Fisheries New Zealand

Tini a Tangaroa

Intertidal shellfish monitoring in the northern North Island region, 2019–20

New Zealand Fisheries Assessment Report 2020/38

K. Berkenbusch
P. Neubauer

ISSN 1179-5352 (online)
ISBN 978-1-99-004328-4 (online)

November 2020

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. (2020). Intertidal shellfish monitoring in the northern North Island region, 2019–20.

New Zealand Fisheries Assessment Report 2020/38. **103 p.**

Recreational and customary fisheries throughout New Zealand target a wide range of marine species, including intertidal bivalves, such as littleneck clam (or cockle, tuangi/tuaki, *Austrovenus stuchburyi*) and pipi (*Paphies australis*). Concerns about their populations in northern North Island have led to regular surveys of cockle and pipi beds that are targeted in non-commercial fisheries in this region. The present study continued the northern North Island survey series, assessing cockles and pipi in the wider Auckland, Bay of Plenty, Northland and Waikato regions in 2019–20. The sites included in the present survey were (in alphabetical order): Bowentown Beach, Cockle Bay, Eastern Beach, Grahams Beach, Little Waihi Estuary, Pataua Estuary, Raglan Harbour, Tairua Harbour, Umupuia Beach, Waiōtahe Estuary, Whangateau Harbour and Whitianga Harbour.

All of the 2019–20 survey sites contained cockle populations, which varied in their abundance and density, depending on the site. The largest cockle population was at Whangateau Harbour, where their abundance estimate was a total of 887.67 million (CV: 10.72%) cockles, followed by Pataua Estuary, with an estimated 362.52 million (CV: 12.71%) cockles in 2019–20. The smallest cockle population was at Grahams Beach, where the total number of individuals was estimated to be 11.40 million (CV: 19.89%) cockles. Grahams Beach also had the lowest population density at 43 cockles per m^2, compared with the highest density at Raglan Harbour of 1716 cockles per m^2. Other sites with relatively high cockle densities ($>$1000 individuals per m^2) were Bowentown Beach, Pataua Estuary, Tairua Harbour and Whitianga Harbour.

Within the cockle populations, large individuals ($\geq$30 mm shell length) were generally scarce, and their abundance and density estimates typically had high uncertainty. Their highest density estimate was 98 cockles per m^2 at Umupuia Beach, followed by density estimates at Eastern Beach and Cockle Bay of 77 and 75 cockles per m^2, respectively. At the remaining sites, this size class was absent or only occurred at low densities (i.e., $<$30 individuals per m^2).

At Waiōtahe Estuary, the cockle population exhibited a substantial decline in 2019–20, caused by the loss of medium-sized individuals since the preceding survey in 2016–17. This estuary has been exposed to considerable faecal bacteria contamination through dairy farm runoff in 2017. It is possible that this habitat degradation led to the recent decline in the resident cockle population.

Pipi populations were surveyed at nine of the sites, and their population sizes ranged from 0.29 million (CV: 15.16%) pipi at Bowentown Beach to 142.30 million (CV: 13.35%) pipi at Little Waihi Estuary. The latter estuary also supported their highest population density, with 849 pipi per m^2; the other three sites with high pipi densities (i.e., $>$100 individuals per m^2) were Waiōtahe Estuary (672 pipi per m^2), followed by Tairua Harbour (309 pipi per m^2) and Whitianga Harbour (163 pipi per m^2). All other pipi populations occurred at densities of 41 pipi per m^2 or less.

Little Waihi Estuary was the only site in 2019–20 with notable numbers of large pipi ($\geq$50 mm shell length), and their density estimate in this estuary was 93 (CV: 18.74%) large pipi per m^2. The next-highest estimate was 16 (CV: 19.02%) large pipi per m^2 at Whitianga Harbour. Large pipi estimates at the remaining sites were markedly lower (i.e., less than seven large individuals per m^2) and had high uncertainty.

Sediment sampling in the cockle strata revealed sediments that were generally low in organic content (i.e., $<$5%) and consisted of varying proportions of sands. The proportion of fines (grain size $<$63 µm) was typically small, but exceeded 10% at several sites, with up to 69% of the sediment recorded in this grain size fraction in 2019–20 (at Umupuia Beach).

1. INTRODUCTION

Non-commercial fisheries in New Zealand include recreational and customary collections of coastal marine invertebrates, such as kina (*Evechinus chloroticus*), pāua (*Haliotis iris*), and different species of bivalves (Miller & Abraham 2011, Wynne-Jones et al. 2014). Intertidal bivalve species that are frequently targeted in these fisheries include littleneck clam (or cockle, tuangi/tuaki; *Austrovenus stuchburyi*) and pipi (*Paphies australis*) (Hartill et al. 2005, King & Lake 2013). Both species are common throughout New Zealand, frequently occur in high-density beds, and are easily accessible at low tide (Grant & Hay 2003). The latter aspect is augmented by their widespread distribution in sheltered, sedimentary environments that include locations close to urban and metropolitan centres.

Cockles are suspension-feeders, relying on food in the water column, provided by water movement and tidal submergence. This species often dominates near-shore benthic communities, reaching high densities (>1000 individuals per m^2) in localised patches and extensive beds (Marsden & Adkins 2010). Their distribution in the intertidal zone has been linked to differences in sediment mud content and tidal submergence (Stewart & Creese 2002, Thrush et al. 2003). Cockle growth studies to date have revealed variable growth rates for this species, indicating that individuals reach sexual maturity at about 18 mm shell length in the second year, and attain a size of about 30 mm shell length in two to five years; their maximum size is about 40 mm shell length (Larcombe 1971).

Pipi are also suspension-feeders and occur in intertidal and subtidal coastal habitats, usually in coarse sediment (Hooker 1995). Intertidal pipi show a preference for clean sediments, often in the vicinity of fast-flowing tidal channels or dynamic flow environments, such as estuary entrances. Similar to cockles, pipi beds can reach high densities in suitable environments, exceeding several thousand individuals per m^2, and their boundaries are typically clearly defined. They reach sexual maturity at about 30 to 40 mm shell length and a maximum size of 60 mm shell length (within three to four years).

In view of their importance as target species for recreational and customary fisheries, and the potential for their overexploitation, northern North Island populations of cockles and pipi have been monitored by Fisheries New Zealand (and its predecessors) since the early 1990s. The initial focus of the bivalve surveys was on intertidal populations in the Auckland area, with the subsequent addition of sites in Northland, Waikato and Bay of Plenty expanding the scope of the monitoring programme to the northern North Island region (Fisheries Management Areas 1 and 9). The sites included in the survey series represent a range of different sedimentary habitats, from sheltered, open beaches to semi-enclosed bays and estuaries. At each of the site, the assessment is focused on particular areas and bivalve beds that are considered to be targeted in recreational and customary fisheries.

Although there have been some changes over time, the survey methods have remained consistent since 1999–2000, with (usually) twelve northern sites surveyed each year (most recently in 2018–19; Berkenbusch & Neubauer 2019). In these surveys, the field sampling is focused on providing information on the abundance, density and size structure of cockle and pipi populations, with summary data allowing comparisons across sites and over time.

Since 2013–14, the collection of field data has also included sediment characteristics (sediment organic content and granulometry), because they may influence the distribution and abundance of these infaunal bivalve species (Berkenbusch et al. 2015). The sediment sampling was initially aimed at providing baseline information about sediment characteristics and was subsequently refined to allow more rigorous analysis of these data from the cockle strata (Berkenbusch & Neubauer 2017).

The current survey continues the northern bivalve monitoring programme by providing data on the abundance and population structure of cockles and pipi at 12 selected northern North Island sites in 2019–20. The overall objective of this survey was "to determine the distribution, abundance and size frequency of cockles and pipi for 2019/20". The 2019–20 survey sites were (in alphabetical order): Bowentown Beach, Cockle Bay, Eastern Beach, Grahams Beach, Little Waihi Estuary, Pataua Estuary, Raglan Harbour, Tairua Harbour, Umupuia Beach, Waiotahe Estuary, Whangateau Harbour and Whitianga Harbour (Figure 1).

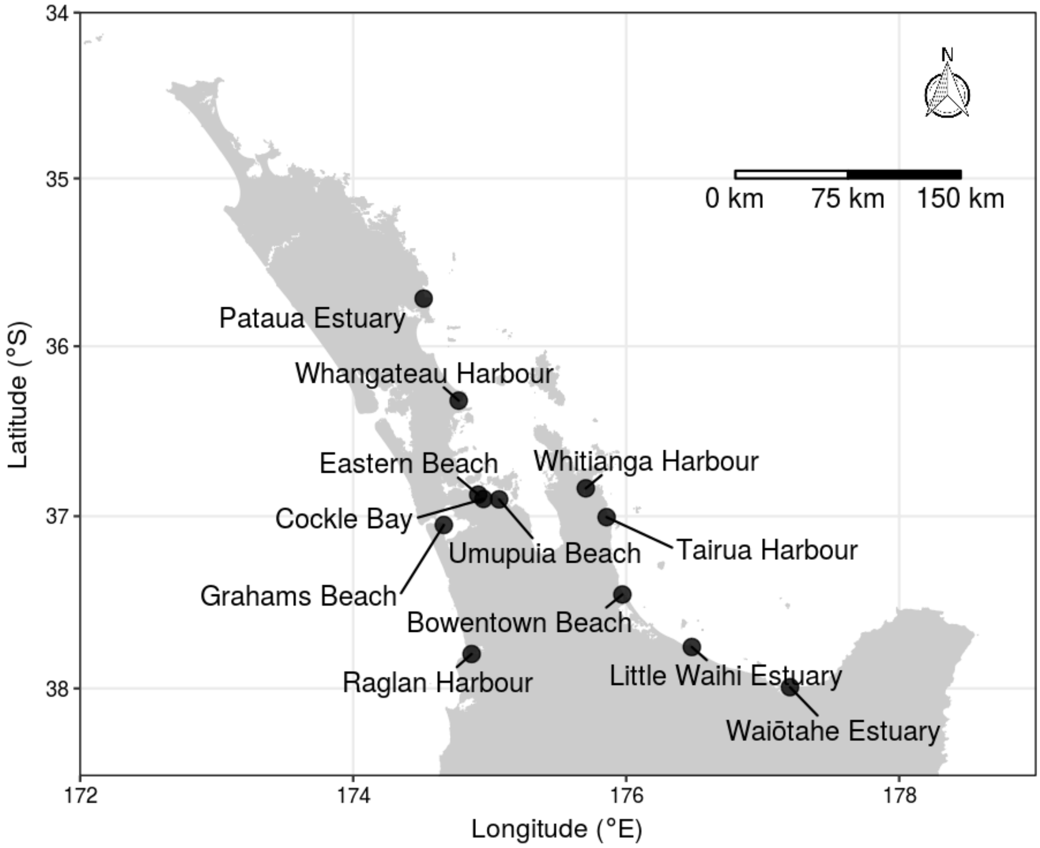


Figure 1: Sites included in the northern North Island intertidal bivalve survey in 2019–20.

2. METHODS

The methods used in the present study were based on previous bivalve assessments that provided temporal comparisons across the northern survey series. Since 1996, the general sampling protocol of the northern North Island bivalve surveys has used 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). For completeness, the methods are included here, following updates to reflect the 2019–20 assessment.

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, with the 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 two sites in 2019–20). The number of required phase-2 samples was calculated using the method of 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 initial 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, because 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 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 February 2020. At 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 a sediment depth of 15 cm; 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.

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 a depth of 10 cm) 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 through a stack of sieves to determine the proportion in each sediment grain size fraction (i.e., $>$63, $>$125, $>$250, $>$500, and $>$2000 µm). Sediment retained on each sieve 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 the 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 size classes (millimetre-length). 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, so 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 Bay of Plenty region, with the survey area at this site located in a sheltered northern part of Tauranga Harbour. The bivalve assessments at Bowentown Beach have focused on both cockles and pipi, which have been sampled six times throughout the survey series, including the current assessment; the most recent preceding assessment was in 2017–18 (see Appendix A, Tables A-1, A-2). Throughout the monitoring series, the sampling extent has remained unchanged, and the 2019–20 survey sampled a total of 90 points across three strata within this sampling extent.

The sediment sampling included all strata, and indicated a low organic content of less than 2% (Figure 2, and see details in Appendix B, Table B-1). Similarly, there was only a small proportion of sediment fines ($<$4%; grain size $<$63-µm), with similar proportions of fine and medium sands (grain sizes $>$125-µm and $>$250-µm) determining the sediment granulometry.

The cockle population at Bowentown Beach was spread across all strata, but had markedly higher abundances and densities in strata B and C compared with stratum A (Figure 3, Table 1). Across the entire sampling extent, the 2019–20 total population estimates for this species were 24.80 million (CV: 5.97%) individuals, and 1656 cockles per m^2 (Table 2). The current estimates reflected a decrease in the cockle population compared with the preceding estimates in 2017–18; however, they were similar to earlier estimates in 2012–13 and 2015–16.

The population of large cockles ($\geq$30-mm shell length) was small, with an estimated 0.12 million (CV: 17.30%) cockles in this size class in 2019–20. Their corresponding density was estimated at 8 large cockles m^2. Throughout the survey series, this size class has been consistently small, following a marked decline in 2010–11.

Large cockles continued to constitute only a small proportion (0.48%) of the total population (Table 3, Figure 4). At the same time, the proportion of recruits ($\leq$15-mm shell length) showed a 50% decline from the previous two surveys, with 9.49% recruits included in the 2019–20 population. Medium-sized cockles continued to determine the unimodal population size structure, and their influence was evident in mean and modal shell lengths, at 21.01 and 23 mm, respectively.

Pipi were also present in all survey strata at Bowentown Beach, although only in small numbers and predominantly in stratum B, close to the tidal channel (Figure 5, Table 4). The current estimate for the total population was 0.29 million (CV: 15.16%) pipi; they occurred at an estimated density of 19 pipi m^2 (Table 5). Even though these values signified a reduction from the preceding survey in 2017–18, they were consistent with generally low estimates throughout the survey series.

Similar to previous surveys, there were few large pipi ($\geq$50-mm shell length) at Bowentown Beach, and the uncertainty associated with their population estimates was high (CV: 75.2%). Within the total population, large pipi represented 1.77% of all individuals, compared with 17.85% of recruits ($\leq$20-mm shell length) (Table 6). Pipi at this site were predominantly at medium sizes, with mean and modal shell lengths of 30 mm, which was reflected in the unimodal population size structure. The latter showed a recent shift towards the medium size class compared with the preceding two surveys, when larger numbers of recruits and small-sized individuals influenced the length-frequency distributions (Figure 6).

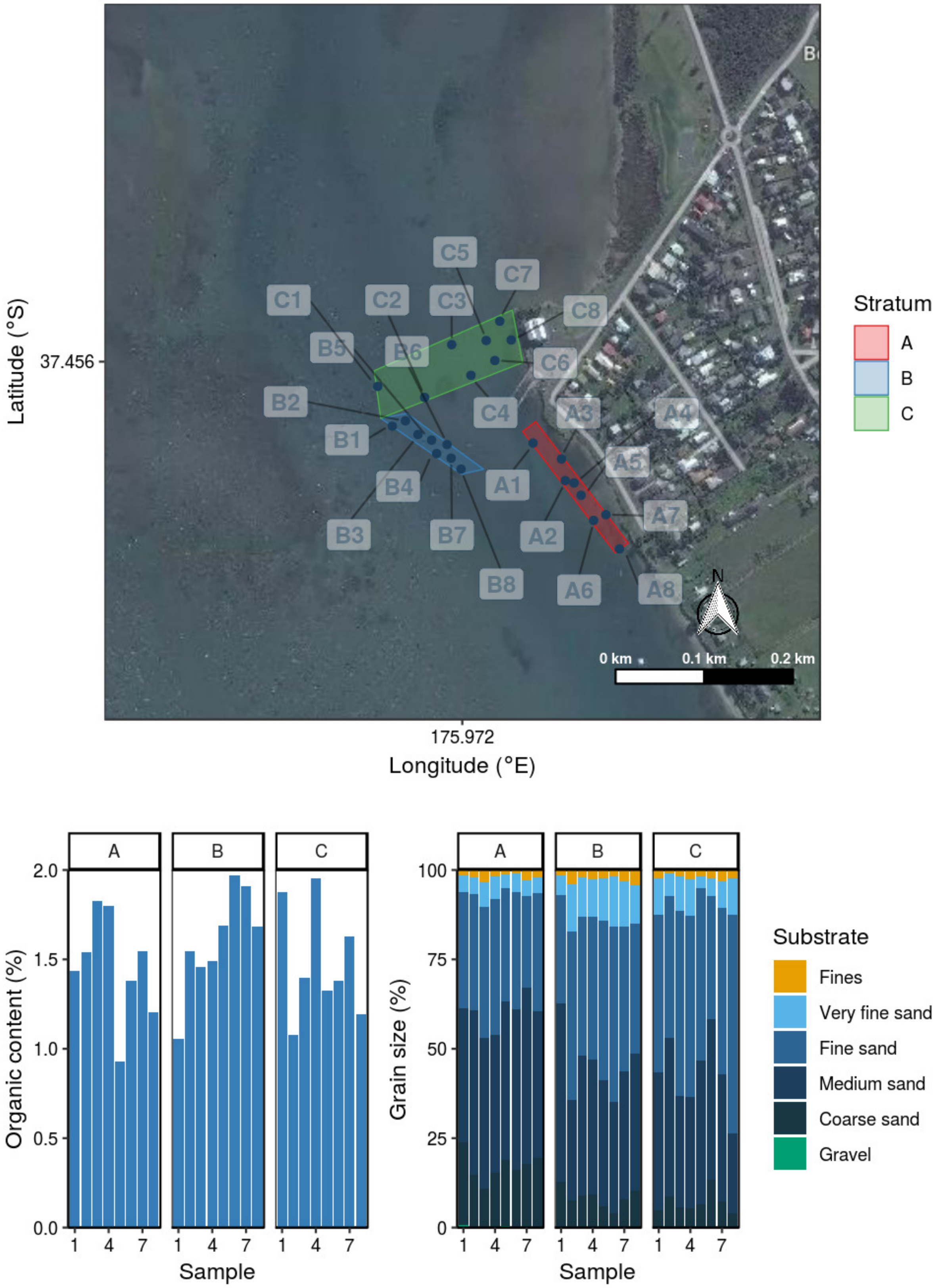


Figure 2: Sediment sample locations and characteristics at Bowentown Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.1.1 Cockles at Bowentown Beach

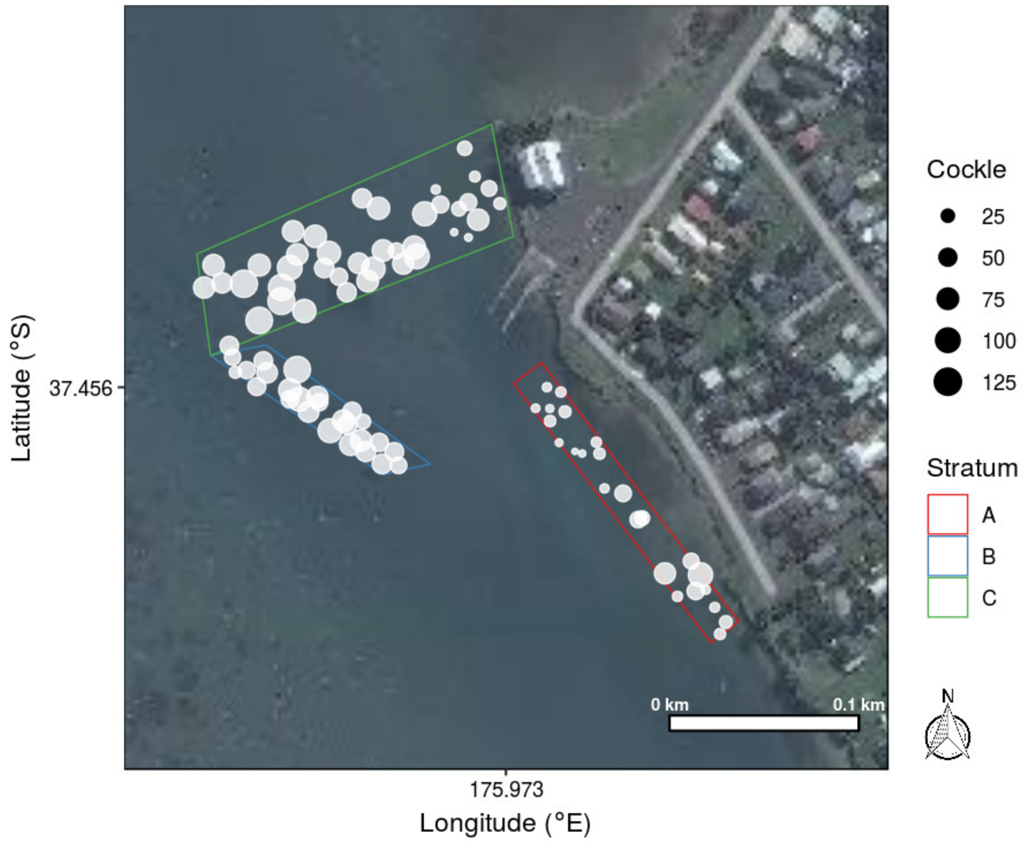


Figure 3: Map of sample strata and individual sample locations for cockles at Bowentown Beach, with the size of the circles proportional to the number of cockles (per 0.035 m²) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Bowentown Beach, by stratum, for 2019–20. 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	602	2.19	688	18.90
B	0.2	25	1 590	4.02	1 817	6.90
C	1.0	40	2 716	18.59	1 940	7.49

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
2019–20	1.5	24.80	1 656	5.97	0.12	8	17.30

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 (%)
2015–16	18.95	20	6–31	19.83	0.12
2017–18	18.99	20	5–35	23.06	0.52
2019–20	21.01	23	5–34	9.49	0.48

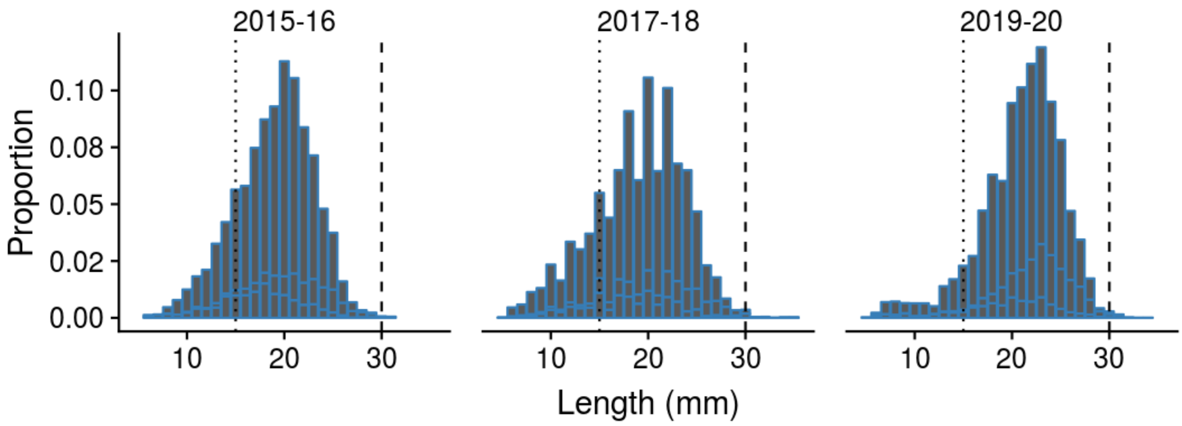


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

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 2019–20. 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	16	0.06	18	46.77
B	0.2	25	79	0.20	90	14.69
C	1.0	40	4	0.03	3	59.91

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
2019–20	1.5	0.29	19	15.16	0.01	<1	75.2

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 (%)
2015–16	29.53	22	9–57	11.40	6.21
2017–18	23.96	15	12–50	38.78	0.53
2019–20	30.62	30	8–56	17.85	1.77

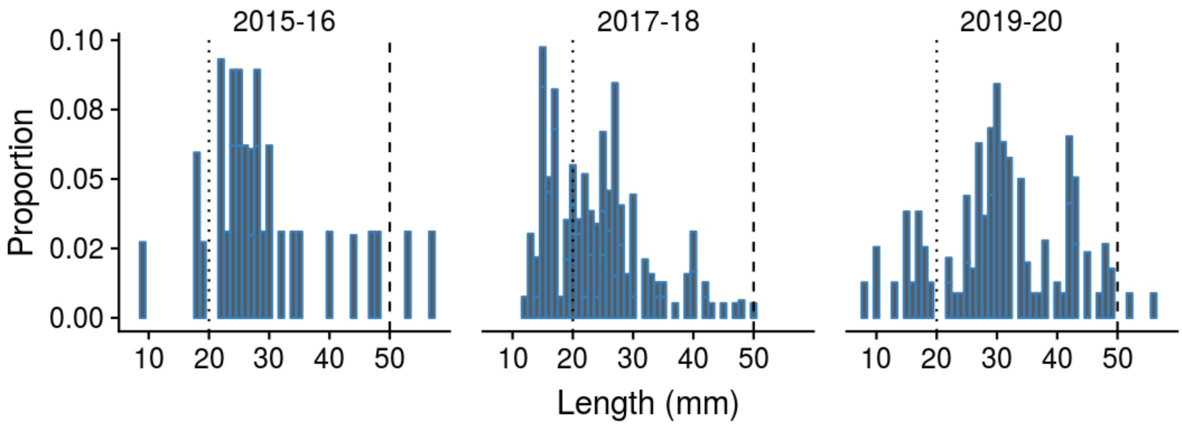


Figure 6: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.2 Cockle Bay

Cockle Bay is one of the survey sites in Auckland, and is a relatively small beach in one of the eastern suburbs. Since 2008, the beach has been closed to the collection of shellfish over summer, between 1 October to 30 April. Outside this seasonal closure, the bag limit is 50 cockles per gatherer per day. There is no discernible pipi population at this beach. The cockle population at this beach was first surveyed in 2009–10, with a total of seven surveys, including the present assessment; the most recent, preceding survey was in 2017–18 (see Appendix A, Tables A-1, A-2). The sampling extent has remained consistent across survey years, with a total of 70 points sampled across two strata.

Sediment samples at Cockle Bay were typically low in organic content, with one sample exceeding 5% (Figure 7, and see details in Appendix B, Table B-1). The sediment grain size was dominated by fine and very fine sands (grain sizes >125-µm and >63-µm), with only small fractions of coarser grain sizes. The proportion of sediment fines (grain size <63-µm) was variable, with relatively high proportions in some samples, up to 37.5%.

The distribution of cockles at this site extended from the upper to the lower shore areas, with most of the population in Stratum A (Figure 8, Table 7). The current population estimates were similar to values in the preceding survey in 2017–18, with a total abundance of 44.41 million (CV: 13.84%) cockles in 2019–20 (Table 8). The mean population density was 282 cockles per m^2. At the same time, there was a decrease in the population of large cockles (≥30-mm shell length) in 2019–20, with an estimated 11.75 million (CV: 15.81%) large cockles, occurring at a mean density of 75 individuals per m^2.

The decrease in the abundance and density of large cockles was evident in their proportion in the total population, which declined from 40.30% in 2017–18 to 26.46% in 2019–20 (Table 9). At the same time, the proportion of recruits (≤15-mm shell length) remained relatively unchanged, reflecting 12.27% of the total cockle population in the current assessment. Corresponding with the smaller population of large cockles, the mean and modal sizes showed a small decrease in 2019–20 to 23.58-mm and 18-mm shell length, respectively.

Considering the length-frequency distributions in the three most recent surveys, there was a discernible shift from a largely unimodal population of large individuals in 2015–16 to a bimodal population of small to medium-sized and of large cockles in 2017–18 (Figure 9). The current reduction in the proportion of large cockles led to a smaller cohort of this size class in 2019–20, in comparison with a stronger cohort of small-sized individuals. The increase in medium-sized cockles meant that this size class contributed to the former cohort.

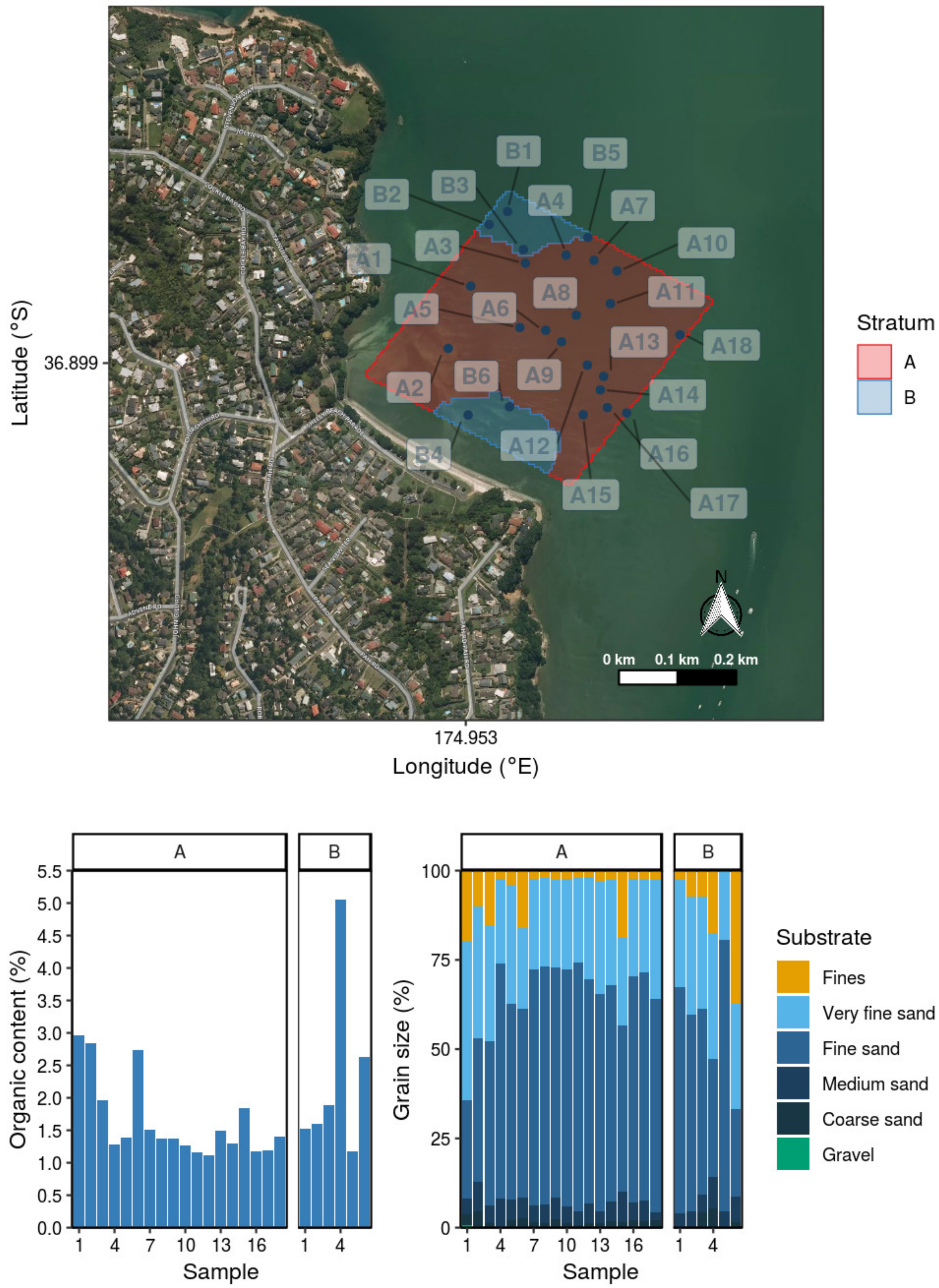


Figure 7: Sediment sample locations and characteristics at Cockle Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

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 2019–20. 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	565	42.71	323	14.25
B	2.5	20	47	1.70	67	50.85

Table 8: Estimates of cockle abundance at Cockle Bay for all sizes and large size ($\geq$30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population $\geq$ 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
2019–20	15.8	44.41	282	13.84	11.75	75	15.81

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 (%)
2015–16	31.82	37	7–50	5.66	71.65
2017–18	25.85	20	7–48	13.25	40.30
2019–20	23.58	18	5–47	12.27	26.46

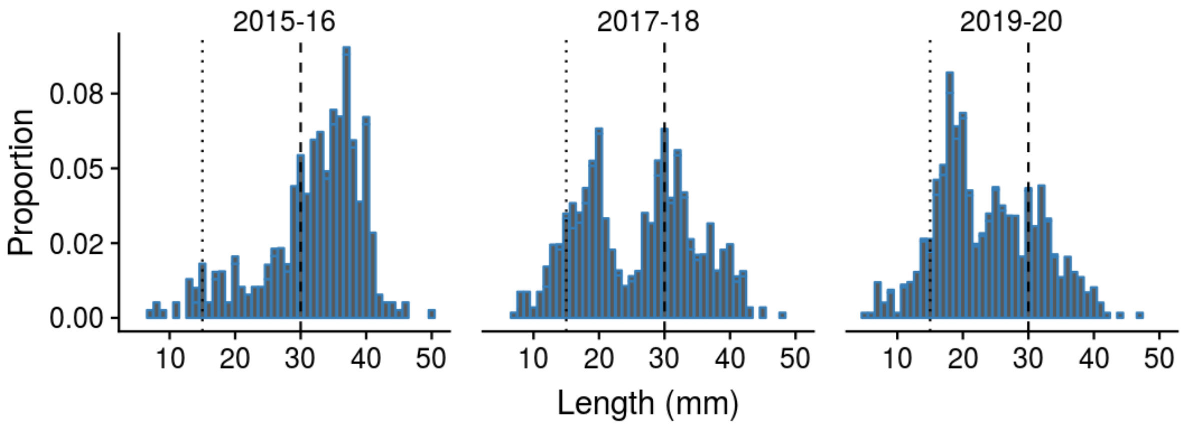


Figure 9: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Cockle Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3 Eastern Beach

Eastern Beach is a relatively long beach in one of Auckland's eastern suburbs. This beach has been permanently closed to the collection of shellfish since 1993 (Morrison et al. 1999). Within the current survey series, bivalves at Eastern Beach have been monitored in four previous surveys, most recently in 2016–17 (see Appendix A, Tables A-1, A-2). In this preceding survey, the sampling extent was re-stratified based on geo-referenced samples, and was also reduced in overall size (see Berkenbusch & Neubauer 2019). The same sampling extent was used in the current survey, with the field sampling based on 80 sampling points. Owing to the lack of pipi at this site, the current assessment focused on cockles only.

