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Intertidal shellfish monitoring in the northern North Island region, 2020–21

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Marine coastal invertebrates that are targeted in non-commercial fishing activities throughout New Zealand include littleneck clam (or cockle, tuangi/tuaki; *Austrovenus stuchburyi*) and pipi (*Paphies australis*). Both species are valued in recreational and customary fishing in this country, and popular target species for shellfish gathering on sheltered beaches, estuaries, and tidal inlets. Their presence in coastal environments makes both cockles and pipi vulnerable to human impacts, such as fishing pressure. Concerns about the sustainability of cockle and pipi populations have led Fisheries New Zealand to commission population surveys at different locations. In northern North Island, a regular (currently annual) survey programme was initiated in the early 1990s, which is focused on particular cockle and pipi beds that are targeted in shore-based recreational and customary fishing activities.

This assessment presents the most recent findings from the northern bivalve monitoring series, based on the survey conducted in 2020–21. The field sampling assessed bivalve populations at eight northern North Island sites, with access to four of the usual 12 survey sites hampered during the field sampling by travel restrictions through Auckland (in response to COVID-19). The eight 2020–21 survey sites were (in alphabetical order): Aotea Harbour, Kawakawa Bay (West), Ōhiwa Harbour, Okoromai Bay, Otūmoetai (Tauranga Harbour), Te Mata and Waipatukahu (Te Mata Bay), Whangamatā Harbour, and Whangapoua Harbour. Te Mata Bay, on the west coast of Coromandel Peninsula was surveyed for the first time.

Cockles were present at seven of the eight survey sites, with no discernible cockle population at Te Mata Bay. Cockle population sizes ranged from 12.61 million (coefficient of variation, CV: 19.44%) individuals at Ōhiwa Harbour to the largest population at Kawakawa Bay (West) of 200.93 million (CV: 12.01%) individuals. Cockle population densities exceeded 300 individuals per m^2 at all of the sites, with the highest density estimate of 884 cockles per m^2 at Whangapoua Harbour, on Coromandel Peninsula. All of the current population estimates met the target CV of less than 20%.

The populations surveyed in 2020–21 contained few large individuals ($\geq$30 mm shell length): this size class was absent at Otūmoetai (Tauranga Harbour), and their densities were low (i.e, less than 10 large individuals per m^2) at Aotea Harbour and Whangapoua Harbour. Their highest density was 43 large cockles per m^2 (19.09%) at Whangamatā Harbour.

Five of the current survey sites supported pipi populations. Total pipi abundance estimates varied between 7.15 million (CV: 10.26%) pipi at Ōhiwa Harbour and 49.01 million (CV: 7.34%) pipi at Otūmoetai (Tauranga Harbour). The lowest density estimate was at Whangamatā Harbour, with 95 pipi per m^2, compared with the highest estimate of 1284 pipi per m^2 at Te Mata Bay. The associated CV of the population estimates was less than 20% at all sites.

Similar to the cockle populations, the pipi populations at the 2020–21 sites contained only a few large individuals ($\geq$50 mm shell length). Across sites, their density estimates ranged from 2 large pipi per m^2 at Otūmoetai to 119 large pipi per m^2 at Te Mata Bay.

The sediment sampling across the different northern sites documented intertidal cockle strata that were generally characterised by low sediment organic content and a small proportion of sediment fines (silt and clay; grain size $<$63 µm). The prevalent grain size fraction was fine sand, followed by very fine sand (grain sizes $>$125 µm and $>$63 µm).

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1. INTRODUCTION

Non-commercial marine fisheries in New Zealand target a variety of coastal invertebrates, including littleneck clam (or cockle, tuangi/tuaki; *Austrovenus stuchburyi*) and pipi (*Paphies australis*). Both species are widely distributed throughout New Zealand, where they often form high-density beds in the intertidal zone of sheltered sedimentary habitats. Cockle beds can reach densities of over 1000 individuals per per m^2, and beds of several thousand individuals per m^2 have been documented for pipi (Hooker 1995, Marsden & Adkins 2010).

The popularity of both species in recreational and customary fisheries has led to concerns about the sustainability of some cockle and pipi populations, particularly in northern North Island. To address these concerns and support the management of northern cockle and pipi populations, Fisheries New Zealand implemented a monitoring programme in the early 1990s, aimed at assessing particular cockle and pipi beds that are targeted in shore-based recreational and customary fishing activities.

The monitoring programme was initially limited to beaches in the Auckland area, but was subsequently expanded to also include semi-enclosed bays, inlets, and estuaries in the wider Auckland region, Northland, Waikato, and Bay of Plenty (Fisheries Management Areas 1 and 9). The survey methods have been relatively consistent since 1999–2000, with the field sampling focused on providing information about the abundance, density, and population size structure of cockles and pipi at the survey sites.

Since 2013–14, the surveys have also included a sediment component, assessing sediment organic content and grain size composition that may influence the distribution and abundance of infaunal bivalves (Berkenbusch et al. 2015). The sediment sampling was amended in 2015–16 to allow a formal analysis of sediment data; at this time, the sediment monitoring was restricted to cockle beds (or strata), which tend to be consistent across surveys, compared with pipi beds which may change in their location and distribution at the survey sites.

This study presents the findings from the northern bivalve field survey conducted across northern North Island sites in 2020–21. Owing to travel restrictions in the Auckland area in February and March 2021, imposed to counter the spread of COVID-19, only 8 of the initially 12 selected sites could be sampled. These sites were (in alphabetical order): Aotea Harbour, Kawakawa Bay (West), Ōhiwa Harbour, Okoromai Bay, Otūmoetai (Tauranga Harbour), Te Mata and Waipatukahu (Te Mata Bay), Whangamatā Harbour, and Whangapoua Harbour (Figure 1). Te Mata Bay, on the west coast of Coromandel Peninsula was surveyed for the first time.

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 2020–21 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

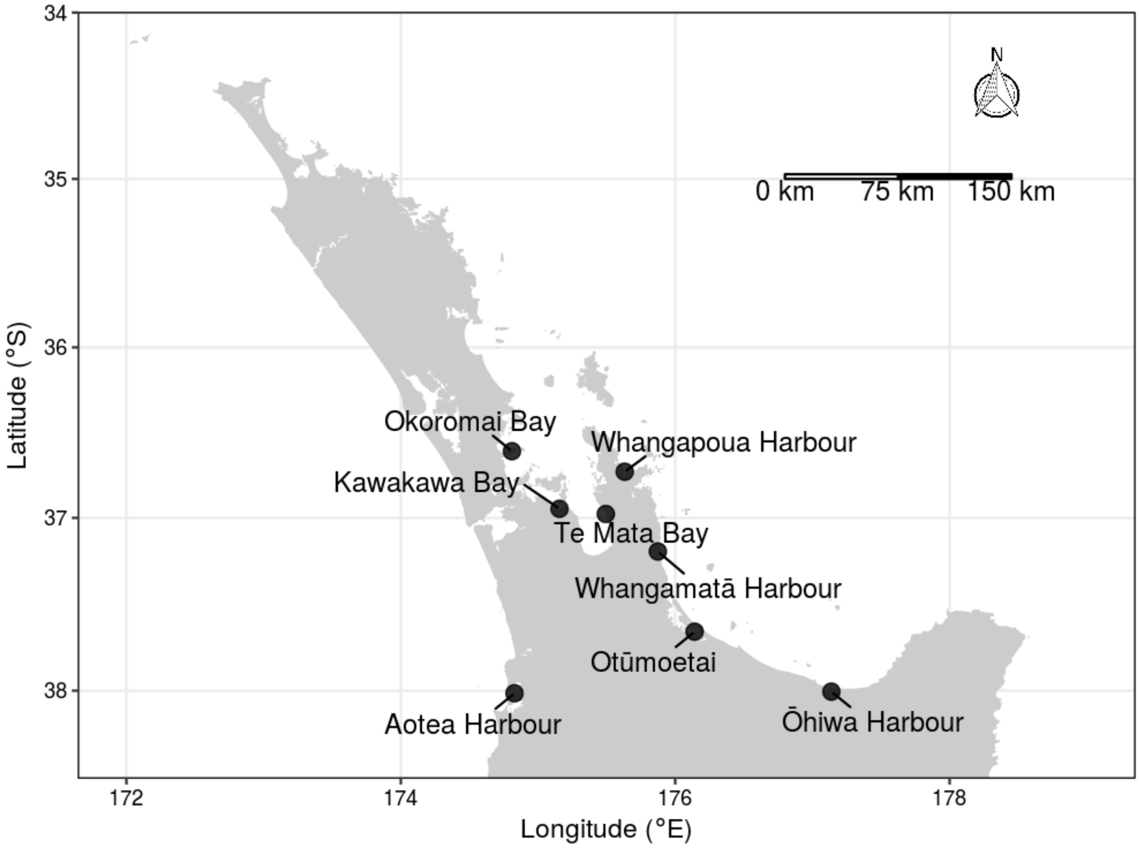


Figure 1: Sites included in the northern North Island intertidal bivalve survey in 2020–21.

boundaries included the acquisition of geographical information through the use of global positioning system (GPS). During sampling, GPS units were used 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. 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 across the eight northern North Island sites was conducted in February and March 2021. During this period, 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, grain size <63 μm) to different sand fractions of very fine to very coarse sands and gravel (i.e., grain sizes 125 to 2000 μm) (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-sized individuals (defined as $\geq$30-mm shell length for cockles, and $\geq$50-mm shell length for pipi) at each site, summing numbers at length of individuals greater than the reference length r for each species:

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

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

Aotea Harbour is one of the large west coast inlets of the Waikato region. Bivalves at this site have been monitored since 2005–06, and the present sampling was the sixth survey in the monitoring series (see Appendix A, Tables A-1, A-2). Throughout the survey series, bivalve assessments at Aotea Harbour have been exclusively focused on cockles; there have been no notable pipi beds since the start of the sampling programme. The sampling extent in the 2020–21 survey was consistent with the area sampled in recent years (i.e., since 2014–15), extending across the intertidal mudflat from the upper to the lower shore, and encompassing one of the harbour's side channels.

The sediment at Aotea Harbour was characterised by a low organic content, which was less than 2.6% across all samples (Figure 2, and see details in Appendix B, Table B-1). The bulk of the sediment consisted of fine sand (grain size $>$125 µm), with 41 to 72% of the sediment in this grain size fraction. There was only a small proportion of sediment fines (grain size $<$63 µm), with a maximum of 15% of sediment comprising fines.

The cockle population was surveyed in a total of 90 sampling points across two strata (Figure 3, Table 1). Cockles were distributed throughout the middle part of the sampling extent, in stratum B, with few cockles in the upper shore area of stratum A. The estimated total population size in 2020–21 was 99.69 million (CV: 9.44%) cockles, with a corresponding population density of 514 cockles per m^2 (Table 2). The current estimates documented a continued increase in the cockle population since 2014–15. At the same time, large individuals ($\geq$30 mm shell length) remained scarce, with 0.60 million (CV: 53.20%) cockles in this size class in 2020–21, at a density of three large individuals per m^2.

Throughout the sampling series, large cockles were consistently scarce at Aotea Harbour, and this size class was missing in 2016–17. In the current assessment, large individuals represented 0.60% of the total population (Table 3, Figure 4). In comparison, 24.79% of the population consisted of recruits ($\leq$15-mm shell length), and their proportion was similar to their proportion in the preceding two surveys. The contribution of recruits was also evident in the generally unimodal population size structure in the three most recent surveys, which was determined by medium-sized cockles. The strong cohort of medium-sized cockles had mean and modal shell lengths of 18.48 and 20 mm in 2020–21, and these mean and modal sizes were similar across the three most recent surveys.

These findings document a stable cockle population at Aotea Harbour, with consistent recruitment and a general lack of large individuals.

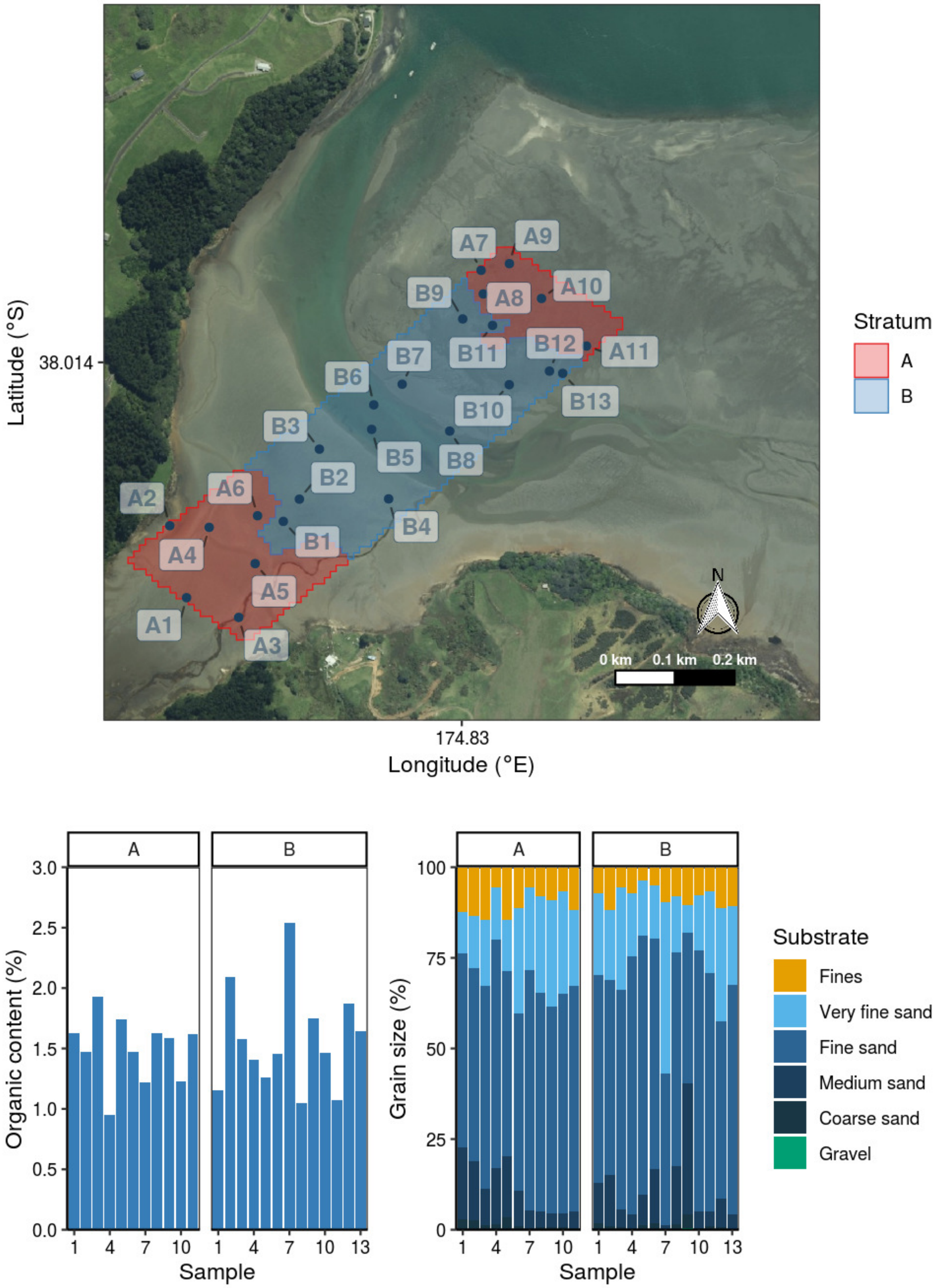


Figure 2: Sediment sample locations and characteristics at Aotea Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, <63 µm), sands (very fine, >63 µm; fine, >125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

3.1.1 Cockles at Aotea Harbour

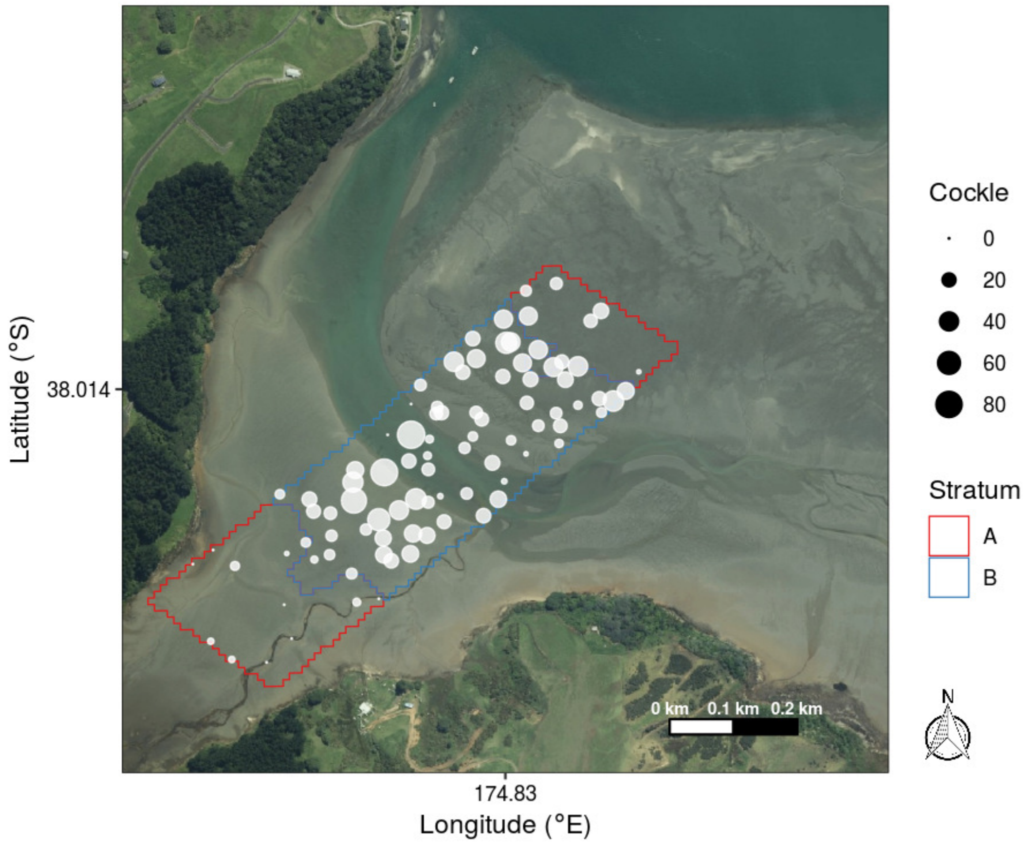


Figure 3: Map of sample strata and individual sample locations for cockles at Aotea Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Aotea Harbour, by stratum, for 2020–21. 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	7.9	20	191	21.46	273	28.55
B	11.5	70	1 661	78.23	678	9.13

