.60809	1.8	2.2	4.3	35.8	34.7	21.2	1.8
	B	9	-36.99387	174.60558	2.8	4.5	10.2	39.5	23.5	17.2	5.1
	B	6	-36.99397	174.60540	3.0	3.0	6.5	21.0	20.6	24.4	24.5
	B	8	-36.99370	174.60550	3.5	6.7	5.9	13.5	20.6	34.8	18.6

Continued on next page

Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	5	-36.99370	174.60544	2.2	4.5	7.9	37.7	18.1	16.3	15.6
	B	2	-36.99364	174.60506	3.0	2.7	6.3	9.2	18.0	38.4	25.3
	B	1	-36.99353	174.60518	3.3	3.9	4.3	18.6	16.3	35.8	21.1
	B	7	-36.99340	174.60559	3.5	1.6	8.6	22.8	23.4	32.9	10.8
	B	4	-36.99343	174.60539	2.7	1.5	4.0	11.6	15.1	37.4	30.4
	B	3	-36.99320	174.60544	2.6	0.8	5.5	13.0	15.7	33.9	31.1
	C	6	-36.99363	174.60696	2.2	7.6	11.8	44.7	19.9	15.2	0.9
	C	9	-36.99415	174.60719	2.7	8.0	8.6	39.5	26.6	16.2	1.1
	C	5	-36.99446	174.60652	5.3	11.1	15.7	23.2	20.7	23.5	5.8
	C	4	-36.99433	174.60648	2.9	8.4	13.8	34.3	22.4	17.4	3.8
	C	3	-36.99434	174.60604	2.3	6.7	11.6	30.6	18.4	22.4	10.3
	C	2	-36.99367	174.60597	2.5	10.1	18.4	38.0	14.7	15.0	3.7
	C	10	-36.99479	174.60720	2.7	6.7	6.3	36.8	29.2	18.4	2.5
	C	8	-36.99457	174.60710	2.7	5.9	7.4	37.4	29.9	18.8	0.7
	C	11	-36.99459	174.60749	1.9	9.7	8.2	36.7	25.2	17.5	2.8
	C	7	-36.99450	174.60703	3.0	4.2	9.7	47.8	25.5	11.2	1.7
	C	1	-36.99374	174.60574	2.5	8.1	12.1	34.6	18.2	21.4	5.6
Okoromai Bay	A	2	-36.61181	174.80864	1.7	1.4	27.8	62.3	3.2	0.7	4.6
	A	1	-36.61182	174.80768	2.4	2.6	18.3	56.6	17.8	1.2	3.5
	A	3	-36.61043	174.80895	2.1	5.1	43.7	42.7	2.2	0.5	5.9
	A	5	-36.61039	174.81104	1.3	1.5	54.1	42.4	0.8	0.1	1.0
	A	6	-36.61126	174.81101	2.2	4.3	43.2	50.2	0.4	0.3	1.5
	A	4	-36.61190	174.81071	1.5	1.2	29.1	66.5	0.2	0.2	2.7
	A	8	-36.60779	174.81227	3.1	4.1	3.8	13.4	17.7	29.4	31.6
	A	9	-36.60907	174.81237	2.5	5.9	61.2	22.8	3.6	1.3	5.3
	A	10	-36.60968	174.81208	1.5	5.2	58.6	33.2	1.4	0.5	1.2
	A	7	-36.61051	174.81168	2.1	2.5	59.9	35.1	1.1	0.4	0.9