Sediment samples at Eastern Beach revealed a low organic content with a maximum value of 2.2% (Figure 10, and see details in Appendix B, Table B-1). The sediment grain size distribution was largely determined by fine and very fine sands (grain sizes $>$125-and $>$63-µm), with a small proportion of fines ($<$5%; grain size $<$63-µm); there was some variability in the coarser grain size fractions.

Cockles at Eastern Beach were distributed throughout most of the sampling extent, but scarce in the northern part, particularly stratum C (Figure 11, Table 10). Based on the 2019–20 survey data, the total abundance estimate for cockles was 117.16 million (CV: 12.98%) individuals, and density estimate was 519 cockles per m^2 (Table 11). Both these estimates documented decreases from the preceding survey in 2016–17, when the population consisted of 176.91 million (CV: 13.05%) individuals, at an average density of 784 cockles per m^2. Nevertheless, the current population estimates were still relatively high compared with early surveys. In addition, the cockle population continued to include large individuals ($\geq$30-mm shell length): their estimated abundance was 17.49 million (CV: 20.74%) cockles in 2019–20, with a density estimate of 77 large cockles per m^2.

The small increase in this size class indicated that the current decreases in the population estimates were not caused by a decline in large cockles. Instead, their contribution to the total population increased from 8.52% in 2016–17 to 14.93% in 2019–20 (Table 12). Although their current contribution to the total population was smaller than it was in 2014–15 (when it was 45.61%), this reduction in their overall contribution was caused by the marked increase in the total cockle population since then.

At the same time, the increase in the proportion of large cockles between 2016–17 and 2019–20 was accompanied by a decrease in the proportion of recruits ($\leq$15-mm shell length). Recruitment at this site has been low in the three most recent surveys, and in 2019–20 recruits made up 3.98% of the cockle population. Length-frequency distributions confirmed the prevalence of medium-sized cockles, which was also evident in the mean and modal sizes of 22- to 23-mm shell length in the unimodal population (Figure 12). Compared with the population size structure in 2016–17, the cohort of medium-sized cockles showed a shift towards larger sizes in 2019–20, confirming their growth towards the large size class threshold.

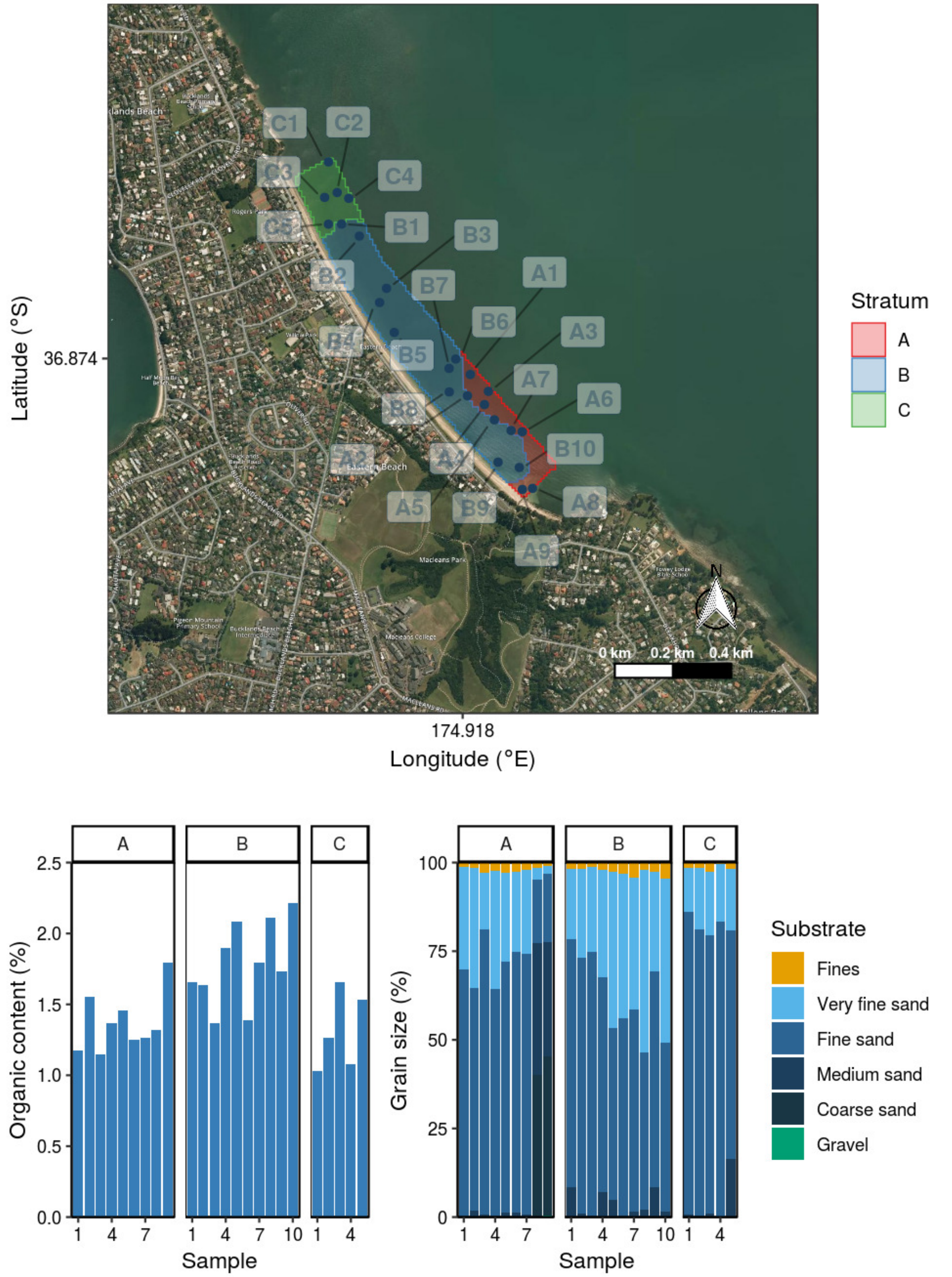


Figure 10: Sediment sample locations and characteristics at Eastern Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.3.1 Cockles at Eastern Beach

Figure 11: Map of sample strata and individual sample locations for cockles at Eastern 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 10: Estimates of cockle abundance at Eastern Beach, by stratum, for 2019–20. 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	3.5	20	141	7.00	201	40.82
B	15.7	50	1 227	109.87	701	13.59
C	3.4	10	3	0.29	9	>100

Table 11: Estimates of cockle abundance at Eastern Beach for all sizes and large size ($\geq$30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population $\geq$ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	48.0	6.39	13	17.17	0.00	0	
2001–02	43.4	13.07	30	17.58	3.00	7	29.93
2014–15	41.4	28.16	68	16.59	12.84	31	26.54
2016–17	22.6	176.91	784	13.05	15.07	67	17.38
2019–20	22.6	117.16	519	12.98	17.49	77	20.74

Table 12: Summary statistics of the length-frequency (LF) distribution of cockles at Eastern 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 (%)
2014–15	28.87	30	7–43	0.12	45.61
2016–17	21.54	17	8–42	7.66	8.52
2019–20	23.88	22	10–40	3.98	14.93

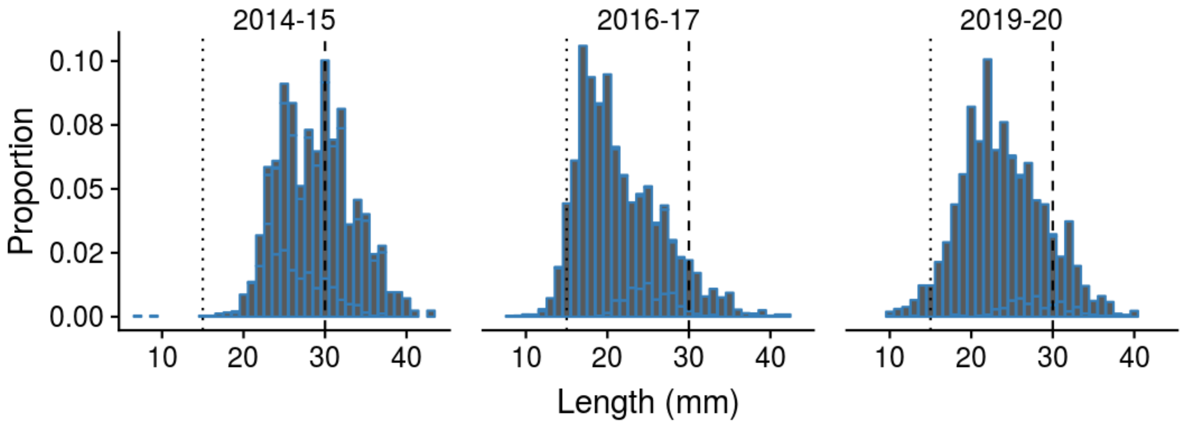


Figure 12: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Eastern Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4 Grahams Beach

Grahams Beach is an extensive beach on the western side of Manukau Harbour, close to the harbour entrance. The bivalve sampling at this site started in 2010–11, and there has been a total of five surveys since then, including the current study (see Appendix A, Tables A-1, A-2). The sampling extent has remained relatively unchanged throughout the survey series, with the current survey based on 90 sampling points across five strata (Figure 13, Table 13). Although there are no designated pipi beds at this site, both cockles and pipi were surveyed across the sampling extent.

Grahams Beach sediment was characterised by a low organic content (about 1 to 2%), exceeding 5% in only one sample (see details in Appendix B, Table B-1). The prevalent sediment grain size fraction was medium sand (grain size >250-µm), with smaller proportions of fine and coarse sands (grain sizes >125- and >500-µm), dependent on the stratum. Although most samples contained no or only a small proportion of sediment fines (grain size <63-µm), the maximum proportion of sediment in this grain size fraction was 16%.

The cockle population at Grahams Beach was restricted in its distribution, with most cockles in the upper-shore area in the central part of the sampling extent (Figure 14, Table 13). This area corresponded with stratum B, and there were few cockles in the other strata. Across the entire sampling extent, the current population estimates were a total of 11.40 million (CV: 19.89%) cockles and a density of 43 cockles per m^2 (Table 14). Both estimates were decreases from the preceding population estimates in 2016–17, but indicated a relatively large cockle population compared with earlier surveys in 2012–13 and 2013–14.

Large cockles (≥30-mm shell length) continued to be absent at this site, and this size class has been lacking throughout the survey series. In contrast, most of the population consisted of recruits (≤15-mm shell length), and these small-sized individuals contributed over 80% of the population in the two most recent surveys (Table 15, Figure 15). This finding highlighted the occurrence of substantial recruitment events at Grahams Beach, but the strong cohort of recruits in 2016–17 did not seem to contribute to larger size classes in 2019–20. This aspect was also evident in the mean and modal sizes, which were both below the cut-off size for recruits at 9- to 11-mm shell lengths in the two most recent surveys.

The pipi population at Grahams Beach showed a patchy distribution, and most pipi occurred on the upper shore (Figure 16, Table 16). Across all strata, there were only 68 pipi sampled, resulting in population estimates with a relatively high CV (i.e., 23.21%): the total abundance was 4.21 million pipi, and their density was 16 pipi per m^2 (Table 17). The current estimates documented a continued decrease in the pipi population in the two most recent surveys at this site, following relatively high estimates in 2013–14; however, the uncertainty associated with previous estimates was also high. There was a small number of large pipi (≥50-mm shell length) in 2019–20, with an estimated 0.34 million (CV: 48.11%) large individuals, occurring at a density of 1 large pipi per m^2.

Following their absence in 2016–17, large pipi made up 8.07% of the population in 2019–20 (Table 18, Figure 17). In comparison, recruits (≤20-mm shell length) constituted the largest size class and contributed over half (51.56%) of all individuals to the population. Recruits consistently dominated the population size structure at Grahams Beach in the three most recent surveys, but their current proportion signified a decline from the 2016–17 assessment, when 81.21% of the pipi population were recruits. This size class continued as a strong cohort in the bimodal population in 2019–20, and mean and modal sizes were correspondingly small, at 25.30-mm and 9-mm shell lengths, respectively.

Overall, these findings illustrate the lack of a distinct pipi population at Grahams Beach, with population data corresponding with the patchy distributions of mostly small-sized individuals.

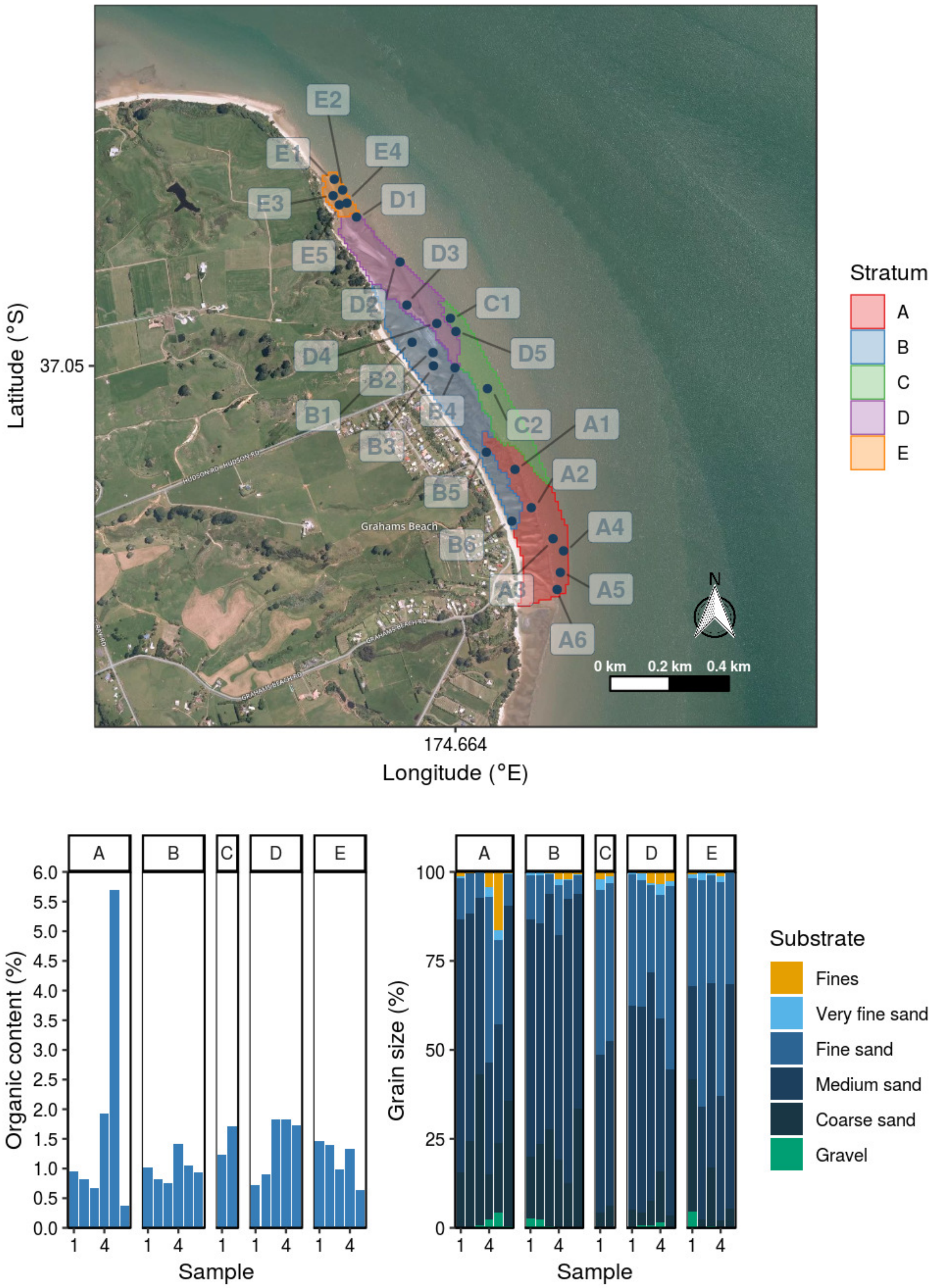


Figure 13: Sediment sample locations and characteristics at Grahams Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.4.1 Cockles at Grahams Beach

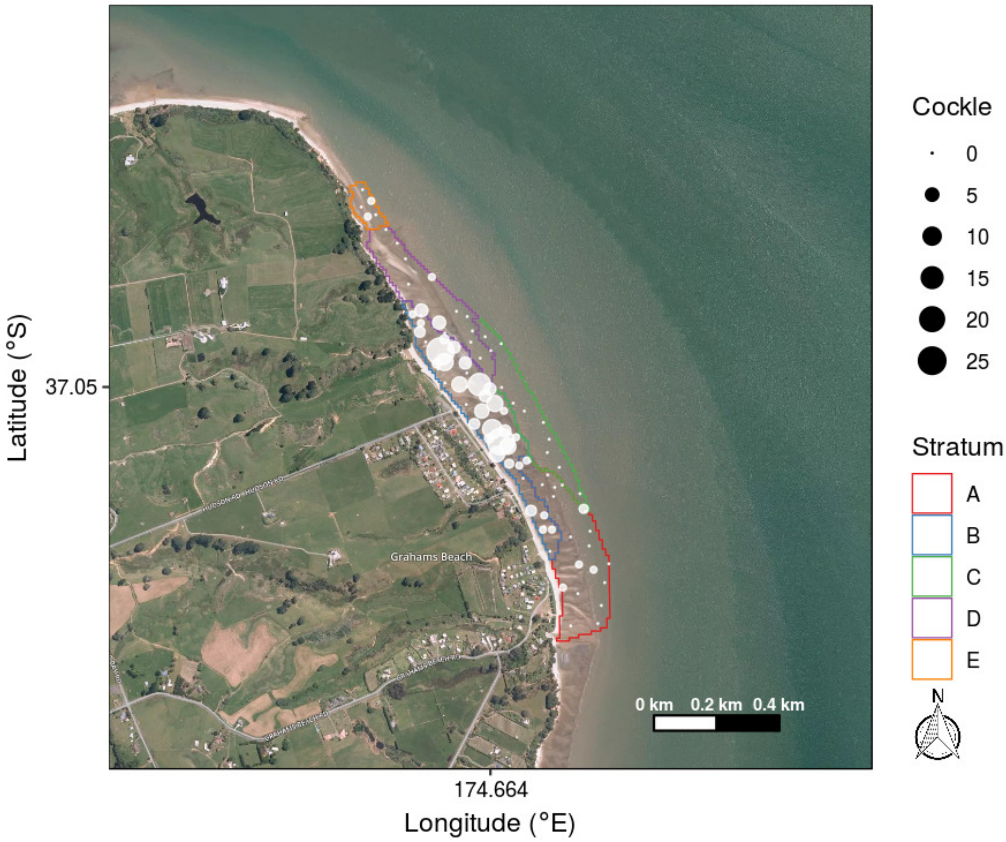


Figure 14: Map of sample strata and individual sample locations for cockles at Grahams Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of cockle abundance at Grahams Beach, by stratum, for 2019–20. 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	7.6	20	6	0.65	9	42.58
B	7.9	40	167	9.46	119	22.51
C	4.7	10	0	0.00	0	
D	5.6	15	11	1.18	21	61.66
E	1.0	5	2	0.11	11	61.24

Table 14: Estimates of cockle abundance at Grahams 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 (%)
2010–11	25.1	25.22	100	20.39	0.02	<1	>100
2012–13	20.1	4.23	21	21.00	0.00	0	
2013–14	26.8	4.70	18	19.10	0.12	<1	>100
2016–17	26.8	17.09	64	21.82	0.00	0	
2019–20	26.8	11.40	43	19.89	0.00	0	

Table 15: Summary statistics of the length-frequency (LF) distribution of cockles at Grahams 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	16.27	10	5–31	52.56	2.56
2016–17	11.13	9	5–25	84.33	0.00
2019–20	10.86	9	4–26	87.19	0.00

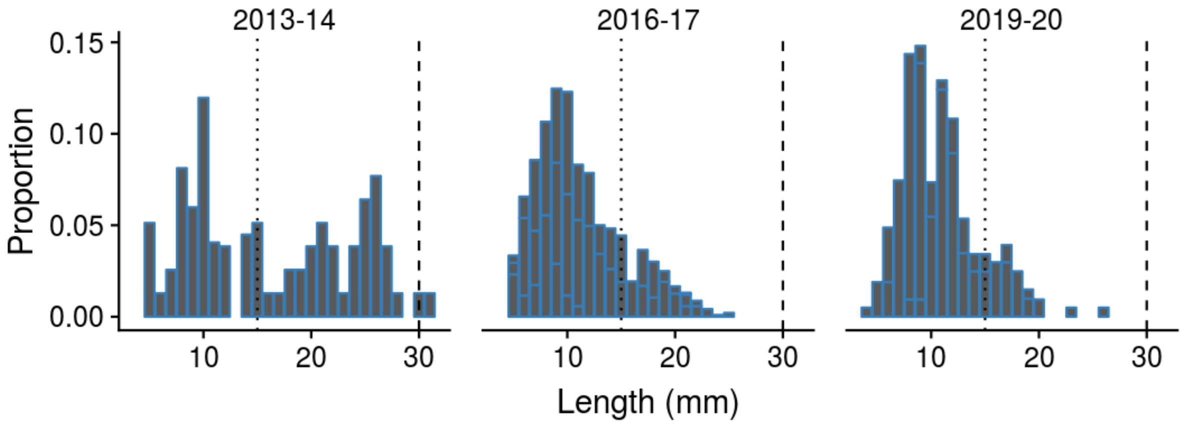


Figure 15: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Grahams Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4.2 Pipi at Grahams Beach

Figure 16: Map of sample strata and individual sample locations for pipi at Grahams 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 16: Estimates of pipi abundance at Grahams Beach, by stratum, for 2019–20. 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	7.6	20	5	0.54	7	81.43
B	7.9	40	33	1.87	24	32.73
C	4.7	10	0	0.00	0	
D	5.6	15	2	0.21	4	68.14
E	1.0	5	28	1.59	160	38.13

Table 17: Estimates of pipi abundance at Grahams 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 (%)
2010–11	25.1	3.75	15	27.65	0.00	0	
2012–13	20.1	2.93	15	35.01	0.00	0	
2013–14	26.8	12.34	46	21.63	0.06	<1	>100
2016–17	26.8	8.77	33	25.66	0.00	0	
2019–20	26.8	4.21	16	23.21	0.34	1	48.11

Table 18: Summary statistics of the length-frequency (LF) distribution of pipi at Grahams 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 (%)
2013–14	25.00	11	4–53	40.27	0.49
2016–17	13.93	8	2–48	81.21	0.00
2019–20	25.30	9	6–56	51.56	8.07

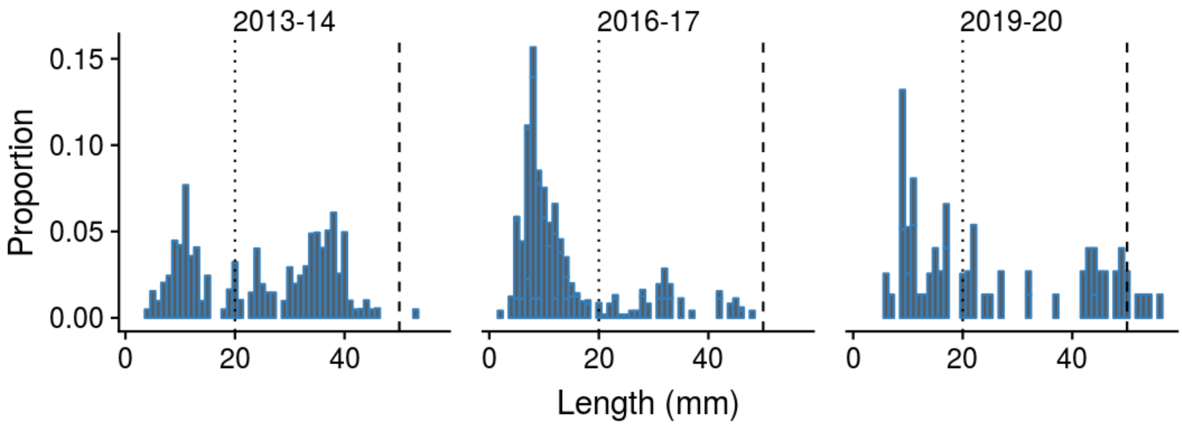


Figure 17: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Grahams Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5 Little Waihi Estuary

Little Waihi Estuary is a small estuary in Bay of Plenty. There have been 11 bivalve surveys in this estuary since 2000–01, including the current assessment (see Appendix A, Tables A-1, A-2). The sampling extent has remained similar in recent surveys (i.e., since 2009–10), encompassing the lower estuary. In the current survey, cockles and pipi were sampled in a total of 170 points, based on two sampling phases (i.e., 85 points in each phase).

The sediment in this estuary had a low organic content of less than 3.9% and a low proportion of sediment fines (grain size <63-µm), with a maximum of 4.3% in this grain size fraction (Figure 18, and see details in Appendix B, Table B-1). Most of the sediment consisted of fine and medium sands (grain sizes >125-µm and >250-µm), with smaller proportions in other grain size fractions.

The cockle population at Little Waihi Estuary was predominantly in the southern part of the sampling extent, in stratum A (Figure 19, Table 19). Within this stratum, cockles were distributed across both intertidal areas on either side of the main channel. Their total abundance in 2019–20 was 39.37 million (CV: 18.00%) cockles, and this estimate corresponded with an estimated average density of 235 cockles per m^2 (Table 20). Considering the cockle population over time, its abundance and density have fluctuated in recent surveys (i.e., since 2009–10), with the current estimates reflecting an increase to the largest total population size in the survey series.

Although the total cockle population underwent a recent increase, the population of large cockles ($\geq$30-mm shell length) remained relatively unchanged since the preceding survey in 2017–18. There were an estimated 0.26 million (CV: 42.8%) large individuals in this size class, and their density was 2 large cockles per m^2. Corresponding with their small population size, large cockles only made a minor contribution (0.66%) to the overall population, which consisted of similar proportions of recruits ($\leq$15-mm shell length) and of medium-sized cockles (Table 21).

The observed recent increase in recruits from 25.17% in 2017–18 to 43.93% in 2019–20 indicated the occurrence of a strong recruitment event prior to the field survey, which was reflected in the marked increase in the total cockle population. This aspect was also evident in the notable decreases in mean and modal shell lengths; for example, the modal size decreased from 20-mm to 7-mm shell length between 2017–18 and 2019–20. The length-frequency distributions of the three most recent surveys illustrated the shift from a unimodal population determined by a strong cohort of medium-sized cockles to a bimodal population size structure including a strong cohort of recruits in 2019–20 (Figure 20).

The pipi population at Little Waihi Estuary showed an opposite pattern to cockles, with their distribution restricted to the tidal channel in both strata (Figure 21, Table 22). Their total estimated abundance was 142.30 million (CV: 13.35%) individuals, corresponding with an average density of 849 pipi per m^2 (Table 23). Both these estimates were notable increases in the total population, and almost double the previous estimates in 2017–18; however, the pipi population at this site has shown considerable fluctuation throughout the survey series. Recent increases were also documented for large pipi ($\geq$50-mm shell length), and their estimated abundance was 15.59 million (CV: 18.74%) individuals in 2019–20, compared with 5.44 million (CV: 64.08%) individuals in 2017–18. The density of large pipi showed a similar three-fold increase, to an estimated 93 large pipi per m^2 in the current assessment.

The population size structure in this estuary was dominated by medium-sized pipi, whereas both large pipi and recruits ($\leq$20-mm shell length) only constituted 10.95% and 16.45% of the population, respectively (Table 24, Figure 22). Compared with the previous two surveys, the length-frequency distribution of pipi showed a shift from a unimodal to a bimodal population, with medium-sized pipi forming a strong cohort, compared with a smaller cohort of recruits. The mean and modal sizes of the 2019–20 pipi population were similar to the previous assessment at 35.41-mm and 44-mm shell length, respectively, albeit with a small increase in the latter population parameter.

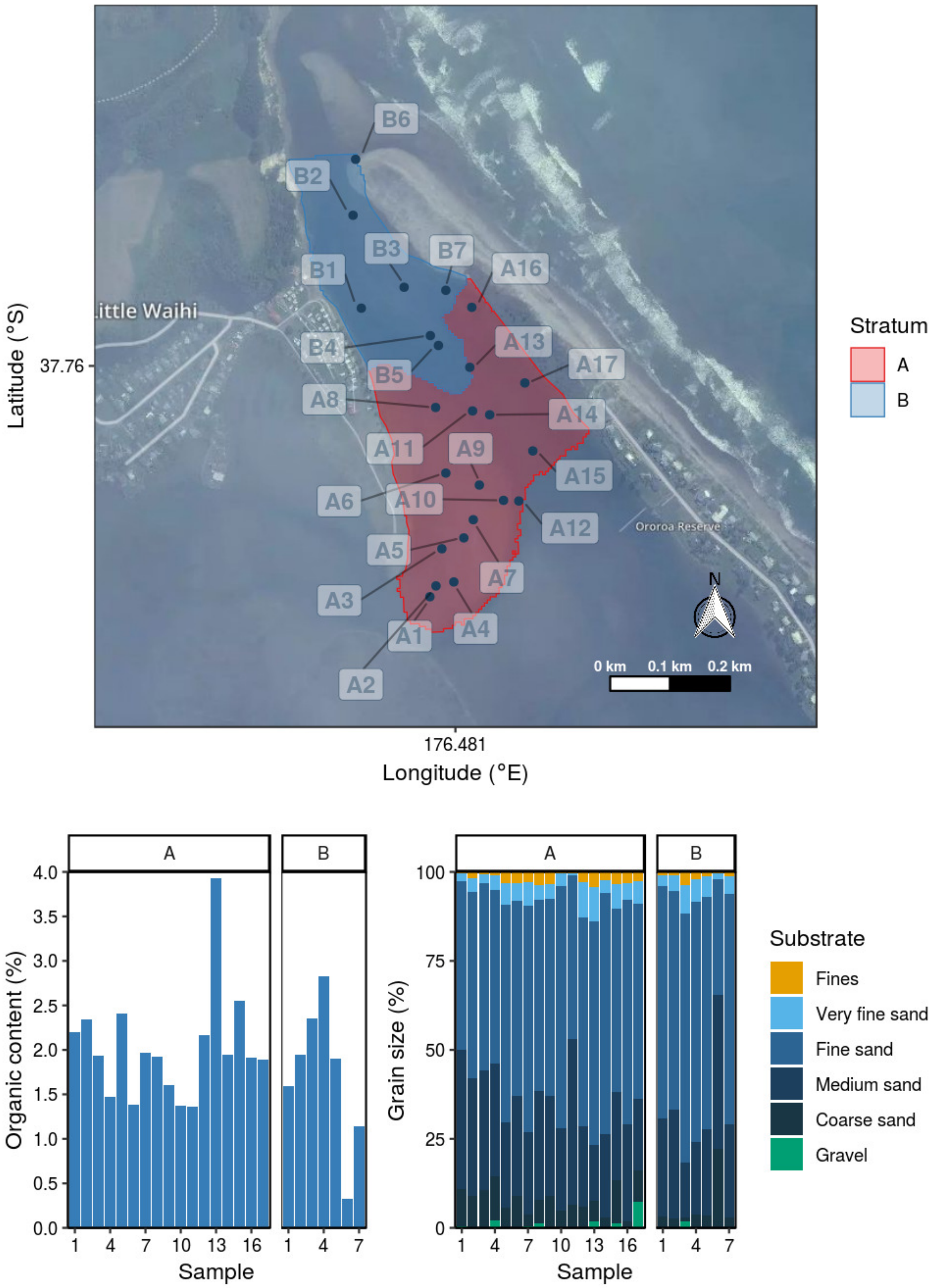


Figure 18: Sediment sample locations and characteristics at Little Waihi Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.5.1 Cockles at Little Waihi Estuary

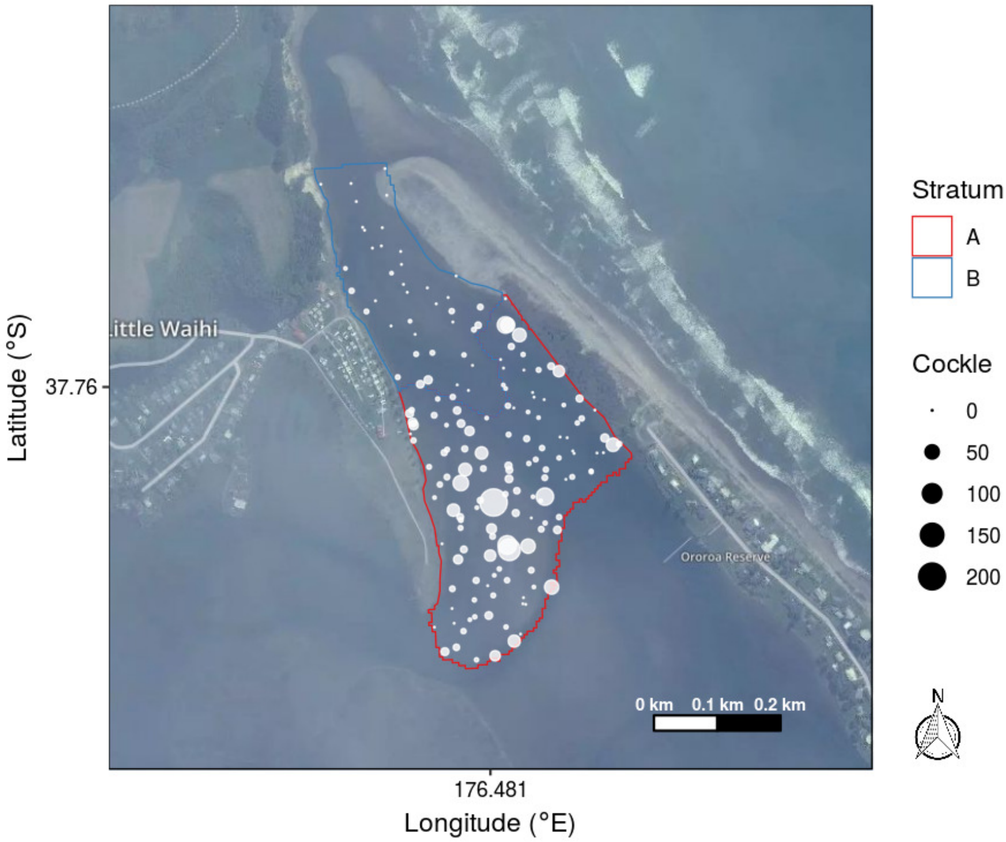


Figure 19: Map of sample strata and individual sample locations for cockles at Little Waihi Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of cockle abundance at Little Waihi Estuary, by stratum, for 2019–20. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	10.8	130	1 559	36.93	343	19.09
B	6.0	40	57	2.44	41	28.75