Table 2: Estimates of cockle abundance at Aotea 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 (%)
2005–06	9.6	30.25	315	4.98	1.18	12	17.18
2009–10	28.1	140.78	501	10.54	3.46	12	27.88
2014–15	19.5	74.20	381	13.37	0.55	3	45.13
2016–17	19.5	76.41	393	11.05	0.00	0	
2018–19	19.5	82.34	423	11.06	0.96	5	32.86
2020–21	19.4	99.69	514	9.44	0.60	3	53.20

Table 3: Summary statistics of the length-frequency (LF) distribution of cockles at Aotea 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 (%)
2016–17	17.06	17	2–29	32.93	0.00
2018–19	18.64	20	5–34	22.44	1.17
2020–21	18.48	20	6–33	24.79	0.60

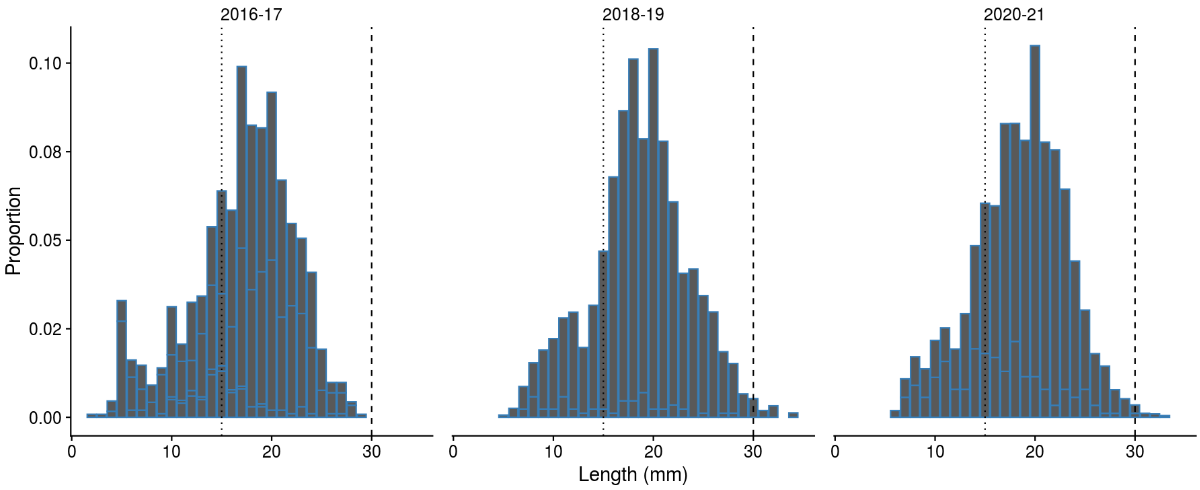


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Aotea Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.2 Kawakawa Bay (West)

Kawakawa Bay (West) is in the Auckland metropolitan area, and was part of the bivalve monitoring series on six occasions, including the current survey (see Appendix A, Tables A-1, A-2). The sampling extent encompasses the entire bay, across an extensive intertidal sandflat. There are no pipi beds at this site, so the survey solely samples cockles.

The sediment in the bay had a low organic content of about 1 to 4% and a variable sediment grain size composition (Figure 5, and see details in Appendix B, Table B-1). Although very fine and fine sands (grain sizes >63 µm and >125 µm) were the prevalent grain size fractions, their relative contribution varied across samples. Similarly, there was marked variation in the proportion of fines (grain size <63 µm; up to 18%) and in the proportions of coarse grain size fractions. For example, the majority of samples contained no gravel (grain size >2000 µm), with 10 to over 40% of gravel in some of the sediment samples.

The field sampling at Kawakawa Bay (West) was based on three cockle strata, with the sampling effort consisting of 98 sampling points (Figure 6, Table 4). Cockles were present throughout most of the bay, except the north-eastern area of stratum C. The total population estimate in 2020–21 was 222.41 million (CV: 12.01%) cockles, including 10.91 million (CV: 27.20%) large individuals (≥30 mm shell length) (Table 5). The total population density was 330 individuals per m^2, with an estimated density of large cockles of 18 individuals per m^2. In comparison with previous recent surveys (i.e., since 2016–17), the total population showed a small decrease, whereas the population of large cockles remained stable, albeit small.

Considering the population size structure at Kawakawa Bay (West), the cockle population was dominated by recruits (≤15 mm shell length) and small individuals (Table 6, Figure 7). The proportion of recruits was 40.80% compared with 5.43% of large cockles. This finding is consistent with the two preceding surveys, which also revealed strong recruitment, evident in the large proportion of recruits (over 30% of the population) and small-sized individuals. Corresponding with the prevalence of these two size classes, mean and modal sizes have remained similar, at or just above the recruit threshold of 15 mm: in 2020–21, mean and modal sizes were 18.01 mm and 15 mm shell length.

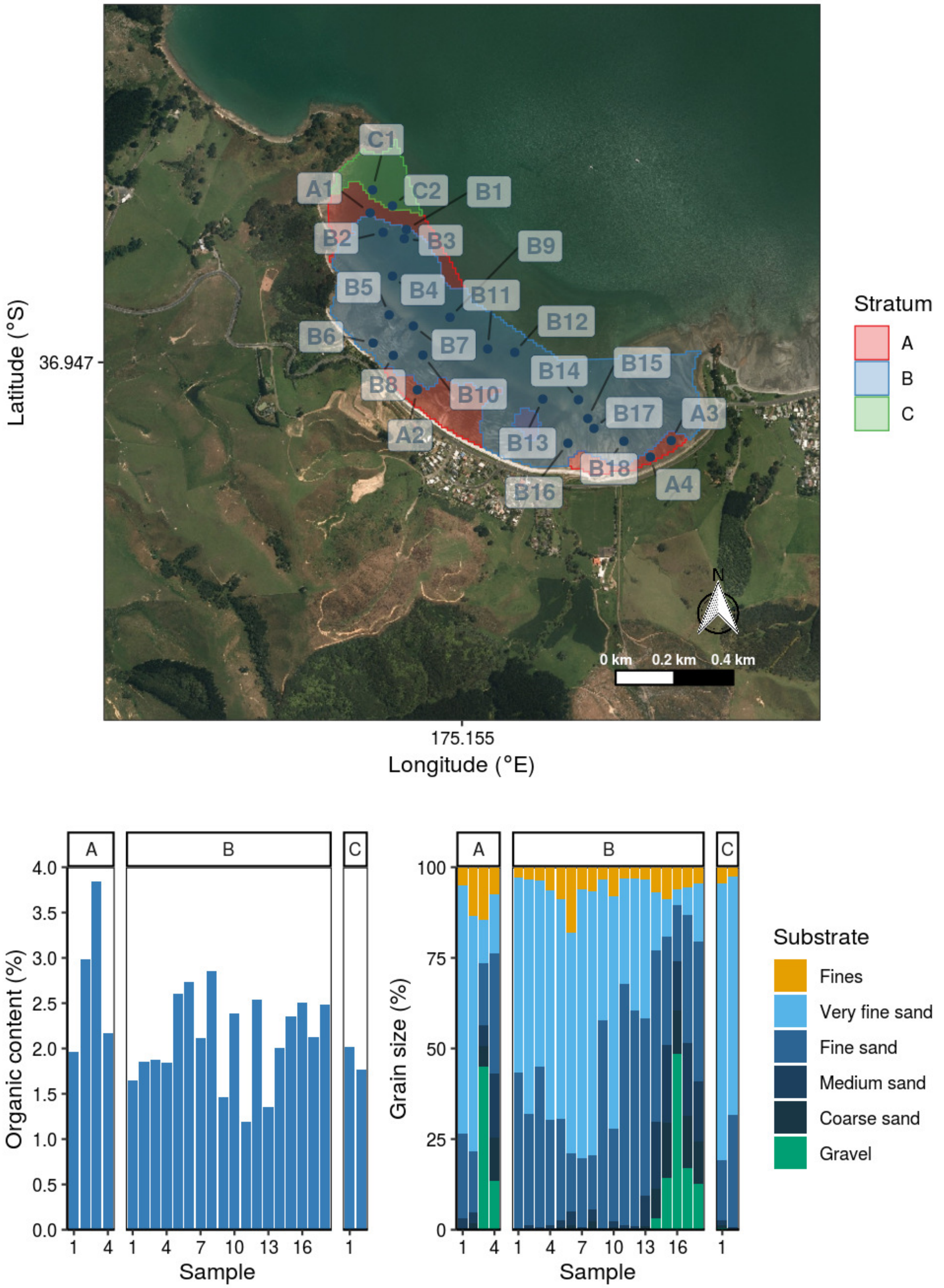


Figure 5: Sediment sample locations and characteristics at Kawakawa Bay (West). Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.2.1 Cockles at Kawakawa Bay (West)

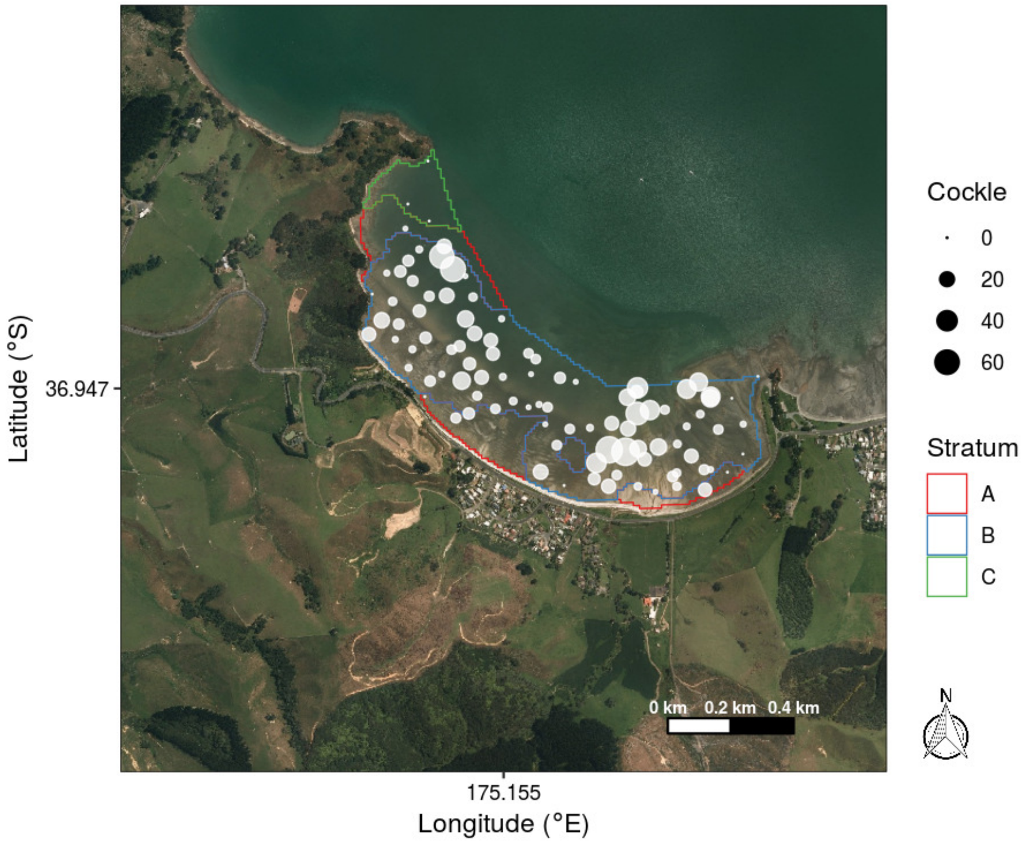


Figure 6: Map of sample strata and individual sample locations for cockles at Kawakawa Bay (West), with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 4: Estimates of cockle abundance at Kawakawa Bay (West), by stratum, for 2020–21. 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	10.9	5	25	15.57	143	62.61
B	46.2	90	1 263	185.36	401	11.91
C	3.8	3	0	0.00	0	

Table 5: Estimates of cockle abundance at Kawakawa Bay (West) 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 (%)
2004–05	60.4	87.68	145	9.19	13.28	22	17.55
2006–07	62.9	86.39	137	10.54	21.23	34	22.75
2014–15	60.9	74.44	122	9.69	19.80	33	15.80
2016–17	60.9	261.21	429	13.84	18.33	30	36.42
2018–19	60.9	222.41	365	17.52	9.34	15	28.81
2020–21	60.9	200.93	330	12.01	10.91	18	27.20

Table 6: Summary statistics of the length-frequency (LF) distribution of cockles at Kawakawa Bay (West). 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 (%)
2016–17	17.75	15	6–46	45.05	7.02
2018–19	18.40	17	6–41	33.33	4.20
2020–21	18.01	15	5–40	40.80	5.43

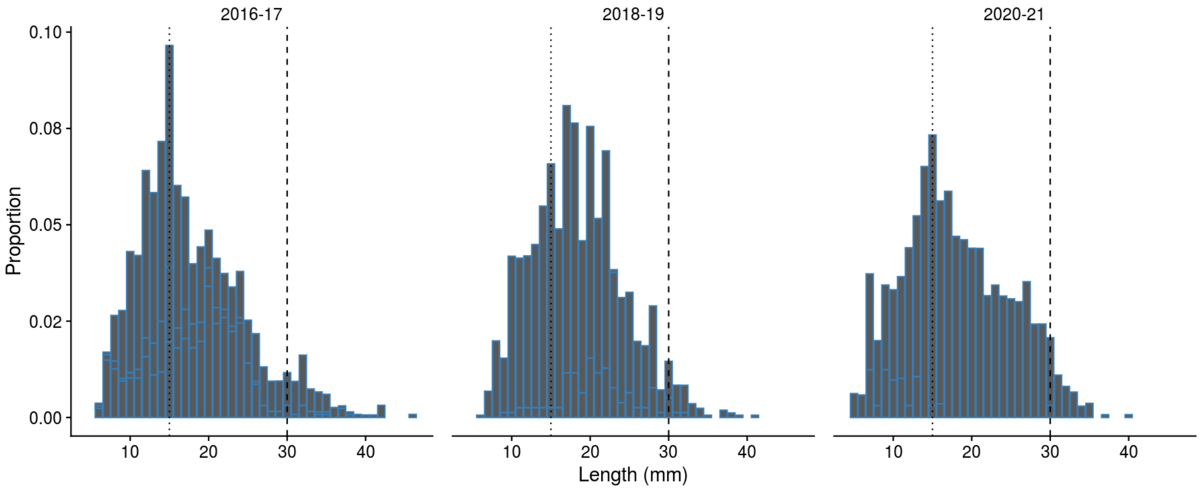


Figure 7: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Kawakawa Bay (West). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3 Ōhiwa Harbour

Ōhiwa Harbour is a large inlet in Bay of Plenty. At this site, the bivalve surveys have focused on cockle and pipi beds in specific areas of the harbour, with some changes in the location and sizes of sampling strata across the eight surveys conducted to date (see Appendix A, Tables A-1, A-2). These changes include the addition of a pipi bed in 2020–21, located off one of the main harbour channels (Kutarere Channel), and accessible from land. Owing to the changes, there have been small differences in the overall size of the sampling extent over time.

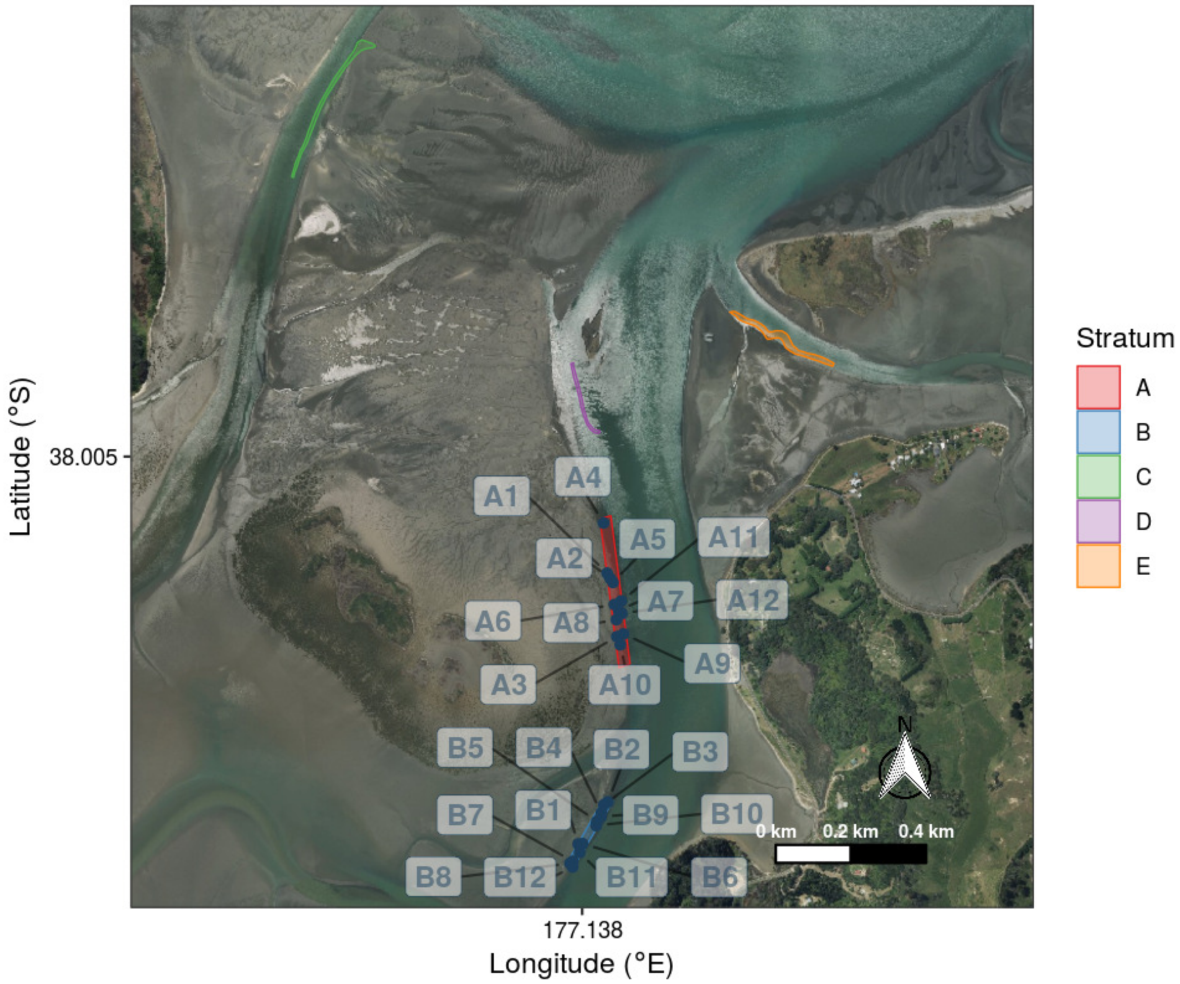
The sediment organic content was low at less than 3%, with a small proportion of fines (grain size <63 µm) of less than 11% (Figure 8, and see details in Appendix B, Table B-1). The sediment grain size composition was dominated by fine sand (grain size >125 µm), with small proportions of other grain size fractions, mostly very fine sand (grain size >63 µm).