Continued on next page

Table B-3 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	B	3	-36.60821	174.80876	2.1	6.3	54.8	28.2	9.0	1.1	0.7
	B	4	-36.60897	174.80882	2.0	4.3	44.3	49.1	1.7	0.5	0.2
	B	5	-36.60952	174.80888	2.4	2.6	54.2	39.4	1.5	1.3	1.1
	B	2	-36.60864	174.80824	2.1	6.9	68.8	21.3	2.4	0.3	0.2
	B	1	-36.60829	174.80839	2.8	8.9	47.7	34.9	7.7	0.8	0.0
	B	9	-36.60835	174.81032	1.8	6.8	61.9	27.5	1.2	0.0	2.5
	B	11	-36.60844	174.81090	1.6	10.6	59.7	21.6	1.7	0.7	5.7
	B	6	-36.60818	174.80962	2.6	10.0	72.6	16.3	0.5	0.5	0.0
	B	7	-36.60954	174.80946	2.1	3.2	66.9	28.3	0.7	0.3	0.6
	B	12	-36.60967	174.81094	1.7	4.0	55.0	38.8	1.3	0.5	0.5
	B	10	-36.61080	174.81046	1.9	1.5	46.2	42.5	0.3	0.6	8.9
	B	8	-36.61075	174.80964	1.9	0.8	48.4	44.2	1.1	0.5	4.9
	B	13	-36.60907	174.81116	1.6	4.8	62.1	20.4	1.2	4.7	6.8
	B	14	-36.60937	174.81154	1.5	4.6	44.8	47.4	0.9	0.6	1.7
Pataua Estuary	A	3	-35.71871	174.51511	1.2	0.9	8.2	48.5	22.6	15.9	4.0
	A	1	-35.71722	174.51543	0.9	0.8	4.3	50.9	19.5	18.0	6.5
	A	6	-35.71779	174.51661	1.1	0.5	5.2	71.0	19.0	3.4	0.8
	A	2	-35.71625	174.51630	1.0	0.5	3.8	65.0	13.3	14.2	3.2
	A	5	-35.71676	174.51688	1.8	2.3	14.3	62.4	11.1	4.7	5.2
	A	4	-35.71627	174.51713	1.4	0.8	9.0	65.1	12.8	10.4	1.9
	A	7	-35.71610	174.51832	1.4	0.6	1.9	37.0	33.7	18.5	8.3
	A	8	-35.71681	174.51803	2.3	3.8	10.6	77.9	5.3	0.9	1.5
	A	11	-35.71818	174.51801	1.3	0.8	5.9	39.9	15.3	20.6	17.5
	A	9	-35.71847	174.51712	1.4	1.8	10.8	68.9	10.5	6.2	1.8
	A	12	-35.71899	174.51686	1.4	1.3	10.7	82.4	2.6	1.1	1.9
	A	10	-35.71745	174.51833	0.9	0.0	2.4	22.2	17.4	31.8	26.2
	B	10	-35.72108	174.51264	1.3	2.5	10.5	33.6	27.6	24.2	1.6

Continued on next page

Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	7	-35.72033	174.51216	1.2	1.7	9.6	34.0	19.4	24.5	10.8
	B	9	-35.72040	174.51269	1.2	2.1	16.1	44.6	12.9	17.6	6.7
	B	1	-35.71849	174.51111	1.0	2.9	10.2	54.3	15.1	16.4	1.1
	B	2	-35.71807	174.51172	1.8	3.0	13.9	70.5	7.3	3.5	1.8
	B	3	-35.71778	174.51279	1.5	3.2	16.9	76.6	1.3	1.0	1.0
	B	4	-35.71900	174.51202	1.4	1.0	7.3	48.6	22.3	15.8	5.0
	B	5	-35.71854	174.51316	0.6	0.8	6.2	84.8	7.2	0.7	0.2
	B	6	-35.71920	174.51267	1.2	0.8	10.9	73.1	8.1	5.8	1.3
	B	11	-35.72019	174.51413	1.0	0.0	8.4	71.7	15.4	3.1	1.4
	B	12	-35.72053	174.51323	2.0	0.7	20.5	65.7	8.1	3.0	1.9
	B	8	-35.72017	174.51341	2.2	3.9	15.9	70.8	4.0	2.9	2.4
Raglan Harbour	A	12	-37.80414	174.86725	1.6	13.2	30.8	52.1	0.8	1.3	1.9
	A	10	-37.80423	174.86704	1.4	10.4	21.0	66.9	0.6	0.5	0.6
	A	11	-37.80284	174.86735	1.4	9.2	12.3	76.2	1.3	0.3	0.7
	A	8	-37.80311	174.86689	0.9	6.4	10.4	65.3	13.7	1.6	2.5
	A	7	-37.80193	174.86712	0.9	5.2	8.1	65.0	18.7	1.5	1.5
	A	9	-37.80336	174.86678	1.1	3.8	7.4	61.9	23.2	2.5	1.3
	A	5	-37.80441	174.86651	1.2	6.1	14.0	74.7	1.9	0.7	2.5
	A	6	-37.80498	174.86646	1.1	9.0	20.2	67.3	1.3	0.7	1.5
	A	4	-37.80519	174.86606	1.1	7.1	15.5	74.3	1.4	0.7	1.0
	A	3	-37.80436	174.86586	1.7	5.2	13.5	76.0	1.9	1.3	2.1
	A	1	-37.80490	174.86549	2.4	9.5	14.3	73.0	1.2	1.3	0.7
	A	2	-37.80520	174.86540	1.8	8.3	16.6	64.0	1.5	2.4	7.3
	D	12	-37.79579	174.87152	0.9	5.4	18.6	63.9	6.7	1.7	3.8
	D	10	-37.79552	174.87112	1.5	7.0	20.4	69.3	0.7	0.6	2.0
	D	11	-37.79575	174.87094	1.6	14.6	14.6	48.8	1.7	3.3	17.0
	D	9	-37.79615	174.87079	1.0	6.4	18.8	63.8	8.1	1.7	1.2