Table 20: 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	4	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	1	51.69
2017–18	18.4	15.50	84	26.09	0.36	2	>100
2019–20	16.8	39.37	235	18.00	0.26	2	42.8

Table 21: 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 (%)
2015–16	17.68	15	4–35	36.45	0.86
2017–18	19.03	20	6–32	25.17	2.33
2019–20	16.70	7	5–31	43.93	0.66

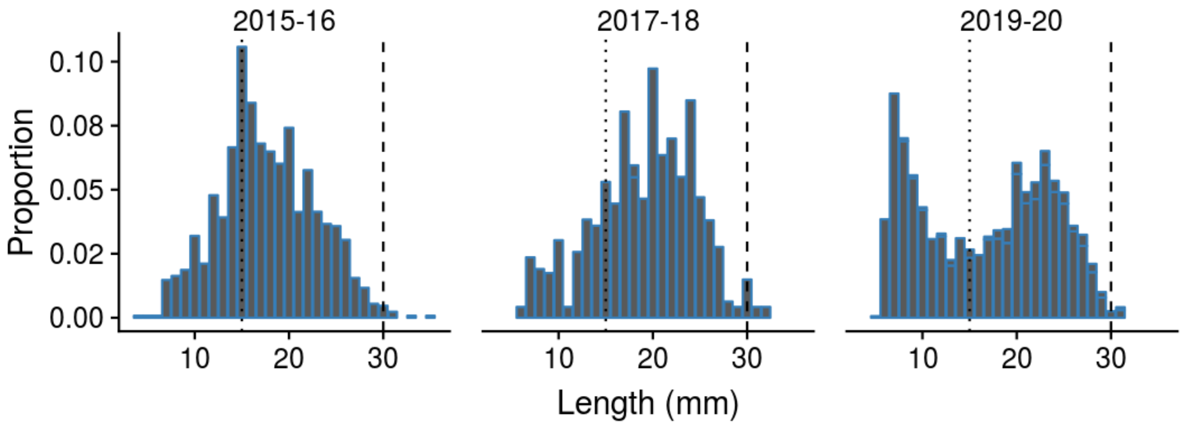


Figure 20: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5.2 Pipi at Little Waihi Estuary

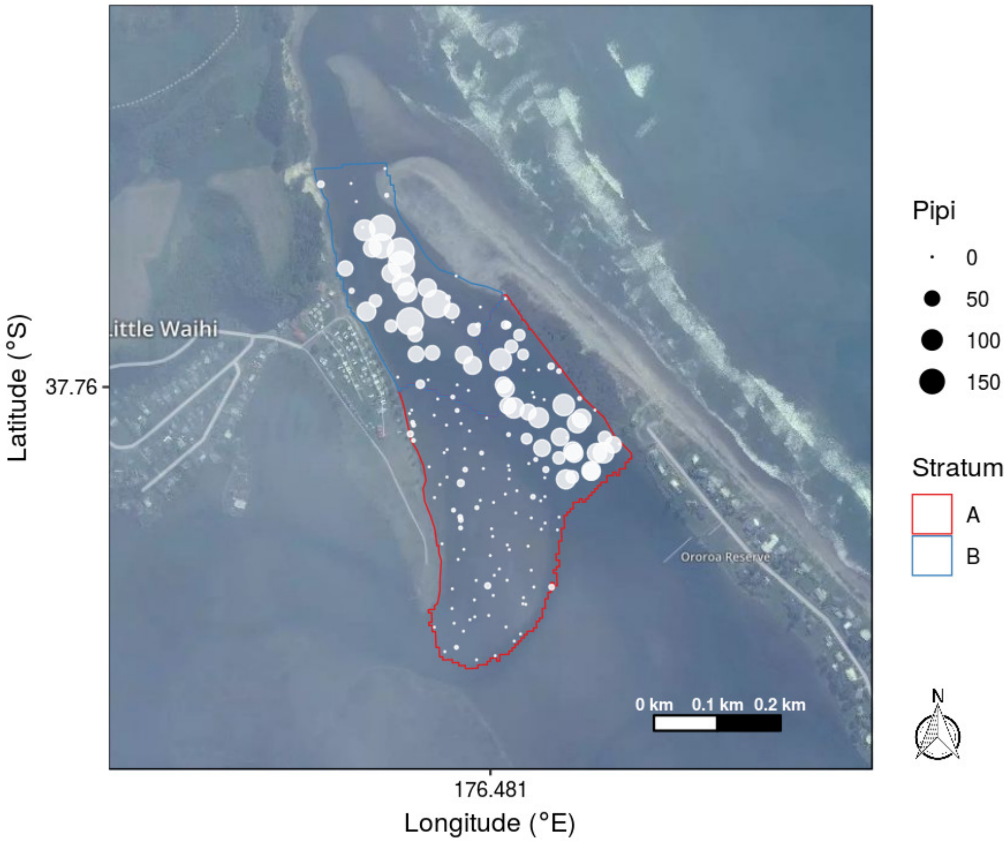


Figure 21: Map of sample strata and individual sample locations for pipi at Little Waihi Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 22: Estimates of pipi abundance at Little Waihi Estuary, by stratum, for 2019–20. 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	10.8	130	1 962	46.48	431	17.89
B	6.0	40	2 243	95.82	1 602	17.83

Table 23: 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	63	10.76
2009–10	13.9	271.99	1 954	11.54	10.12	73	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
2019–20	16.8	142.30	849	13.35	15.59	93	18.74

Table 24: 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 (%)
2015–16	31.88	32	5–57	16.01	2.81
2017–18	35.48	40	7–58	14.53	6.88
2019–20	35.41	44	1–58	16.45	10.95

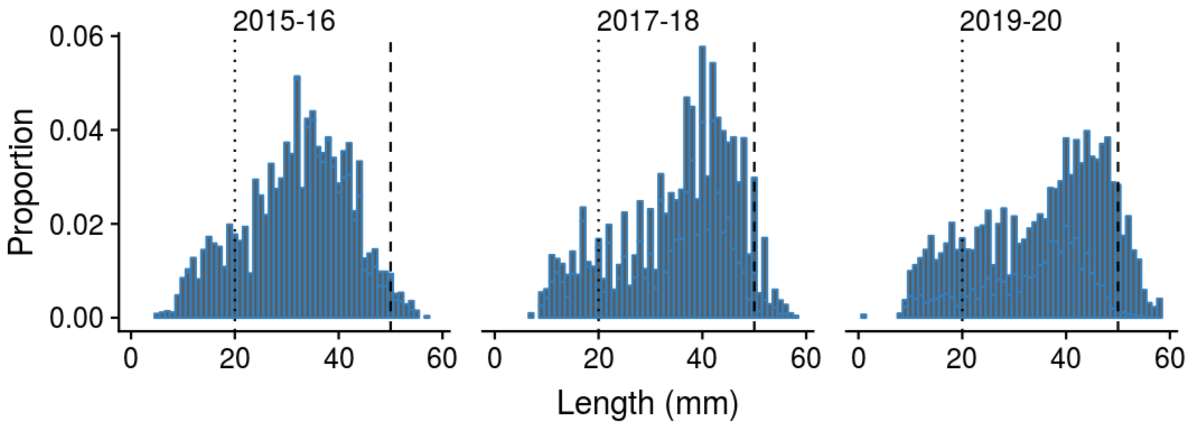


Figure 22: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Pataua Estuary

Pataua Estuary is one of the Northland survey sites and is a small estuary north of Whangārei. The estuary has been included in six previous surveys, with the 2017–18 assessment immediately preceding the current study (see Appendix A, Tables A-1, A-2). Since 2013–14, the sampling extent within the estuary has remained relatively unchanged, with small modifications to the spatial extent and location of pipi strata across surveys. In 2019–20, there were two cockle strata and one pipi stratum included in the field sampling, with a total of 80 sampling points.

The sediment samples from the cockle strata were similar in sediment organic content (<2.5%), but some of the samples varied in their sediment grain size distribution (Figure 23, and see details in Appendix B, Table B-1). Although the proportion of fines was generally small (maximum of 3%), and the main size fraction was fine sand (grain size >250-µm), there was some variation in the coarser grain size fractions, with some samples consisting of a relatively large proportion of coarse sand and gravel (grain sizes >500- and >2000-µm).

Cockles at Pataua Estuary were relatively evenly distributed throughout both strata A and B (Figure 24, Table 25). The 2019–20 population estimate for this species was a total of 362.52 million (CV: 12.71%) cockles, and their mean density was 1299 individuals per m^2 (Table 26). The current estimates were similar to values in recent surveys. Included in the total population was a small number of large cockles (≥30-mm shell length), and the current abundance of this size class was an estimated 3.96 million (CV: 44.65%) large cockles, which occurred at a density of 14 large individuals per m^2.

Owing to their low abundance, large cockles only made up a small proportion (1.09%) of the total population, in contrast to 28.48% of recruits (≤15-mm shell length) (Table 27, Figure 25). Recruits were part of the strong cohort dominated by medium-sized cockles, with mean and modal sizes of 18.41-mm and 17-mm shell length just above the threshold for the latter size class. The current population size structure was similar to length-frequency distributions in the two preceding surveys, showing little change in the unimodal size structure of the population.

The pipi bed in Pataua Estuary was in stratum D and was characterised by high abundance and density (Figure 26, Table 28). Current estimates for the total population were substantially higher than preceding estimates in 2017–18, increasing from 2.04 million (CV: 35.38%) to 9.45 million pipi (CV: 18.50%) in 2019–20, with the corresponding density increasing from 7 to 34 pipi per m^2 (Table 29). These increases resulted in the highest pipi population estimates since 2003–04. Throughout the survey series, there have been few large pipi (≥50-mm shell length) in the population, and their estimates had high uncertainty in most years. In 2019–20, this size class consisted of 0.05 million (CV: 52.35%) individuals, and their density was <1 large pipi per m^2.

Large individuals contributed 0.48% to the current pipi population (Table 30). There was also only a small proportion (8.16%) of recruits (≤20-mm shell length) in 2019–20, particularly compared with the preceding survey two years earlier, when recruits made up about a third of the pipi population in this estuary. The reduction in this size class and the concomitant increase in medium-sized pipi led to larger mean and modal sizes (Figure 27). The strong cohort of medium-sized pipi was centred around the modal shell length of 38 mm, following the change from a bimodal to a unimodal population size structure between the two most recent surveys.

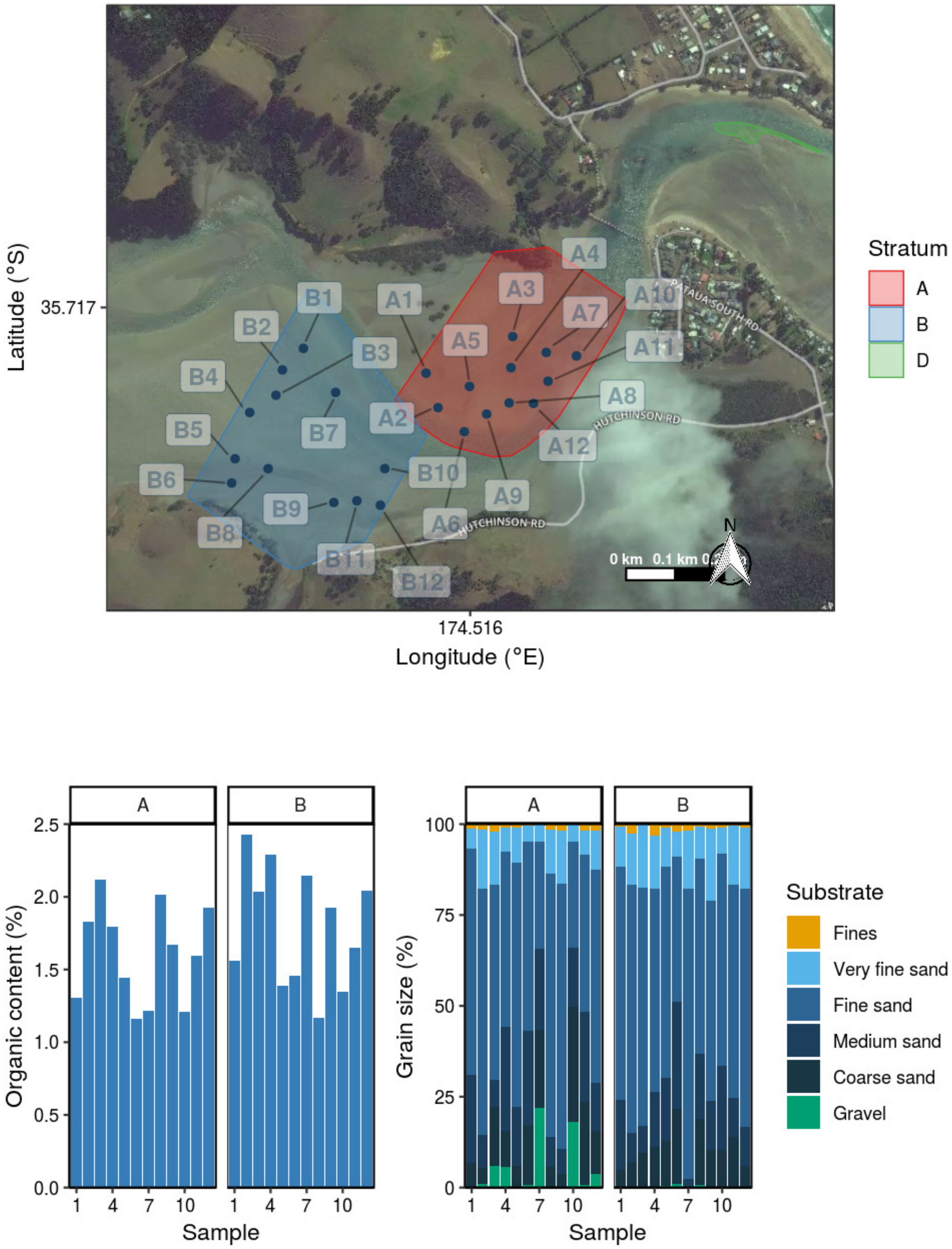


Figure 23: Sediment sample locations and characteristics at Pataua Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.6.1 Cockles at Pataua Estuary

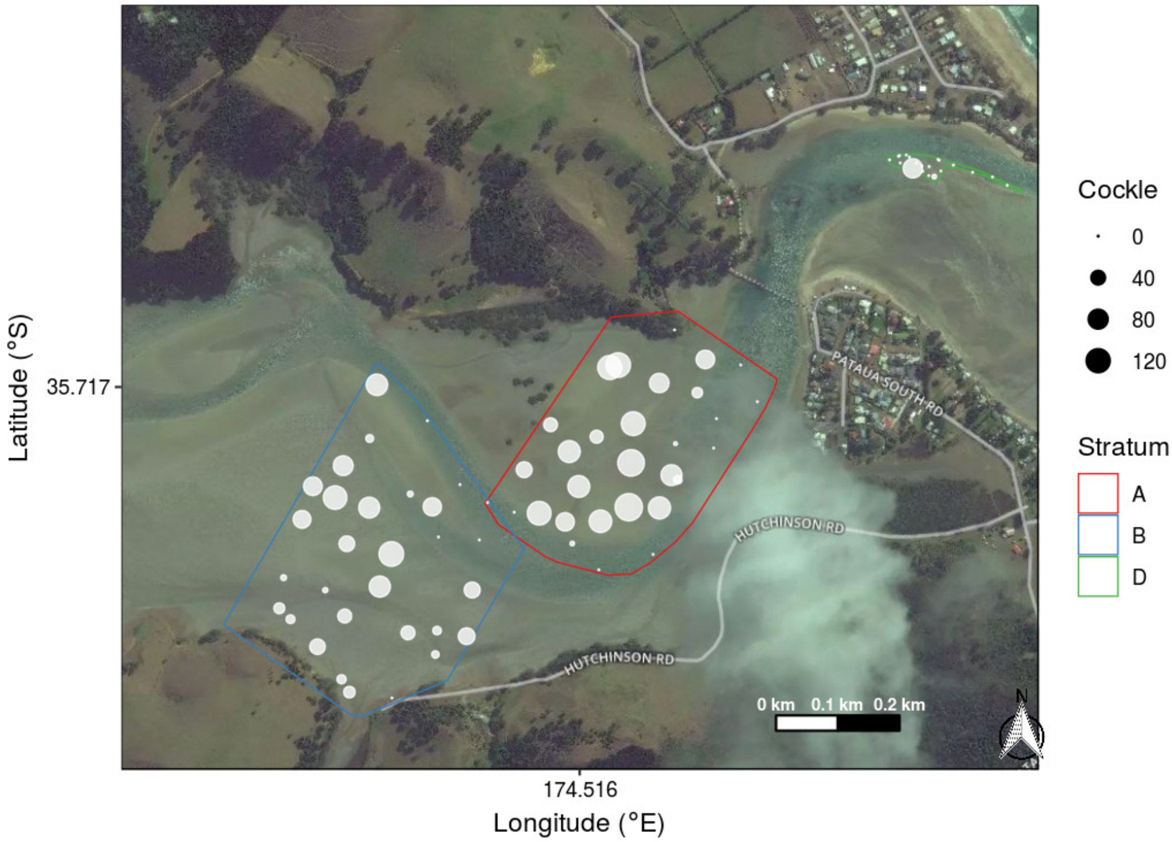


Figure 24: Map of sample strata and individual sample locations for cockles at Pataua Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 25: Estimates of cockle abundance at Pataua Estuary, by stratum, for 2019–20. 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	1 641	191.78	1 563	18.05
B	15.3	30	1 167	170.39	1 111	17.86
D	0.3	20	77	0.35	110	97.30

Table 26: 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	190	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
2019–20	27.9	362.52	1 299	12.71	3.96	14	44.65

Table 27: 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 (%)
2015–16	19.11	20	5–36	21.80	1.29
2017–18	17.73	17	4–35	30.76	1.12
2019–20	18.41	17	5–48	28.48	1.09

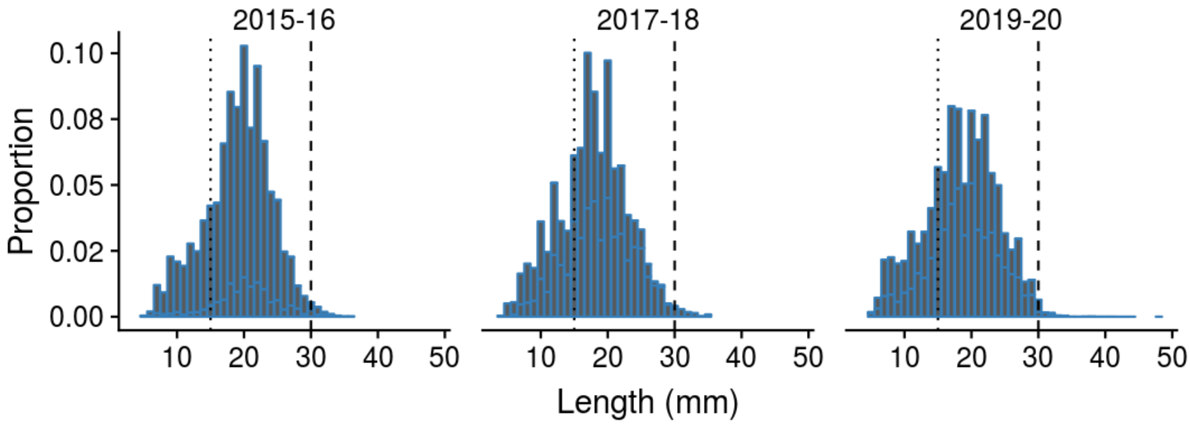


Figure 25: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6.2 Pipi at Pataua Estuary

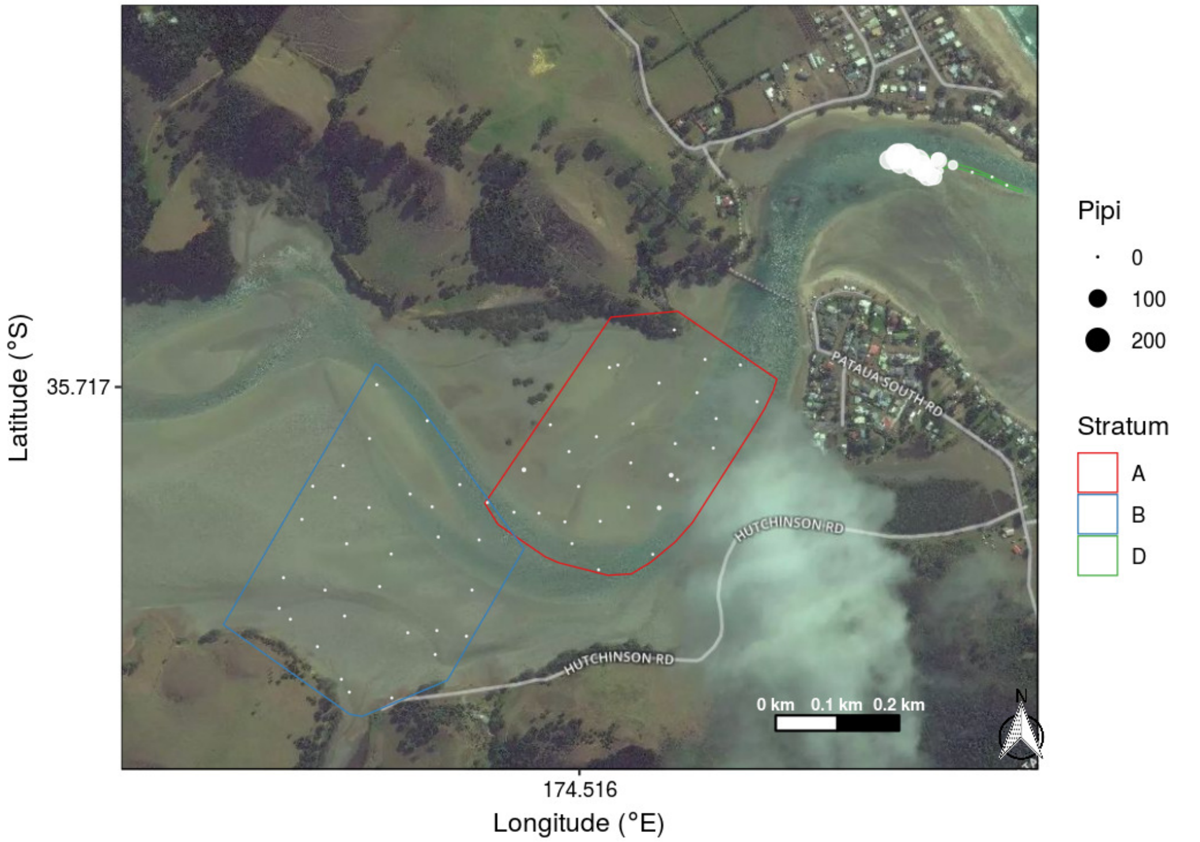


Figure 26: Map of sample strata and individual sample locations for pipi at Pataua Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 28: Estimates of pipi abundance at Pataua Estuary, by stratum, for 2019–20. 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	3	0.35	3	55.71
B	15.3	30	0	0.00	0	
D	0.3	20	2 030	9.10	2 900	19.10

Table 29: 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
2019–20	27.9	9.45	34	18.50	0.05	<1	52.35

Table 30: 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 (%)
2015–16	31.54	27	8–56	19.52	2.94
2017–18	28.17	15	11–59	30.87	9.24
2019–20	34.82	38	8–60	8.16	0.48

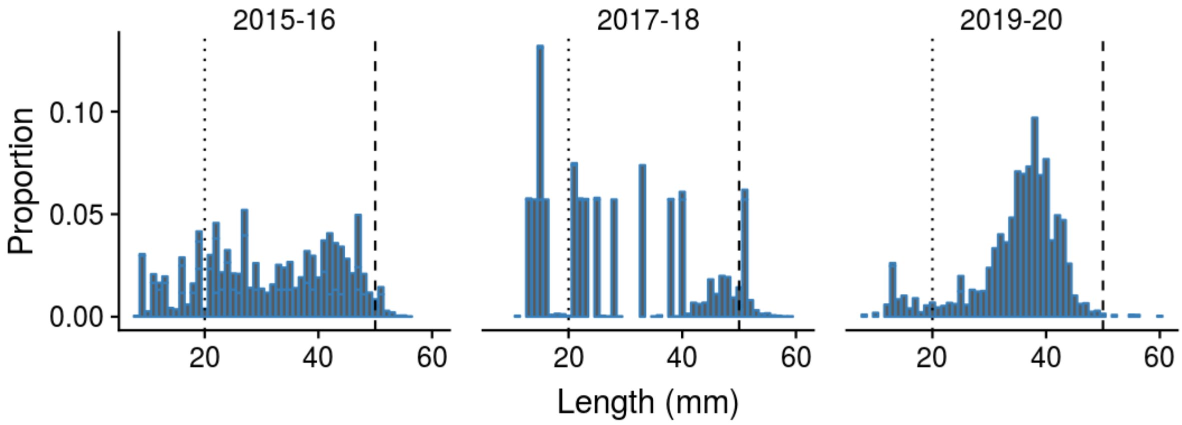


Figure 27: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7 Raglan Harbour

Raglan Harbour is on the west coast of the Waikato region and has been part of the northern survey series since 1999–2000; the most recent survey preceding the current assessment was in 2017–18 (see Appendix A, Tables A-1, A-2). The field sampling at this site has focused on two separate areas close to the harbour entrance, with a similar sampling extent since 2013–14. The current survey sampled 90 points across two separate cockle and one pipi strata.

Sediment in the cockle strata was low in organic content, usually about 1.5 to 2.0% (Figure 28, and see details in Appendix B, Table B-1). Most of the sediment was fine sand (grain size >125-µm), with a smaller proportion of very fine sand (grain size >63-µm), and little sediment in coarser grain size fractions. The proportion of fines (grain size <63-µm) was variable, and ranged between 2 and 14% across all samples.

Cockles at Raglan Harbour were predominantly in strata A and D, although their distribution extended into the pipi bed, where they occurred in relatively low numbers (Figure 29, Table 31). The current estimates for this population were 126.74 million (CV: 6.07%) individuals at an average density of 1716 cockles per m^2 (Table 32). These estimates were consistent with previous assessments, which indicated a stable population at this site, with small fluctuations over time (i.e., since 2009–10). Similarly, the current estimates for the small population of large cockles (≥30-mm shell length) were consistent with recent previous estimates: there were 2.15 million (CV: 22.01%) individuals in this size class in 2019–20, with an average density of 29 large cockles per m^2.

Based on their low abundance, large cockles contributed few individuals (1.70%) to the total population and had little influence on the population size structure (Table 33, Figure 30). At the same time, the population contained 17.71% recruits (≤15-mm shell length), with continued but variable recruitment throughout the three most recent surveys at this site. In 2017–18, these small-sized individuals constituted a small second cohort in the previously unimodal population. The concomitant increase in medium-sized cockles resulted in a comparatively strong cohort of this size class, which dominated the population size structure in 2019–20. This finding was reflected in the mean and modal sizes, which remained similar to previous shell lengths at about 20 mm.

The pipi bed at Raglan Harbour was in stratum C, with few pipi occurring in the cockle strata (Figure 31, Table 34). This species had an estimated population size of 3.03 million (CV: 13.52%) pipi in 2019–20, and occurred at an average density of 41 pipi per m^2 (Table 35). These population estimates indicated a marked increase in the total population, resulting in the highest abundance and density estimates in the survey series, although the population of large pipi (≥50-mm shell length) remained small. There were an estimated 0.12 million (CV: 55.64%) individuals in this size class, and their corresponding density was 2 large pipi per m^2.

The proportion of large pipi in the total population was small, constituting 3.95% of all individuals in 2019–20 (Table 36). At the same time, recruits (≤20-mm shell length) contributed 11.09% of individuals in 2019–20, reflecting a steady influx in juveniles which was also evident in the two preceding surveys. Although this size class of small individuals had some influence, medium-sized pipi have consistently determined the population size structure at Raglan Harbour (Figure 32). The prevalence of medium-sized pipi was evident in mean and modal sizes of 34.12-mm and 32-mm shell length, respectively.

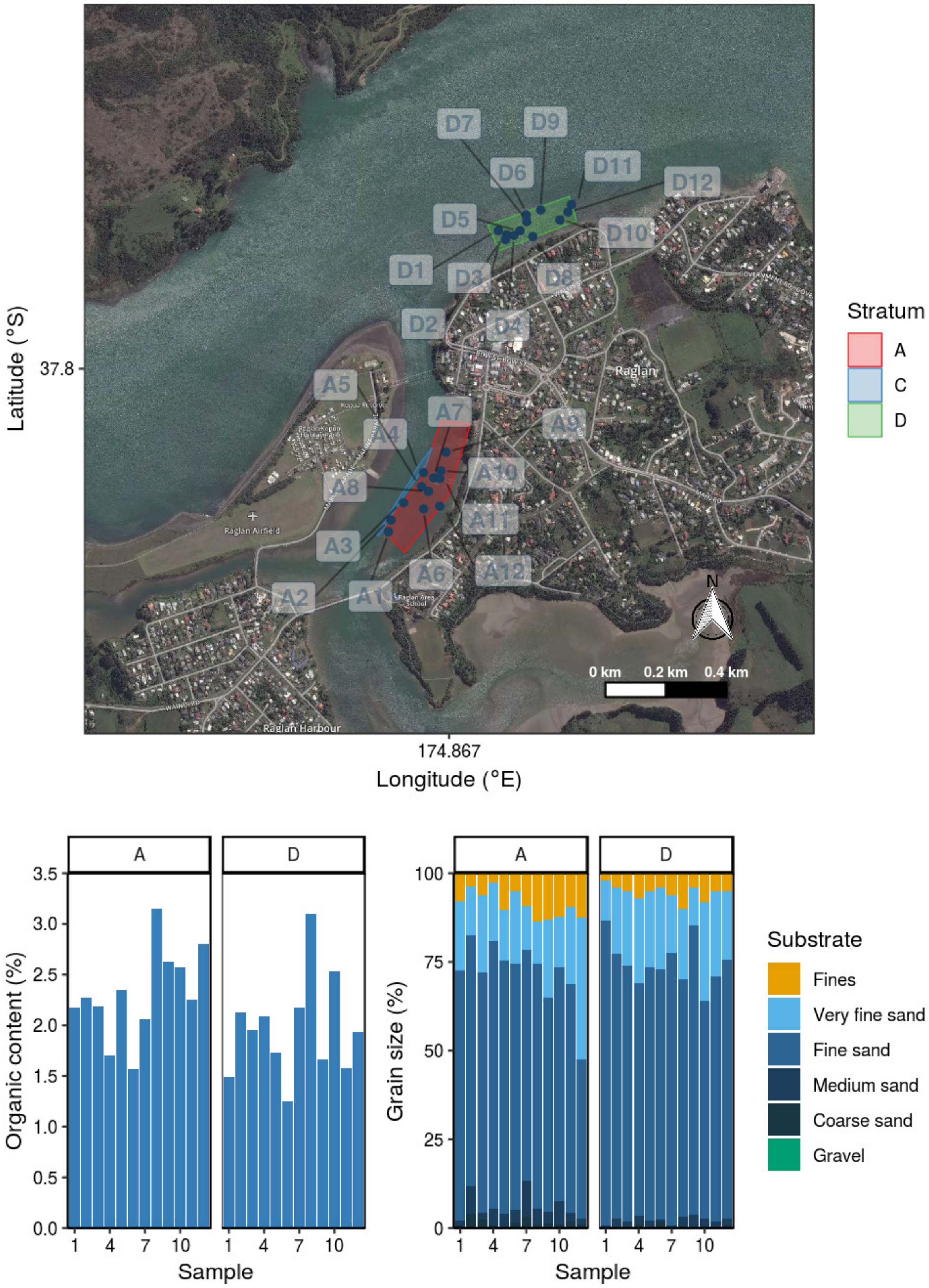


Figure 28: Sediment sample locations and characteristics at Raglan Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.7.1 Cockles at Raglan Harbour

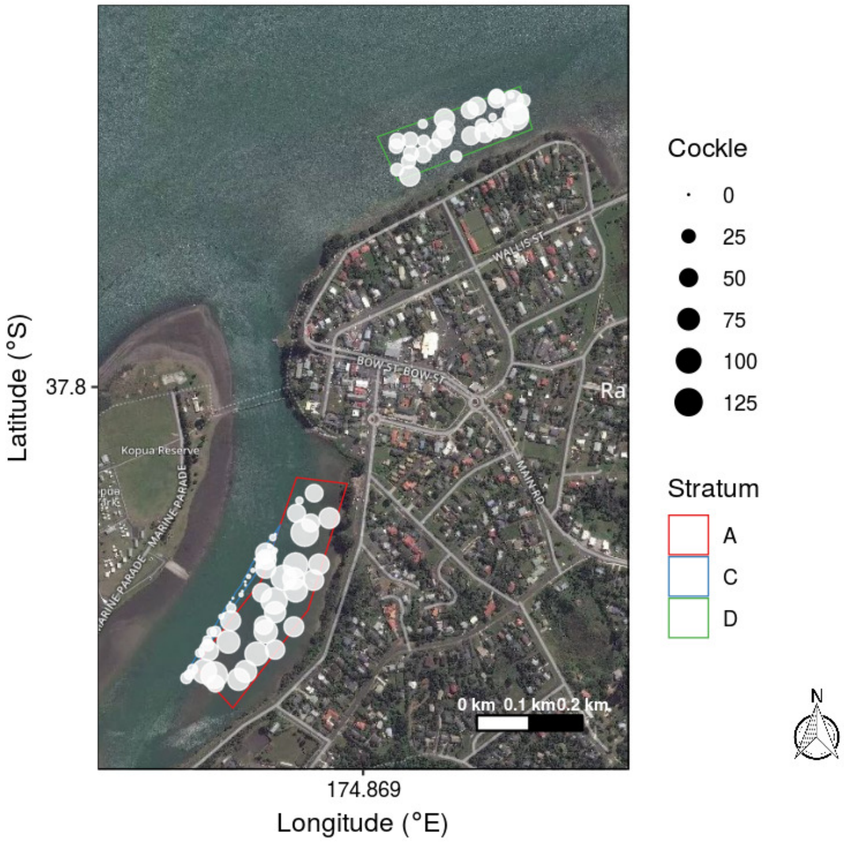


Figure 29: Map of sample strata and individual sample locations for cockles at Raglan Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of cockle abundance at Raglan Harbour, by stratum, for 2019–20. 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	2 207	95.69	2 102	7.33
C	0.4	30	279	0.97	266	33.05
D	2.5	30	1 281	30.08	1 220	10.43