The current sampling effort was spread across five separate strata, with a total of 193 sampling points (Figure 8, Table 7). Cockles were distributed throughout three of the strata (A to C). Their total abundance was 12.61 million (CV: 19.44%) cockles, and their density 476 cockles per m^2 (Table 8). The current estimates signified an over two-fold increase in the sampled cockle population. The latter included few large cockles ($\geq$30 mm shell length), with abundance and density estimates for this size class of 0.42 million (CV: 20.71%) individuals and 16 large cockles per m^2, respectively.

The population of large cockles has been consistently small at Ōhiwa Harbour, although the current estimates reflected a 50% decrease in their abundance and density from estimates in 2018–19. There was a concomitant decrease in their overall proportion, declining from 14.69% of the population in 2018–19 to 3.35% in 2020–21 (Table 9). Compared with large cockles, the proportion of recruits ($\leq$15 mm shell length) was similar to their proportion in 2018–19, with this size class contributing 15.15% of the cockle population in 2020–21. The current mean and modal sizes of 20.20 mm and 20 mm reflected a small size reduction of the single cohort, which was characterised by small-sized individuals (Figure 10). Small- to medium-sized cockles consistently determined the unimodal population structure at Ōhiwa Harbour in the three most recent surveys.

The 2020–21 sampling of pipi at Ōhiwa Harbour included an additional pipi bed, stratum E (Figure 11, Table 10). Across all strata, the total population estimate for this species was 7.15 million (CV: 10.26%) pipi, and pipi occurred at an estimated mean density of 270 pipi per m^2 (Table 11). These estimates reflected a notable reduction in the pipi population, particularly in view of the additional pipi bed that was sampled in the current survey; the 2020–21 values were the lowest pipi estimates since 2005–06, following high estimates in 2012–13 and 2015–16, and subsequent decreases. Part of the overall decline may be due to the loss of habitat in one of the pipi beds, stratum D, which was greatly reduced in size between surveys, caused by sand movement through the harbour channel.

Within the population, the size class of large pipi ($\geq$50 mm shell length) continued to be small, with current estimates of 0.86 million (CV: 21.48%) large pipi with 33 m^2. The recent decline in the total population meant that the relative proportion of large pipi increased in 2020–21, even though their abundance and density decreased from estimates in the two preceding surveys (Table 12, Figure 12). Overall, this size class continued to be only a small part (12.09%) of the population. There were also relatively few recruits ($\leq$20 mm shell length), with this size class constituting 3.91% of the current pipi population, which was largely determined by medium-sized pipi. Between 2015–16 and 2020–21, the population size structure distinctly changed from a bimodal to a unimodal population, accompanied by a marked increase in mean and modal sizes over this time. Over this period, the mean shell length increased from 25.71 mm to 39.55 mm, with an increase in modal size from 20 mm to 40 mm shell length.



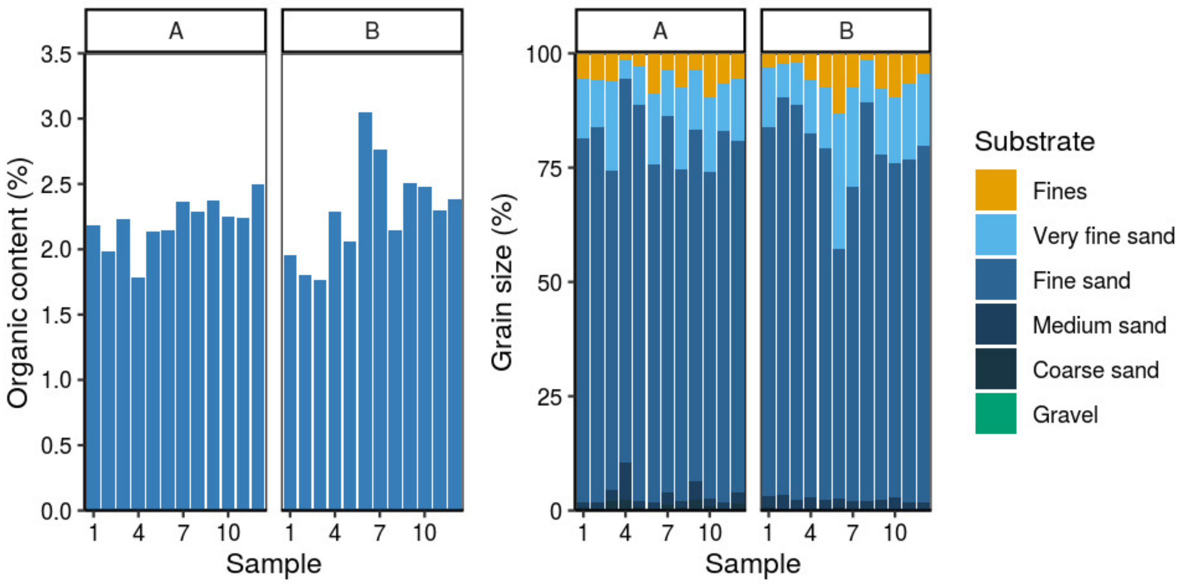


Figure 8: Sediment sample locations and characteristics at Ōhiwa Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.3.1 Cockles at Ōhiwa Harbour

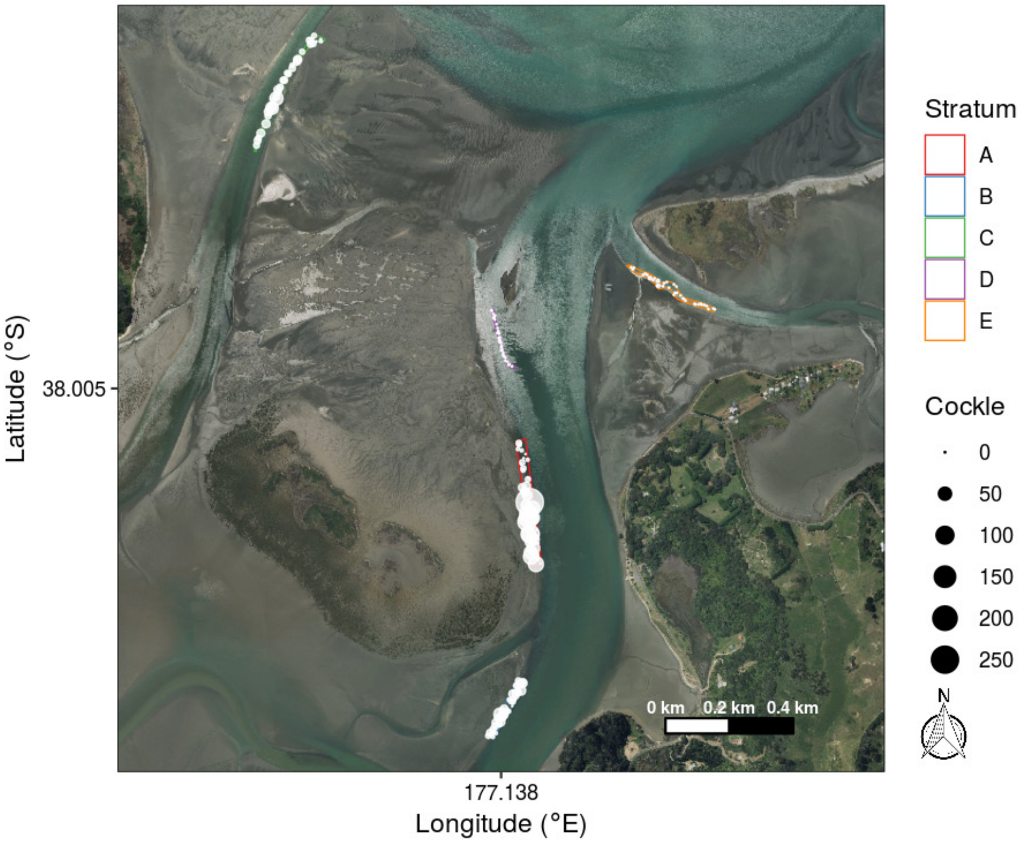


Figure 9: Map of sample strata and individual sample locations for cockles at Ōhiwa Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 7: Estimates of cockle abundance at Ōhiwa Harbour, by stratum, for 2020–21. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	1.2	44	1 334	10.46	866	23.29
B	0.5	45	320	0.94	203	16.42
C	0.4	34	364	1.19	306	17.41
D	0.1	35	0	0.00	0	
E	0.5	35	3	0.01	2	56.01

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	2.2	4.53	201	7.82	0.16	7	22.37
2005–06	2.7	3.69	137	7.07	0.17	6	15.69
2006–07	5.7	17.48	307	10.59	1.12	20	14.47
2009–10	2.1	6.47	308	8.79	0.03	1	51.49
2012–13	2.6	9.05	344	10.49	0.05	2	36.42
2015–16	3.4	11.27	334	13.38	0.08	2	99.96
2018–19	2.5	5.57	219	13.38	0.82	32	39.04
2020–21	2.6	12.61	476	19.44	0.42	16	20.71

Table 9: Summary statistics of the length-frequency (LF) distribution of cockles at Ōhiwa 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	19.32	22	5–33	24.59	1.27
2018–19	22.47	24	5–62	19.65	14.69
2020–21	20.20	20	7–36	15.15	3.35

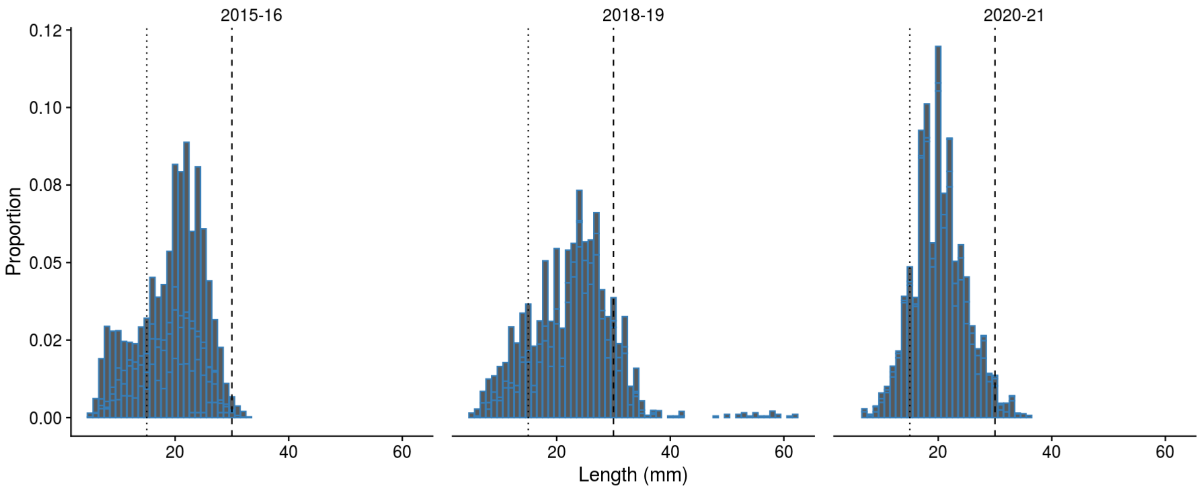


Figure 10: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ōhiwa Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3.2 Pipi at Ōhiwa Harbour

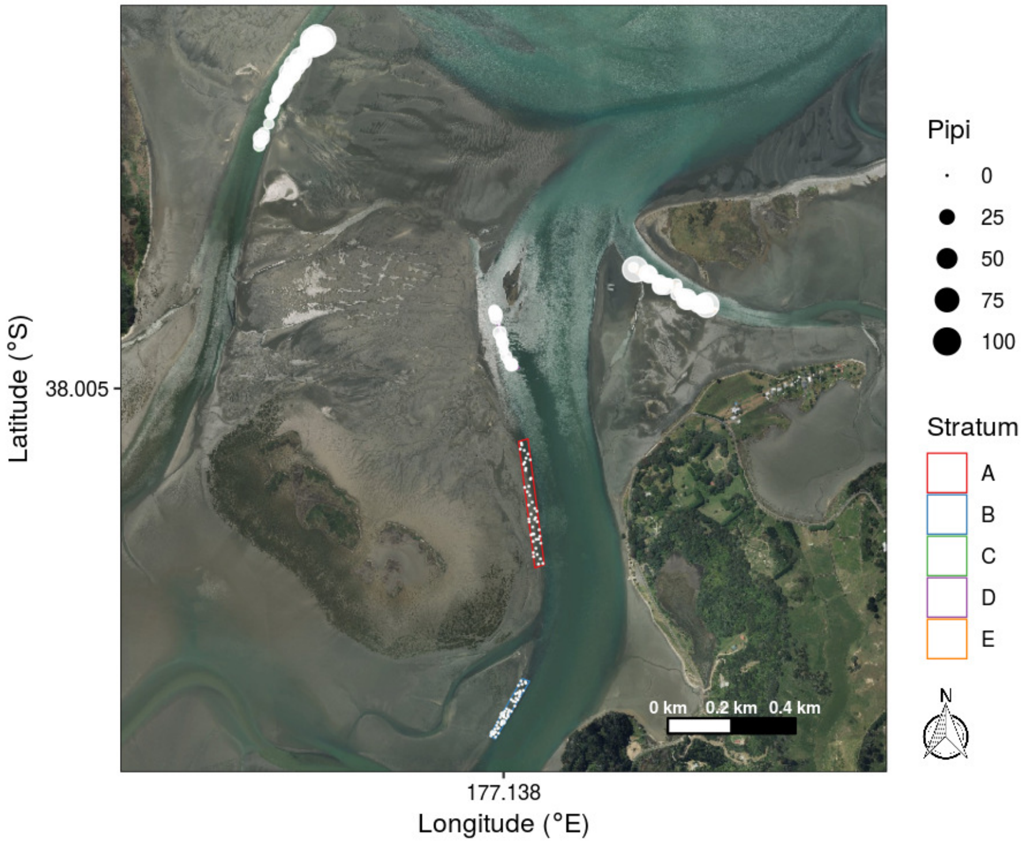


Figure 11: Map of sample strata and individual sample locations for pipi at Ōhiwa Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 10: Estimates of pipi abundance at Ōhiwa Harbour, by stratum, for 2020–21. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	1.2	44	0	0.00	0	
B	0.5	45	3	0.01	2	56.41
C	0.4	34	1 294	4.24	1 087	12.64
D	0.1	35	193	0.21	158	21.38
E	0.5	35	730	2.69	596	18.53

Table 11: Estimates of pipi abundance at Ōhiwa Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	2.2	5.67	252	6.88	2.14	95	7.46
2005–06	2.7	3.40	126	7.27	2.52	93	6.36
2006–07	5.7	8.27	145	10.52	2.14	38	13.78
2009–10	2.1	15.25	726	14.46	1.63	78	18.77
2012–13	2.6	41.59	1 581	14.39	1.03	39	31.52
2015–16	3.4	41.24	1 221	12.10	3.70	109	18.37
2018–19	2.5	13.05	514	13.00	1.24	49	19.69
2020–21	2.6	7.15	270	10.26	0.86	33	21.48

Table 12: Summary statistics of the length-frequency (LF) distribution of pipi at Ōhiwa 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	25.71	20	7–64	53.42	8.96
2018–19	32.67	30	6–64	11.26	9.47
2020–21	39.55	40	9–64	3.91	12.09

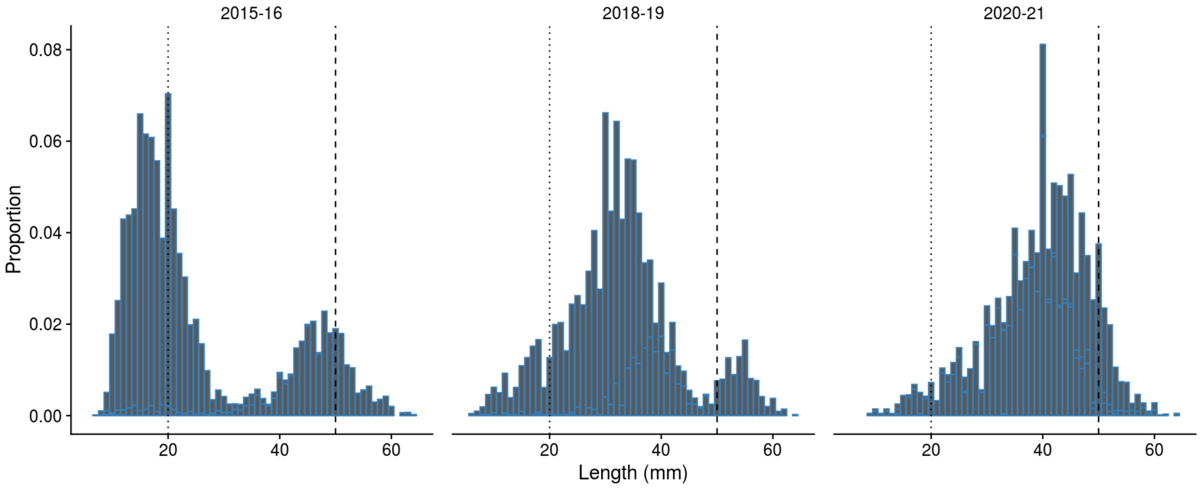


Figure 12: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ōhiwa Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4 Okoromai Bay

Okoromai Bay is a sheltered, south-facing bay north of Auckland on Whangaparoa Peninsula. The bay was included in ten previous bivalve surveys, most recently in 2017–18 (see Appendix A, Tables A-1, A-2). There are no pipi beds at this site, so that the monitoring is solely focused on cockles. The sampling extent has remained the same throughout the survey series.