Continued on next page

Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	D	8	-37.79597	174.87060	0.8	4.7	16.3	72.4	3.7	1.4	1.4
	D	7	-37.79633	174.87011	0.8	4.9	13.3	70.6	6.7	2.3	2.2
	D	6	-37.79645	174.86992	0.9	6.1	13.7	69.2	7.1	2.2	1.7
	D	5	-37.79611	174.86975	0.9	5.0	13.7	80.2	0.7	0.2	0.2
	D	4	-37.79581	174.86979	0.5	2.1	17.0	75.0	1.3	1.5	3.0
	D	2	-37.79613	174.86956	2.3	8.1	16.5	73.6	0.9	0.4	0.5
	D	1	-37.79672	174.86930	1.7	6.9	11.8	65.9	8.8	2.5	4.2
	D	3	-37.79670	174.86956	0.4	3.5	10.8	78.4	5.9	0.5	0.8
Tairua Harbour	A	4	-37.00591	175.85422	2.8	3.5	11.2	38.0	36.9	8.7	1.8
	A	3	-37.00668	175.85413	2.0	2.1	6.0	39.5	43.4	7.6	1.4
	A	2	-37.00694	175.85355	1.4	1.0	7.7	42.7	40.6	7.6	0.4
	A	1	-37.00729	175.85330	1.2	2.3	4.2	31.7	51.3	9.8	0.6
	A	5	-37.00569	175.85495	1.1	0.8	7.1	40.4	42.9	8.3	0.4
	A	6	-37.00486	175.85490	1.3	1.0	10.7	39.3	38.1	9.1	1.7
	A	7	-37.00490	175.85514	1.4	3.5	11.0	42.3	34.8	7.9	0.6
	B	4	-37.00592	175.85457	1.8	4.4	10.2	45.1	35.8	3.9	0.6
	B	3	-37.00575	175.85427	3.1	6.1	10.7	38.2	32.6	7.9	4.6
	B	2	-37.00601	175.85310	2.6	0.8	5.3	48.8	36.0	6.9	2.2
	B	1	-37.00625	175.85290	3.8	6.3	6.7	46.9	28.9	9.1	2.1
	B	8	-37.00556	175.85560	1.4	9.2	11.6	52.5	19.5	6.6	0.6
	B	7	-37.00519	175.85505	1.9	5.5	11.8	51.2	25.6	5.0	0.9
	B	6	-37.00512	175.85498	1.6	5.6	17.2	45.2	26.4	4.2	1.3
	B	5	-37.00613	175.85522	1.2	1.7	3.0	25.7	46.7	22.3	0.7
	C	1	-37.00714	175.85234	2.6	0.7	2.6	29.1	46.9	16.2	4.5
	C	2	-37.00692	175.85252	4.1	0.8	1.5	23.0	60.1	14.1	0.5
	C	4	-37.00665	175.85244	4.3	2.0	17.3	55.5	19.3	4.0	1.9
	C	5	-37.00690	175.85278	4.4	6.1	5.6	40.5	34.8	12.0	1.0