Table 32: 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	64	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
2019–20	7.4	126.74	1 716	6.07	2.15	29	22.01

Table 33: 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 (%)
2014–15	21.61	22	6–39	9.87	2.22
2017–18	19.04	20	4–40	26.08	2.94
2019–20	20.02	20	4–36	17.71	1.70

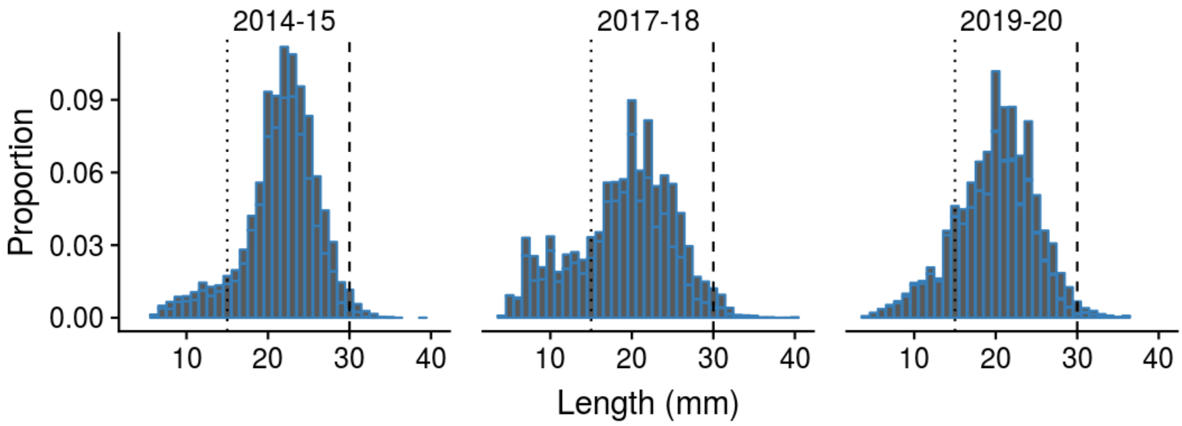


Figure 30: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Raglan Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7.2 Pipi at Raglan Harbour

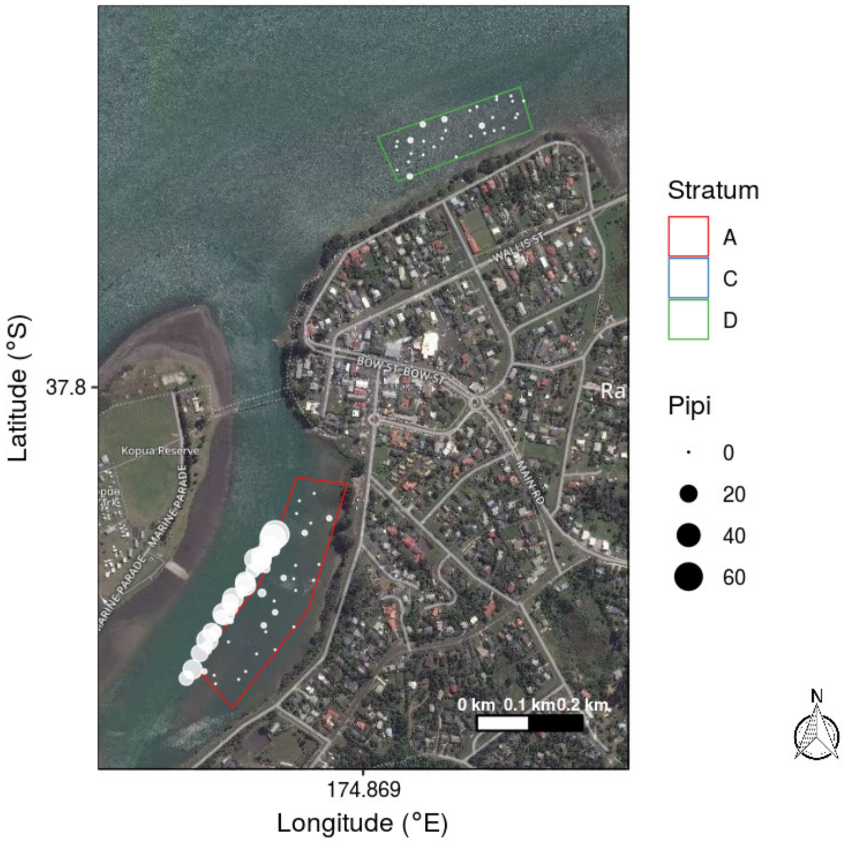


Figure 31: Map of sample strata and individual sample locations for pipi at Raglan Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of pipi abundance at Raglan Harbour, by stratum, for 2019–20. 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	20	0.87	19	33.99
C	0.4	30	585	2.04	557	13.70
D	2.5	30	5	0.12	5	41.52

Table 35: 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
2019–20	7.4	3.03	41	13.52	0.12	2	55.64

Table 36: 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 (%)
2014–15	37.49	43	8–59	5.83	6.09
2017–18	36.07	37	8–56	16.55	5.81
2019–20	34.12	32	10–57	11.09	3.95

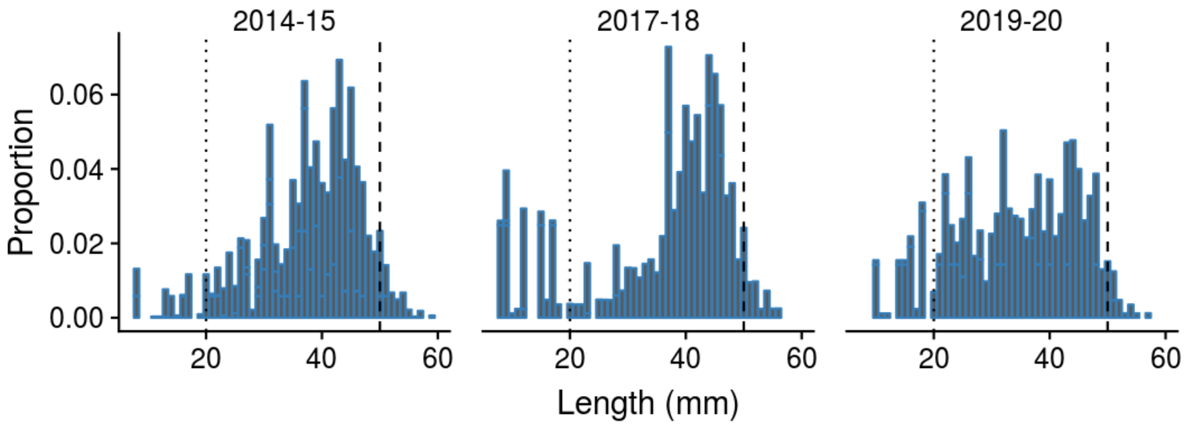


Figure 32: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Raglan Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Tairua Harbour

Tairua Harbour is one of the Waikato sites, situated on the eastern side of Coromandel Peninsula. The current assessment was the ninth bivalve survey in the northern monitoring series at this site, following on from the most recent survey in 2017–18 (see Appendix A, Tables A-1, A-2). Across the different surveys, cockle and pipi populations have been surveyed in several strata north and south of the main harbour channel, with changes to the sampling extent corresponding with changes to the pipi beds. These changes included the construction of a marina close to the pipi beds at the harbour entrance (between 2013–14 and 2015–16). The current sampling included five strata, with a pipi stratum each on either side of the channel. The sampling effort was a total of 90 sampling points across all strata.

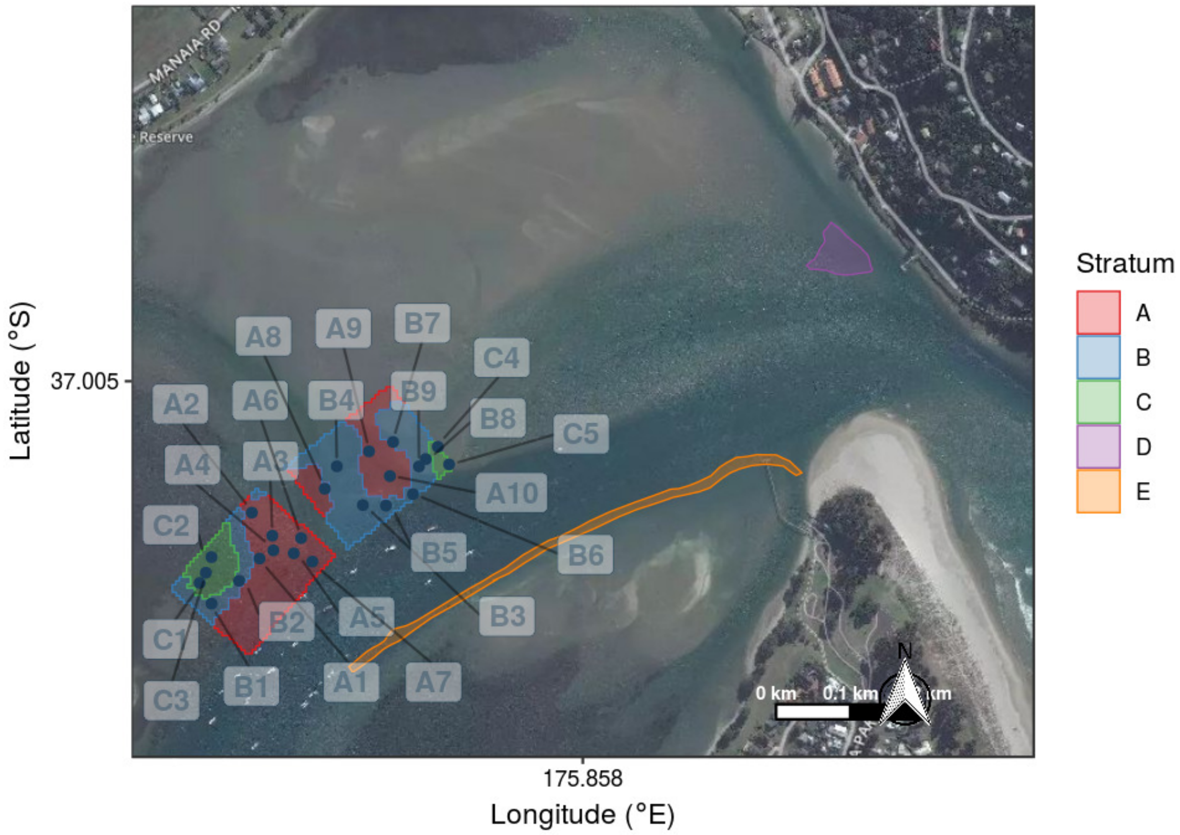
Tairua Harbour sediment in the cockle strata was variable in organic content (1.5 to 5.1%) and in sediment fines (0.3 to 11.7%; grain size $<$63-µm) (Figure 33, and see details in Appendix B, Table B-1). Other sediment grain size fractions were also variable, but were mostly fine and medium sands (grain sizes $>$125- and $>$250-µm). A number of samples also contained variable proportions of coarser sediment.

Cockles at Tairua Harbour were distributed throughout the sampling extent, but were predominantly in the cockle strata (Figure 34, Table 37). Their total abundance and density estimates signified an increase from previous estimates, and were the highest values in the survey series, even though the sampling extent has varied over this period: there were 74.73 million (CV: 9.88%) cockles in 2019–20, and their density was an average 1221 cockles per m^2 (Table 38). Included in these estimates was a small population of large cockles ($\geq$30-mm shell length), but this size class did not exhibit a similar increase, with an estimated 0.69 million (CV: 35.93%) large individuals at a mean density of 11 large cockles per m^2.

Throughout the survey series, large cockles continued to decline to low estimates that are accompanied by high uncertainty (i.e., CV values $>$20%). Owing to their decline, their proportion within the overall cockle population has become negligible (around 1%) in recent assessments; it was 0.92% in 2019–20 (Table 39). Whereas large cockles have become scarce, recruitment of small-sized individuals ($\leq$15-mm shell length) has been consistently about 20% in recent Tairua Harbour surveys. Their influence on the unimodal population size structure was illustrated in mean and modal sizes of about 20-mm shell length, corresponding with a cockle population composed of recruits and small to medium-sized individuals (Figure 35).

Pipi numbers were highest in the northern pipi bed, in stratum D, and also in high-density patches in the cockle strata associated with a side channel of the harbour (Figure 36, Table 40). Their estimated abundance was 18.89 million (CV: 19.23%) individuals, corresponding with an average density of 309 pipi per m^2 (Table 41). Both these estimates were marked decreases from abundance and density estimates in previous surveys, such as in 2017–18, when there were 31.67 million (CV: 9.29%) pipi, at a density of 489 individuals per m^2. Similarly, the small population of large pipi ($\geq$50-mm shell length) decreased from 3.52 million (CV: 21.56%) pipi in 2017–18 to 0.34 million (CV: 32.27%) large pipi in 2019–20, with their corresponding density estimates declining from 54 to 6 large pipi per m^2 between these two surveys.

Corresponding with the marked reduction in the large pipi size class, their proportion in the overall population declined from 11.13% in 2017–18 to 1.83% in 2019–20 (Table 42). There was also a decrease in the proportion of recruits ($\leq$20-mm shell length) to 15.44% of the total population, compared with 23.20% in 2017–18; however, this size class continued to constitute a small second cohort in the bimodal population, similar to the length-frequency distribution in two years earlier (Figure 37). Concomitant with the lower recruitment was an increase in the strong cohort of medium-sized pipi, and population size parameters reflected the prevalence of this size class, e.g., the modal shell length was 40 mm.



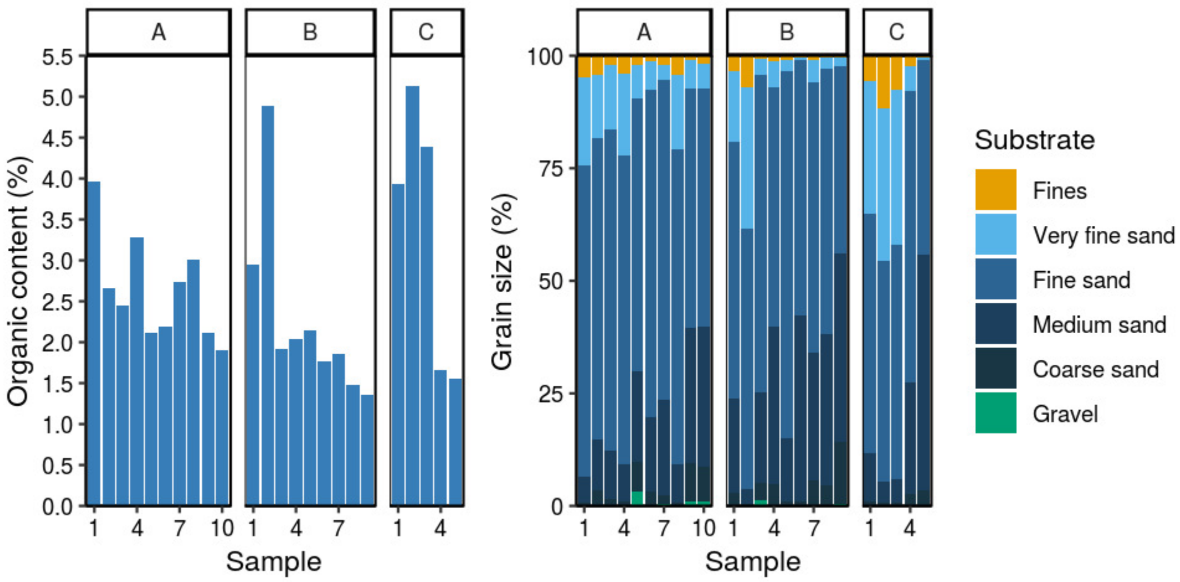


Figure 33: Sediment sample locations and characteristics at Tairua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.8.1 Cockles at Tairua Harbour

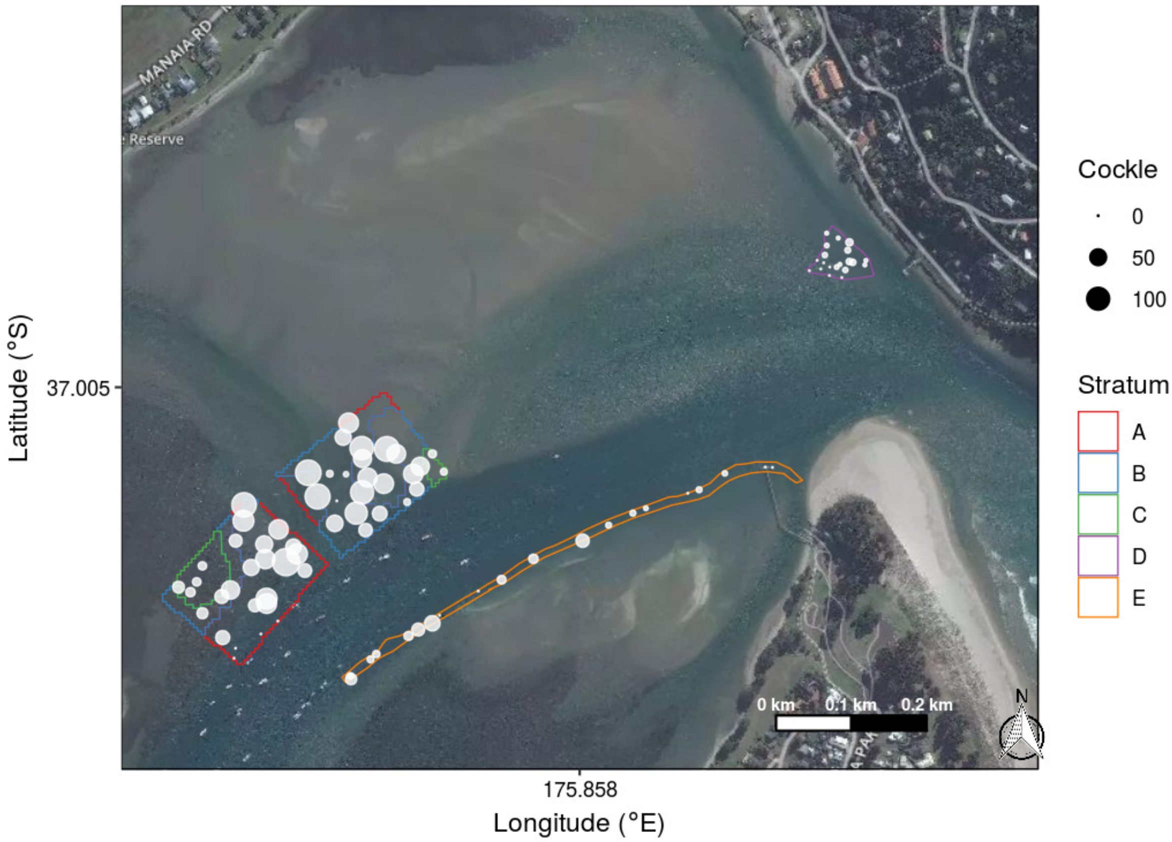


Figure 34: Map of sample strata and individual sample locations for cockles at Tairua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 37: Estimates of cockle abundance at Tairua Harbour, by stratum, for 2019–20. 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	25	1 568	45.61	1 792	12.89
B	2.0	20	905	25.51	1 293	17.38
C	0.5	5	48	1.43	274	11.69
D	0.3	20	36	0.18	51	25.68
E	0.7	20	191	2.00	273	27.54

Table 38: Estimates of cockle abundance at Tairua Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

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	121	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
2019–20	6.1	74.73	1 221	9.88	0.69	11	35.93

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2015–16	19.38	20	5–35	18.16	0.64
2017–18	19.61	22	5–35	21.50	1.44
2019–20	19.14	20	5–34	20.64	0.92

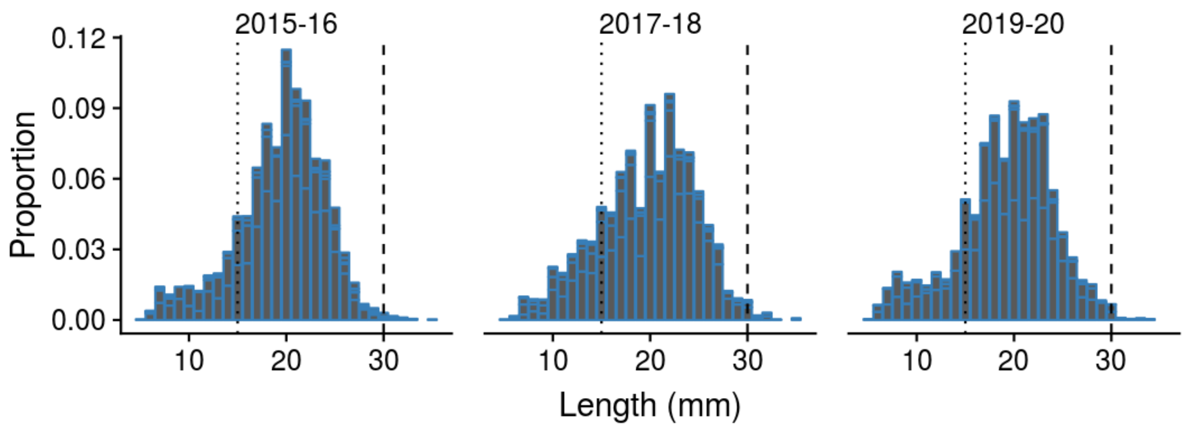


Figure 35: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8.2 Pipi at Tairua Harbour

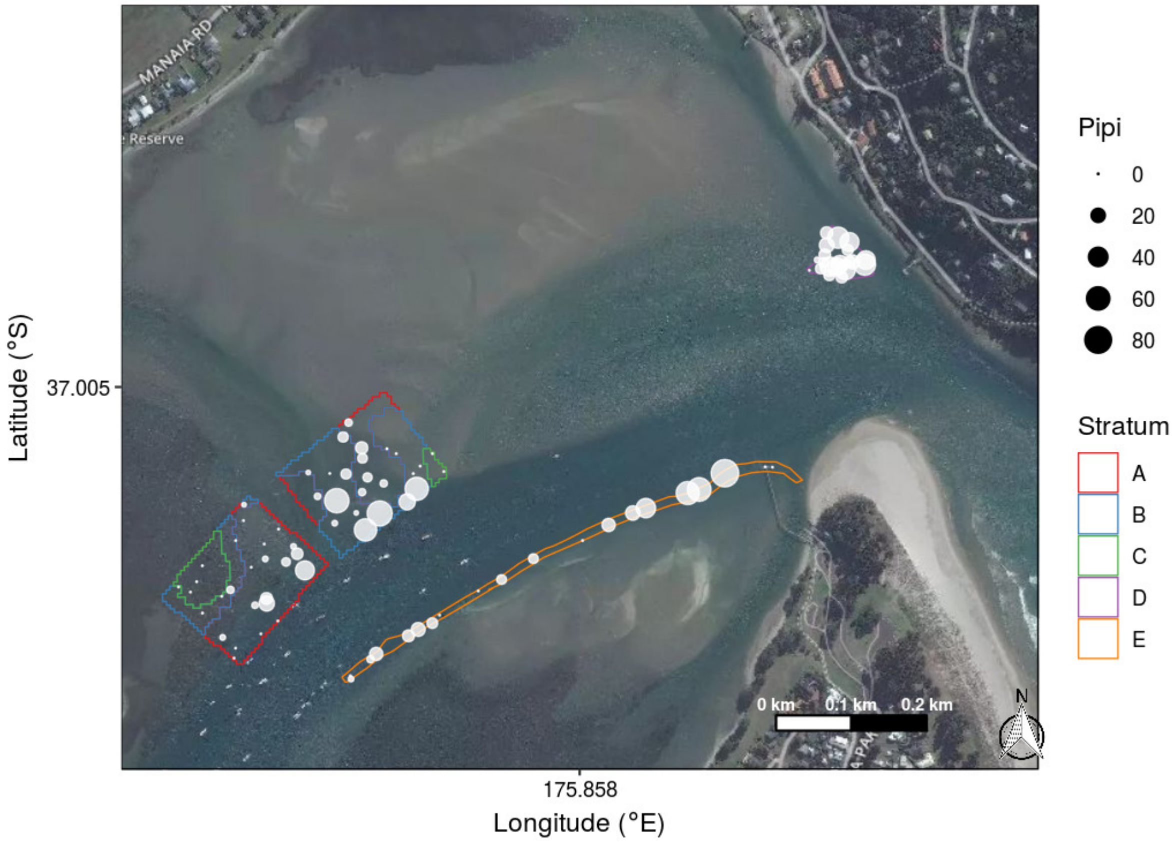


Figure 36: Map of sample strata and individual sample locations for pipi at Tairua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 40: Estimates of pipi abundance at Tairua Harbour, by stratum, for 2019–20. 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	25	147	4.28	168	30.21
B	2.0	20	303	8.54	433	37.22
C	0.5	5	0	0.00	0	
D	0.3	20	457	2.26	653	15.77
E	0.7	20	365	3.82	521	29.86

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	3.7	9.41	254	6.56	3.81	103	5.79
2000–01	3.9	8.35	214	6.25	2.11	54	7.78
2001–02	3.9	4.28	110	11.30	0.84	22	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	18	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	14	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
2019–20	6.1	18.89	309	19.23	0.34	6	32.27

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2015–16	36.58	40	8–52	6.72	1.41
2017–18	33.95	42	7–65	23.20	11.13
2019–20	33.70	40	5–55	15.44	1.83

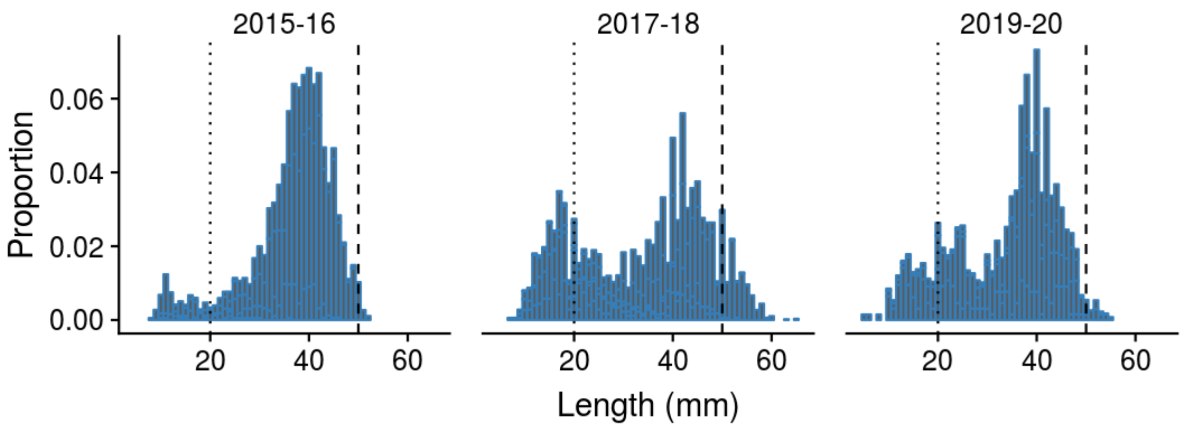


Figure 37: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9 Umupuia Beach

Umupuia Beach is a sheltered site in Auckland's southeastern metropolitan area and is part of the Hauraki Gulf Marine Park. This beach has been closed to cockle collections since October 2008, when a rāhui (total closure) was implemented. The beach has been frequently sampled in the northern monitoring series, with fifteen surveys since 1999–2000, including the current assessment (see Appendix A, Tables A-1, A-2). The sampling at this beach has encompassed most of the bay, from the upper to the lower intertidal areas, and the sampling extent has remained similar throughout the survey series. There is no discernible pipi population at this beach, so that the surveys have solely focused on cockles. The 2019–20 field survey sampled cockles in a total of 90 points.

The sediment at Umupuia Beach had a variable organic content, ranging from 1.0 to 6.6% (Figure 38, and see details in Appendix B, Table B-1). In addition, there was considerable variation in the sediment grain size composition, most notably in the proportion of fines (grain size $<$63-µm): although it was generally less than 8%, values of this sediment size fraction ranged between 27.4 and 69.1% in three of the samples. The largest proportions of sediment were very fine and fine sands (grain sizes $>$65-µm and $>$125-µm), with only small amounts of sediment in coarser size fractions.

Most cockles were in stratum A, with only two individuals in stratum B (Figure 39, Table 43). The current population estimates were a total abundance of 90.05 million (CV: 18.45%) cockles, and a mean density of 269 cockles per m^2 (Table 44). Both population estimates were similar to values in the preceding two surveys, indicating a stable population; however, these recent estimates were notably lower than estimates in earlier surveys, such as in 2013–14, when the population consisted of 170.35 million (CV: 16.79%) individuals, and their mean density was 503 cockles per m^2.

Irrespective of population fluctuations, the Umupuia Beach cockle population has typically included a large proportion of large cockles ($\geq$30-mm shell length), and this size class continued to be abundant in 2019–20: the current population estimate was 32.61 million (CV: 21.90%) large cockles, and their average density was 98 large cockles per m^2. Both estimates reflected a recent decrease in large cockles and were the lowest estimates of this size class since 2012–13.

Nevertheless, 36.21% of the current Umupuia Beach population consisted of large individuals, which largely shaped the population size structure (Table 45, Figure 40). Although there was a small decrease in modal length (from 30-mm shell length in 2017–18 to 27-mm shell length in 2019–20), the unimodal population consisted of a strong cohort of medium-sized and large individuals. There was a small proportion of recruits ($\leq$15-mm shell length) in the previous two surveys, but the near absence of these small-sized individuals, i.e., 0.48% in the current population indicated the lack of a recruitment event prior to the survey.