The sediment sampling at Okoromai Bay documented a low sediment organic content of less than 3% (Figure 13, and see details in Appendix B, Table B-1). The sediment grain size composition was dominated by two size fractions, very fine and fine sands (grain sizes >65 µm and >125 µm). There was only a small proportion of fines (grain size <63 µm), generally less than 10%, with one sample containing 15% of sediment in this grain size fraction. None of the sediment samples contained gravel (grain size >2000 µm).

In 2020–21, the sampling extent was divided into two strata, with a total of 90 sampling points (Figure 14, Table 13). Cockles were predominantly in the mid-and low-shore areas of stratum A, with few cockles in stratum B. The estimated total abundance of the cockle population was 64.37 million (CV: 15.53%) individuals, which occurred at a mean density of 325 cockles per m^2 (Table 14). Included in the population were an estimated 6.10 million (CV: 24.50%) large cockles (≥30 mm shell length), and their density was 31 large individuals per m^2. The current estimates for both the total population and large cockles reflected increases from the preceding survey in 2017–18, with the overall population continuing the increasing trend that started in 2013–14.

Within the overall population, the proportion of large cockles remained small at 9.48%, following a decrease in the preceding survey in 2017–18 (Table 15). In this earlier survey, the population consisted largely of recruits (≤15 mm shell length) with 60.38% of all individuals in this size class; in 2020–21, their proportion was 12.51%.

The reduction in recruits was also evident in the distinct change in population size structure over time, which shifted from a bimodal population in 2015–16 and 2017–18 to a unimodal size structure in 2020–21 (Figure 15). This shift was accompanied by a recent increase in mean and modal sizes from 15.54- and 10-mm shell length in 2017–18 to 22.55- and 24-mm shell length.

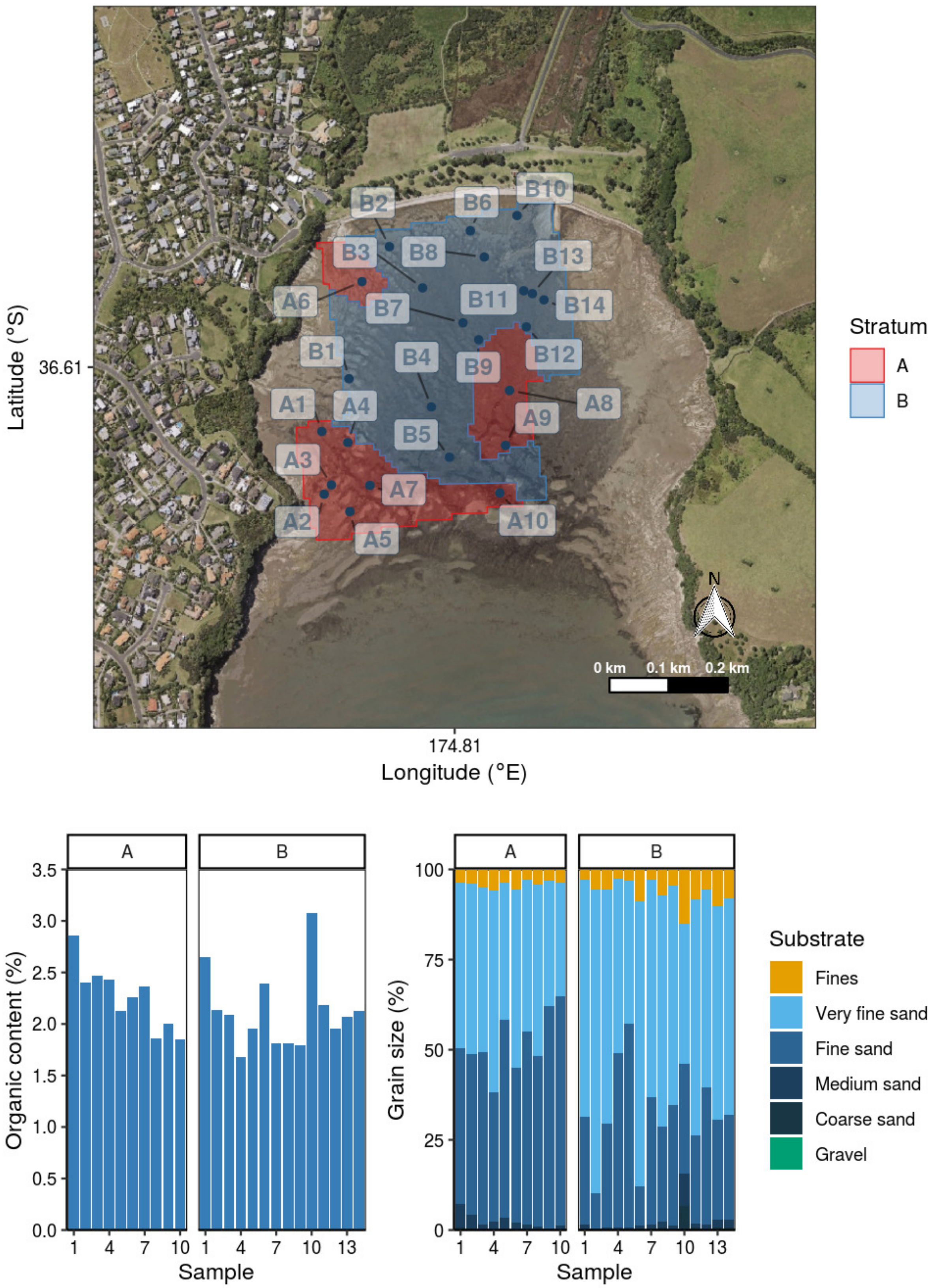


Figure 13: Sediment sample locations and characteristics at Okoromai Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, <63 µm), sands (very fine, >63 µm; fine, >125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

3.4.1 Cockles at Okoromai Bay

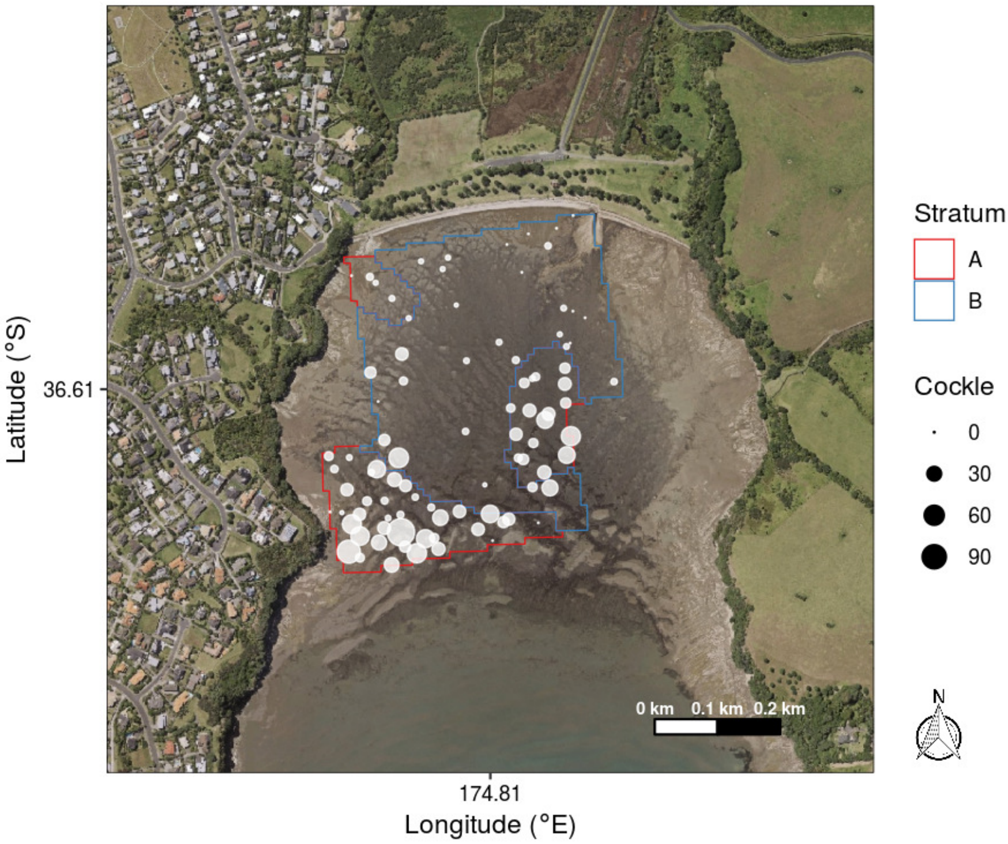


Figure 14: Map of sample strata and individual sample locations for cockles at Okoromai Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of cockle abundance at Okoromai Bay, by stratum, for 2020–21. 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	6.7	60	1 227	39.09	584	13.63
B	13.1	30	202	25.28	192	33.45

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	20.0	90.05	450	4.26	24.38	122	5.30
2001–02	24.0	27.26	114	7.78	8.66	36	8.31
2002–03	20.0	26.86	134	5.10	7.05	35	6.56
2003–04	20.0	27.96	140	11.48	12.01	60	10.62
2004–05	20.0	34.50	172	7.44	13.80	69	4.37
2006–07	20.0	17.39	87	9.08	7.03	35	12.18
2009–10	20.0	29.62	148	9.60	13.07	65	10.84
2012–13	20.0	28.50	142	10.61	13.61	68	11.92
2013–14	19.8	28.14	142	12.69	4.48	23	19.47
2015–16	19.8	34.78	175	19.45	8.48	43	19.44
2017–18	19.8	52.25	263	15.24	4.29	22	19.79
2020–21	19.8	64.37	325	15.53	6.10	31	24.50

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2015–16	21.73	16	6–41	29.64	24.37
2017–18	15.54	10	3–43	60.38	8.21
2020–21	22.55	24	5–39	12.51	9.48

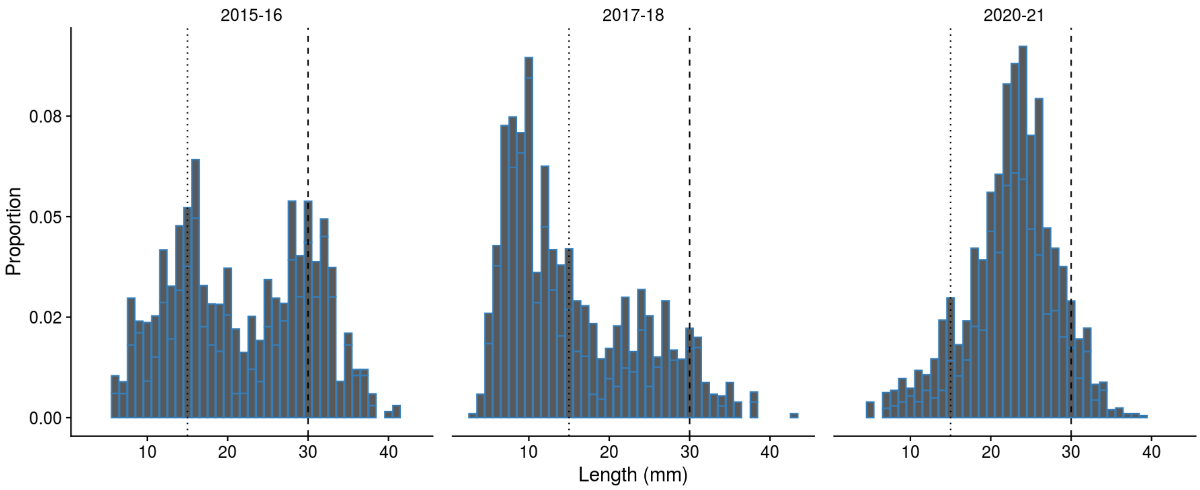


Figure 15: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Okoromai Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5 Otūmoetai (Tauranga Harbour)

Otūmoetai is a large intertidal sandflat that is part of Tauranga Harbour, in Bay of Plenty. Since 2000–01, there have been nine surveys at this site, including the current bivalve assessment (see Appendix A, Tables A-1, A-2). Throughout the time series, the field sampling has been based on two separate areas for cockles and pipi, with changes to the pipi bed resulting in some variation in the sampling extent over time.

Sediment samples from the cockle strata documented an organic content of 1 to 2% and a small proportion of fines (grain size <63 µm; less than 2%) across all samples (Figure 16, and see details in Appendix B, Table B-1). The most prevalent grain size fraction was fine sand (grain size >125 µm), with varying proportions of medium sand (grain size >250 µm) and only minor fractions of sediment at other grain sizes.

The total survey effort in 2020–21 was 85 sampling points across three strata (Figure 17, Table 16). Cockles were distributed throughout strata A and C, and particularly concentrated in the upper-shore stratum A. There were an estimated 22.43 million (CV: 10.78%) cockles at Otūmoetai in 2020–21; their estimated mean density was 344 cockles per m^2 (Table 17). The total population estimates were comparable with estimates in the preceding survey in 2018–19 and indicated that the population remained small following its marked decline in 2018–19.

There were no large individuals (≥30 mm shell length) in the cockle population, and this size class was scarce in previous surveys. In addition to the absence of large individuals, a significant proportion (38.56%) of the population consisted of recruits (≤15 mm shell length) (Table 18, Figure 18). This size class also contributed about half of the cockle population in 2016–17 and 2018–19, and the unimodal population size structure was centred around the 15-mm cut-off length. Both mean and modal sizes remained relatively unchanged in recent surveys and were 16.73 mm and 17 mm shell length in 2020–21. Cockles at this site are recruits and small-sized individuals, showing little growth to medium and large sizes over time.

The pipi bed at Otūmoetai is associated with one of the harbour's side channels; pipi were concentrated in this bed, in stratum C (Figure 19, Table 19). This species had an estimated abundance of 49.01 million (CV: 7.34%) individuals, including 0.13 million (CV: 48.62%) large pipi (≥50 mm shell length) (Table 20). Corresponding with these abundance estimates, mean densities were 752 pipi per m^2 and two large pipi per m^2. The estimates signified a continuing decline in the total population, with a smaller decrease in the population of large pipi. Large pipi have only been a minor part of the Otūmoetai population since 2002–03, when this size class showed a notable decrease.

Their overall contribution to the total population has been minor throughout most of the survey series; they made up 0.27% of the population in 2020–21 (Table 21). At the same time, the proportion of recruits (≤20 mm shell length) has also diminished in recent surveys, with 5.66% and 2.83% recruits in 2018–19 and 2020–21, respectively. With only small proportions of recruits and large individuals, the pipi population at this site was determined by medium-sized pipi, forming a single, strong cohort (Figure 20). Mean and modal sizes documented the prevalence of this size class, which have been similar since 2016–17. In 2020–21, the modal shell length was 32 mm. The size-frequency distributions indicate a stable population with little recruitment and also few large individuals in the two most recent surveys.