Continued on next page

Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	C	7	-37.00670	175.85275	3.8	6.9	10.8	44.0	31.2	5.1	2.0
	C	6	-37.00651	175.85248	3.6	2.4	4.5	42.5	28.8	7.5	14.4
	C	3	-37.00716	175.85253	3.0	5.5	8.1	42.3	35.5	8.2	0.4
	C	9	-37.00552	175.85593	1.3	4.5	8.4	43.0	35.6	7.5	1.1
	C	8	-37.00568	175.85592	1.3	1.3	2.8	24.6	47.9	21.8	1.6
Umupuia Beach	A	14	-36.90211	175.07168	0.7	2.8	22.7	58.8	9.6	1.4	4.6
	A	13	-36.90168	175.07191	0.9	3.4	35.8	57.6	3.1	0.1	0.0
	A	18	-36.90366	175.07372	2.7	7.7	22.9	7.6	4.2	17.6	40.0
	A	3	-36.89981	175.06613	0.6	4.5	22.6	55.2	15.8	1.1	0.8
	A	6	-36.90117	175.06816	0.7	2.6	30.0	53.2	10.3	1.9	1.9
	A	10	-36.90240	175.06917	1.0	7.0	33.1	50.9	6.2	1.2	1.5
	A	7	-36.90170	175.06856	0.7	3.6	33.4	55.0	5.9	1.0	1.1
	A	8	-36.90262	175.06860	2.6	20.6	18.4	19.9	14.2	14.2	12.8
	A	16	-36.90327	175.07288	2.1	3.9	45.2	29.7	8.8	5.2	7.3
	A	12	-36.90277	175.07055	0.8	6.2	53.3	36.8	2.6	0.8	0.3
	A	11	-36.90170	175.07066	1.1	2.3	27.8	55.6	6.6	1.9	5.9
	A	15	-36.90360	175.07204	2.8	7.4	54.2	35.8	1.3	0.8	0.5
	A	9	-36.90336	175.06825	1.7	8.9	8.4	34.7	28.9	13.9	5.3
	A	17	-36.90393	175.07247	6.9	22.9	7.0	4.0	2.9	7.3	55.9
	A	1	-36.89901	175.06537	0.9	5.3	32.8	50.4	7.9	1.3	2.2
	A	2	-36.89943	175.06521	1.4	8.9	39.8	37.1	12.3	1.3	0.6
	A	4	-36.89884	175.06691	0.7	1.4	21.6	67.5	8.9	0.4	0.2
	A	5	-36.90020	175.06710	1.1	1.7	28.9	63.1	5.7	0.6	0.0
	B	3	-36.90205	175.07420	0.6	2.3	20.1	65.5	11.7	0.4	0.0
	B	4	-36.90207	175.07443	0.7	3.2	29.1	63.6	3.8	0.2	0.1
	B	6	-36.90222	175.07535	0.6	1.3	32.3	62.9	3.3	0.1	0.1
	B	5	-36.90333	175.07497	1.0	3.9	34.6	13.7	5.9	16.7	25.2

Continued on next page

Table B-3 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	B	2	-36.89711	175.06586	0.5	2.0	13.7	65.7	6.0	1.4	11.1
	B	1	-36.89664	175.06562	0.8	1.6	10.5	71.0	16.2	0.5	0.2
Whangateau Harbour	A	1	-36.33106	174.76350	0.5	0.0	3.6	88.1	7.7	0.2	0.4
	A	3	-36.33104	174.76415	0.6	0.0	2.5	77.2	18.8	1.4	0.2
	A	7	-36.32829	174.76695	0.8	0.6	6.6	70.6	9.2	3.2	9.8
	A	9	-36.32827	174.76898	0.4	0.8	1.9	69.8	21.1	3.1	3.2
	A	10	-36.32529	174.77056	0.8	1.4	4.1	68.5	14.0	5.1	6.9
	A	13	-36.32574	174.77256	0.7	1.6	2.9	84.9	3.1	0.9	6.6
	A	11	-36.32679	174.77044	0.8	0.4	3.2	72.5	14.9	4.1	4.9
	A	12	-36.32683	174.77150	1.1	1.0	6.3	71.5	9.5	4.0	7.7
	A	8	-36.32708	174.76855	0.6	0.0	2.3	82.4	10.2	2.1	3.0
	A	6	-36.33539	174.76507	1.0	0.7	8.0	72.2	9.4	2.7	7.0
	A	4	-36.33294	174.76473	0.7	0.9	3.5	71.6	15.2	2.0	6.8
	A	2	-36.33249	174.76384	0.4	0.0	3.2	91.1	4.9	0.3	0.6
	A	5	-36.33444	174.76438	0.9	0.8	4.8	46.8	5.3	0.8	41.5
	B	2	-36.31503	174.78178	0.7	0.5	1.5	63.7	33.5	0.8	0.1
	B	1	-36.31529	174.77824	0.5	0.2	0.0	13.8	64.8	16.0	5.2
	C	2	-36.31466	174.77930	0.7	2.1	2.6	57.6	35.0	1.6	1.2
	C	3	-36.31448	174.78071	0.8	0.3	1.8	73.1	24.0	0.6	0.1
	C	1	-36.31600	174.77650	0.7	2.0	0.3	34.1	39.3	9.9	14.5
	D	6	-36.31045	174.77797	0.8	1.6	5.6	60.3	28.5	2.6	1.4
	D	4	-36.31494	174.77743	0.7	0.7	0.3	46.6	44.6	5.9	1.9
	D	3	-36.31514	174.77602	0.3	0.0	0.3	50.9	44.1	3.1	1.6
	D	2	-36.31484	174.77520	0.5	0.4	0.4	85.1	13.0	0.6	0.6
	D	5	-36.31140	174.77495	1.0	3.9	6.3	42.2	42.3	3.3	2.0
	D	1	-36.31289	174.77230	0.9	3.4	4.0	48.6	35.2	6.3	2.4
Whitianga Harbour	B	20	-36.84397	175.70061	2.3	4.9	4.0	68.7	19.9	2.4	0.2