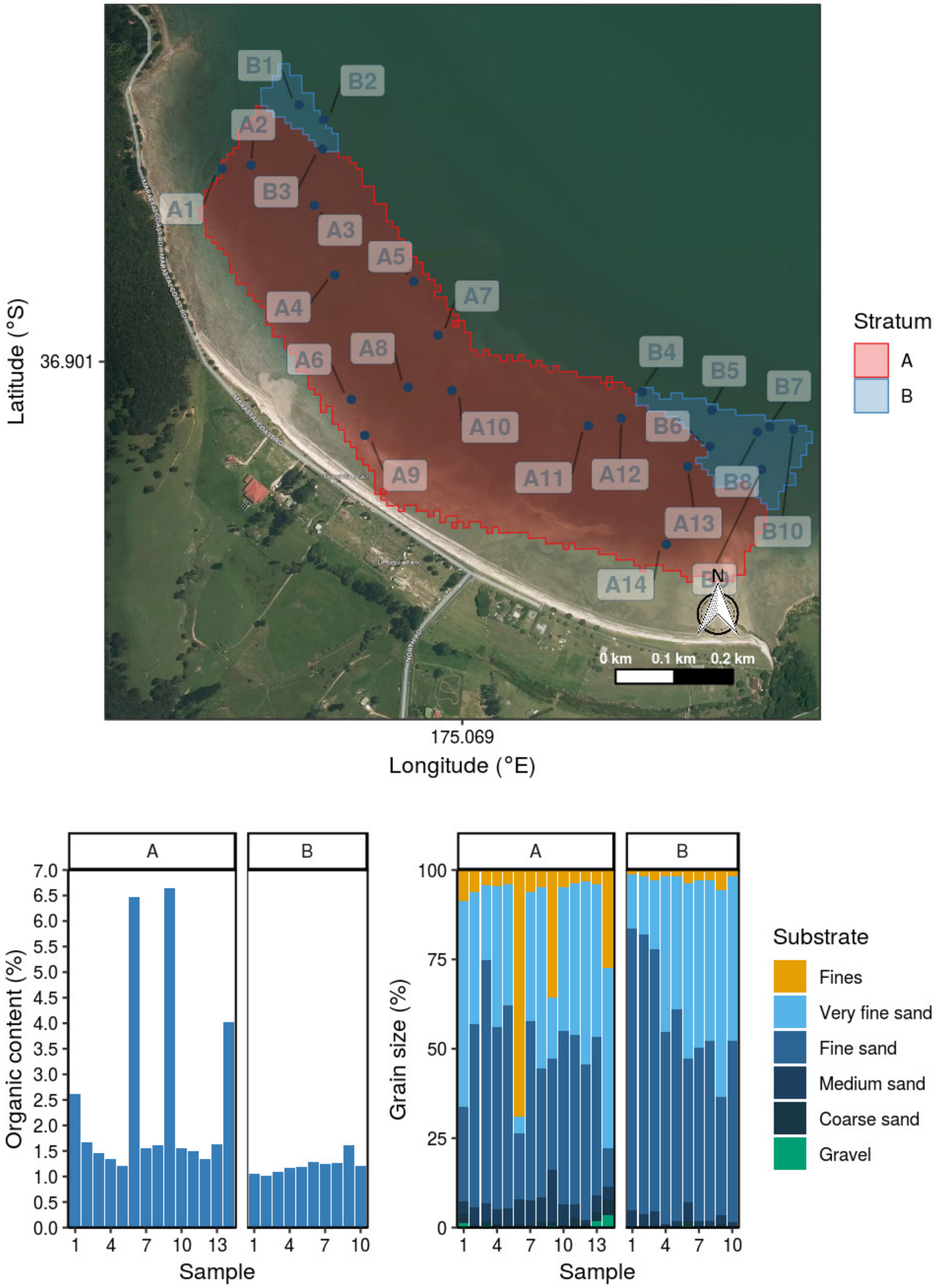


Figure 38: Sediment sample locations and characteristics at Umupuia Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.9.1 Cockles at Umupuia Beach

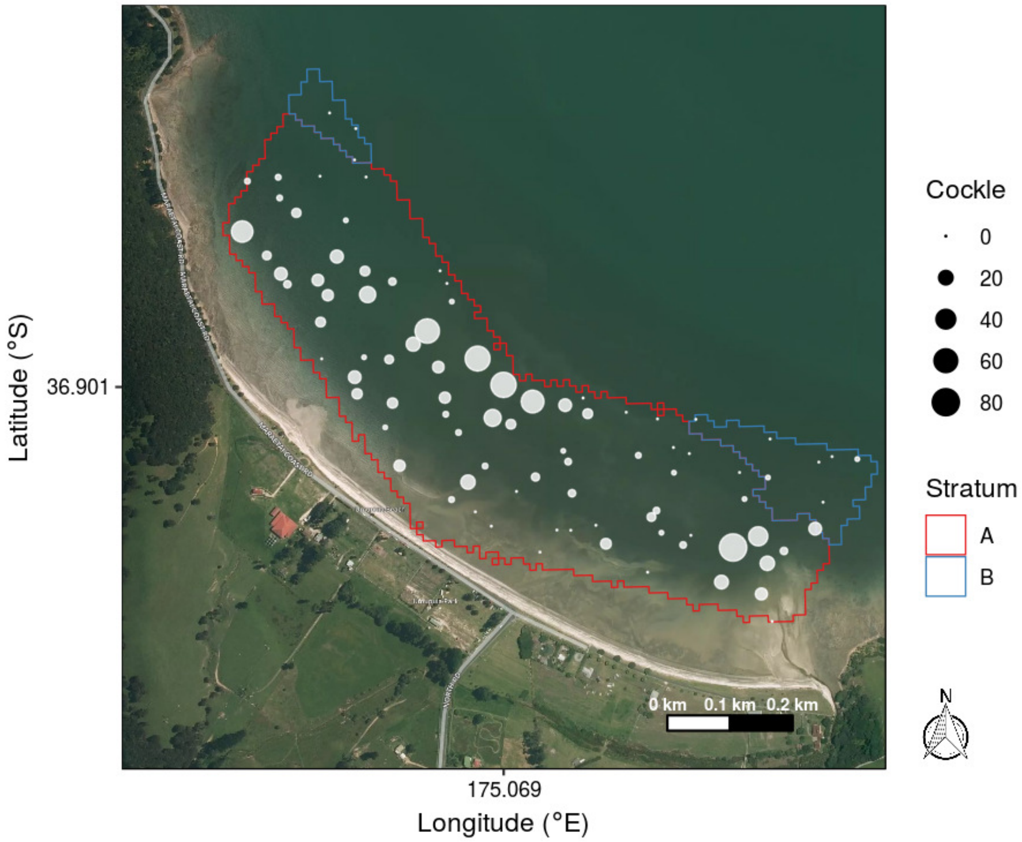


Figure 39: Map of sample strata and individual sample locations for cockles at Umupuia Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 43: Estimates of cockle abundance at Umupuia Beach, by stratum, for 2019–20. 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	80	840	89.85	300	18.49
B	3.5	10	2	0.20	6	66.67

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	25.0	84.41	338	5.51	18.59	74	7.99
2000–01	36.0	177.48	493	5.50	66.98	186	8.32
2001–02	36.0	66.22	184	7.00	29.49	82	9.42
2002–03	36.0	64.43	179	5.26	24.96	69	7.87
2003–04	36.0	29.94	83	9.53	21.62	60	11.44
2004–05	36.0	41.49	115	6.95	30.72	85	7.97
2005–06	36.0	26.86	75	9.99	14.53	40	15.93
2006–07	36.0	11.59	32	13.84	5.07	14	23.91
2009–10	36.0	61.58	171	11.30	1.89	5	20.84
2010–11	36.0	103.08	286	9.96	9.32	26	17.10
2012–13	36.0	125.18	348	14.17	47.99	133	14.64
2013–14	33.9	170.35	503	16.79	44.29	131	17.80
2015–16	33.9	98.88	292	15.93	39.12	115	10.61
2017–18	33.4	92.15	276	19.27	41.70	125	22.25
2019–20	33.4	90.05	269	18.45	32.61	98	21.90

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2015–16	26.80	22	8–43	2.04	39.56
2017–18	27.77	30	10–49	4.85	45.25
2019–20	27.74	27	12–46	0.48	36.21

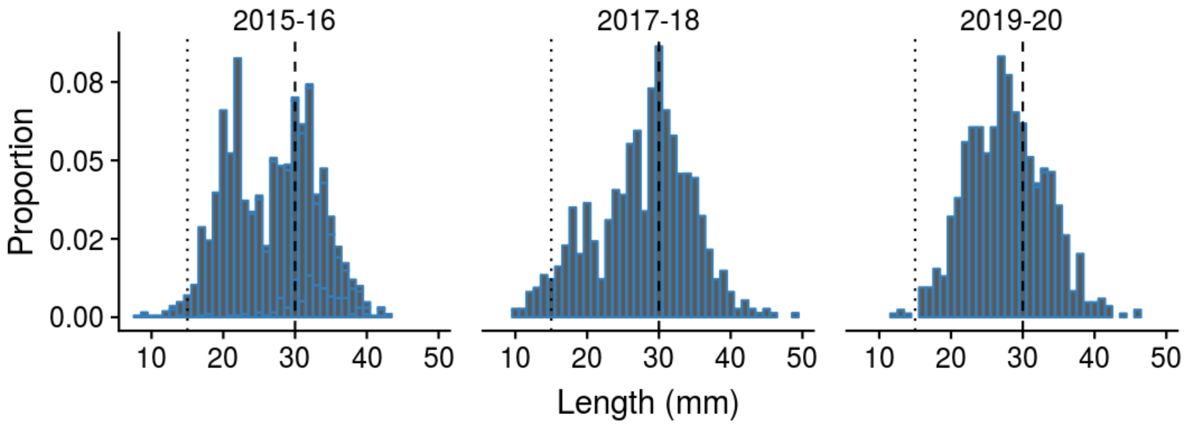


Figure 40: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Umupuia Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10 Waiōtahe Estuary

Waiōtahe Estuary is located in the eastern Bay of Plenty. This small estuary received considerable attention in 2017, when faecal bacteria (*Escherichia coli*) were contaminating the pipi beds, preventing the collection of bivalves at this site. Within the northern shellfish series, cockle and pipi populations in Waiōtahe Estuary have been monitored since 2002–03, with a total of eight surveys, including the current 2019–20 assessment (see Appendix A, Tables A-1, A-2). The most recent previous bivalve survey was in 2017–18.

Throughout the survey series, the sampling extent has been in the lower part of the estuary and included the main channel. The current sampling effort was spread across three strata within this sampling extent, with a total of 160 sampling points, including 80 points in phase 2.

Sediment samples were relatively uniform in organic content (1.2 to 2.3%), but showed some variation in sediment composition, particularly across strata (Figure 41, and see details in Appendix B, Table B-1). Although the bulk of sediment was fine sand (grain size $>$125-µm), samples varied in the proportions of very fine sand (grain size $>$63-µm) and fines (grain size $<$63-µm) with a maximum of 13% in the latter grain size fraction in stratum A.

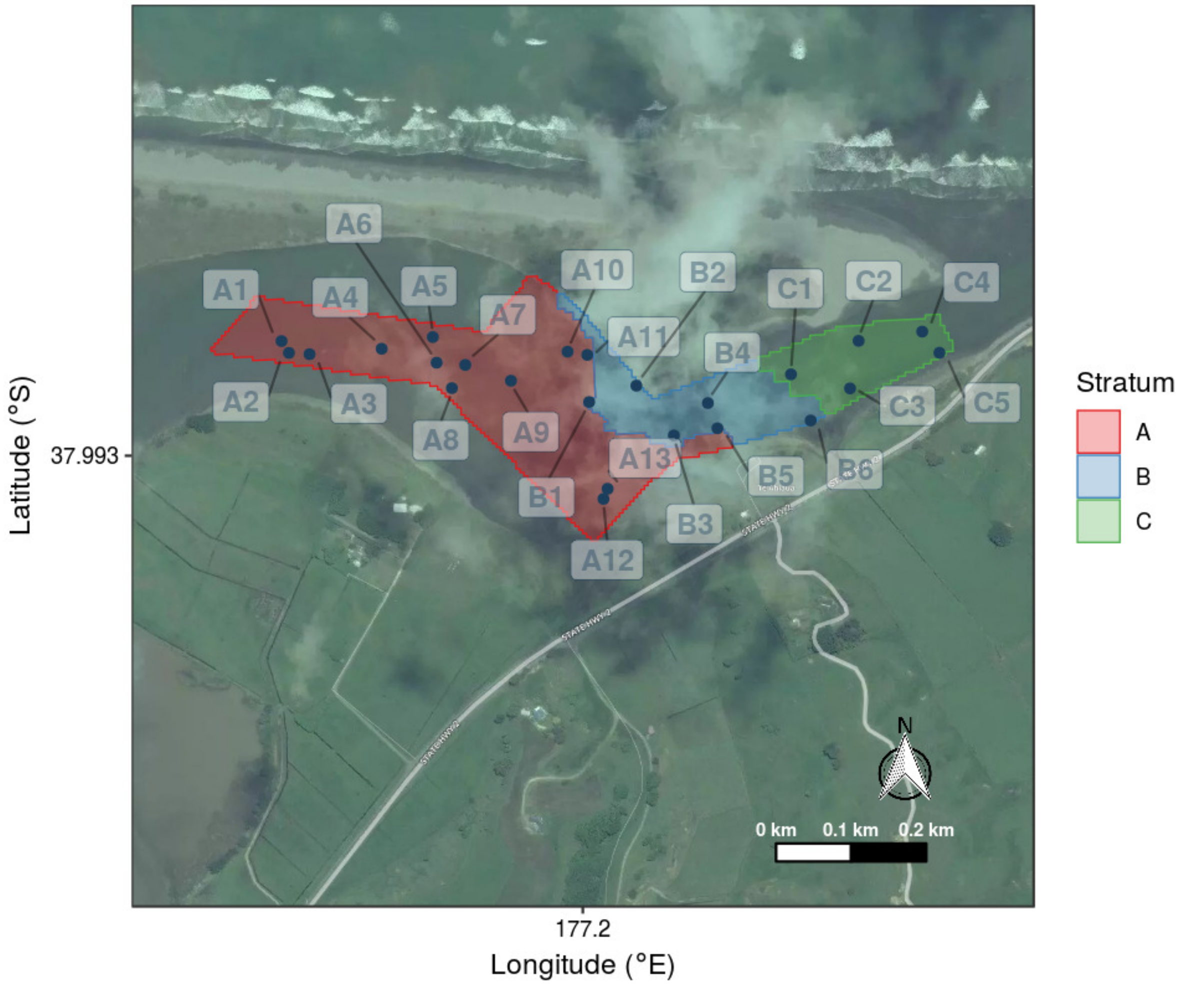
The cockle population in this estuary was concentrated on the intertidal sandflat, in stratum A, with few cockles in the other strata (Figure 42, Table 46). Current abundance and density estimates were 13.51 million (CV: 12.26%) cockles and 113 cockles per m^2 (Table 47). These estimates highlighted a marked reduction in the cockle population compared with the three preceding surveys, e.g., estimates in 2016–17 were 48.61 million (CV: 16.66%) cockles, and a mean density of 406 cockles per m^2.

Large cockles ($\geq$ 30-mm shell length) have been absent or scarce at Waiōtahe Estuary throughout the survey series. Their current population estimates continued to have a high associated uncertainty for the total abundance of 0.07 million (CV: 69.67%) cockles, and their corresponding density of <1 large cockles per m^2.

Whereas large individuals contributed few individuals (0.54%), recruits ($\leq$15-mm shell length) made up 45.39% of the current cockle population (Table 48, Figure 43). This finding was consistent with the two preceding surveys, which documented large proportions of this size class influencing the population size structure, particularly in 2013–14. Since then, an influx of medium-sized cockles led to the increase in mean and modal sizes in 2016–17, with a subsequent shift from a unimodal to a bimodal population consisting of a cohort each of recruits and of medium-sized cockles.

Pipi at Waiōtahe Estuary were mostly in the channel, particularly in stratum B (Figure 44, Table 49). The current pipi estimates documented a marked decline in 2019–20, reflecting a 50% reduction in the pipi population compared with estimates in 2016–17: the total abundance was 80.45 million (CV: 17.15%) pipi in 2019–20, and their density 672 pipi per m^2 (Table 50). The current estimates were the lowest values since 2009–10. There were few large pipi ($\geq$50-mm shell length) included in the population, and this size class has been small throughout the survey series, with abundance and density estimates that frequently had high uncertainty. In 2019–20, there were 0.69 million (CV: 55.33%) large pipi at Waiōtahe Estuary, and their corresponding density was 6 large pipi per m^2.

This size class contributed few individuals (0.86%) to the total population, which was dominated by medium-sized pipi, forming a strong cohort around the modal size of 34-mm shell length. There was also a small proportion ($<$15%) of recruits ($\leq$20-mm shell length) in 2016–17 and 2019–20, indicating consistent recruitment to the population.



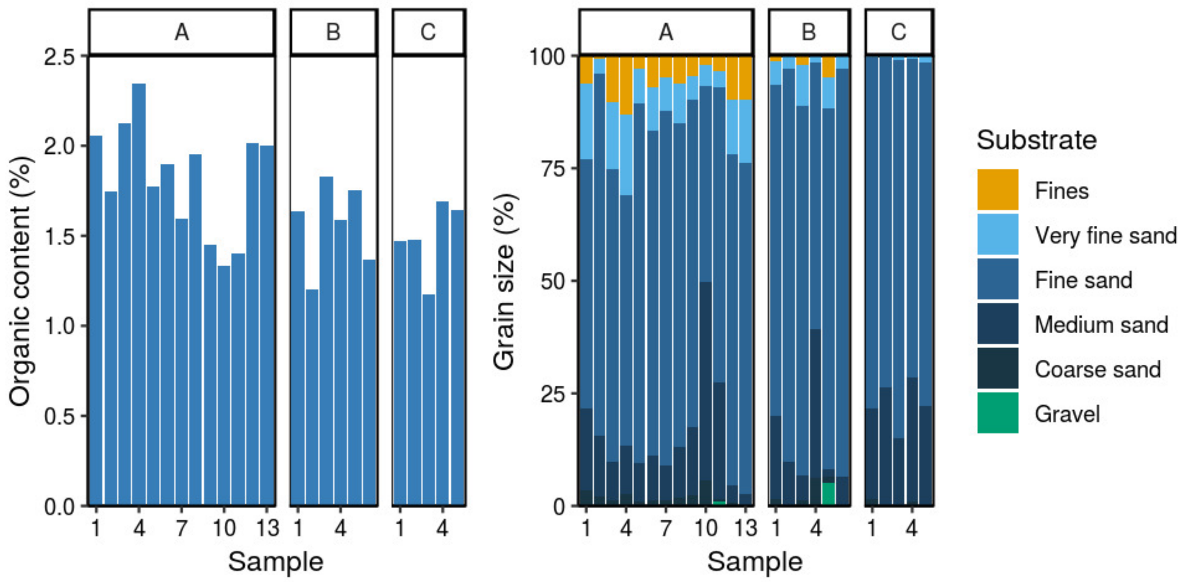


Figure 41: Sediment sample locations and characteristics at Waiōtahe Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.10.1 Cockles at Waiōtahe Estuary

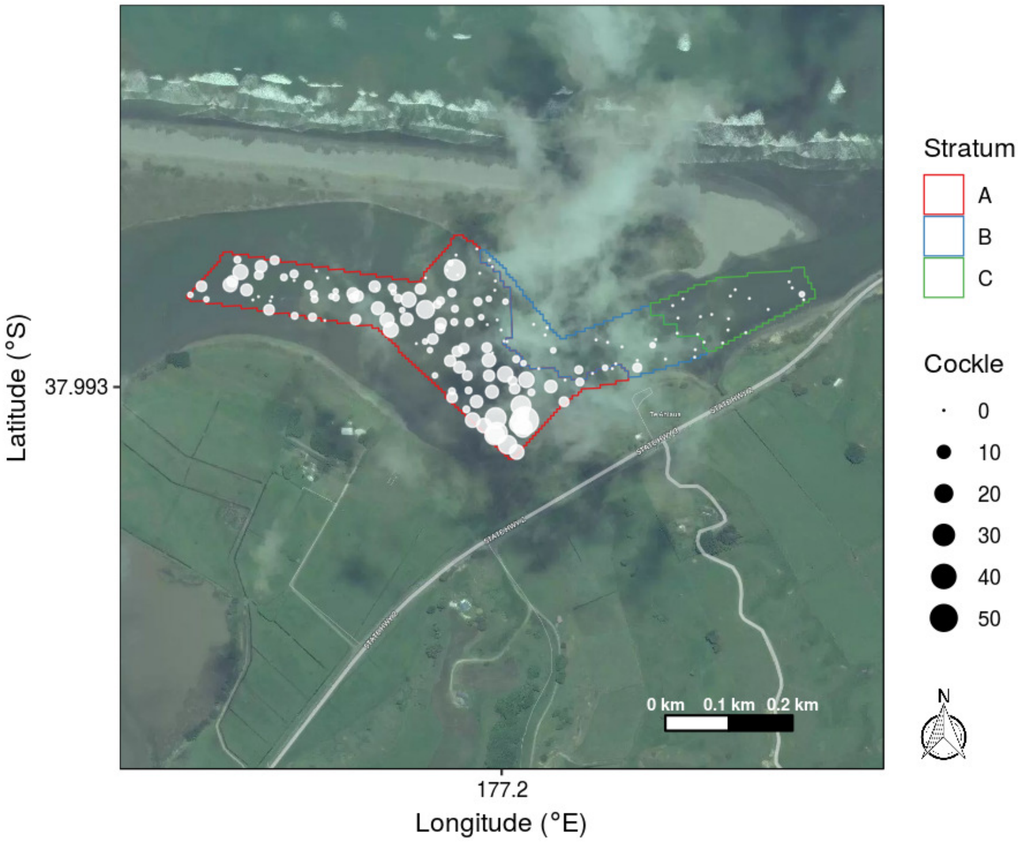


Figure 42: Map of sample strata and individual sample locations for cockles at Waiōtahe Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 46: Estimates of cockle abundance at Waiōtahe Estuary, by stratum, for 2019–20. 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	7.7	120	718	13.10	171	12.57
B	2.4	20	11	0.38	16	44.68
C	1.9	20	1	0.03	1	>100

Table 47: Estimates of cockle abundance at Waiōtahe 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	8.5	36.66	431	8.08	0.51	6	16.53
2002–03	8.5	36.67	431	8.08	0.52	6	16.42
2003–04	8.5	5.77	68	9.16	0.09	1	34.2
2004–05	9.5	1.13	12	12.12	0.04	<1	>100
2005–06	9.5	5.88	62	10.53	0.09	<1	52.32
2009–10	9.5	20.17	212	15.50	0.06	<1	70.81
2013–14	11.2	47.37	422	10.10	0.00	0	
2016–17	12.0	48.61	406	16.66	0.12	1	80.6
2019–20	12.0	13.51	113	12.26	0.07	<1	69.67

Table 48: Summary statistics of the length-frequency (LF) distribution of cockles at Waiōtahe 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	11.70	10	2–28	84.98	0.00
2016–17	17.71	20	5–30	31.44	0.25
2019–20	16.57	22	6–31	45.39	0.54

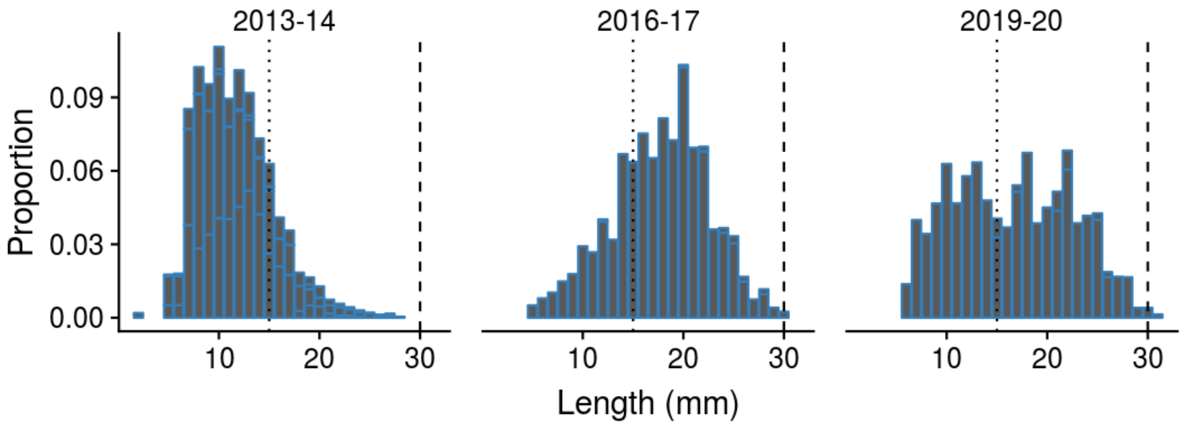


Figure 43: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Waiōtahe Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10.2 Pipi at Waiōtahe Estuary

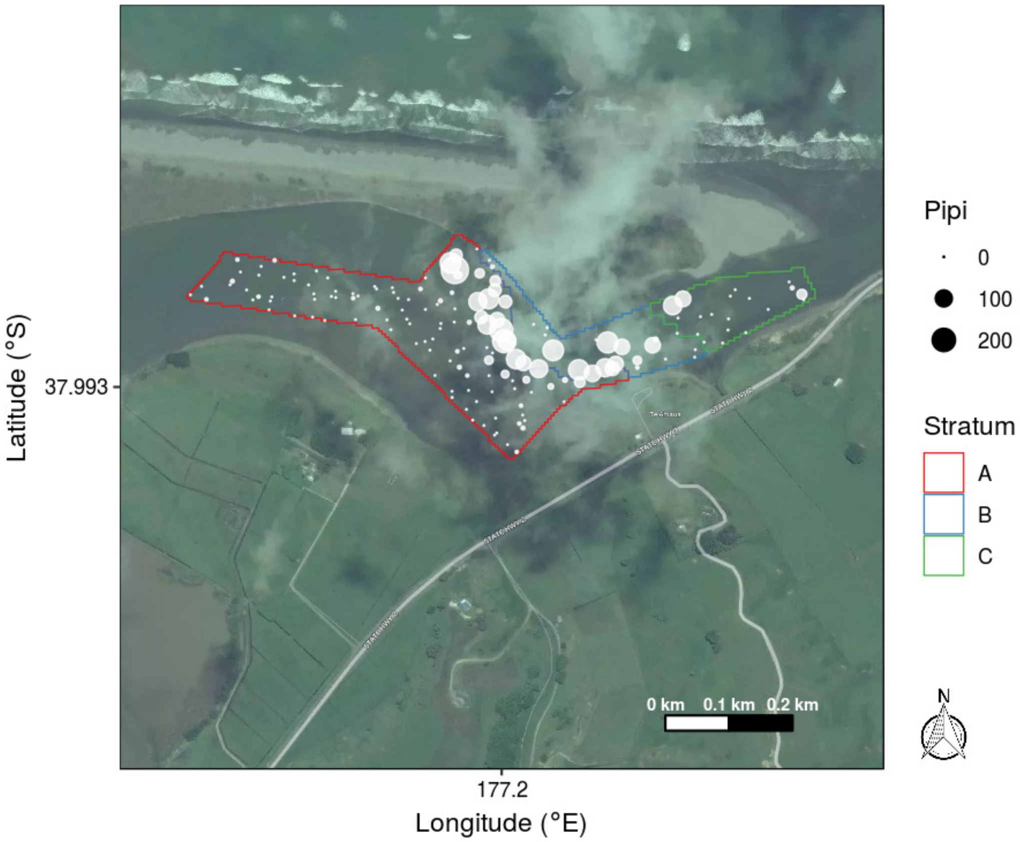


Figure 44: Map of sample strata and individual sample locations for pipi at Waiōtahe Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 49: Estimates of pipi abundance at Waiōtahe Estuary, by stratum, for 2019–20. 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	7.7	120	2 097	38.26	499	24.32
B	2.4	20	1 029	35.86	1 470	26.27
C	1.9	20	236	6.33	337	61.00

Table 50: Estimates of pipi abundance at Waiōtahe 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	8.5	183.91	2 164	5.14	1.46	17	15.83
2002–03	8.5	183.91	2 164	5.14	1.46	17	15.83
2003–04	8.5	47.91	564	5.70	0.20	2	19.63
2004–05	9.5	41.41	436	5.00	0.81	9	12.10
2005–06	9.5	40.61	427	9.30	1.24	13	19.83
2009–10	9.5	96.71	1 018	12.48	3.56	38	23.71
2013–14	11.2	150.21	1 338	12.57	0.09	<1	65.16
2016–17	12.0	166.25	1 388	18.36	1.05	9	43.81
2019–20	12.0	80.45	672	17.15	0.69	6	55.33

Table 51: Summary statistics of the length-frequency (LF) distribution of pipi at Waiōtahe 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	23.00	20	4–112	45.08	0.06
2016–17	30.73	35	7–54	12.08	0.63
2019–20	31.15	34	9–59	14.86	0.86

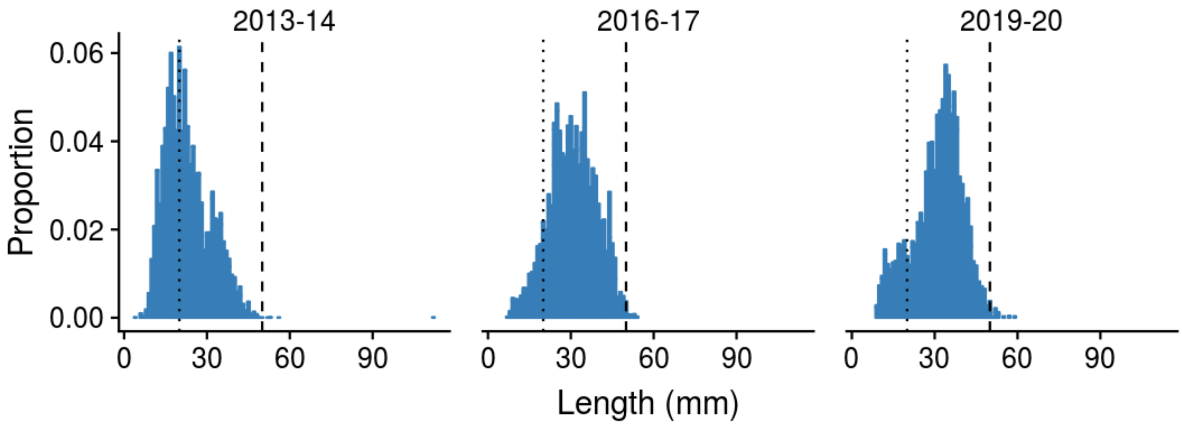


Figure 45: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Waiōtahe Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Whangateau Harbour

Whangateau Harbour is a large estuary in Hauraki Gulf, located north of Auckland. The harbour was closed to shellfish collections in 2010, and this closure is currently still in place. Cockles at this site have experienced a mass-mortality event in 2009, which was attributed to a combination of parasites and bacteria. Whangateau Harbour was first included in the northern survey series in 1999–2000, and the current assessment was the eleventh survey in the series (see Appendix A, Tables A-1, A-2). The sampling at this site has been consistently focused on three separate areas, with cockle strata close to the harbour entrance and in the southwestern part of the harbour (by the causeway), and a pipi bed in the main channel (Figure 46). The current assessment was based on the same sampling extent as the preceding three surveys, with a sampling effort of 90 points across five strata.

Sediment at Whangateau Harbour was low in organic content (about 1.0%) and mostly consisted of fine sand (grain size >125-µm), with a variable proportion of medium sand (grain size >250-µm) (Figure 46, and see details in Appendix B, Table B-1). There was little sediment in other sediment grain size fractions, including sediment fines (grain size <63-µm), which varied between 0.0 and 4.6%.

Cockles at this site were predominantly in strata A and D, with no or few cockles in the other strata (Figure 47, Table 52). The total cockle population consisted of an estimated 887.67 million (CV: 10.72%) individuals, reflecting the highest estimate in the survey series and continuing the increase in abundance (particularly since 2013–14, when the sampling area was extended) (Table 53). There was a corresponding increase in population density with an estimated 801 cockles per m^2 in 2019–20. The population of large cockles (≥30-mm shell length) remained relatively unchanged compared with 2017–18, and their estimates were an abundance of 32.10 million (CV: 37.02%) individuals and an average density of 29 large cockles per m^2; however, the uncertainty associated with these estimates also remained high (i.e., CV>20%).

The population size structure confirmed the stability of the cockle population at Whangateau Harbour (Table 54, Figure 48). In the three most recent surveys, large cockles made up a small proportion of the total population (3.62% in 2019–20), whereas significant recruitment events resulted in recruits (≤15-mm shell length) contributing between 23 and 30% of individuals to the total population. The mean and modal sizes of about 20-mm shell length reflected the influence of recruits and medium-sized cockles, which formed a strong cohort in the unimodal population.

Assessments of the pipi population at Whangateau Harbour have focused on the pipi bed in the main channel, which was in stratum E in the current survey (Figure 49, Table 55). Pipi were concentrated in this stratum, and their total population estimate based on the entire sampling extent was 29.96 million pipi, with a corresponding density of 27 pipi per m^2 (Table 56). Similar to previous surveys, the uncertainty of the current estimates was high (72.05%), owing to the patchy occurrence of a few individuals in stratum D. Abundance and density estimates restricted to the pipi bed (i.e., stratum E) were 5.14 million individuals and 1675 pipi per m^2, with a CV of less than 20% (18.63%). Although there have been some changes to the location and spatial extent of the pipi stratum across surveys, 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 , and 3.89 million (CV: 9.31%) pipi at a density of 1149 pipi per m^2 in 2017–18 (Berkenbusch & Neubauer 2016, 2018). Based on these estimates, there has been a continued increase in the pipi population at this site.

Comparison of the different size classes illustrated a consistent pipi population size structure in the three most recent surveys (Table 57, Figure 50). There were only few large pipi (≥50-mm shell length) included in the population (e.g., 0.87% in 2019–20), whereas regular strong recruitment resulted in recruits (≤20-mm shell length) representing over 30% of the population between 2015–16 and 2019–20. The corresponding mean and modal lengths showed a small reduction over this period, from 26-mm shell length in 2015–16 to 24-mm shell length in the current assessment. The shift towards smaller sizes was also evident in the length-frequency distributions, which documented a unimodal pipi population that was increasingly determined by small-sized individuals over this period.