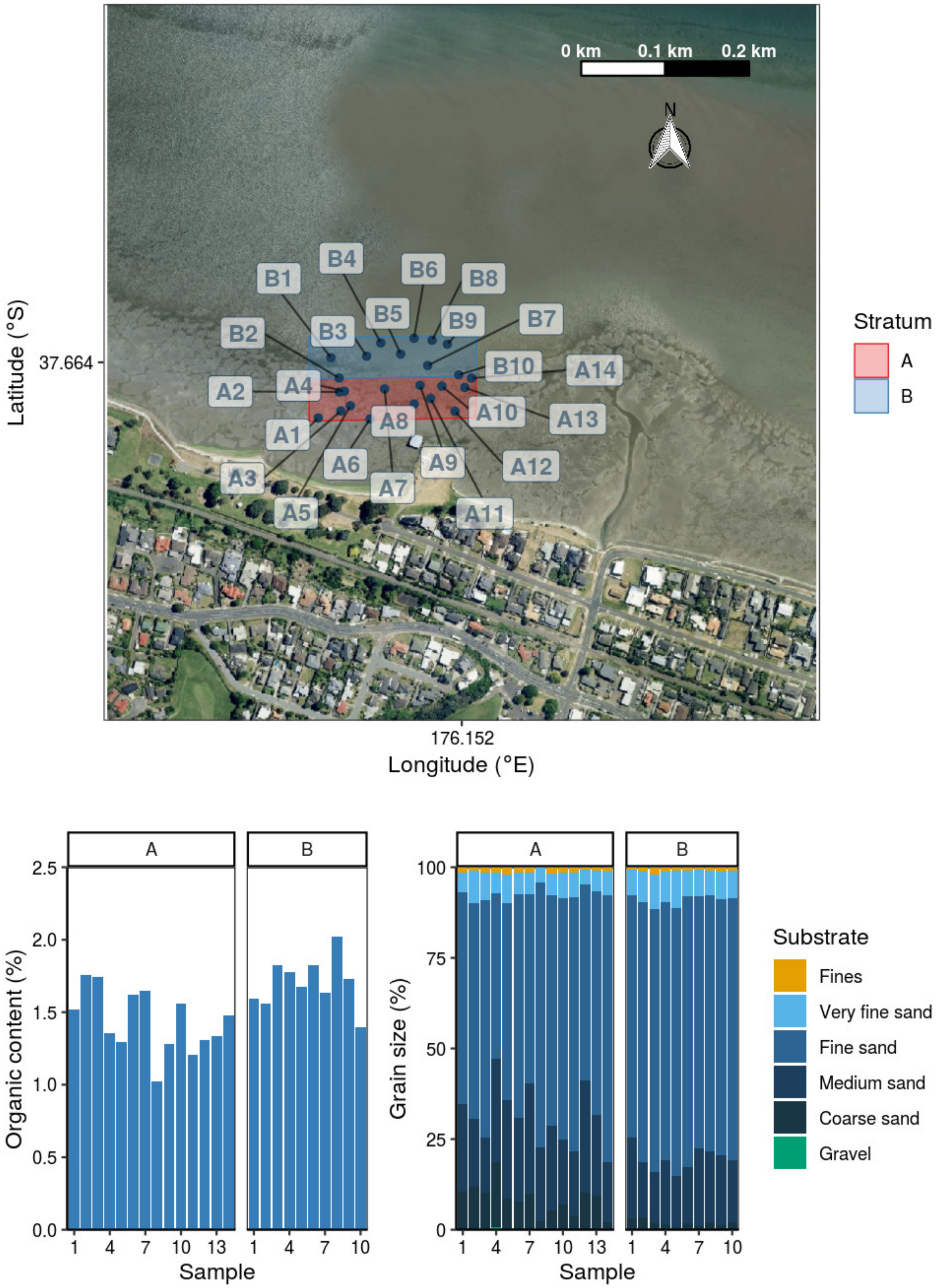


Figure 16: Sediment sample locations and characteristics at Otūmoetai (Tauranga Harbour). Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.5.1 Cockles at Otūmoetai (Tauranga Harbour)

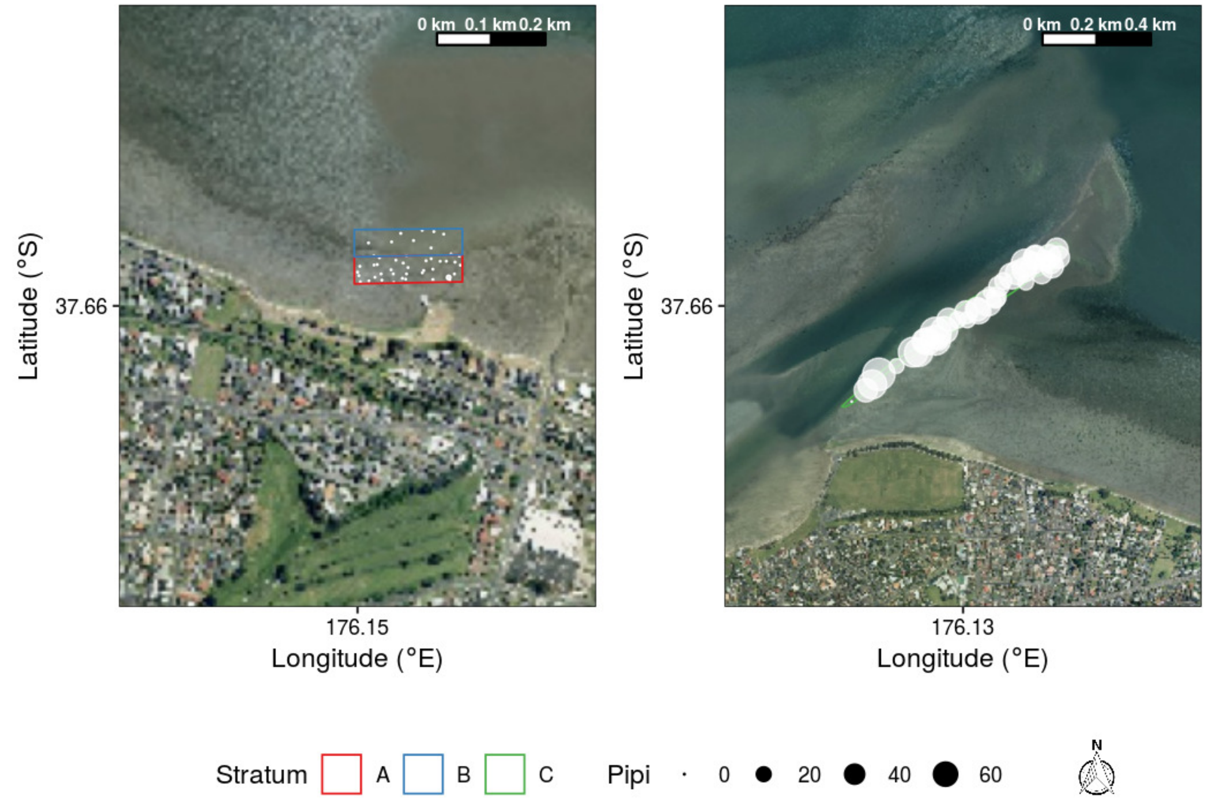


Figure 17: Map of sample strata and individual sample locations for cockles at Otūmoetai (Tauranga Harbour), with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 16: Estimates of cockle abundance at Otūmoetai (Tauranga Harbour), by stratum, for 2020–21. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	1.0	35	1 071	8.74	874	12.66
B	1.0	10	2	0.06	6	>100
C	4.5	40	421	13.63	301	15.77

Table 17: Estimates of cockle abundance at Otūmoetai (Tauranga 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 (%)
2000–01	5.6	5.62	100	9.04	0.54	10	12.88
2002–03	5.6	11.25	201	5.71	0.03	<1	35.73
2005–06	4.6	2.21	48	10.27	0.02	<1	79.03
2006–07	4.6	10.67	232	10.13	0.04	<1	54.78
2009–10	5.6	14.73	263	10.85	0.20	4	80.85
2014–15	7.7	37.28	486	7.20	0.02	<1	>100
2016–17	8.1	40.11	496	14.56	0.34	4	>100
2018–19	8.1	21.95	272	10.48	0.01	<1	100
2020–21	6.5	22.43	344	10.78	0.00	0	

Table 18: Summary statistics of the length-frequency (LF) distribution of cockles at Otūmoetai (Tauranga 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 (%)
2016–17	15.49	15	5–39	52.88	0.85
2018–19	15.80	15	5–30	48.12	0.04
2020–21	16.73	17	5–29	38.56	0.00

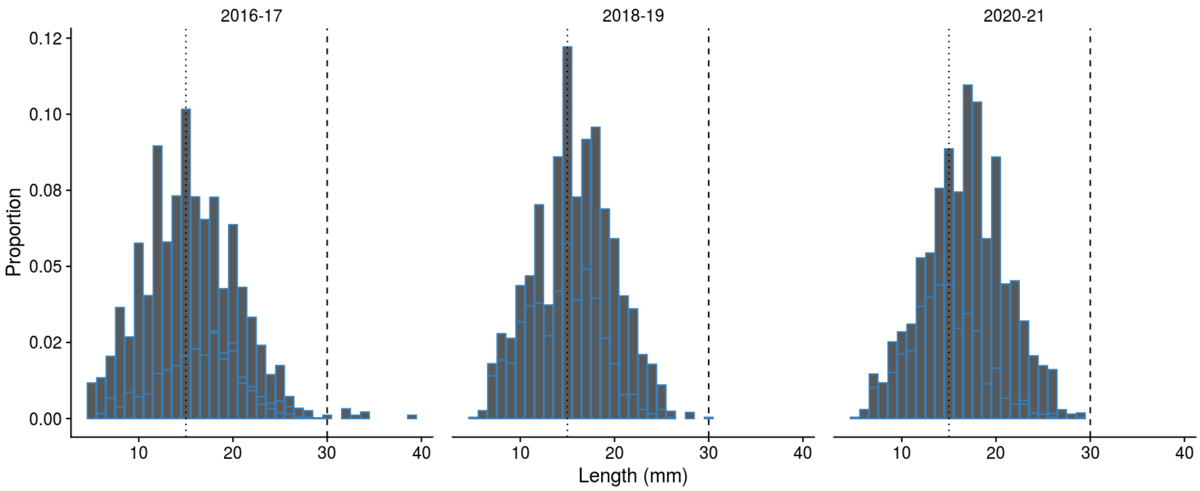


Figure 18: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Otūmoetai (Tauranga Harbour). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5.2 Pipi at Otūmoetai (Tauranga Harbour)

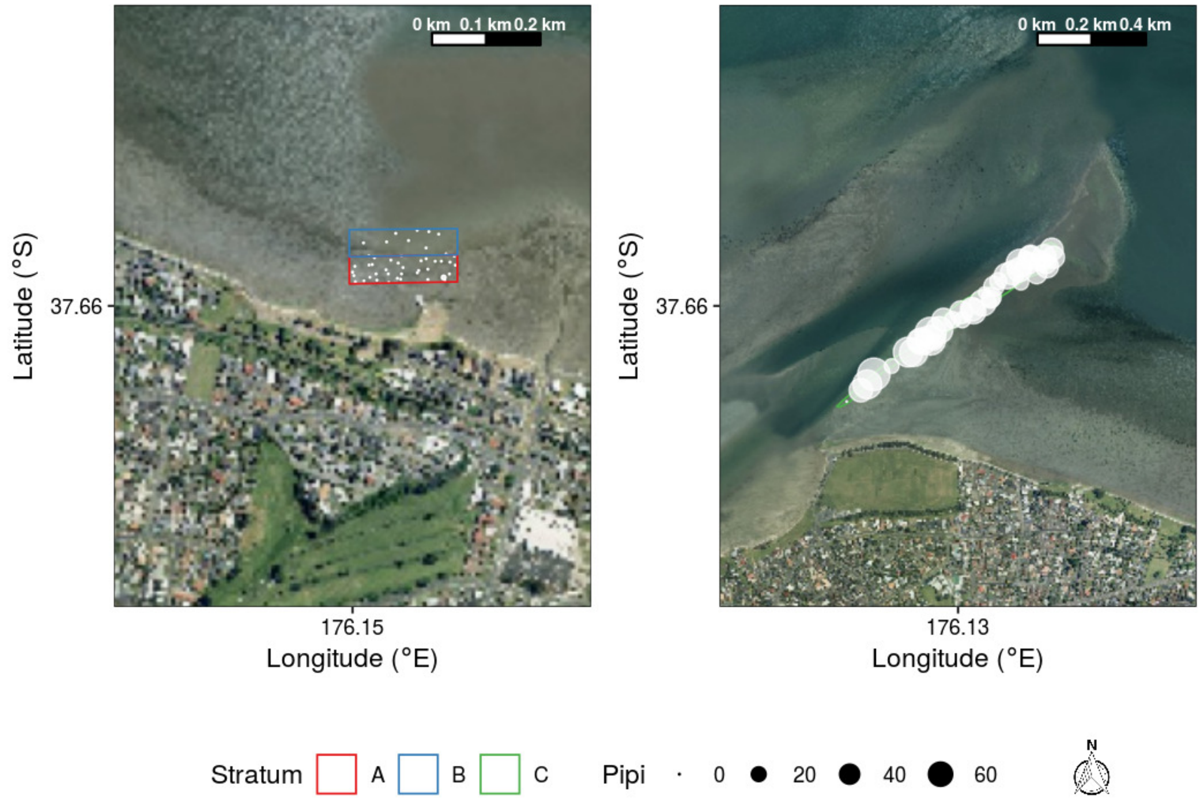


Figure 19: Map of sample strata and individual sample locations for pipi at Otūmoetai (Tauranga Harbour), with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of pipi abundance at Otūmoetai (Tauranga Harbour), by stratum, for 2020–21. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	1.0	35	1	0.01	<1	>100
B	1.0	10	0	0.00	0	
C	4.5	40	1 513	49.00	1081	7.34

Table 20: Estimates of pipi abundance at Otūmoetai (Tauranga 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 (%)
2000–01	5.6	24.76	442	3.30	9.17	164	3.56
2002–03	5.6	20.37	364	3.63	2.06	37	7.56
2005–06	4.6	34.26	745	2.76	1.62	35	7.11
2006–07	4.6	23.63	514	6.61	1.02	22	17.46
2009–10	5.6	17.35	310	7.23	0.63	11	27.44
2014–15	7.7	92.59	1 207	5.59	0.47	6	29.21
2016–17	8.1	71.90	889	11.16	0.13	2	56.94
2018–19	8.1	58.86	731	10.94	0.30	4	40.75
2020–21	6.5	49.01	752	7.34	0.13	2	48.62

Table 21: Summary statistics of the length-frequency (LF) distribution of pipi at Otūmoetai (Tauranga 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 (%)
2016–17	29.91	34	3–50	17.23	0.18
2018–19	30.85	30	7–52	5.66	0.52
2020–21	32.71	32	12–53	2.83	0.27

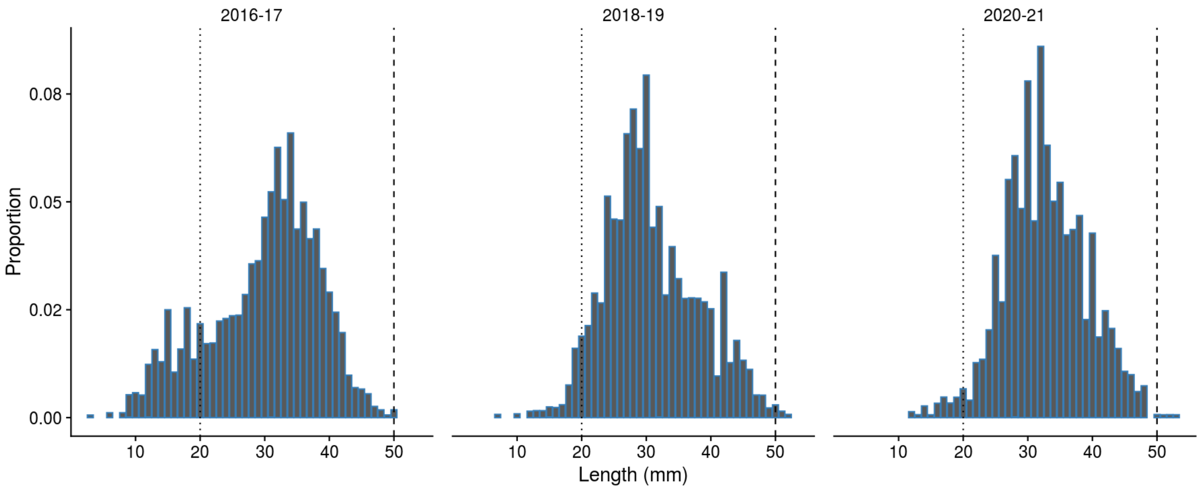


Figure 20: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Otūmoetai (Tauranga Harbour). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Te Mata Bay

Te Mata and Waipatukahu (‘Te Mata Bay’) are on the western side of Coromandel Peninsula, just north of Thames. This assessment was the first time this site was included in the northern bivalve surveys. It is currently subject to a temporary closure (effective 10 July 2020), prohibiting the take of cockles, pipi, and several species of mussels and oysters until July 2022 (Department of Internal Affairs 2020). The identification of survey areas at this site was guided by Ngāti Tamaterā and included extensive on-site reconnaissance prior to the survey. The reconnaissance explored the presence of infaunal bivalves at 261 points that were distributed across the intertidal and shallow subtidal zones from north of Te Mata River to south of Tapu River, extending to a distance of about 300 m from the shore (see map in Appendix C, Figure C-1).

The intertidal zone at Te Mata and Waipatukahu is predominantly coarse sand and gravel, interspersed with cobble and boulders (see illustration in Appendix C, Figure C-2). Two haphazardly-collected sediment samples contained 37 and 50% gravel (grain size >2000 µm). Only one cockle was found during the reconnaissance, so that the current survey only assessed pipi. The sampling extent encompassed two separate pipi beds, with one bed each associated with Te Mata River and Tapu River, respectively (Figure 21). The pipi population was surveyed in a total of 80 points across the two strata (Table 22). Both strata supported abundant pipi populations, with particularly high numbers and densities in the southern bed, in stratum B.

Based on the field sampling, the estimate for the total pipi population was 12.46 million (CV: 7.31%) pipi at Te Mata Bay. Their corresponding density was 1284 individuals per m^2 (Table 23). The population included large pipi (≥50 mm shell length), and there were an estimated 1.16 million (CV: 14.38%) individuals in this size class.

Across the different size classes, large pipi represented 9.29% of the total population in 2020–21 (Table 24). At the same time, there was also some recruitment at this site, with 4.48% of pipi at shell lengths of up to 20 mm.

The prevalent size class was medium-sized pipi, which determined the unimodal population size structure (Figure 22). Their influence on the length-frequency distribution was evident in the mean and modal sizes of 39.39 mm and 42 mm shell length. The largest pipi size at Te Mata Bay (and for all of the 2020–21 sites that contained pipi) was 61 mm shell length.

3.6.1 Pipi at Te Mata Bay

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

Table 22: Estimates of pipi abundance at Te Mata Bay, by stratum, for 2020–21. 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	0.6	40	1 344	5.84	960	9.55
B	0.4	40	2 559	6.62	1 828	10.89

Table 23: Estimates of pipi abundance at Te Mata Bay for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2020–21	1.0	12.46	1 284	7.31	1.16	119	14.38

Table 24: Summary statistics of the length-frequency (LF) distribution of pipi at Te Mata Bay. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2020–21	39.39	42	9–61	4.48	9.29

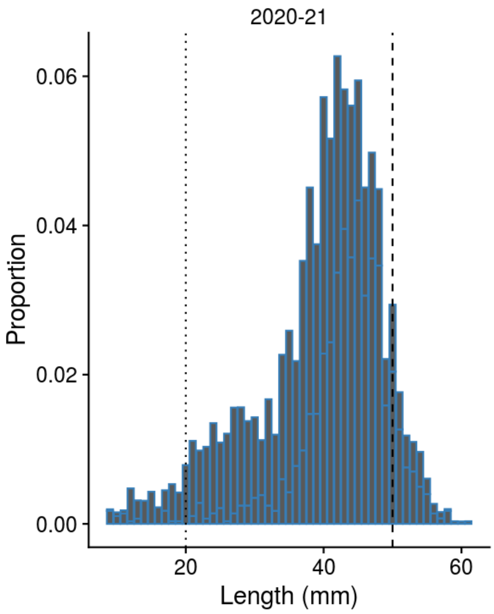


Figure 22: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Te Mata Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7 Whangamatā Harbour

Whangamatā Harbour is a large tidal inlet in the Waikato region, on eastern Coromandel Peninsula. The harbour has been part of eleven previous surveys, which have been biennial since 2014–15 (see Appendix A, Tables A-1, A-2). The sampling at this site is focused on bivalves in the lower harbour, where the sampling area is divided by a tidal channel of Moanaanuanu Estuary. In recent surveys (i.e., since 2014–15), the sampling extent has remained similar in size, with small variations relating to the distribution of pipi.