Continued on next page

Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	19	-36.84370	175.70071	2.3	4.8	10.2	75.8	7.3	1.0	1.0
	B	21	-36.84366	175.70113	1.6	4.4	6.5	66.3	19.6	2.6	0.6
	B	22	-36.84393	175.70097	2.3	3.8	4.6	68.0	20.5	2.9	0.2
	B	23	-36.84314	175.70148	1.3	2.5	6.9	77.5	9.9	1.2	2.0
	B	24	-36.84343	175.70133	1.0	3.7	3.8	67.5	21.4	2.2	1.4
	B	18	-36.84298	175.70069	1.3	3.7	12.7	67.4	10.3	2.9	3.1
	B	3	-36.84381	175.69882	2.2	4.6	7.9	54.4	23.9	8.5	0.6
	B	4	-36.84383	175.69890	1.6	7.8	10.4	51.2	12.8	5.7	12.2
	B	1	-36.84406	175.69851	1.9	3.0	9.6	43.6	17.3	8.9	17.6
	B	2	-36.84440	175.69843	2.7	8.2	11.3	59.9	13.0	5.4	2.2
	B	5	-36.84461	175.69888	2.3	6.0	4.4	58.0	24.4	6.8	0.4
	B	6	-36.84472	175.69897	1.7	8.0	4.8	56.7	19.8	7.1	3.6
	B	7	-36.84461	175.69925	2.8	4.8	4.4	55.4	22.3	7.8	5.3
	B	8	-36.84483	175.69905	2.3	13.3	7.7	58.1	15.5	4.8	0.6
	B	12	-36.84313	175.70000	2.4	8.3	8.7	41.7	13.5	9.4	18.4
	B	16	-36.84306	175.70023	1.5	4.5	11.5	63.8	11.0	5.3	3.8
	B	17	-36.84332	175.70031	1.3	5.1	11.3	67.4	13.7	2.1	0.3
	B	13	-36.84359	175.69987	2.1	5.4	11.2	60.7	16.4	4.7	1.5
	B	9	-36.84356	175.69960	1.8	6.2	11.3	54.3	19.5	8.0	0.7
	B	10	-36.84410	175.69957	1.6	4.7	5.5	69.1	14.4	3.5	2.9
	B	14	-36.84395	175.70000	1.8	2.5	5.9	71.3	13.3	2.7	4.2
	B	11	-36.84415	175.69972	1.5	5.6	3.8	65.7	17.0	3.6	4.2
	B	15	-36.84414	175.70004	2.8	5.1	3.4	49.2	33.9	8.2	0.3

APPENDIX C: Pipi bed at Marsden Bank

Figure C-1: Pipi bed at Marsden Bank, February 2018. Top left: Beach morphology with elevated sandbank and deep, waterlogged depressions in the eastern part of the pipi bed. Top right: Moribund and decaying bivalves in localised areas of the pipi bed.

APPENDIX D: Cockle mortality at Mill Bay

Figure D-2: Illustration of cockle mortality at Mill Bay in February 2018. Decaying and gaping cockles in water-logged depressions on the intertidal mudflat.