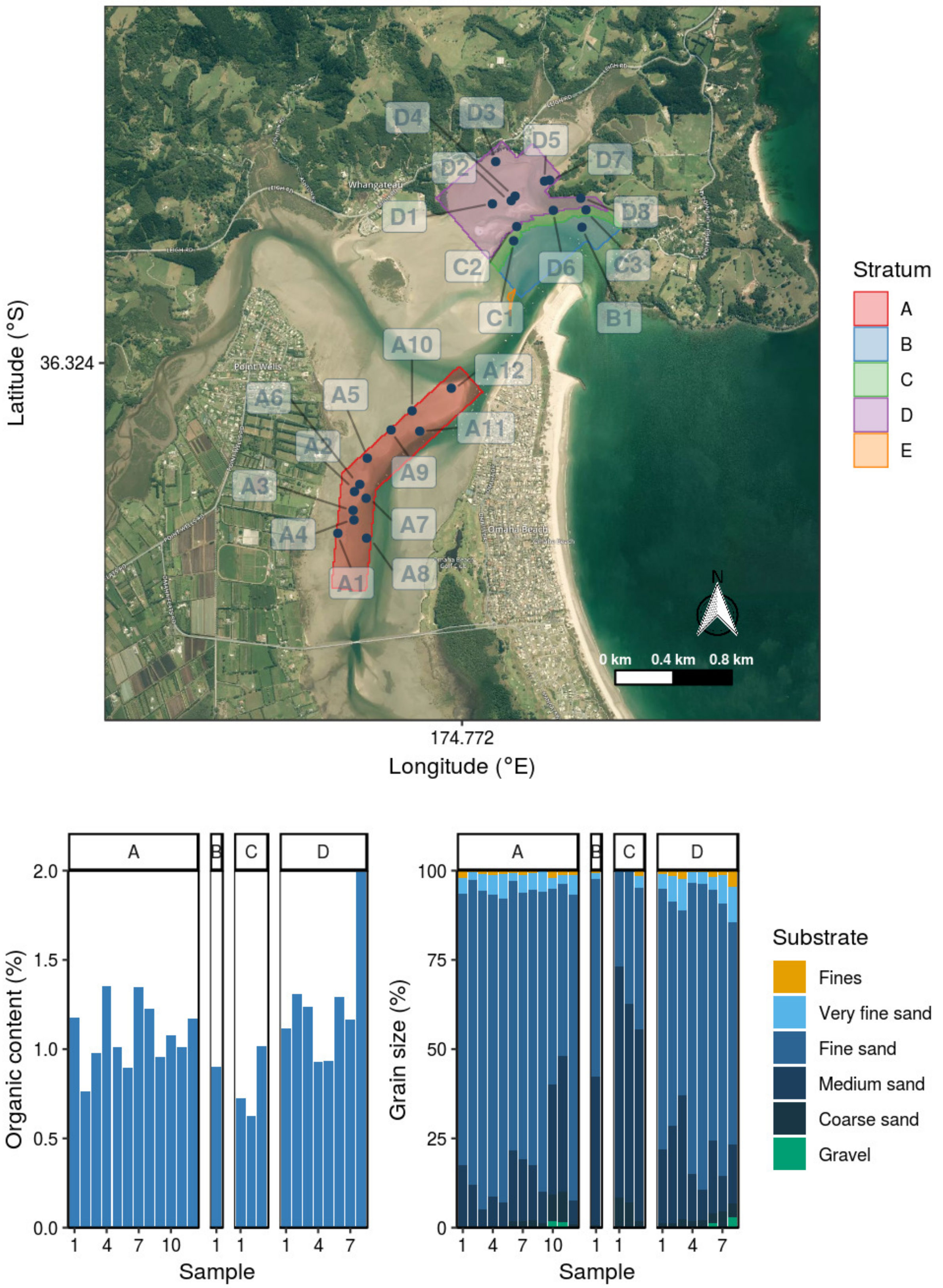


Figure 46: Sediment sample locations and characteristics at Whangateau Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.11.1 Cockles at Whangateau Harbour

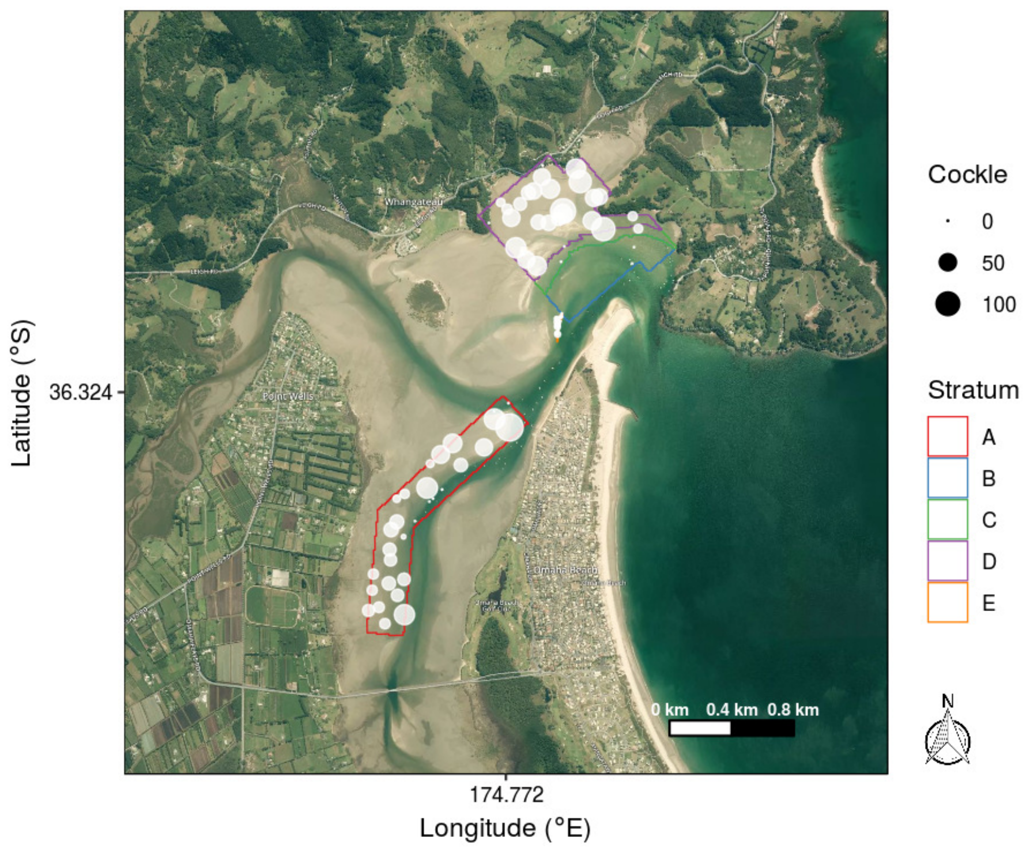


Figure 47: Map of sample strata and individual sample locations for cockles at Whangateau Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 52: Estimates of cockle abundance at Whangateau Harbour, by stratum, for 2019–20. 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	30	860	352.12	819	19.74
B	20.9	2	0	0.00	0	
C	7.1	3	11	7.49	105	>100
D	39.5	25	1 170	528.01	1 337	12.23
E	0.3	30	18	0.05	17	34.46

Table 53: 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	41	18.77
2017–18	110.9	852.27	768	9.28	33.69	30	28.12
2019–20	110.9	887.67	801	10.72	32.10	29	37.02

Table 54: 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 (%)
2015–16	19.88	20	4–44	23.81	6.12
2017–18	18.64	20	4–41	30.94	3.95
2019–20	18.49	18	4–37	30.18	3.62

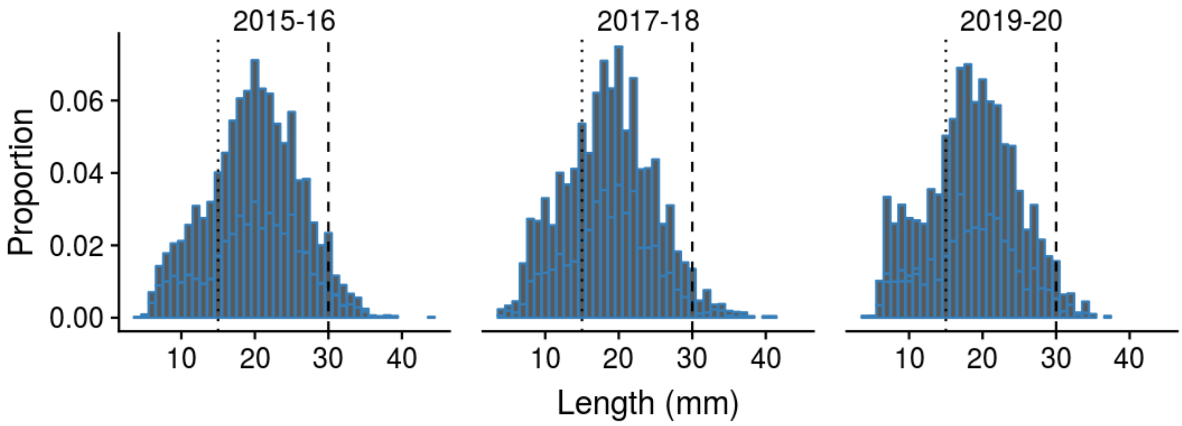


Figure 48: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11.2 Pipi at Whangateau Harbour

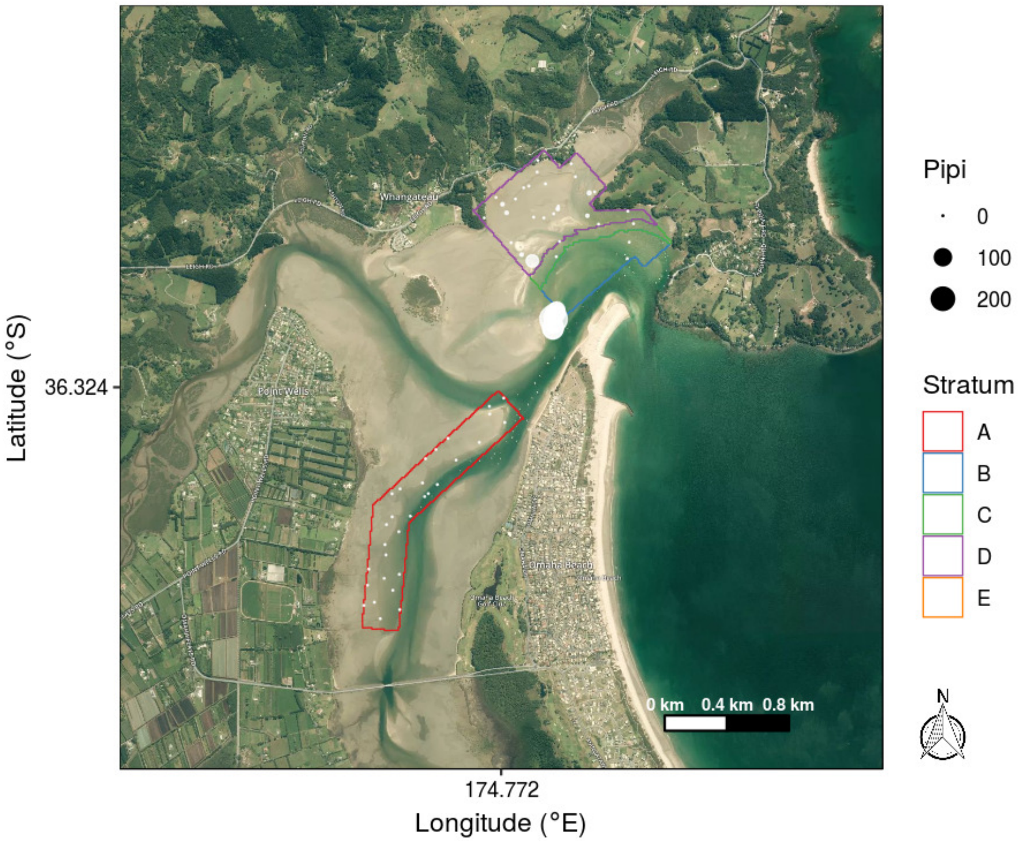


Figure 49: Map of sample strata and individual sample locations for pipi at Whangateau Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 55: Estimates of pipi abundance at Whangateau Harbour, by stratum, for 2019–20. 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	30	0	0.00	0	
B	20.9	2	0	0.00	0	
C	7.1	3	0	0.00	0	
D	39.5	25	55	24.82	63	86.88
E	0.3	30	1 759	5.14	1 675	18.63

Table 56: 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	<1	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	<1	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
2019–20	110.9	29.96	27	72.05	0.26	<1	22.41

Table 57: 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 (%)
2015–16	26.26	26	9–67	32.19	2.68
2017–18	26.06	25	10–58	31.77	0.47
2019–20	24.42	24	9–57	33.15	0.87

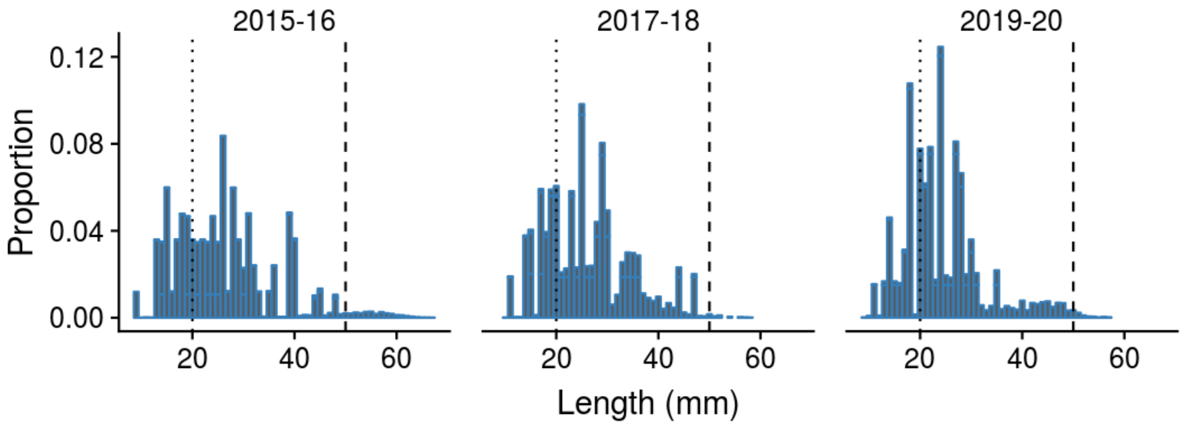


Figure 50: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12 Whitianga Harbour

Whitianga Harbour is on the eastern side of Coromandel Peninsula and is one of the Waikato survey sites. It was first included in the monitoring programme in 2012–13, when the sampling was limited to the pipi bed close to the harbour entrance. The subsequent assessment in 2015–16 also included an intertidal mudflat area inhabited by cockles, because this area is included in the Hauraki Gulf Forum community monitoring programme (e.g., Auckland Council 2013). Overall, there have been three previous bivalve assessments at this site, most recently in 2017–18 (see Appendix A, Tables A-1, A-2). The current field sampling was based on a total of 80 sampling points across both cockle and pipi strata.

The sediment sampling in the cockle stratum indicated similar sediment characteristics, including a sediment organic content between 2.4 and 4.1% (Figure 51, and see details in Appendix B, Table B-1). Fine sand (grain size >250-µm) made up most of the sediment, with markedly smaller proportions of other grain size fractions. The proportion of sediment fines (grain size <63-µm) varied between 2.6 and 14.6%.

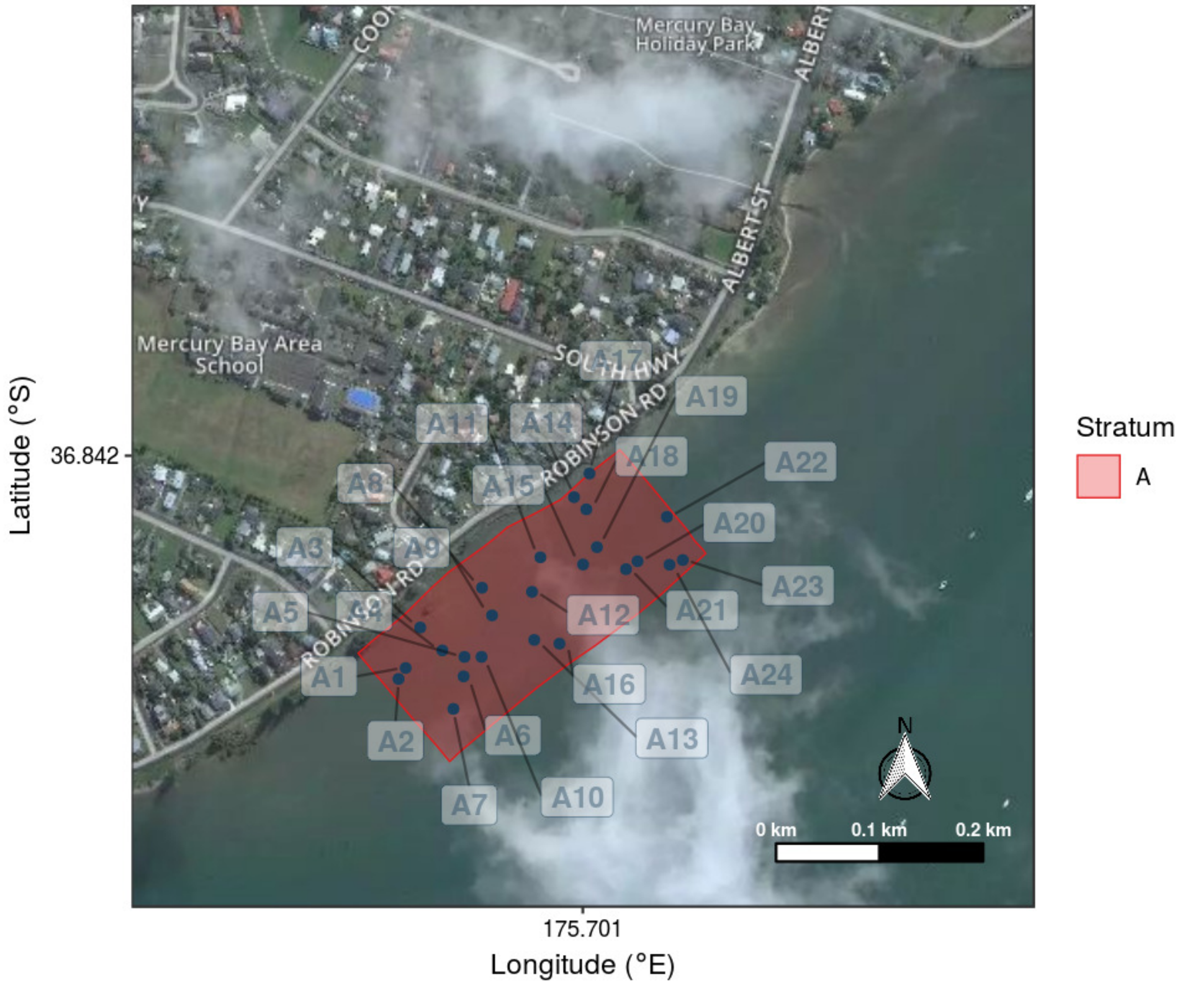
The distribution of cockles at Whitianga Harbour was restricted to stratum B, with only two individuals sampled in the pipi bed (Figure 52, Table 58). The current population estimates reflected a recent increase from previous surveys, with an estimated abundance of 59.00 million (CV: 11.21%) individuals that occurred at a density of 1084 cockles per m^2. In comparison, the preceding estimates were 51.43 million (CV: 11.21%) cockles and an average density of 885 cockles per m^2 in 2017–18 (Table 59). There were no large cockles (≥30-mm shell length) at this site, and this size class was also absent in 2015–16 and 2017–18.

In addition, the size class of medium-sized cockles was comparatively small, with recruits (≤15-mm shell length) constituting most (68.63%) of the current population (Table 60, Figure 53). Recruitment events also determined the population size and structure in the previous two surveys, and mean and modal shell lengths were consistently small at 12 to 15 mm. Recruits formed a strong cohort in the unimodal population in 2017–18, with a recent shift towards the 15-mm cut-off indicating some growth towards the larger size class.

Pipi at Whitianga Harbour were distributed throughout most of stratum B (Figure 54, Table 61). Current population estimates for this species were a total of 8.86 million (CV: 13.38%) pipi and a corresponding density of 163 pipi per m^2—both current estimates signified a substantial decline in the pipi population, reflecting about 10% of the 2017–18 estimates; however, they were similar to values in 2015–16 (Table 62). This fluctuation in the pipi population seemed to be largely determined by recruitment events, because the comparatively high estimates in the preceding survey coincided with a significant proportion of recruits (≤20-mm shell length), which made up over 50% of the pipi population in 2017–18. In 2019–20, their contribution was reduced to 0.18% of the total population (Table 63).

At the same time, there were few large pipi (≥50-mm shell length) at Whitianga Harbour, following a recent decline from an estimated 2.37 million (CV: 14.68%) individuals in 2017–18 to 0.86 million (CV: 19.02%) large pipi in 2019–20. Their density also decreased, from 41 to 16 large pipi per m^2 over the same two-year period.

Large pipi only made up a small proportion (9.68%) of the total population, which was predominantly formed by medium-sized individuals (Table 63, Figure 55). Owing to the lack of recruitment, mean and modal sizes increased to over 40-mm shell length in 2019–20, with a concomitant shift in the unimodal population from a strong cohort of recruits to medium-sized pipi.



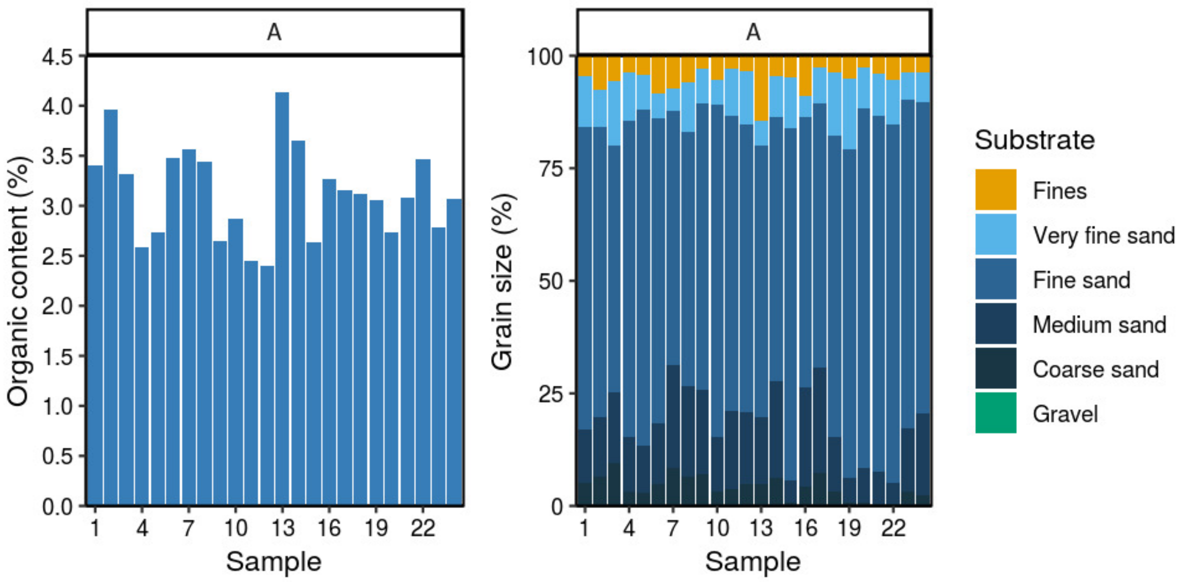


Figure 51: Sediment sample locations and characteristics at Whitianga Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.12.1 Cockles at Whitianga Harbour

Figure 52: 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 58: Estimates of cockle abundance at Whitianga Harbour, by stratum, for 2019–20. 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	4.4	40	1 874	58.98	1 339	12.50
B	1.0	40	2	0.01	1	69.80

Table 59: Estimates of cockle abundance at Whitianga Harbour for all sizes and large size ($\geq$30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population $\geq$ 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	
2019–20	5.4	59.00	1 084	12.50	0.00	0	

Table 60: Summary statistics of the length-frequency (LF) distribution of cockles at Whitianga Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of $\leq$15 mm and large individuals by a shell length of $\geq$30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2015–16	13.76	15	5–26	66.41	0.00
2017–18	12.46	12	5–26	81.25	0.00
2019–20	14.14	15	5–24	68.63	0.00

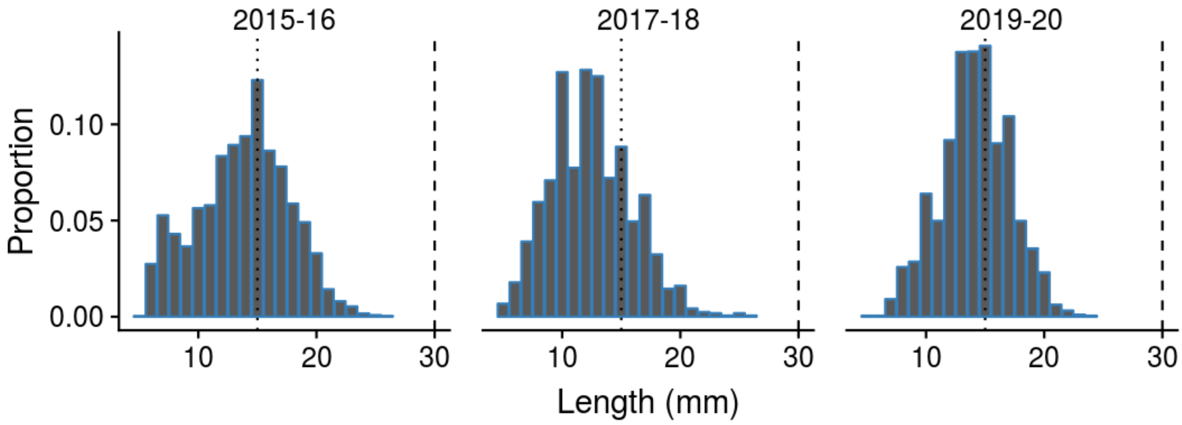


Figure 53: Weighted length-frequency (LF) distribution of cockles for the present survey at Whitianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12.2 Pipi at Whitianga Harbour

Figure 54: 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 61: Estimates of pipi abundance at Whitianga Harbour, by stratum, for 2019–20. 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	4.4	40	0	0.00	0	
B	1.0	40	1 198	8.86	856	13.38

Table 62: 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
2019–20	5.4	8.86	163	13.38	0.86	16	19.02

Table 63: 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 (%)
2015–16	45.13	46	8–62	2.41	30.03
2017–18	21.16	22	6–65	54.82	2.49
2019–20	40.01	42	10–64	0.18	9.68

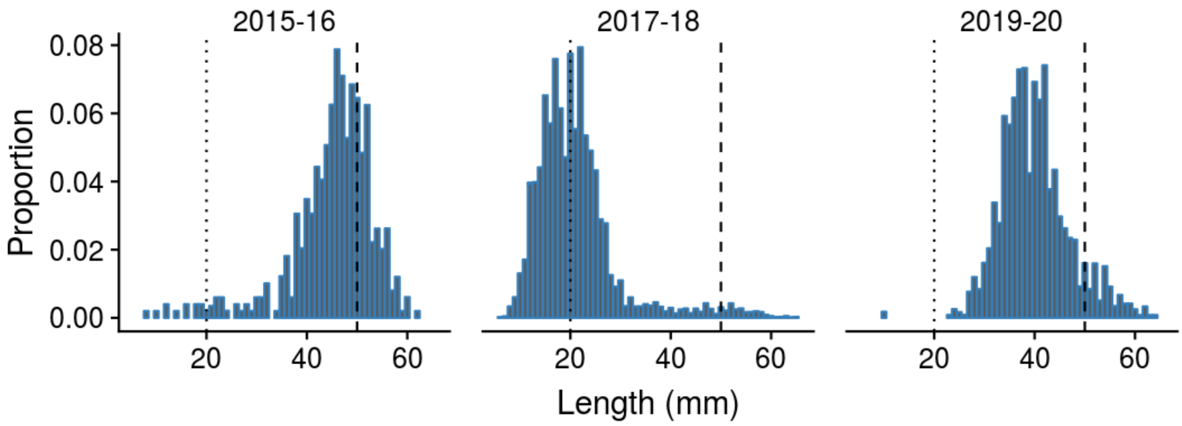


Figure 55: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whitianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

The current assessment sampled cockle populations at all of the 2019–20 survey sites, representing different habitats in the northern North Island region, including Auckland, Northland, Waikato and Bay of Plenty (Table 64). For each of the sites, the field sampling and data analysis provided population estimates with an uncertainty below the target CV of 20%. At two sites, meeting this target CV required additional sampling effort, with phase-2 sampling carried out at Little Waihi and Waiōtahe estuaries.

Summarising the population estimates from the 2019–20 survey sites allowed comparisons of the current status of the cockle populations and an assessment of temporal trends across the northern North Island region (Table 64). Comparison of the 2019–20 estimates revealed four sites that supported relatively large cockle populations, indicated by abundance estimates that exceeded 100 million individuals: the largest cockle population was at Whangateau Harbour (887.67 million individuals), followed by Pataua Estuary, Raglan Harbour and Eastern Beach (117.16 to 362.52 million cockles). At the other sites, abundance estimates ranged from 11.40 million cockles at Grahams Beach, to 90.05 million (CV: 18.45%) individuals at Umupuia Beach.

At most sites, population densities exceeded several hundred individuals per m^{-2}, excepting Grahams Beach and Waiōtahe Estuary, where cockle densities were 43 and 113 cockles per m^{-2}, respectively. Densities were particularly high (>1000 individuals per m^{-2}) at five sites, with similarly high estimates at Raglan Harbour and Bowentown Beach, where densities were over 1600 cockles per m^{-2}; at Whitianga Harbour, Tairua Harbour and Pataua Estuary densities ranged between 1084 and 1299 cockles per m^{-2}.

In spite of high abundance and density estimates at some of the sites, few of the 2019–20 cockle populations included large individuals (≥30-mm shell length). Cockles in this size class were absent or scarce at Grahams Beach, Little Waihi Estuary, Waiōahe Estuary and Whitianga Harbour. In addition, their population size and density estimates were generally low at the other sites, particularly in comparison with the total population. Nevertheless, at three of the current sites, the density of large cockles was comparatively high, with the highest estimate at Umupuia Beach of 98 large cockles per m^{-2} (albeit with a CV of 21.90%), followed by Cockle Bay (75 individuals per m^{-2}; CV: 15.81%) and Eastern Beach (77 individuals per m^{-2}; CV: 20.74%).

Considering population trends over time revealed some fluctuations in total cockle densities, and also highlighted differences between some of the survey sites (Figure 56). The most notable recent changes were an increase in cockle density at Little Waihi Estuary and a decline at Waiōtahe Estuary in 2019–20. At Little Waihi Estuary, cockle densities were variable throughout the time series, and the current increase immediately followed a previously-recorded decrease in cockle density. At Waiōtahe Estuary, the current decline in the density estimate was in contrast to consistent increases in recent previous surveys. Recent decreases in cockle density were also recorded at other sites, such as Bowentown Beach and Eastern Beach, but these declines were relatively small. Nevertheless, when considering survey data over time, a number of sites had markedly lower estimates in 2019–20 than at the start of the survey series; in addition to Waiōtahe Estuary, these sites were Cockle Bay, Grahams Beach and Tairua Harbour. At Cockle Bay and Tairua Harbour, the current density estimates were still comparatively high, regardless of the overall decrease.

Length-frequency distributions of the cockle populations over time illustrated a universal shift towards smaller size classes at the survey sites (Figure 57). At most sites, the current cockle population had a unimodal size structure that was determined by medium-sized cockles, with their strong cohort including a considerable proportion of recruits (≤15-mm shell length). Although large cockles (≥30-mm shell length) influenced the population size structure at some of the sites in earlier surveys, this size class was generally under-represented in more recent length-frequency distributions (i.e., since 2005–06).

The consistent decline of large cockles was also evident in their estimated densities over time (Figure 58). Although initial densities varied across sites, there was a consistent decrease in large cockles at nine of the survey sites, excepting Cockle Bay, Eastern Beach and Umupuia Beach. At all of the nine sites, the decline led to the scarcity or lack of large cockles in the current population. Of the remaining three sites, both Cockle Bay and Umupuia Beach experienced increases and decreases in large cockles throughout the survey series, with relatively little change in their density estimates in recent surveys. Across the 12 sites, Eastern Beach contained the only cockle population that showed a consistent increase in large cockles over time, and their current density was the highest estimate in the survey series, following the lack of this size class in the initial assessment.

Table 64: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2019–20 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	24.80	1 656	5.97	0.12	8	17.30
Cockle Bay	44.41	282	13.84	11.75	75	15.81
Eastern Beach	117.16	519	12.98	17.49	77	20.74
Grahams Beach	11.40	43	19.89	0.00	0	
Little Waihi Estuary	39.37	235	18.00	0.26	2	42.80
Pataua Estuary	362.52	1 299	12.71	3.96	14	44.65
Raglan Harbour	126.74	1 716	6.07	2.15	29	22.01
Tairua Harbour	74.73	1 221	9.88	0.69	11	35.93
Umupuia Beach	90.05	269	18.45	32.61	98	21.90
Waiōtahe Estuary	13.51	113	12.26	0.07	<1	69.67
Whangateau Harbour	887.67	801	10.72	32.10	29	37.02
Whitianga Harbour	59.00	1 084	12.50	0.00	0	

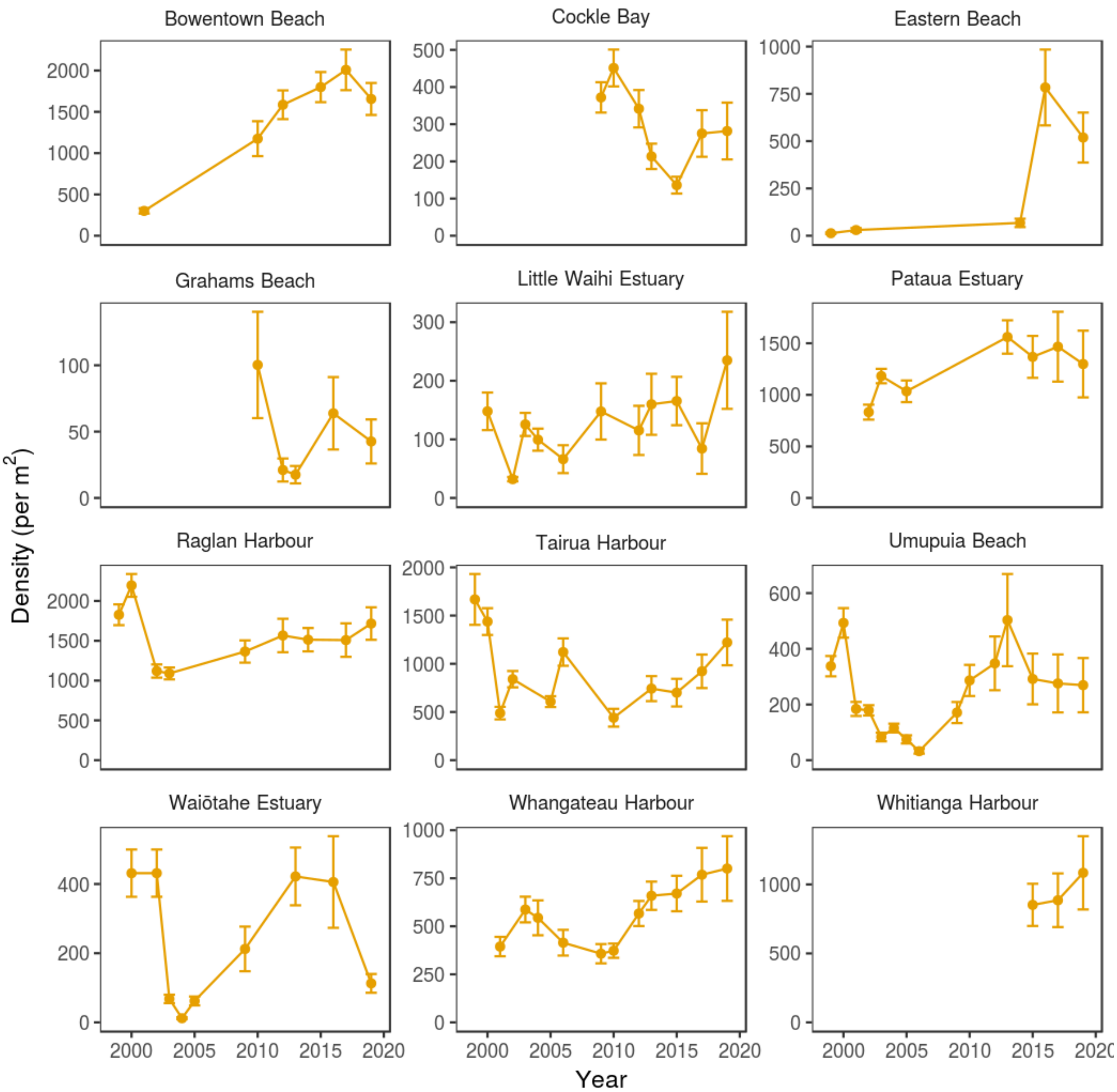


Figure 56: Estimated density of cockles for all sites included in the 2019–20 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

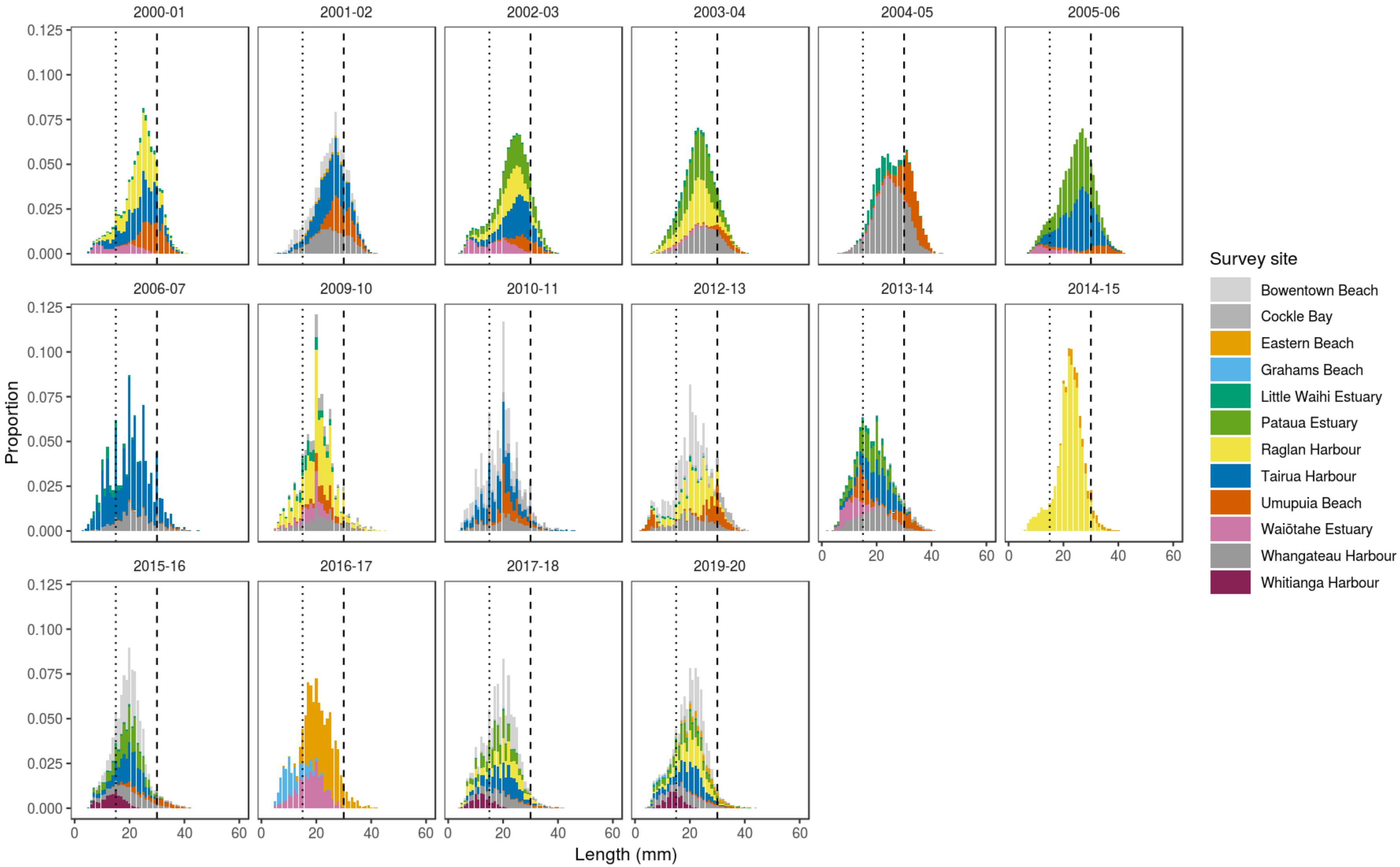


Figure 57: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2019–20 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