The survey in 2020–21 documented sediment samples that were low in organic content (less than 3.5%) (Figure 23, and see details in Appendix B, Table B-1). There was a small but varying proportion of sediment fines (grain size <63 μm), with 0.5 to 7.0% of sediment in this grain size fraction. In contrast, fine sand (grain size >125 μm) generally made up most of the sediment (up to 79%). The proportions of other grain size fractions were small, except for medium sand (grain size >250 μm), with several samples containing over 30% of medium sand.

In 2020–21, cockles and pipi were sampled across four strata in a total of 101 sampling points (Figure 24, Table 25). Cockles were predominantly in stratum C, which extended across both sides of the tidal channel. Their estimated total population size was 61.20 million (CV: 8.70%) cockles, with an estimated mean density of 748 cockles per m^2 (Table 26). The current estimates documented that the cockle population continued to decrease from comparatively high abundance and density estimates in 2014–15 (104.53 million (CV: 6.59%) cockles and 1372 cockles per m^2, respectively).

Throughout most of the assessment period, the cockle population contained a small number of large individuals ($\geq$30 mm shell length), with 3.49 million (CV: 19.09%) cockles in this size class in 2020–21. There were an estimated 43 large cockles per m^2 , and both population metrics showed some variation over time.

Considering the population size structure, large cockles represented 5.69% of the current population, compared with 23.83% recruits ($\leq$15 mm shell length) (Table 27, Figure 25). The latter size class was also prominent in the two preceding assessments, indicating consistently strong recruitment at this site, contributing to the stable population dominated by medium-sized cockles. The influence of recruits was evident in the mean and modal sizes of the unimodal population: in 2020–21, these sizes were 20.37 mm and 24 mm shell length, respectively.

The pipi population at Whangamatā Harbour was concentrated in stratum D, which is a shallow, high-flow area associated with the main harbour channel (Figure 26, Table 28). The 2020–21 abundance and density estimates for the pipi population were 7.79 million (CV: 8.64%) pipi and 95 pipi per m^2 (Table 29). The population contained 1.79 million (CV: 18.97%) large pipi ($\geq$50 mm shell length); their estimated mean density was 22 large pipi per m^2. The current estimates signified decreases in the total population and in the abundance and density of large pipi.

Owing to the overall decrease in the pipi population, large pipi still represented a notable proportion of the current population, even though it showed a distinct reduction in two most recent surveys: their proportion declined from 50.90% in 2016–17 to 23.01% in 2020–21 (Table 30, Figure 27). At the same time, there was little recruitment at this site, with 1.26% of the 2020–21 population consisting of recruits ($\leq$20 mm shell length). Across the three recent surveys, medium-sized pipi were the dominant size class, with a recent shift in the unimodal population towards the large-size cut-off with current mean and modal shell lengths of 43.31 mm and 46 mm, respectively.

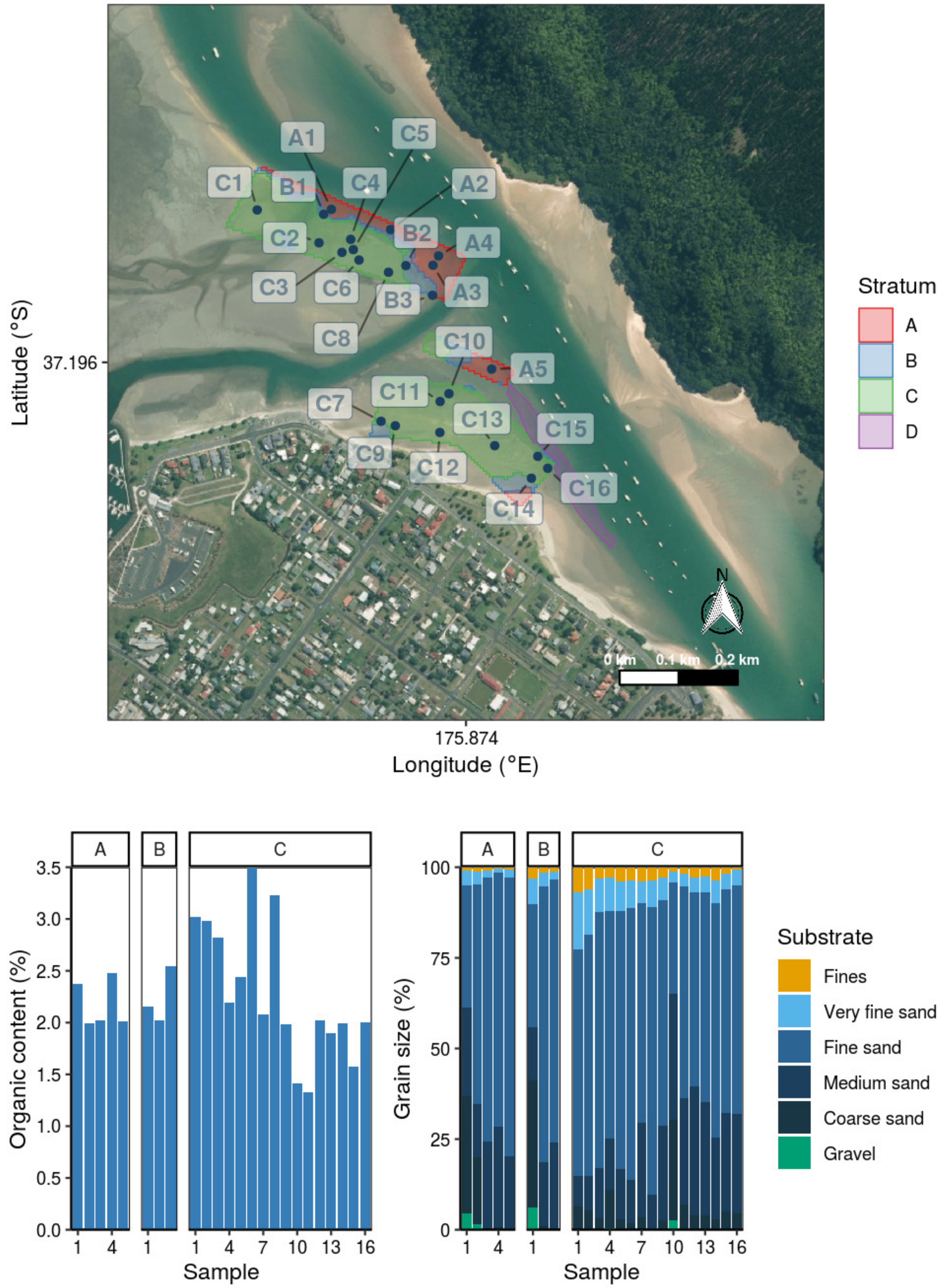


Figure 23: Sediment sample locations and characteristics at Whangamatā Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, <63 µm), sands (very fine, >63 µm; fine,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

3.7.1 Cockles at Whangamatā Harbour

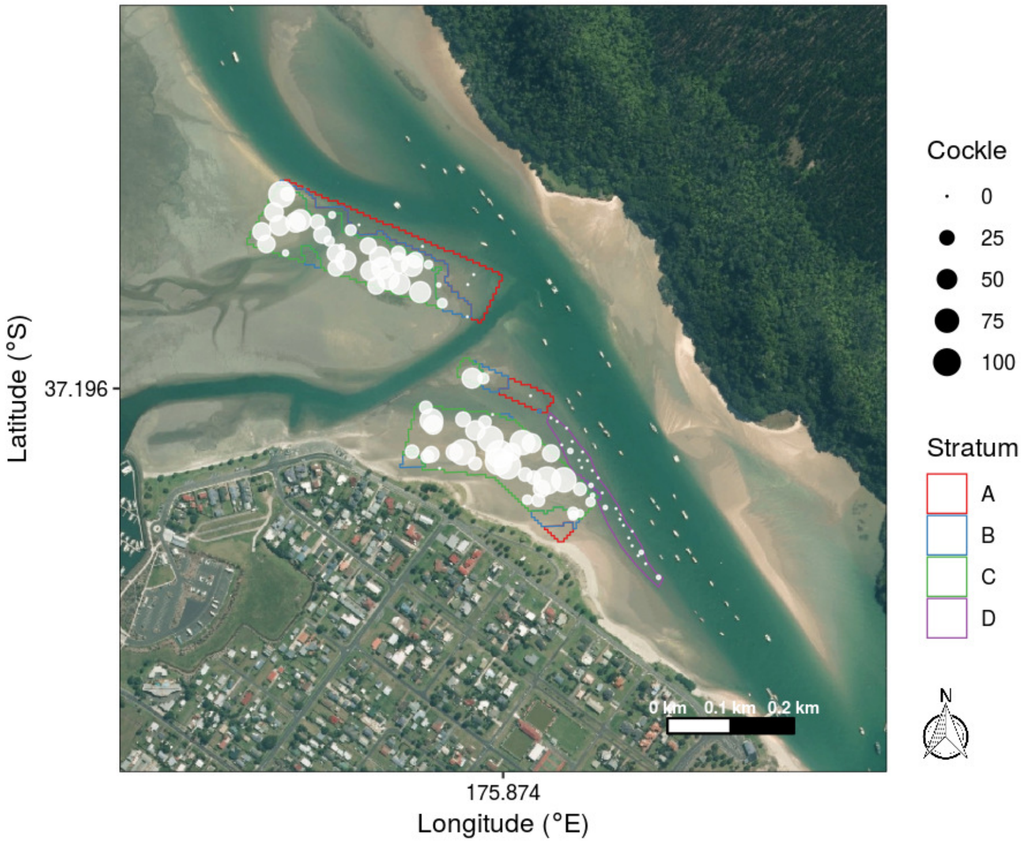


Figure 24: Map of sample strata and individual sample locations for cockles at Whangamatā Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 25: Estimates of cockle abundance at Whangamatā Harbour, by stratum, for 2020–21. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	1.3	5	0	0.00	0	
B	1.0	3	14	1.34	133	89.50
C	5.1	68	2 770	59.81	1 164	8.67
D	0.7	25	6	0.05	7	43.57

Table 26: Estimates of cockle abundance at Whangamatā 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	5.5	70.55	1 287	4.31	17.14	313	6.65
2000–01	5.5	60.33	1 101	4.29	13.95	255	7.60
2001–02	5.5	38.80	708	4.08	6.87	125	7.24
2002–03	5.5	29.78	543	6.61	8.03	146	9.27
2003–04	5.5	43.47	793	4.18	13.10	239	5.18
2004–05	5.5	38.85	709	4.64	9.94	181	4.62
2006–07	24.6	348.01	1 414	0.71	2.86	12	12.99
2010–11	5.9	84.83	1 441	7.06	1.38	23	18.66
2014–15	7.6	104.53	1 372	6.59	2.73	36	19.83
2016–17	7.7	86.78	1 125	7.86	4.00	52	24.60
2018–19	7.5	78.98	1 047	11.38	2.41	32	36.69
2020–21	8.2	61.20	748	8.70	3.49	43	19.09

Table 27: Summary statistics of the length-frequency (LF) distribution of cockles at Whangamatā 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 (%)
2016–17	21.21	24	5–58	15.55	4.61
2018–19	18.74	20	4–58	31.45	3.05
2020–21	20.37	24	4–42	23.83	5.69

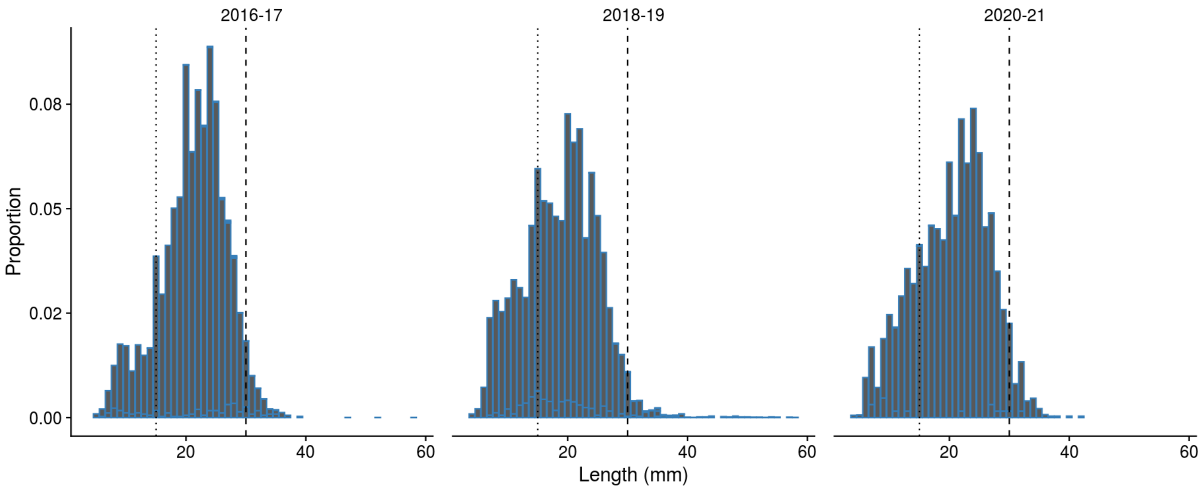


Figure 25: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangamatā Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7.2 Pipi at Whangamatā Harbour

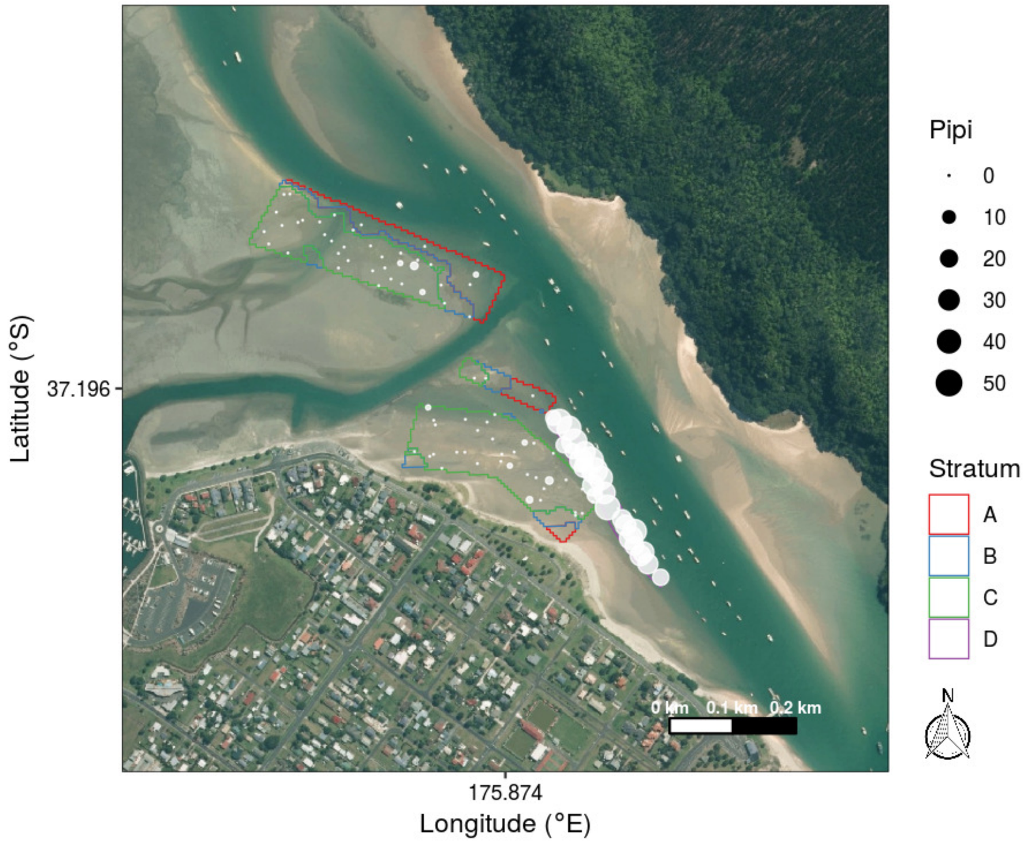


Figure 26: Map of sample strata and individual sample locations for pipi at Whangamatā Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 28: Estimates of pipi abundance at Whangamatā Harbour, by stratum, for 2020–21. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	1.3	5	1	0.07	6	>100
B	1.0	3	0	0.00	0	
C	5.1	68	29	0.63	12	57.15
D	0.7	25	845	7.09	966	7.97

Table 29: Estimates of pipi abundance at Whangamatā 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	5.5	15.07	275	9.25	7.25	132	10.78
2000–01	5.5	11.86	216	11.17	5.05	92	21.86
2001–02	5.5	6.38	116	10.45	2.71	50	19.77
2002–03	5.5	5.95	109	10.95	1.60	29	10.55
2003–04	5.5	4.84	88	7.82	2.03	37	9.50
2004–05	5.5	2.30	42	11.13	1.26	23	12.05
2006–07	24.6	3.26	13	7.50	1.49	6	15.43
2010–11	5.9	5.56	94	15.02	1.62	27	39.20
2014–15	7.6	3.79	50	19.69	1.53	20	75.18
2016–17	7.7	7.65	99	24.21	3.87	50	20.49
2018–19	7.5	10.01	133	27.66	2.79	37	43.95
2020–21	8.2	7.79	95	8.64	1.79	22	18.97

Table 30: Summary statistics of the length-frequency (LF) distribution of pipi at Whangamatā 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 (%)
2016–17	46.71	60	7–70	6.30	50.90
2018–19	40.82	34	6–66	8.94	27.90
2020–21	43.31	46	14–62	1.26	23.01

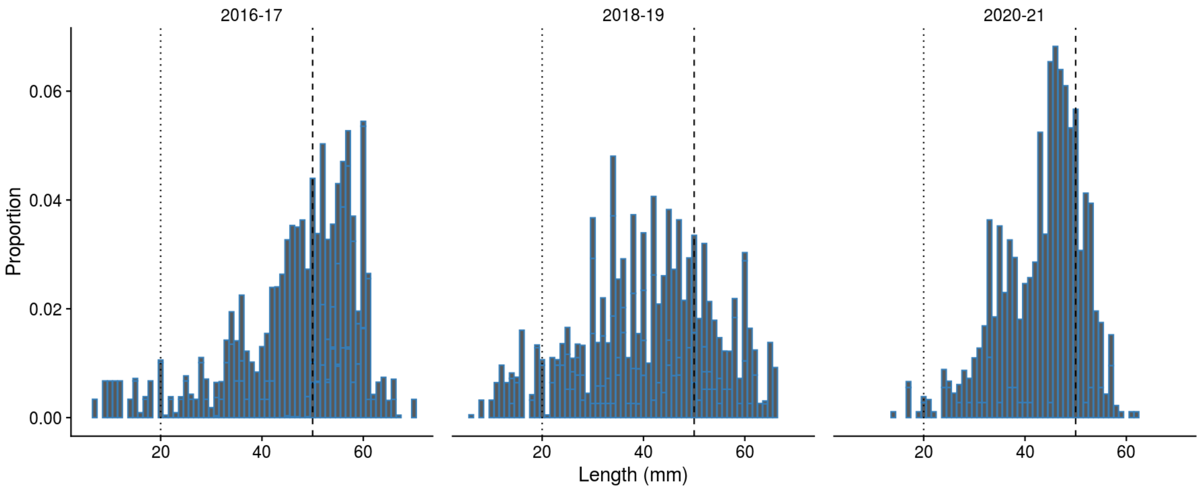


Figure 27: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangamatā Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Whangapoua Harbour

Whangapoua Harbour is located on north-eastern Coromandel Peninsula, in the Waikato region. This large tidal inlet was first included in the northern monitoring series in 2002–03, and there have been nine bivalve assessments since then, including the current survey. Throughout this period, the size and location of the sampling extent has been relatively consistent, with some variation in the location and extent of the pipi bed in the northwestern part of the harbour.