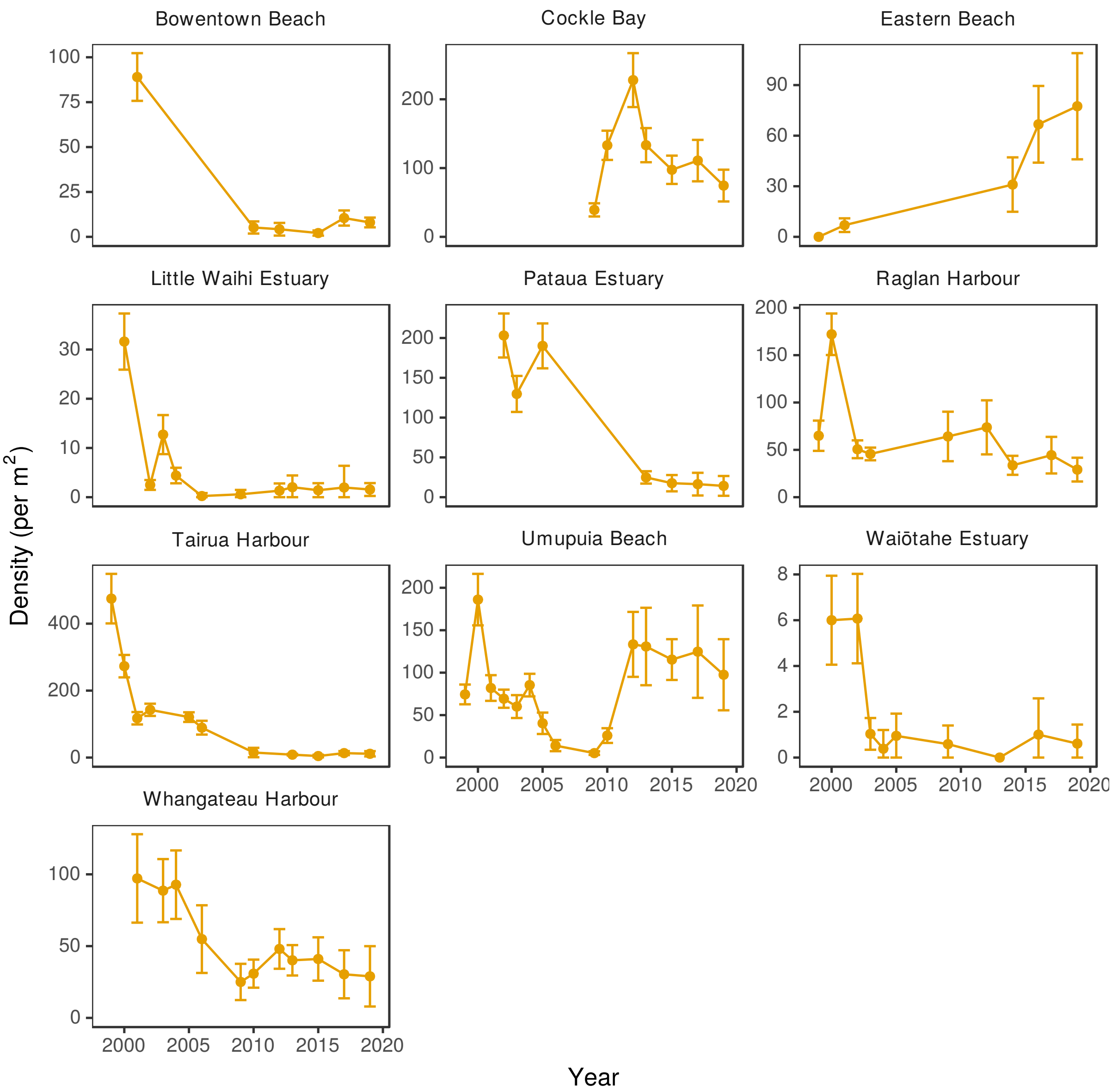


Figure 58: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.2 Pipi populations

Nine of the survey sites in 2019–20 supported pipi populations although their population was small at Bowentown Beach, where the estimated abundance was 0.29 million pipi (Table 65). In contrast, the largest population of this species was at Little Waihi Estuary, with an estimated total abundance of 142.30 million individuals. This site also supported the highest population density at 849 pipi per m^2. At the other sites, abundance estimates ranged from 3.03 million pipi at Raglan Harbour to 80.45 million pipi at Waiōtahe Estuary. The pipi population in the latter estuary also had the second-highest density of 672 pipi per m^2, but this estimate signified a recent decline in this population parameter at Waiōtahe Estuary. Densities were also high at Tairua Harbour and Whitianga Harbour, at 309 and 163 pipi per m^2. At the remaining sites, pipi densities were 41 pipi per m^2 or less.

Population estimates for this species met the target CV of less than 20% at all sites, except at Grahams Beach and Whangateau Harbour. There was no designated pipi bed at Grahams Beach, but pipi formed localised patches in particular areas. Similarly, at Whangateau Harbour, the low occurrence of pipi outside the pipi bed led to high uncertainty in the total population estimates compared with estimates restricted to the pipi stratum only.

Large pipi ($\geq$50 mm shell length) were scarce at most of the sites, with high uncertainty associated with their estimates. The highest number of large pipi was at Little Waihi Estuary, where their total abundance was 15.59 million individuals. This estimate also corresponded with the highest average density for this size class at this estuary, with an estimated 93 large pipi per m^2 . The next highest abundance and density estimates were both at Whitianga Harbour; these estimates were considerably lower, at an abundance of 0.86 million large pipi and a density of 16 large pipi per m^2.

At most of the survey sites, there was considerable variation in population densities over time (Figure 59). At three of the sites, Bowentown Beach, Raglan Harbour and Whangateau Harbour, these fluctuations resulted in an overall increase in the current pipi densities compared with initial estimates, although the uncertainty at the latter site was high. In addition, in spite of the increases, the current density estimates were relatively low (i.e., less than 50 pipi per m^2) at these sites. At Pataua Estuary and Waiōtahe Estuary, initially high densities underwent a marked decrease early in the reporting period, without subsequent increases, leading to comparatively low estimates in 2019–20, particularly at the former estuary. At Grahams Beach, Little Waihi Estuary, Tairua Harbour and Whitianga Harbour, estimated densities at the beginning of the survey series were similar to current estimates, with marked fluctuations in the interim period. Some of these fluctuations (e.g., at Whitianga Harbour) were caused by a large influx of recruits ($\leq$20 mm shell length) through strong recruitment events, with the subsequent reduction in these small-sized individuals leading to decreases in pipi densities overall.

The influence of recruits on the overall population size structure was also evident in the combined length-frequency distributions over time (Figure 60). Although large pipi determined some of the population size structure in early surveys by contributing individuals to the dominant cohort, their influence lessened as they became more scarce and the size distribution shifted towards smaller-sized individuals. In recent surveys, the uni- or bimodal population structures were largely determined by medium-sized pipi, followed by recruits.

The decline or lack of large pipi was also evident in time series data across sites (Figure 61). Of the eight sites that contained large pipi in at least one survey since 1999–2000, densities of large pipi exceeded 100 individuals per m^2 only at Little Waihi Estuary and Tairua Harbour. At Little Waihi Estuary, there was recent increase in the density of large pipi, and the current density estimate for this large size class was comparatively high. At Tairua Harbour, density estimates of large pipi decreased considerably over time, resulting in the lack of large pipi in 2019–20.

At the remaining sites, density estimates for this size class were low, so that changes over time were generally small. The exception was Whitianga Harbour, where density estimates for large pipi slightly increased in the first three assessments, before they showed a marked decline in 2019–20.

Table 65: Estimates of pipi abundance for all sites where more than ten pipi were sampled in the 2019–20 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	0.29	19	15.16	0.01	<1	75.20
Grahams Beach	4.21	16	23.21	0.34	1	48.11
Little Waihi Estuary	142.30	849	13.35	15.59	93	18.74
Pataua Estuary	9.45	34	18.50	0.05	<1	52.35
Raglan Harbour	3.03	41	13.52	0.12	2	55.64
Tairua Harbour	18.89	309	19.23	0.34	6	32.27
Waiōtahe Estuary	80.45	672	17.15	0.69	6	55.33
Whangateau Harbour	29.96	27	72.05	0.26	<1	22.41
Whitianga Harbour	8.86	163	13.38	0.86	16	19.02

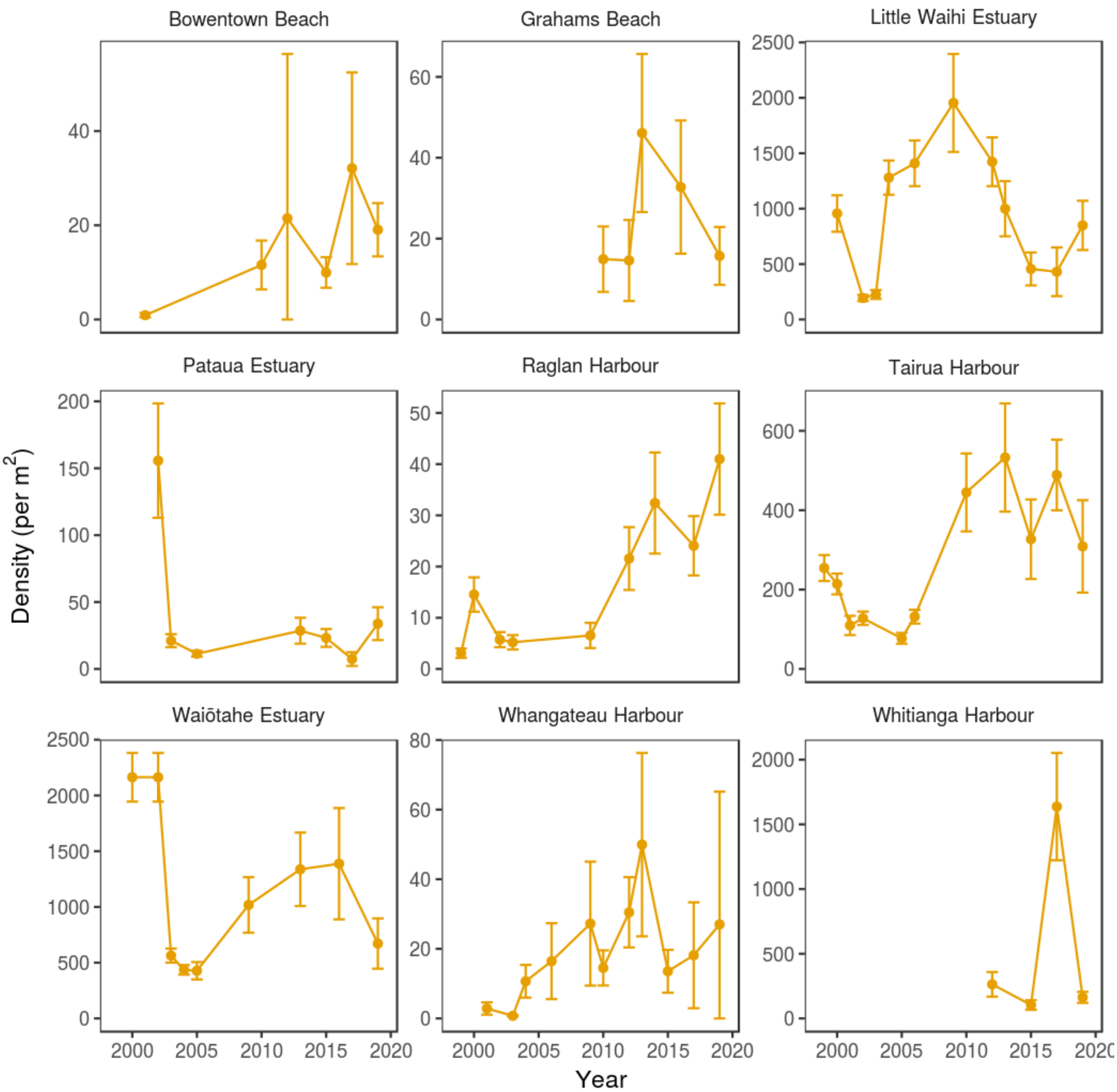


Figure 59: Estimated density of pipi for all sites included in the 2019–20 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

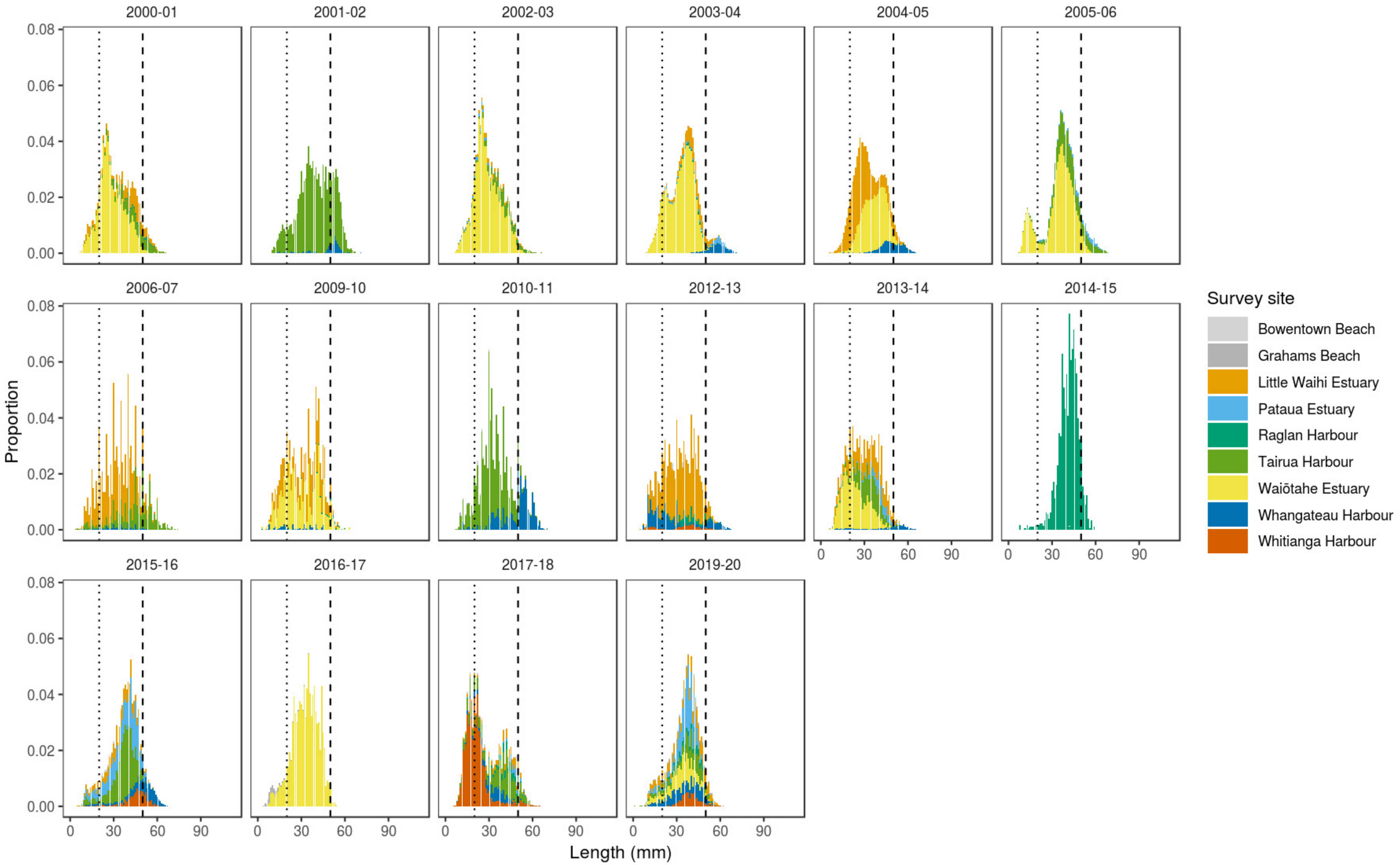


Figure 60: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2019–20 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

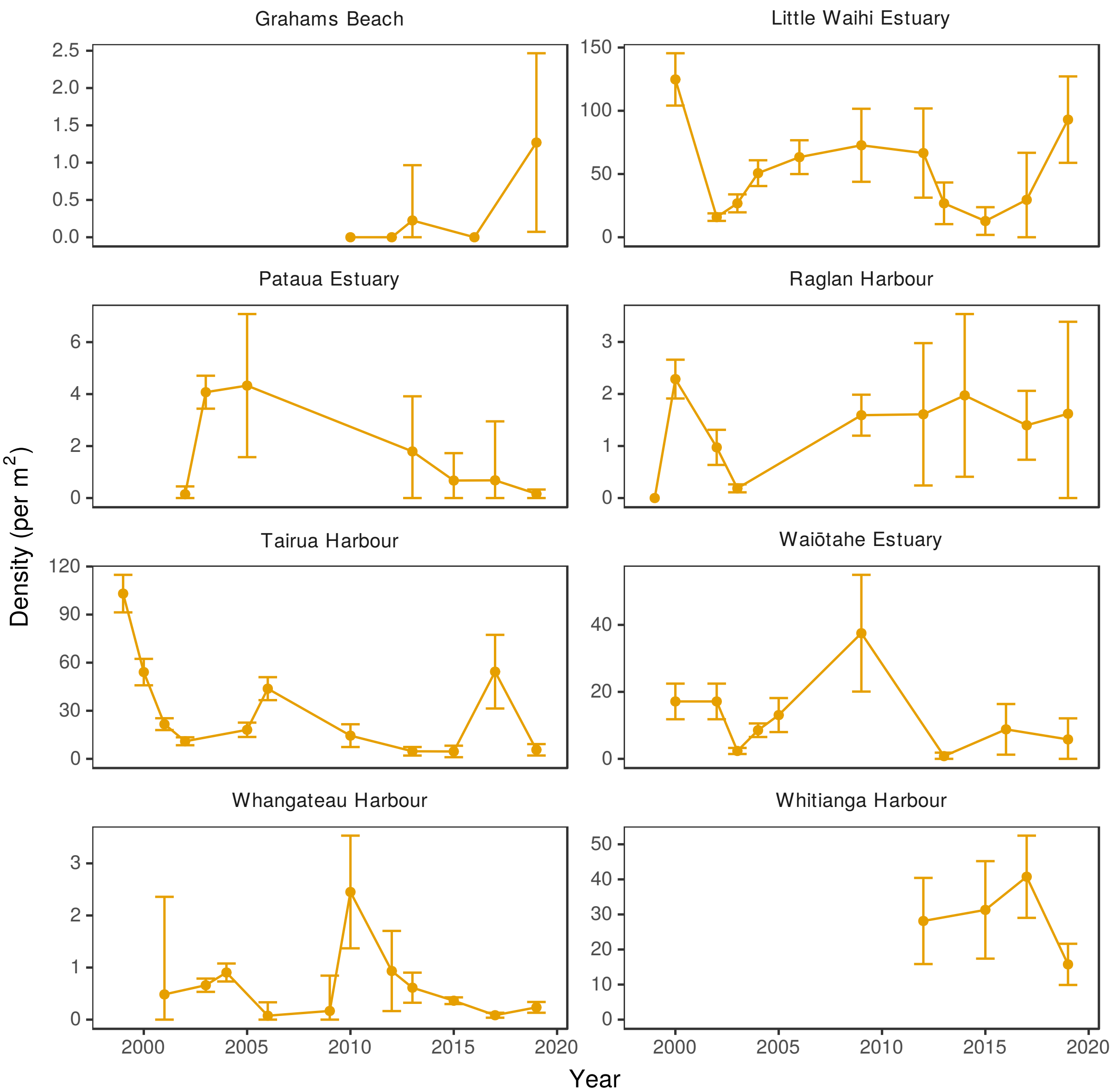


Figure 61: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

5. DISCUSSION

The current study continued the northern survey series and provided population data for cockles and pipi across 12 North Island sites in 2019–20. The survey sites encompassed a range of different intertidal habitats, including beaches in Auckland (Cockle Bay and Eastern Beach) and its wider region (Umupuia and Grahams beaches), different-sized estuaries in Northland (Whangateau Harbour and Pataua Estuary) and Waikato (Raglan, Whitianga and Tairua harbours), and a beach and estuaries in Bay of Plenty (Bowentown Beach, Little Waihi and Waiōtahe estuaries).

All of the sites contained cockle populations, but there was a general lack of large cockles. For some of these populations, the lack of large individuals and concurrent prevalence of recruits meant that population dynamics were largely determined by recruitment events. For example, most (>80%) of the population at Grahams Beach consisted of recruits in the two most recent surveys, corresponding with a notably larger cockle population compared with 2013–14, when recruits made up a smaller proportion (52%) of the population. At the same time, the strong cohort of recruits in 2017–18 did not seem to shift into the medium size class over time, i.e., past the 15-mm threshold. Similarly, at Little Waihi Estuary, the observed increase in the cockle population in 2019–20 corresponded with a relatively large recruitment event, with an increase in recruits (from 25 to 44%) between 2017–18 and 2019–20, whereas the dominant size class of medium-sized cockles decreased over this period.

In comparison, sites with consistent but less variable recruitment supported more stable cockle populations, such as at Bowentown Beach, Pataua Estuary, Raglan Harbour, Tairua Harbour and Whangateau Harbour. Length-frequency data from these sites indicate that some of the recruits subsequently contributed to the size class of medium-sized cockles. Nevertheless, this apparent growth to medium sizes did not seem to continue past the 30-mm cut-off for large individuals.

For large cockles, time series data documented their presence at most sites at the start of the survey series (although there were distinct differences in their initial densities across sites). The exception was Eastern Beach, where large cockles were absent in 1999–2000, and cockles at other sizes were also scarce. Eastern Beach was closed to the collection of shellfish in 1993, following concerns about the sustainability of its cockle population (Morrison & Browne 1999). Although recovery since then has been slow, recent surveys indicate a return of the cockle population to this site, including a steady increase in the density of large cockles.

Increases in the large-cockle size class were also documented at two other sites—Cockle Bay and Umupuia Beach. At Cockle Bay, there was a marked increase in the density of large cockles early in the survey series, but it was followed by subsequent and ongoing declines. This pattern was reversed at Umupuia Beach, where early decreases were followed by an increase in large cockles, and estimates have been relatively high and stable in recent surveys.

It is worth noting that the three sites with reported increases in large cockles all have fishery closures in place. At Eastern Beach and Umupuia Beach, the closures are permanent (i.e., year-round), compared with a seasonal (summer) closure at Cockle Bay. Similar increases in large cockles were not observed at the fourth site with a fishery closure, Whangateau Harbour, where density estimates for this size class have remained similar in recent surveys, after continued declines early in the time series (i.e., before the closure). In addition, the reversal of the decreasing population trend at this site coincided with the implementation of the fishery closure, and total cockle densities have continued to increase since then.

A number of factors influence the distribution and abundance of cockles and pipi, including biological and environmental factors, and also human activities that impact on bivalve populations and their habitat. The current survey programme provides some information about the habitat suitability of the survey sites by monitoring sediment characteristics; however, the lack of other data, particularly fishery information pertaining to the number and sizes of bivalves taken in shellfish collections, prevent the assessment of fishing impacts. For this reason, it is difficult to determine the efficacy of the fishery closures, even though observed population trends at closed sites indicate that these management measures support the recovery of cockle populations.

Waiōtahe Estuary was the only site where the cockle population exhibited a substantial decline in 2019–20, and a similar marked decrease was also evident in the pipi population. With few changes to the proportions of large individuals and recruits, the observed declines in both species were caused by the loss of medium-sized individuals between 2016–17 and 2019–20. Waiōtahe Estuary was exposed to considerable faecal bacteria contamination through dairy farm runoff in 2017, leading to the ongoing closure of shellfish beds at this site. In addition to the health implications from the contamination of shellfish, repercussions from this pollution appear to extent to adverse impacts on the resident bivalve populations through habitat degradation.

Similar to some of the cockle populations in 2019–20, fluctuations in the abundance and density of pipi at some sites seemed to be largely determined by recruitment events. Most notably, the present declines in pipi at Bowentown, Grahams and Whitianga beaches coincided with marked decreases in the proportion of recruits. These data confirm the ongoing availability of recruits at these sites, but also highlighted that strong recruitment events did not generally correspond with population increases over time or with subsequent increases in the medium and large size classes.

In this context, the only pipi population with a high density of large individuals was at Little Waihi Estuary, where the current estimates resulted from a recent increase; there was also a concomitant increase in the total population in 2019–20. Throughout the time series, pipi populations in this estuary have undergone considerable fluctuations, so that these high estimates may not persist, even over a short period (e.g., two to three years).

In addition to surveying cockle and pipi populations, the current survey also assessed sediment properties in the cockle strata. The corresponding sediment data provide some information about the habitat suitability of areas inhabited by cockles, and allow the future analysis of cockle population parameters in relation to sediment properties (see Neubauer et al. 2015). Examples of this analysis include the exploration of cockle densities in relation to the proportion of sediment fines, with ealrier studies documenting that this species occurs at highest densities in sediments in relation to the proportion of sediment fines, with earlier studies documenting highest densities of this species in sediments that contain less than 11% mud (Thrush et al. 2005, Anderson 2008). In the current survey, sediment in the cockle strata was typically low in organic content (i.e., <5%), with only a small proportion of fines, although this grain size fraction exceeded 10% at several sites. The latter included Umupuia Beach, where sediment fines constituted up to 69% of the sediment. In view of the limited tolerance of cockles to this sediment grain size fraction, it is possible that sediment characteristics at some of the northern sites impact the distribution and abundance of this species.

6. ACKNOWLEDGMENTS

Many thanks to the field assistants who helped conduct the northern bivalve surveys: Amy Archer, Brian Boyce, Matt House, Beth McKinnel, Steph Mangan, Tom Miles and Frank Ross. Marine Pomarède helped with the field sampling at Whangateau Harbour. Thanks are also due to Emma Crawford for conducting the sediment analyses, and to Tom Miles for providing lab support. Thanks to Tom Myers for his support during the reconnaissance.

We are grateful to local communities and iwi who shared their knowledge of the sites and provided guidance for the surveys.

This project was funded by Ministry for Primary Industries project AKI2018/01.

7. REFERENCES

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

Auckland Council (2013). Hauraki Gulf Forum community monitoring programme annual report 2012–13. Unpublished report held by Auckland Council, Auckland.

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. Retrieved from https://fs.fish.govt.nz/Doc/23774/FAR_2015_15_2850_AKI2013-01%5C%20(MS5).pdf.ashx.

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://fs.fish.govt.nz/Page.aspx?pk=113&dk=23960.

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 https://fs.fish.govt.nz/Page.aspx?pk=113%5C&dk=24186.

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://fs.fish.govt.nz/Page.aspx?pk=113%5C&dk=24505.

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. Retrieved from https://fs.fish.govt.nz/Page.aspx?pk=113%5C&dk=24620.

Berkenbusch, K.; Neubauer, P. (2019). Intertidal shellfish monitoring in the northern North Island region, 2018–19. *New Zealand Fisheries Assessment Report 2019/32*. 106 p. Retrieved from https://fs.fish.govt.nz/Page.aspx?pk=113&dk=24738.

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.

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.

King, N.; Lake, R. (2013). Bivalve shellfish harvesting and consumption in New Zealand, 2011: data for exposure assessment. *New Zealand Journal of Marine and Freshwater Research 47*: 62–72.

Larcombe, M.F. (1971). Ecology, population dynamics, and energetics of some soft shore molluscs. Doctoral dissertation, University of Auckland, Auckland, New Zealand.

Marsden, I.D.; Adkins, S.C. (2010). Current status of cockle bed restoration in New Zealand. *Aquaculture International 18*: 83–97.

Miller, S.L.; Abraham, E.R. (2011). Characterisation of New Zealand kina fisheries. *New Zealand Fisheries Assessment Report 2011/7*. 95 p. Retrieved from http://fs.fish.govt.nz/Doc/22817/11_07_FAR.pdf.ashx.

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

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

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 Fisheries New Zealand, Wellington).

Stewart, M.; Creese, R. (2002). Transplants of intertidal shellfish for enhancement of depleted populations: preliminary trials with the New Zealand little neck clam. *Journal of Shellfish Research 21*: 21–27.

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

Thrush, S.; Hewitt, J.E.; Herman, P.M.J.; Ysebaert, T. (2005). Multi-scale analysis of species-environment relationships. *Marine Ecology Progress Series 302*: 13–26.

Wynne-Jones, J.; Gray, A.; Hill, L.; Heinemann, A. (2014). National panel survey of marine recreational fishers 2011–12: harvest estimates. *New Zealand Fisheries Assessment Report 2014/67*. 139 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 1999–2000. Fishing years are referred to by the latter year (e.g., 1999–2000 is shown as 2000).

Survey site	Year																	
	2000	2001	2002	2003	2004	2005	2006	2007	2010	2011	2013	2014	2015	2016	2017	2018	2019	2020
Aotea Harbour							■		■				■		■		■	
Bowentown Beach			■							■	■			■		■		■
Cheltenham Beach														■				
Clarks Beach						■												
Cockle Bay									■	■	■	■		■		■		■
Cornwallis Wharf			■															
Eastern Beach			■										■		■			■
Grahams Beach								■		■	■	■			■			■
Hokianga Harbour																	■	
Howick Harbour							■											
Kawakawa Bay (West)						■		■					■		■		■	
Little Waihi Estuary		■		■	■	■		■	■		■	■		■		■		■
Mangawhai Harbour	■	■	■	■	■					■			■		■		■	
Marokopa Estuary							■			■				■				
Marsden Bank									■		■	■				■		
Mill Bay	■	■	■		■	■	■		■				■			■	■	
Ngunguru Estuary					■	■				■			■		■		■	
Ohiwa Harbour			■				■	■	■		■			■			■	
Okoromai Bay	■		■	■	■	■		■	■		■	■		■		■		
Otūmoetai (Tauranga Harbour)		■		■			■	■	■				■		■		■	
Papamoa Beach	■																	
Pataua Estuary				■	■		■					■		■		■		■
Raglan Harbour	■	■		■	■				■		■		■			■		■
Ruakaka Estuary								■		■			■		■		■	
Tairua Harbour	■	■	■	■			■	■		■		■		■		■		■
Te Haumi Bay	■	■	■	■				■	■		■		■		■		■	
Umupuia Beach	■	■	■	■	■	■	■	■	■	■	■	■		■		■		■
Waikawau Beach	■	■				■	■					■						
Waiōtahe Estuary				■	■	■	■		■			■			■			■
Whangamatā Harbour	■	■	■	■	■	■		■		■			■		■		■	
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 2019–20. 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
	2018–19	3 Feb	19.46	AKI2018-01
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	22 Feb	1.50	AKI2017-01
	2019–20	25 Feb	1.50	AKI2018-01
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	27 Jan–28 Jan	15.77	AKI2017-01
	2019–20	15 Feb	15.77	AKI2018-01
Cornwallis Wharf	2001–02	26 Mar–20 Apr	2.65	AKI2001-01
Eastern Beach	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
	2019–20	10 Feb	22.58	AKI2018-01
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
	2019–20	9 Feb	26.78	AKI2018-01
Hokianga Harbour	2018–19	20 Feb	10.07	AKI2018-01
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
	2018–19	4 Feb–25 Feb	60.89	AKI2018-01
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

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2017–18	23 Feb–24 Feb	18.38	AKI2017-01
	2019–20	28 Feb–29 Feb	16.76	AKI2018-01
Mangawhai Harbour	1999–00	23 Mar–30 Jun	9.40	AKI1999-01
	2000–01	29 Jan–31 Jan	8.40	AKI2000-01
	2001–02	15 Mar–14 Apr	8.40	AKI2001-01
	2002–03	1 Jan–31 Jan	8.40	AKI2002-01
	2003–04	1 Jan–31 Jan	8.40	AKI2003-01
	2010–11	24 Mar–15 Apr	9.00	AKI2010-01
	2014–15	21 Jan–22 Jan	8.55	AKI2014-01
	2016–17	11 Feb–16 Feb	8.59	AKI2016-01
	2018–19	18 Jan–19 Jan	7.23	AKI2018-01
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	4 Feb–5 Feb	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	30 Jan–31 Jan	4.86	AKI2017-01
	2018–19	26 Jan	4.86	AKI2018-01
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
	2018–19	22 Feb	6.47	AKI2018-01
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
	2018–19	1 Feb–2 Feb	2.54	AKI2018-01
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

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2013–14	31 Mar	19.84	AKI2013-01
	2015–16	11 Jan	19.84	AKI2015-01
	2017–18	6 Feb	19.83	AKI2017-01
Otūmoetai (Tauranga Harbour)	2000–01	27 Mar–2 Apr	5.60	AKI2000-01
	2002–03	3 Mar–5 Mar	5.60	AKI2002-01
	2005–06	15 Feb–28 Feb	4.60	AKI2005-01
	2006–07	13 Jun–14 Jun	4.60	AKI2006-01
	2009–10	1 Mar–17 Mar	5.60	AKI2009-01
	2014–15	31 Jan–1 Feb	7.67	AKI2014-01
	2016–17	20 Feb–21 Feb	8.09	AKI2016-01
	2018–19	30 Jan–31 Jan	8.06	AKI2018-01
Papamoa Beach	1999–00	1 May–3 May	2.00	AKI1999-01
Pataua Estuary	2002–03	4 Mar–28 Mar	10.65	AKI2002-01
	2003–04	14 Feb–16 Feb	10.45	AKI2003-01
	2005–06	14 Feb–16 Feb	10.45	AKI2005-01
	2013–14	3 Feb–6 Feb	26.30	AKI2013-01
	2015–16	12 Jan–13 Jan	27.78	AKI2015-01
	2017–18	3 Feb–4 Feb	27.71	AKI2017-01
	2019–20	13 Feb	27.92	AKI2018-01
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 Jan	7.24	AKI2017-01
	2019–20	8 Feb	7.38	AKI2018-01
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
	2018–19	23 Feb	3.93	AKI2018-01
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	20 Feb–22 Feb	6.48	AKI2017-01
	2019–20	23 Feb	6.12	AKI2018-01
Te Haumi Bay	1999–00	7 Mar–30 Mar	10.00	AKI1999-01
	2000–01	12 Mar	13.53	AKI2000-01
	2000–01	15 Jan–26 Jan	9.90	AKI2000-01
	2001–02	15 Mar–15 Apr	9.90	AKI2001-01
	2002–03	21 Jan–22 Apr	9.90	AKI2002-01

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	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
	2018–19	21 Feb–24 Feb	11.91	AKI2018-01
Umupuia Beach	1999–00	1 Apr–12 Apr	25.00	AKI1999-01
	2000–01	15 Feb–16 Feb	36.00	AKI2000-01
	2001–02	28 Mar–12 Apr	36.00	AKI2001-01
	2002–03	28 Dec–2 Jan	36.00	AKI2002-01
	2003–04	25 Mar–28 Mar	36.00	AKI2003-01
	2004–05	22 Jan–23 Jan	36.00	AKI2004-01
	2005–06	28 Jan–29 Jan	36.00	AKI2005-01
	2006–07	18 Apr	36.00	AKI2006-01
	2009–10	15 Feb	36.00	AKI2009-01
	2010–11	4 May	36.00	AKI2010-01
	2012–13	13 Mar	36.00	AKI2012-01
	2013–14	30 Mar–1 Apr	33.86	AKI2013-01
	2015–16	18 Jan–19 Jan	33.90	AKI2015-01
	2017–18	28 Jan	33.43	AKI2017-01
	2019–20	14 Feb	33.43	AKI2018-01
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
Waiōtahe Estuary	2016–17	22 Feb	11.98	AKI2016-01
	2019–20	26 Feb–27 Feb	11.98	AKI2018-01
Waiōtahe 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
Whangamatā Harbour	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
	2018–19	29 Jan–30 Jan	7.55	AKI2018-01
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

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	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
	2018–19	27 Jan–28 Jan	5.28	AKI2018-01
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
	2017–18	1 Feb–2 Feb	110.91	AKI2017-01
	2019–20	11 Feb	110.88	AKI2018-01
Whitianga Harbour	2012–13	7 Feb	7.08	AKI2012-01
	2015–16	5 Feb	6.10	AKI2015-01
	2017–18	19 Feb–21 Feb	5.81	AKI2017-01
	2019–20	24 Feb	5.44	AKI2018-01

APPENDIX B: Sediment properties

Table B-1: Sediment organic content and sediment grain size distributions at sites surveyed in 2018–19 as part of the northern North Island bivalve surveys. Position of the sampling points is indicated in decimal degrees (World Geodetic System 1984). Sediment 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.

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Bowentown Beach	A	1	-37.45648	175.97292	1.4	1.4	4.8	32.5	37.5	23.1	0.7
	A	2	-37.45687	175.97333	1.5	2.2	4.5	32.6	45.8	14.9	0.0
	A	3	-37.45665	175.97328	1.8	3.5	7.0	36.4	42.2	11.0	0.0
	A	4	-37.45689	175.97344	1.8	1.8	6.4	37.8	38.6	15.4	0.0
	A	5	-37.45701	175.97353	0.9	1.3	3.8	31.6	44.4	18.3	0.5
	A	6	-37.45727	175.97369	1.4	1.1	5.1	32.9	45.0	16.0	0.0
	A	7	-37.45721	175.97385	1.5	3.0	4.2	25.6	49.4	17.6	0.2
	A	8	-37.45756	175.97402	1.2	2.2	4.4	32.9	41.1	19.4	0.0
	B	1	-37.45631	175.97112	1.1	1.4	5.5	30.3	50.0	12.7	0.1
	B	2	-37.45626	175.97128	1.5	3.9	13.2	47.3	27.9	7.6	0.1
	B	3	-37.45640	175.97144	1.5	2.0	10.9	39.0	39.0	9.1	0.0
	B	4	-37.45659	175.97168	1.5	2.6	10.4	40.1	37.8	9.1	0.0
	B	5	-37.45646	175.97162	1.7	2.4	11.9	44.4	35.3	6.0	0.0
	B	6	-37.45650	175.97182	2.0	1.9	13.9	49.1	31.1	4.1	0.0
	B	7	-37.45664	175.97187	1.9	3.2	12.6	40.5	35.8	7.9	0.0
	B	8	-37.45675	175.97199	1.7	4.3	10.8	36.3	38.2	10.4	0.0
	C	1	-37.45591	175.97093	1.9	2.5	10.0	44.0	38.7	4.8	0.0
	C	2	-37.45602	175.97153	1.1	0.9	6.2	39.9	44.2	8.8	0.0
	C	3	-37.45548	175.97188	1.4	1.7	9.8	51.9	31.1	5.6	0.0
	C	4	-37.45580	175.97212	2.0	2.7	10.0	50.7	31.1	5.5	0.0
	C	5	-37.45544	175.97232	1.3	1.7	3.4	48.3	40.2	6.4	0.0
	C	6	-37.45565	175.97243	1.4	2.2	5.1	34.5	44.8	13.4	0.0

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	C	7	-37.45525	175.97249	1.6	3.1	7.5	46.6	35.6	7.2	0.0
	C	8	-37.45544	175.97264	1.2	2.3	10.2	61.1	22.5	3.9	0.0
Cockle Bay	A	1	-36.89828	174.95300	3.0	19.8	44.5	27.5	4.4	3.1	0.8
	A	2	-36.89924	174.95257	2.8	10.1	36.8	40.3	8.1	4.7	0.0
	A	3	-36.89793	174.95405	2.0	15.2	32.6	46.1	4.9	1.2	0.0
	A	4	-36.89780	174.95483	1.3	2.2	23.9	65.8	7.8	0.3	0.0
	A	5	-36.89892	174.95394	1.4	4.1	33.3	54.6	5.8	2.1	0.0
	A	6	-36.89896	174.95444	2.7	16.1	22.5	52.9	5.7	2.7	0.0
	A	7	-36.89788	174.95537	1.5	2.2	25.4	66.1	4.7	1.6	0.0
	A	8	-36.89873	174.95503	1.4	2.1	24.6	66.7	5.2	1.3	0.0
	A	9	-36.89914	174.95475	1.4	2.5	24.5	64.4	6.1	2.4	0.0
	A	10	-36.89805	174.95581	1.3	2.3	25.4	66.4	4.7	1.2	0.0
	A	11	-36.89855	174.95568	1.2	2.0	23.8	69.5	3.9	0.7	0.0
	A	12	-36.89950	174.95524	1.1	1.7	28.8	62.8	5.4	1.4	0.0
	A	13	-36.89967	174.95555	1.5	2.8	31.7	60.9	3.5	1.2	0.0
	A	14	-36.89988	174.95549	1.3	2.6	29.4	60.8	5.6	1.7	0.0
	A	15	-36.90026	174.95516	1.8	18.9	24.6	46.5	8.4	1.6	0.0
	A	16	-36.90023	174.95600	1.2	2.3	27.2	63.4	4.9	2.1	0.0
	A	17	-36.90015	174.95562	1.2	2.2	26.3	63.9	5.5	2.0	0.0
	A	18	-36.89903	174.95702	1.4	2.5	33.4	59.8	2.2	2.1	0.0
	B	1	-36.89713	174.95371	1.5	2.6	29.9	63.5	3.7	0.2	0.0
	B	2	-36.89733	174.95335	1.6	7.4	33.0	55.2	3.9	0.5	0.1
	B	3	-36.89772	174.95401	1.9	7.4	31.2	52.1	4.9	4.1	0.3
	B	4	-36.90026	174.95295	5.1	17.4	35.4	32.9	8.8	5.4	0.0
	B	5	-36.89753	174.95525	1.2	0.0	19.4	76.0	4.5	0.1	0.0
	B	6	-36.90013	174.95375	2.6	37.4	29.5	24.5	7.2	1.4	0.0

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Eastern Beach	A	1	-36.87440	174.91791	1.2	1.3	28.8	69.6	0.4	0.0	0.0
	A	2	-36.87506	174.91780	1.6	1.4	33.9	62.8	1.7	0.1	0.0
	A	3	-36.87492	174.91861	1.1	2.8	16.0	80.4	0.8	0.0	0.0
	A	4	-36.87533	174.91845	1.4	2.4	33.3	63.9	0.4	0.0	0.0
	A	5	-36.87581	174.91884	1.5	3.0	25.0	70.6	1.3	0.1	0.0
	A	6	-36.87617	174.91992	1.3	2.6	22.6	73.6	1.2	0.1	0.0
	A	7	-36.87614	174.91949	1.3	2.2	23.5	73.6	0.8	0.0	0.0
	A	8	-36.87793	174.92031	1.3	1.6	3.1	18.0	37.3	40.0	0.0
	A	9	-36.87796	174.91992	1.8	0.9	2.2	19.3	32.3	44.9	0.4
	B	1	-36.86975	174.91293	1.7	1.9	19.7	69.9	8.3	0.1	0.0
	B	2	-36.87012	174.91362	1.6	1.8	24.9	72.3	0.9	0.1	0.0
	B	3	-36.87173	174.91467	1.4	1.1	23.9	74.5	0.4	0.0	0.0
	B	4	-36.87217	174.91440	1.9	2.1	30.3	60.6	6.8	0.1	0.0
	B	5	-36.87310	174.91496	2.1	2.5	44.2	48.4	4.7	0.2	0.0
	B	6	-36.87392	174.91734	1.4	3.1	40.8	55.7	0.5	0.0	0.0
	B	7	-36.87421	174.91709	1.8	4.2	37.3	56.8	1.5	0.1	0.0
	B	8	-36.87494	174.91709	2.1	2.1	51.4	44.4	2.0	0.1	0.0
	B	9	-36.87712	174.91898	1.7	2.5	28.3	60.7	8.3	0.2	0.0
	B	10	-36.87728	174.91980	2.2	4.6	46.4	47.4	1.4	0.3	0.0
	C	1	-36.86782	174.91242	1.0	1.4	12.5	85.4	0.4	0.2	0.0
	C	2	-36.86877	174.91276	1.3	1.4	17.4	80.8	0.3	0.1	0.0
	C	3	-36.86892	174.91227	1.7	2.6	17.8	78.5	0.8	0.3	0.0
	C	4	-36.86895	174.91320	1.1	0.3	16.3	83.2	0.1	0.1	0.0
	C	5	-36.86975	174.91242	1.5	1.9	17.1	64.6	16.1	0.2	0.0
Grahams Beach	A	1	-37.05346	174.66638	1.0	1.2	0.6	11.5	71.2	15.5	0.0
	A	2	-37.05462	174.66700	0.8	0.3	0.2	11.4	63.9	24.3	0.0

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	A	3	-37.05556	174.66782	0.7	0.2	0.1	7.1	49.4	42.6	0.6
	A	4	-37.05593	174.66822	1.9	4.2	2.8	46.5	31.6	12.4	2.5
	A	5	-37.05659	174.66810	5.7	16.3	2.8	23.8	33.2	19.7	4.2
	A	6	-37.05711	174.66798	0.4	0.4	0.2	9.0	54.6	35.2	0.5
	B	1	-37.04960	174.66246	1.0	0.2	0.7	12.5	66.6	17.3	2.7
	B	2	-37.04991	174.66326	0.8	0.3	0.7	13.4	62.0	21.3	2.4
	B	3	-37.05032	174.66328	0.8	0.5	0.2	5.5	66.0	27.4	0.3
	B	4	-37.05037	174.66409	1.4	2.1	1.7	14.1	63.1	18.8	0.3
	B	5	-37.05294	174.66529	1.1	1.9	0.3	5.3	79.8	12.4	0.2
	B	6	-37.05503	174.66626	0.9	0.6	0.3	5.4	60.3	33.4	0.0
	C	1	-37.04887	174.66392	1.2	2.0	3.0	46.3	44.3	4.4	0.0
	C	2	-37.05101	174.66533	1.7	1.3	1.7	44.5	46.3	6.0	0.2
	D	1	-37.04580	174.66035	0.7	0.0	0.8	36.7	57.6	4.9	0.1
	D	2	-37.04716	174.66200	0.9	0.3	1.9	35.5	57.9	3.6	0.7
	D	3	-37.04847	174.66226	1.8	3.2	0.6	24.4	64.2	6.7	0.8
	D	4	-37.04903	174.66340	1.8	3.3	3.1	34.6	43.0	14.5	1.5
	D	5	-37.04927	174.66413	1.7	2.6	1.4	51.4	41.0	3.5	0.1
	E	1	-37.04465	174.65951	1.5	0.7	1.0	30.3	26.2	37.2	4.6
	E	2	-37.04498	174.65982	1.4	0.2	2.0	63.6	31.6	2.5	0.0
	E	3	-37.04515	174.65946	1.0	0.5	0.4	30.3	51.7	16.7	0.4
	E	4	-37.04537	174.65999	1.3	1.2	1.8	60.1	34.8	2.1	0.0
	E	5	-37.04543	174.65970	0.6	0.0	0.3	31.1	63.2	5.4	0.0
Little Waihi Estuary	A	1	-37.76338	176.48063	2.2	0.3	2.3	47.4	39.1	10.5	0.4
	A	2	-37.76322	176.48074	2.3	1.8	3.8	52.4	33.1	8.8	0.1
	A	3	-37.76266	176.48085	1.9	0.8	2.4	52.6	33.6	10.5	0.1
	A	4	-37.76316	176.48108	1.5	0.9	4.2	48.9	31.6	12.3	2.1

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	5	-37.76249	176.48127	2.4	3.2	6.1	61.0	24.1	5.6	0.0
	A	6	-37.76152	176.48093	1.4	3.2	4.9	54.7	28.1	9.0	0.0
	A	7	-37.76222	176.48145	2.0	2.9	6.5	63.8	23.3	3.3	0.3
	A	8	-37.76053	176.48073	1.9	3.8	4.1	53.6	30.5	6.7	1.2
	A	9	-37.76170	176.48157	1.6	3.5	4.2	55.1	28.1	9.1	0.0
	A	10	-37.76193	176.48203	1.4	0.5	3.6	67.9	23.0	5.0	0.0
	A	11	-37.76058	176.48144	1.4	0.4	0.6	45.8	46.8	6.4	0.0
	A	12	-37.76194	176.48232	2.2	2.8	10.0	58.7	22.6	5.9	0.0
	A	13	-37.75993	176.48138	3.9	4.3	9.7	62.7	15.6	5.9	1.8
	A	14	-37.76064	176.48176	1.9	2.2	3.7	67.7	23.4	3.0	0.0
	A	15	-37.76119	176.48258	2.6	3.4	6.9	51.5	24.7	12.1	1.4
	A	16	-37.75903	176.48142	1.9	3.0	4.9	63.0	27.2	1.8	0.0
	A	17	-37.76016	176.48243	1.9	2.6	6.2	54.8	20.1	9.0	7.2
	B	1	-37.75904	176.47932	1.6	0.9	3.3	65.3	27.4	3.2	0.0
	B	2	-37.75764	176.47916	1.9	0.9	4.4	61.4	30.6	2.7	0.0
	B	3	-37.75872	176.48014	2.4	3.7	8.0	70.1	15.3	1.3	1.7
	B	4	-37.75945	176.48063	2.8	1.9	6.6	67.4	20.2	3.6	0.2
	B	5	-37.75960	176.48079	1.9	1.3	5.6	65.4	24.2	3.4	0.0
	B	6	-37.75680	176.47921	0.3	0.4	1.6	32.5	43.2	22.3	0.0
	B	7	-37.75877	176.48093	1.1	1.2	5.1	64.6	26.3	2.9	0.0
Pataua Estuary	A	1	-35.71806	174.51501	1.3	1.3	5.6	62.2	24.1	6.9	0.0
	A	2	-35.71869	174.51528	1.8	1.4	16.4	67.6	9.1	4.5	1.0
	A	3	-35.71738	174.51697	2.1	2.1	14.4	53.8	7.5	16.2	6.0
	A	4	-35.71796	174.51693	1.8	1.1	6.4	48.3	28.7	9.9	5.7
	A	5	-35.71830	174.51599	1.4	0.9	9.6	67.2	16.5	5.8	0.0
	A	6	-35.71913	174.51588	1.2	0.4	4.4	52.1	25.9	16.7	0.6

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	A	7	-35.71767	174.51773	1.2	0.0	4.8	29.4	22.4	21.3	22.0
	A	8	-35.71860	174.51689	2.0	1.5	12.2	72.5	8.2	5.7	0.0
	A	9	-35.71881	174.51638	1.7	1.8	14.5	73.1	6.7	3.8	0.0
	A	10	-35.71774	174.51842	1.2	0.2	4.5	29.2	16.4	31.7	18.0
	A	11	-35.71820	174.51777	1.6	1.9	6.6	43.1	24.8	23.1	0.6
	A	12	-35.71861	174.51745	1.9	1.8	10.7	58.7	13.2	11.9	3.7
	B	1	-35.71760	174.51223	1.6	0.7	11.0	64.2	19.3	4.8	0.0
	B	2	-35.71800	174.51176	2.4	2.5	14.1	68.2	8.2	7.0	0.0
	B	3	-35.71846	174.51161	2.0	0.2	17.4	65.4	7.4	9.6	0.0
	B	4	-35.71878	174.51102	2.3	3.1	14.5	55.9	15.1	11.3	0.0
	B	5	-35.71963	174.51069	1.4	0.9	10.8	58.2	17.4	12.3	0.4
	B	6	-35.72008	174.51061	1.5	1.9	7.1	39.8	29.5	20.8	0.9
	B	7	-35.71841	174.51296	2.1	1.7	16.0	79.9	2.1	0.3	0.0
	B	8	-35.71981	174.51144	1.2	0.8	8.6	53.8	17.8	18.4	0.6
	B	9	-35.72044	174.51292	1.9	1.1	20.0	55.1	13.4	10.3	0.0
	B	10	-35.71981	174.51408	1.3	0.9	7.1	58.6	23.0	10.4	0.0
	B	11	-35.72040	174.51345	1.7	0.3	16.2	58.7	10.8	13.9	0.0
	B	12	-35.72049	174.51398	2.0	0.9	16.8	65.7	10.7	6.0	0.0
Raglan Harbour	A	1	-37.80516	174.86513	2.2	7.8	19.6	70.7	1.1	0.8	0.0
	A	2	-37.80481	174.86522	2.3	3.8	13.7	70.7	7.8	4.1	0.0
	A	3	-37.80429	174.86570	2.2	6.1	21.9	67.8	1.9	2.3	0.0
	A	4	-37.80340	174.86645	1.7	2.7	16.4	75.5	4.7	0.7	0.0
	A	5	-37.80382	174.86637	2.4	10.4	14.3	71.3	3.6	0.5	0.0
	A	6	-37.80448	174.86646	1.6	5.0	20.5	69.4	3.6	1.5	0.0
	A	7	-37.80356	174.86684	2.1	9.3	12.3	65.1	10.2	3.1	0.0
	A	8	-37.80395	174.86663	3.1	13.7	11.7	69.2	4.5	0.9	0.0

Continued on next page

Table B-1 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	A	9	-37.80279	174.86729	2.6	13.0	22.1	60.2	3.4	1.3	0.0
	A	10	-37.80335	174.86710	2.6	12.3	14.2	66.0	6.7	0.9	0.0
	A	11	-37.80357	174.86706	2.3	9.5	21.6	64.6	2.5	1.8	0.0
	A	12	-37.80439	174.86706	2.8	12.5	40.0	45.0	1.6	0.9	0.0
	D	1	-37.79620	174.86927	1.5	2.0	11.5	85.7	0.7	0.1	0.0
	D	2	-37.79632	174.86959	2.1	3.9	18.9	74.5	2.3	0.4	0.0
	D	3	-37.79646	174.86953	2.0	5.1	20.9	72.1	1.5	0.4	0.0
	D	4	-37.79634	174.86985	2.1	7.1	23.8	65.5	2.5	1.0	0.1
	D	5	-37.79620	174.87008	1.7	5.2	21.3	71.3	1.8	0.4	0.0
	D	6	-37.79573	174.87031	1.2	3.9	23.1	70.6	0.5	1.9	0.0
	D	7	-37.79593	174.87034	2.2	6.2	16.4	76.8	0.5	0.2	0.0
	D	8	-37.79638	174.87056	3.1	10.1	19.7	66.9	2.8	0.5	0.0
	D	9	-37.79559	174.87086	1.7	3.9	10.9	81.3	3.6	0.3	0.0
	D	10	-37.79589	174.87158	2.5	8.0	28.0	61.4	2.2	0.4	0.0
	D	11	-37.79542	174.87202	1.6	5.2	23.8	69.1	1.4	0.5	0.0
	D	12	-37.79564	174.87188	1.9	5.1	19.3	73.0	1.9	0.6	0.0
Tairua Harbour	A	1	-37.00675	175.85319	4.0	4.7	19.6	69.1	5.8	0.7	0.0
	A	2	-37.00619	175.85307	2.7	4.2	14.1	66.9	11.4	3.4	0.0
	A	3	-37.00647	175.85338	2.4	2.2	14.3	71.4	10.6	1.4	0.1
	A	4	-37.00665	175.85340	3.3	4.0	18.2	68.7	8.2	1.0	0.0
	A	5	-37.00669	175.85371	2.1	2.0	7.4	60.7	20.1	6.5	3.3
	A	6	-37.00650	175.85382	2.2	1.2	6.4	72.7	16.5	3.2	0.0
	A	7	-37.00679	175.85399	2.7	2.0	3.5	70.9	21.3	1.9	0.4
	A	8	-37.00590	175.85418	3.0	4.3	16.4	69.9	8.5	0.8	0.0
	A	9	-37.00545	175.85486	2.1	1.0	6.3	53.1	30.1	8.7	0.9
	A	10	-37.00575	175.85517	1.9	1.9	5.5	53.0	31.1	7.5	1.1

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	1	-37.00730	175.85246	2.9	3.4	15.8	57.0	20.9	2.9	0.0
	B	2	-37.00702	175.85288	4.9	7.1	31.3	57.9	3.1	0.5	0.0
	B	3	-37.00610	175.85476	1.9	0.7	3.5	70.6	20.1	3.8	1.3
	B	4	-37.00563	175.85437	2.0	1.2	5.9	53.0	35.0	4.8	0.1
	B	5	-37.00611	175.85511	2.1	1.1	2.2	81.6	14.0	1.0	0.0
	B	6	-37.00597	175.85553	1.8	0.5	0.5	56.7	41.4	1.0	0.0
	B	7	-37.00533	175.85522	1.9	0.9	5.1	59.9	28.4	5.5	0.2
	B	8	-37.00554	175.85572	1.5	0.3	2.6	59.0	33.5	4.7	0.0
	B	9	-37.00563	175.85562	1.4	0.4	1.8	41.8	41.8	13.7	0.5
	C	1	-37.00705	175.85228	3.9	5.5	29.6	53.2	10.7	0.9	0.0
	C	2	-37.00673	175.85246	5.1	11.7	33.7	49.3	4.6	0.6	0.0
	C	3	-37.00692	175.85237	4.4	7.6	34.3	52.2	5.3	0.6	0.0
	C	4	-37.00539	175.85590	1.7	2.4	5.4	64.7	24.7	2.6	0.2
	C	5	-37.00561	175.85608	1.6	0.4	0.4	43.4	52.2	3.6	0.0
Umupuia Beach	A	1	-36.89814	175.06450	2.6	8.7	57.5	26.4	3.7	2.4	1.2
	A	2	-36.89809	175.06505	1.7	6.2	36.9	51.1	5.1	0.6	0.0
	A	3	-36.89871	175.06627	1.4	4.3	20.9	67.9	5.4	1.0	0.5
	A	4	-36.89978	175.06666	1.3	4.6	39.2	51.0	4.2	0.9	0.0
	A	5	-36.89988	175.06817	1.2	4.0	34.0	56.6	5.1	0.3	0.0
	A	6	-36.90168	175.06698	6.5	69.1	4.7	18.3	6.8	1.1	0.0
	A	7	-36.90070	175.06864	1.6	6.1	36.3	50.0	6.8	0.8	0.0
	A	8	-36.90150	175.06806	1.6	4.9	50.6	35.9	7.1	1.4	0.0
	A	9	-36.90224	175.06723	6.7	35.5	17.1	31.2	14.6	1.1	0.6
	A	10	-36.90155	175.06891	1.6	4.9	40.1	48.6	5.6	0.8	0.0
	A	11	-36.90209	175.07153	1.5	3.7	42.3	47.5	3.8	2.4	0.3
	A	12	-36.90197	175.07216	1.3	3.3	51.1	43.4	1.2	1.0	0.0

Continued on next page

Table B-1 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	A	13	-36.90271	175.07344	1.6	4.0	42.6	44.3	4.9	2.4	1.8
	A	14	-36.90391	175.07302	4.0	27.4	50.2	11.0	3.4	4.5	3.5
	B	1	-36.89716	175.06597	1.0	1.2	15.2	78.8	4.6	0.1	0.0
	B	2	-36.89739	175.06645	1.0	1.8	16.3	78.1	3.7	0.1	0.0
	B	3	-36.89784	175.06642	1.1	2.8	19.3	73.4	3.9	0.6	0.0
	B	4	-36.90157	175.07256	1.2	1.9	43.3	53.8	1.0	0.1	0.0
	B	5	-36.90185	175.07390	1.2	1.7	37.4	59.1	1.8	0.1	0.0
	B	6	-36.90241	175.07386	1.3	3.7	49.0	40.3	5.1	1.5	0.5
	B	7	-36.90211	175.07501	1.2	2.9	46.7	48.5	1.8	0.0	0.0
	B	8	-36.90218	175.07477	1.3	3.0	44.7	50.5	1.7	0.1	0.0
	B	9	-36.90276	175.07485	1.6	5.8	57.7	33.2	2.5	0.9	0.0
	B	10	-36.90214	175.07546	1.2	1.8	45.9	50.6	1.6	0.0	0.0
Waiōtahe Estuary	A	1	-37.99206	177.19572	2.1	6.3	16.6	55.5	18.3	3.4	0.0
	A	2	-37.99220	177.19583	1.7	0.5	3.5	80.2	13.5	2.1	0.1
	A	3	-37.99222	177.19615	2.1	10.2	14.9	65.0	8.6	1.3	0.0
	A	4	-37.99215	177.19724	2.3	13.0	17.9	55.9	10.7	2.6	0.1
	A	5	-37.99201	177.19802	1.8	2.9	7.7	79.9	8.4	1.1	0.0
	A	6	-37.99232	177.19808	1.9	6.9	9.8	72.2	9.8	1.2	0.0
	A	7	-37.99234	177.19852	1.6	4.8	7.3	78.7	8.0	1.1	0.0
	A	8	-37.99262	177.19831	2.0	6.2	8.8	71.8	11.3	1.9	0.0
	A	9	-37.99253	177.19921	1.5	4.6	5.1	72.8	15.2	2.3	0.0
	A	10	-37.99219	177.20007	1.3	2.0	4.8	43.6	43.9	5.8	0.0
	A	11	-37.99222	177.20037	1.4	3.5	3.5	65.7	25.8	0.5	1.1
	A	12	-37.99395	177.20062	2.0	9.7	12.3	73.5	3.8	0.6	0.0
	A	13	-37.99383	177.20068	2.0	9.8	13.8	73.7	2.4	0.3	0.0
	B	1	-37.99279	177.20040	1.6	1.2	5.2	73.7	18.2	1.6	0.0

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	B	2	-37.99259	177.20112	1.2	0.0	2.9	87.3	9.6	0.2	0.0
	B	3	-37.99319	177.20169	1.8	2.0	9.2	82.0	5.4	1.4	0.0
	B	4	-37.99280	177.20221	1.6	0.2	1.2	59.1	33.1	6.3	0.0
	B	5	-37.99311	177.20236	1.8	4.7	7.0	80.1	1.8	1.2	5.2
	B	6	-37.99301	177.20378	1.4	0.0	2.9	90.7	6.3	0.1	0.0
	C	1	-37.99246	177.20348	1.5	0.0	0.4	77.9	20.3	1.5	0.0
	C	2	-37.99206	177.20450	1.5	0.0	0.5	73.1	26.2	0.1	0.0
	C	3	-37.99263	177.20437	1.2	0.0	1.0	84.0	14.9	0.1	0.0
	C	4	-37.99194	177.20547	1.7	0.0	0.8	70.8	27.5	1.0	0.0
	C	5	-37.99220	177.20574	1.6	0.0	1.4	76.2	22.2	0.1	0.0
Whangateau Harbour	A	1	-36.33429	174.76288	1.2	2.0	4.6	75.9	17.2	0.3	0.0
	A	2	-36.33171	174.76416	0.8	0.4	2.1	85.5	11.7	0.4	0.0
	A	3	-36.33287	174.76405	1.0	1.0	4.6	89.2	5.0	0.2	0.0
	A	4	-36.33347	174.76412	1.4	1.2	5.4	84.7	8.4	0.3	0.0
	A	5	-36.32964	174.76514	1.0	1.0	6.8	85.1	6.8	0.3	0.0
	A	6	-36.33126	174.76457	0.9	0.6	2.2	75.5	19.8	1.8	0.0
	A	7	-36.33212	174.76505	1.3	1.3	5.0	74.4	17.5	1.7	0.0
	A	8	-36.33459	174.76509	1.2	0.8	4.6	77.0	15.4	2.2	0.0
	A	9	-36.32789	174.76697	1.0	0.2	5.6	84.0	8.9	1.3	0.0
	A	10	-36.32671	174.76858	1.1	2.2	3.0	54.7	31.0	7.3	1.8
	A	11	-36.32797	174.76918	1.0	1.1	2.6	48.3	38.0	8.3	1.7
	A	12	-36.32530	174.77160	1.2	1.2	5.4	85.9	6.4	1.1	0.0
	B	1	-36.31533	174.78164	0.9	0.8	1.6	55.2	41.8	0.6	0.0
	C	1	-36.31617	174.77639	0.7	0.0	0.2	26.5	65.0	8.2	0.1
	C	2	-36.31529	174.77662	0.6	0.0	0.2	37.0	55.8	7.0	0.0
	C	3	-36.31426	174.78195	1.0	1.5	3.2	39.8	53.5	1.9	0.0

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	D	1	-36.31388	174.77476	1.1	1.1	4.1	73.0	20.5	1.3	0.0
	D	2	-36.31369	174.77620	1.3	1.6	7.2	62.8	27.1	1.3	0.0
	D	3	-36.31127	174.77501	1.2	2.4	8.7	51.8	34.8	2.3	0.0
	D	4	-36.31340	174.77650	0.9	0.3	3.2	81.6	13.1	1.8	0.0
	D	5	-36.31248	174.77876	0.9	0.5	3.2	85.8	8.6	2.0	0.0
	D	6	-36.31429	174.77943	1.3	1.8	3.6	70.1	20.4	2.9	1.2
	D	7	-36.31241	174.77915	1.2	1.3	8.0	76.1	10.1	4.5	0.0
	D	8	-36.31354	174.78154	2.0	4.6	9.9	62.3	16.5	3.7	3.0
Whitianga Harbour	A	1	-36.84434	175.69858	3.4	4.7	11.0	67.3	11.9	5.1	0.0
	A	2	-36.84444	175.69850	4.0	7.7	8.1	64.5	13.4	6.4	0.0
	A	3	-36.84399	175.69874	3.3	5.6	14.2	54.8	15.7	9.6	0.0
	A	4	-36.84419	175.69898	2.6	3.8	10.5	70.2	12.2	3.3	0.0
	A	5	-36.84424	175.69922	2.7	4.2	7.9	74.7	10.3	3.0	0.0
	A	6	-36.84441	175.69921	3.5	8.5	5.5	67.6	13.6	4.8	0.0
	A	7	-36.84470	175.69910	3.6	7.4	5.0	56.5	22.8	8.4	0.0
	A	8	-36.84364	175.69941	3.4	5.8	11.1	56.4	20.1	6.4	0.1
	A	9	-36.84388	175.69952	2.6	3.0	7.7	63.6	18.5	7.1	0.0
	A	10	-36.84424	175.69941	2.9	5.3	5.6	73.8	12.0	3.3	0.0
	A	11	-36.84338	175.70005	2.5	2.8	10.4	65.8	17.1	3.8	0.0
	A	12	-36.84368	175.69995	2.4	3.5	11.7	64.0	16.0	4.8	0.0
	A	13	-36.84410	175.69998	4.1	14.6	5.4	60.3	14.9	4.7	0.1
	A	14	-36.84285	175.70041	3.7	4.5	9.2	58.7	21.5	6.1	0.0
	A	15	-36.84344	175.70051	2.6	4.8	11.3	78.3	5.0	0.7	0.0
	A	16	-36.84413	175.70025	3.3	9.0	4.5	60.1	22.2	4.2	0.0
	A	17	-36.84265	175.70058	3.2	2.6	8.1	58.5	23.4	7.4	0.0
	A	18	-36.84296	175.70054	3.1	3.7	13.9	67.0	12.1	3.3	0.0

Continued on next page

Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	19	-36.84329	175.70066	3.1	5.0	15.7	73.1	5.4	0.8	0.0
	A	20	-36.84341	175.70110	2.7	2.7	8.9	80.0	7.7	0.6	0.0
	A	21	-36.84348	175.70098	3.1	4.0	9.4	78.9	7.1	0.6	0.0
	A	22	-36.84303	175.70142	3.5	5.3	9.9	79.6	4.8	0.4	0.0
	A	23	-36.84340	175.70159	2.8	3.8	6.1	72.8	14.1	3.3	0.0
	A	24	-36.84344	175.70145	3.1	3.8	6.6	69.1	18.1	2.4	0.0