The sediment at this site had a low organic content of 2% or less and only contained a small proportion of fines (grain size <63 μm), ranging between 0.3 and 3% (Figure 28, and see details in Appendix B, Table B-1). The bulk of the sediment was fine sand (grain size >125 μm), or medium sand (grain size >250 μm), with their respective proportions reaching 86 and 62%, respectively. All other grain size fractions were markedly smaller.

The bivalve sampling at Whangapoua Harbour was spread across four separate strata, with an overall effort of 160 sampling points (Figure 29, Table 31). Cockles were abundant throughout three strata (A to C), with few individuals in the pipi bed, in stratum D. Current population estimates reflected notable decreases in the total cockle population from the preceding survey in 2018–19: total abundance declined from 64.97 million (CV: 10.62%) cockles in 2018–19 to the current estimate of 46.59 million (CV: 8.85%) cockles (Table 32). There was a corresponding decrease from 1229 cockles per m^2 in the preceding survey to 884 cockles per m^2 in 2020–21. The current estimates were similar to the relatively low values in 2016–17.

The abundance and density of large cockles (≥30 mm shell length) were similar to estimates in 2018–19, with 0.49 million (CV: 18.95%) large cockles at a density of ten individuals per m^2 in 2020–21. Large cockles represented only a minor proportion (1.04%) of the population, which largely consisted of medium-sized individuals (Table 33, Figure 30). The latter size class formed a single strong cohort, with a small contribution (11.42%) from recruits (≤15 mm shell length). The population size structure has remained similar in recent surveys, with a diminishing proportion of recruits resulting in a shift towards medium-sized individuals and a strengthening of this cohort at about 20 mm modal length.

Pipi were only present in stratum D, which was adjacent to the main harbour channel and close to the entrance (Figure 31, Table 34). Abundance and density estimates for the total population were 5.50 million (CV: 13.42%) pipi and 104 individuals per m^2 (Table 35). There was a small number of large pipi (≥50 mm shell length) within the population and their total number was 0.41 million (CV: 18.90%), with an estimated mean density of 8 large pipi per m^2.

Compared with previous recent estimates, the current total population size and density were marked increases (and the highest estimates since 2004–05); however, there was a discernible decline in large pipi, even though this size class showed some fluctuation over time. Their proportion within the population decreased from over 30% in the two preceding surveys to 7.51% in 2020–21. At the same time, recruitment remained stable, with about 20 to 30% of the population consisting of recruits (≤20 mm shell length). The decrease in large pipi was evident in the length-frequency distributions from the three most recent assessments: the bimodal population of recruits and large individuals changed to a largely unimodal population dominated by medium-sized pipi over this period (Table 36, Figure 32). The concomitant reduction in mean and modal sizes reflected this shift, particularly the decrease in modal size from 55 mm and 52 mm shell length in 2016–17 and 2018–19 to the current modal length of 30 mm.

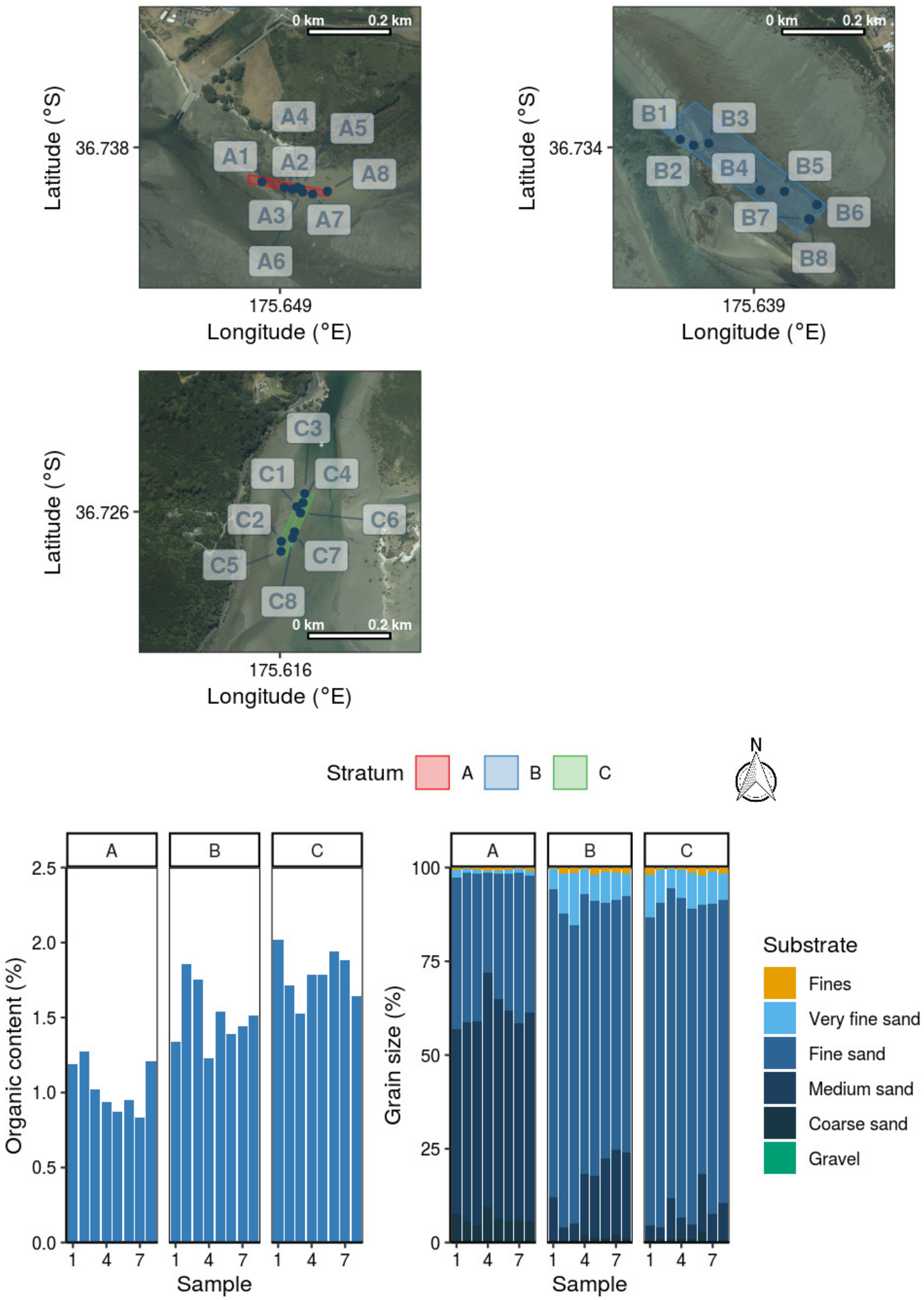


Figure 28: Sediment sample locations and characteristics at Whangapoua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, <63 µm), sands (very fine, >63 µm; fine,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

3.8.1 Cockles at Whangapoua Harbour

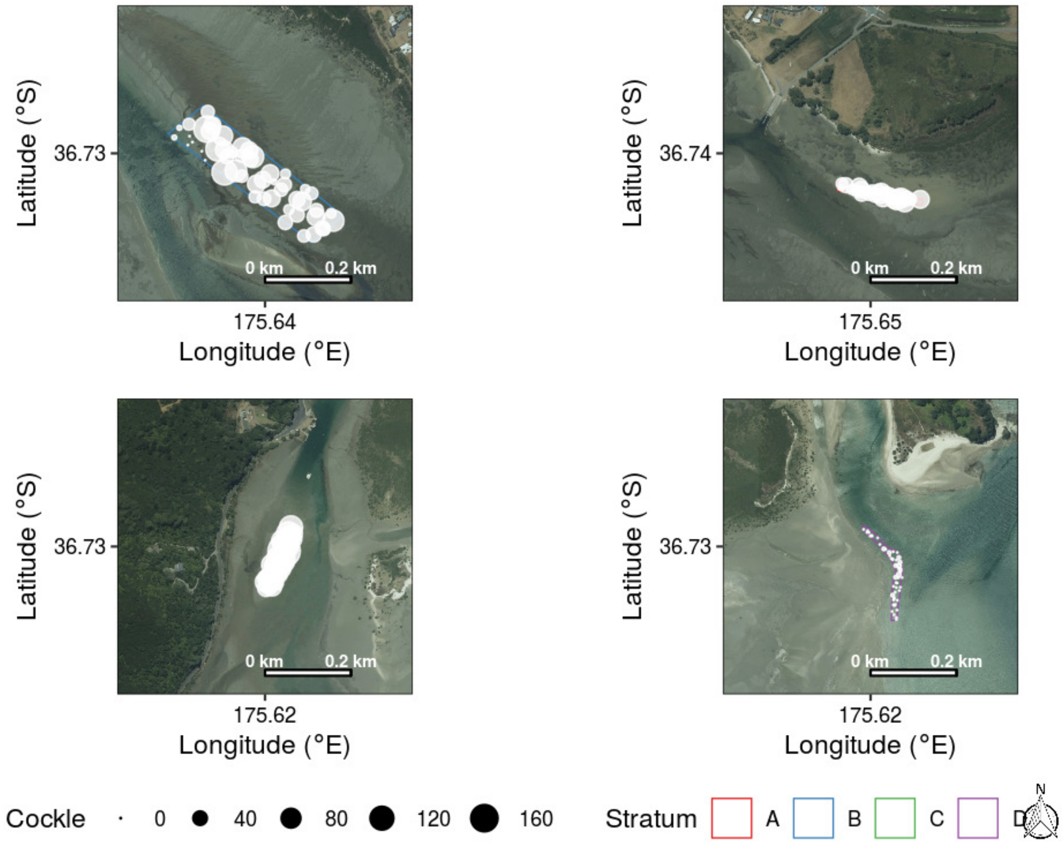


Figure 29: Map of sample strata and individual sample locations for cockles at Whangapoua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of cockle abundance at Whangapoua Harbour, by stratum, for 2020–21. 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	30	785	2.54	748	11.86
B	4.1	50	1 551	36.18	886	11.12
C	0.5	30	1 719	7.84	1 637	10.63
D	0.4	50	12	0.03	7	30.49

Table 32: Estimates of cockle abundance at Whangapoua 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 (%)
2002–03	1.7	11.30	680	4.87	2.71	163	7.69
2003–04	5.2	19.19	369	4.23	6.37	122	8.45
2004–05	5.2	33.19	638	4.07	5.18	100	9.22
2010–11	5.2	32.06	617	9.71	2.83	54	18.88
2014–15	6.3	33.67	533	9.54	1.43	23	15.18
2016–17	5.3	43.80	827	16.02	1.08	17	16.30
2018–19	5.3	64.97	1 229	10.62	0.52	10	27.22
2020–21	5.3	46.59	884	8.85	0.49	9	18.95

Table 33: Summary statistics of the length-frequency (LF) distribution of cockles at Whangapoua 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 (%)
2016–17	17.92	20	5–58	32.84	2.47
2018–19	18.25	21	5–38	28.93	0.80
2020–21	20.26	20	5–36	11.42	1.04

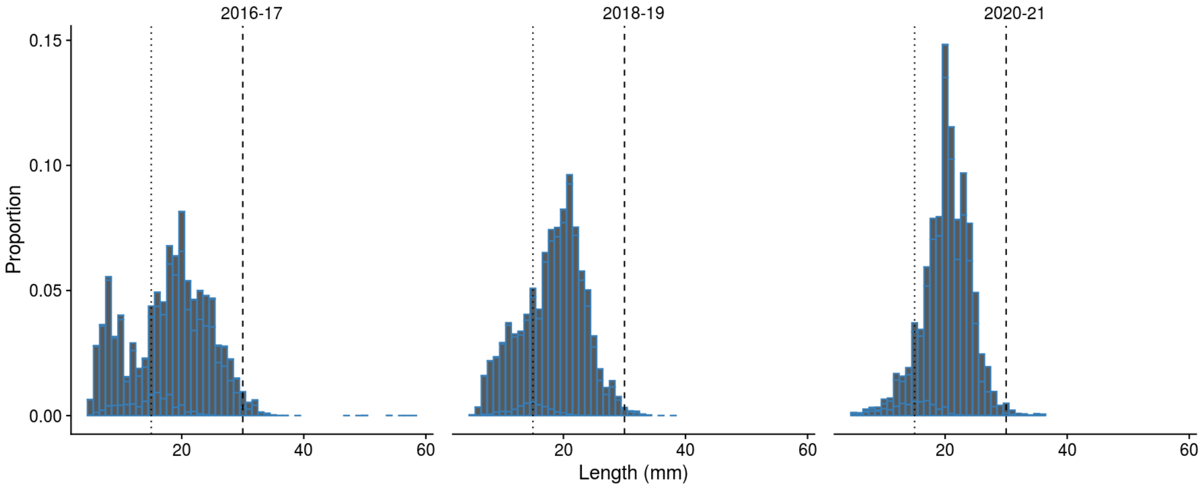


Figure 30: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangapoua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8.2 Pipi at Whangapoua Harbour

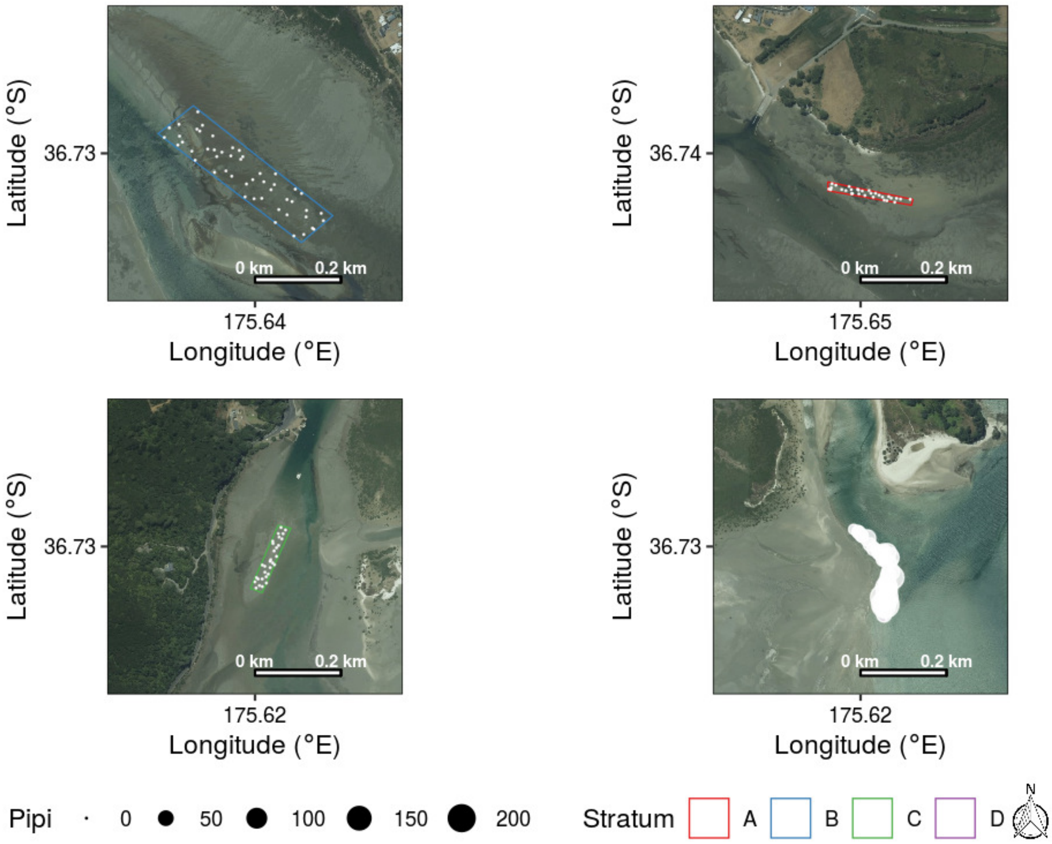


Figure 31: Map of sample strata and individual sample locations for pipi at Whangapoua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of pipi abundance at Whangapoua Harbour, by stratum, for 2020–21. 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	30	0	0.00	0	
B	4.1	50	0	0.00	0	
C	0.5	30	0	0.00	0	
D	0.4	50	2 591	5.50	1 481	13.42

Table 35: Estimates of pipi abundance at Whangapoua 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 (%)
2002–03	1.7	5.62	338	10.16	1.73	104	8.28
2003–04	5.2	5.05	97	9.98	1.75	34	7.90
2004–05	5.2	7.47	144	5.25	3.75	72	5.08
2010–11	5.2	2.74	53	18.82	1.18	23	22.54
2014–15	6.3	2.27	36	20.24	0.34	5	22.32
2016–17	5.3	2.01	38	21.05	0.66	10	29.84
2018–19	5.3	4.17	79	14.71	1.44	27	13.32
2020–21	5.3	5.50	104	13.42	0.41	8	18.90

Table 36: Summary statistics of the length-frequency (LF) distribution of pipi at Whangapoua 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 (%)
2016–17	34.19	55	5–65	34.36	33.19
2018–19	36.49	52	8–66	23.59	34.64
2020–21	30.65	30	6–64	21.28	7.51

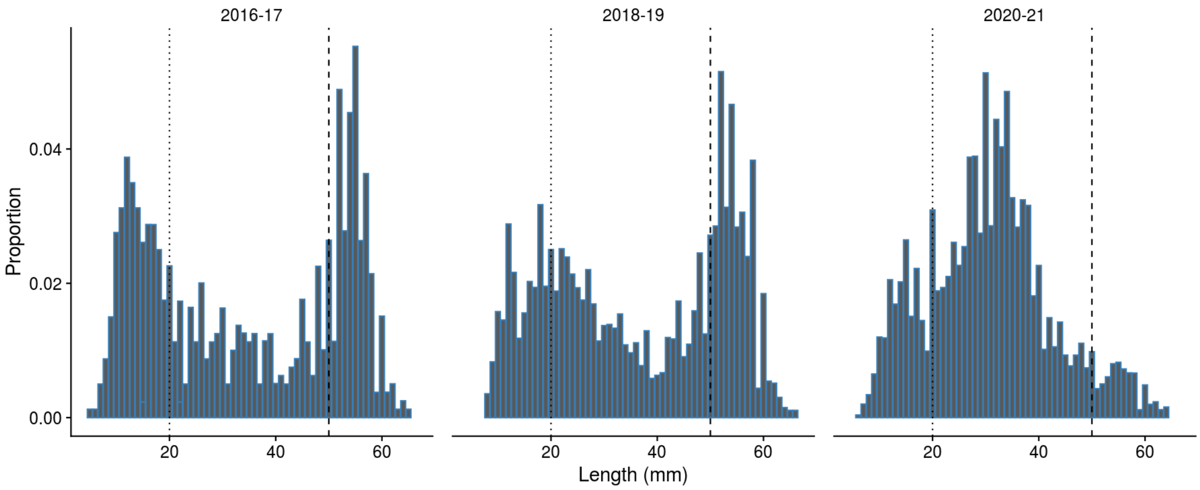


Figure 32: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangapoua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

Comparing cockle populations across the 2020–21 survey sites documented their presence across a variety of habitats in the northern North Island region (Table 37). Cockles were present at seven of the eight survey sites; there were no cockles at Te Mata Bay. Their total population sizes ranged from 12.61 million (CV: 19.44%) individuals at Ōhiwa Harbour to the largest population at Kawakawa Bay (West) of 200.93 million (CV: 12.01%) individuals. All of the current population estimates had a CV value of less than 20%.

At all of the sites, the population densities exceeded 300 individuals per m^2. Estimated mean densities were similar and comparatively low at Kawakawa Bay (West) and Okoromai Bay (both in the Auckland area), and at Otūmoetai (Tauranga Harbour, Bay of Plenty). Their highest population densities were at sites on Coromandel Peninsula, with 748 and 884 cockles per m^2, at Whangamatā Harbour and Whangapoua Harbour, respectively.

None of the sites surveyed in 2020–21 supported a notable proportion of large cockles ($\geq$30-mm shell length), and individuals in this size class were absent at Otūmoetai (Tauranga Harbour) or only present at low densities (i.e, less than 10 large individuals per m^2) at Aotea Harbour and Whangapoua Harbour; their highest density was at Whangamatā Harbour, where there were 43 large individuals per m^2 (19.09%) in 2020–21.

Time series data for the northern sites documented some fluctuations in the cockle populations and an overall increase at all sites over time, except at Whangamatā Harbour (Figure 33). At this site, there was an ongoing decline in the cockle population from 2014–15 onwards, following particularly high densities in earlier surveys. The decreases between recent surveys were relatively small, except in 2020–21; however, the population remained at a density of over 700 cockles per m^2 at this site. Similarly, the two other cockle populations with recent decreases, at Whangapoua Harbour and Kawakawa Bay (West), persisted at comparatively high population densities. At the remaining four sites, cockle densities showed an increase in 2020–21, but this population trend was only pronounced at Ōhiwa Harbour.

The population size structures at the current survey sites showed a shift towards smaller sizes over time (Figure 34). Throughout the survey series, most sites were characterised by a unimodal population of predominantly medium-sized cockles, and this population size structure was consistent across sites in 2020–21. The only site that showed a different pattern in earlier surveys was Okoromai Bay, where recruits formed a second cohort in 2013–14 and 2017–18. The shift towards a smaller size within the single cohort was in part determined by recruitment events and also by the decrease in large cockles within the different populations.

The overall decrease in large cockles was confirmed in the time series of their density estimates across sites (Figure 35). At most of the current survey sites, the estimated mean densities of large individuals were consistently low throughout the survey series. Although large cockle densities were comparatively high (at least 100 individuals per m^2) at the start of the survey series at three of the sites, Okoromai Bay, Whangamatā Harbour, and Whangapoua Harbour, they showed marked declines in subsequent surveys, resulting in low estimates, including in 2020–21. This decline in large cockles was also evident at the other sites that generally only had low densities of large cockles.

Table 37: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2020–21 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 (%)
Aotea Harbour	99.69	514	9.44	0.60	3	53.20
Kawakawa Bay	200.93	330	12.01	10.91	18	27.20
Ōhiwa Harbour	12.61	476	19.44	0.42	16	20.71
Okoromai Bay	64.37	325	15.53	6.10	31	24.50
Otūmoetai	22.43	344	10.78	0.00	0	
Whangamatā Harbour	61.20	748	8.70	3.49	43	19.09
Whangapoua Harbour	46.59	884	8.85	0.49	9	18.95

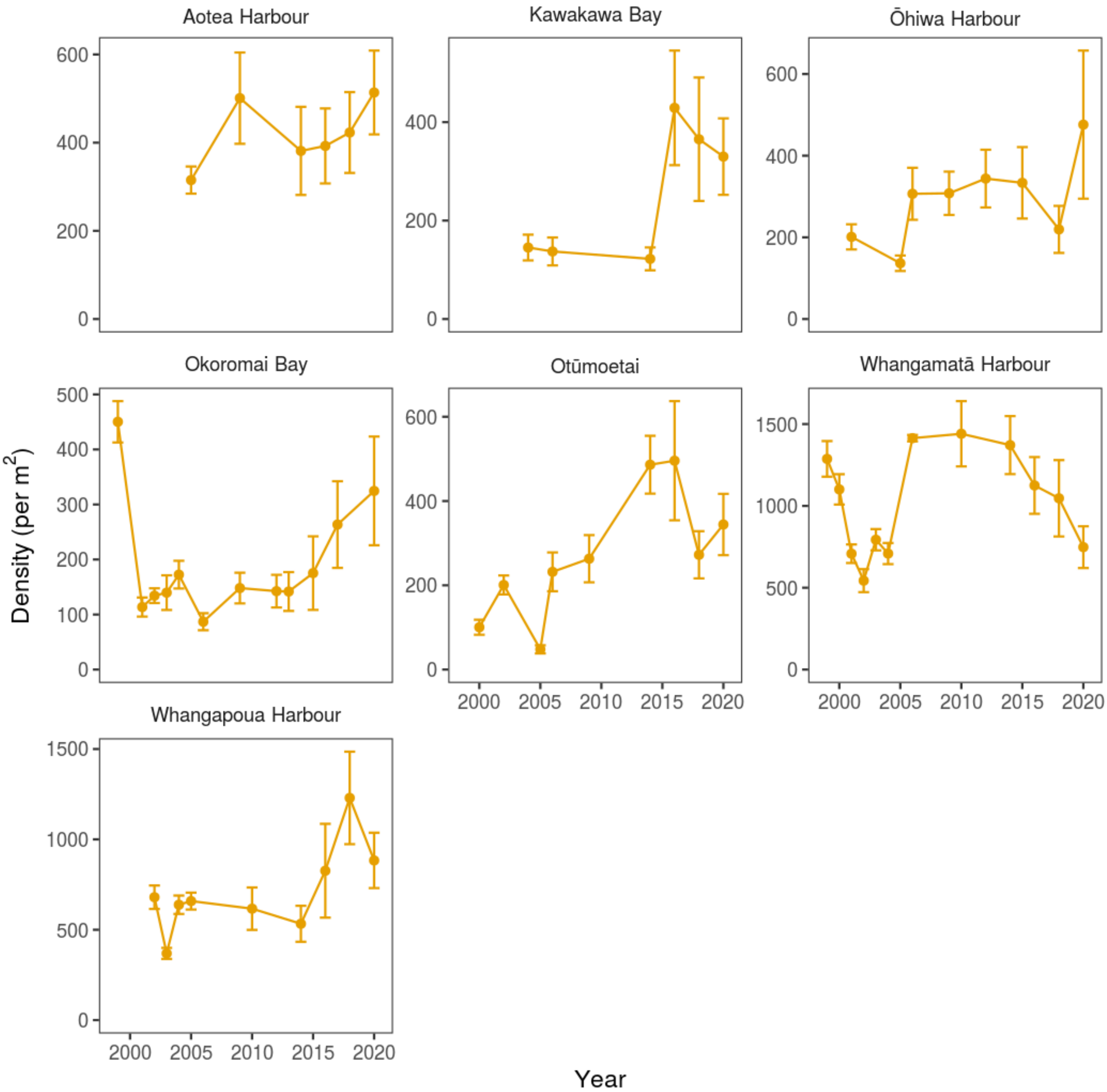


Figure 33: Estimated density of cockles for all sites included in the 2020–21 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

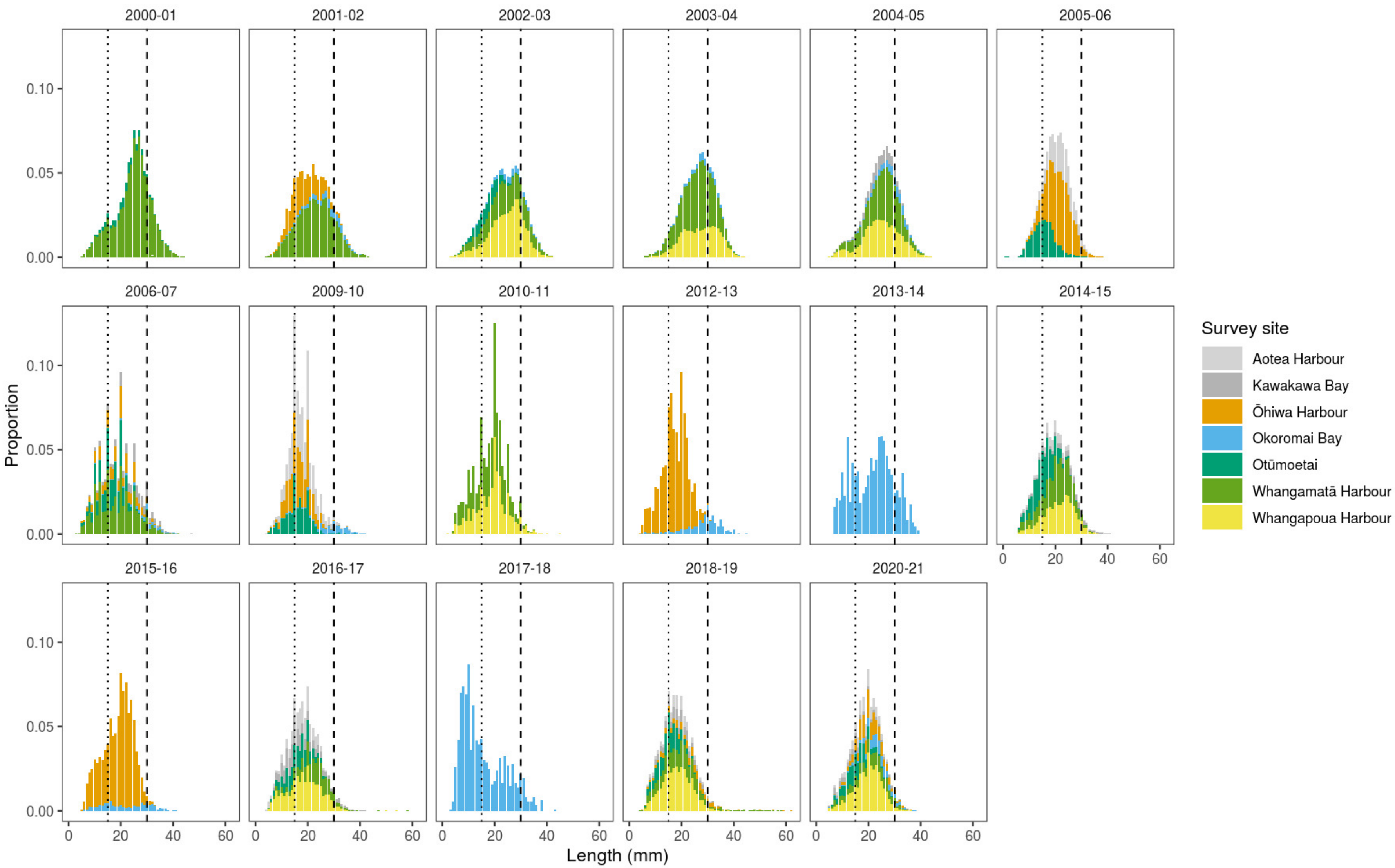


Figure 34: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2020–21 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

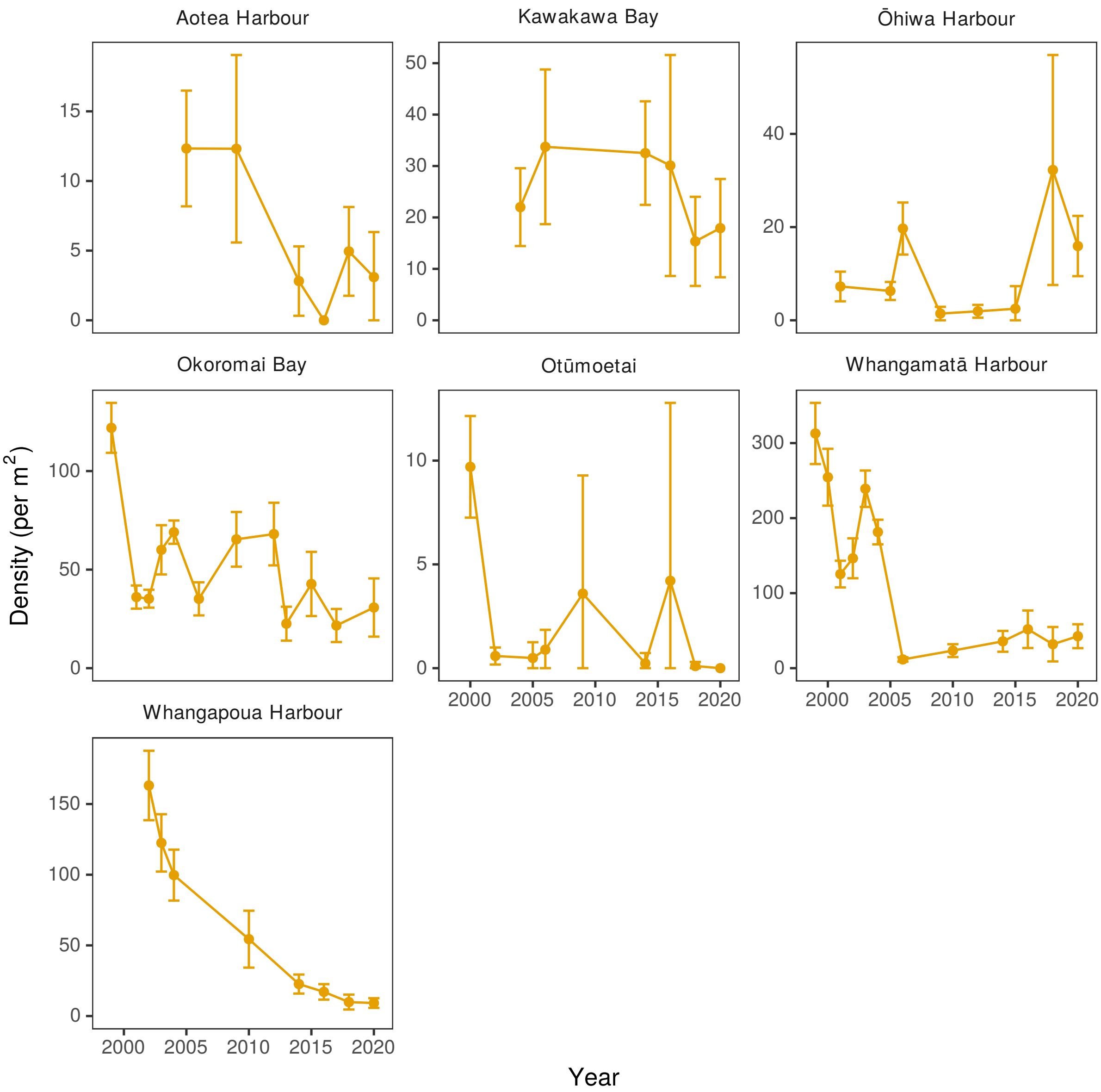


Figure 35: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.2 Pipi populations

The current assessment surveyed pipi beds at five of the northern sites, with two sites in Bay of Plenty and three sites on Coromandel Peninsula (Table 38). The latter sites included Te Mata Bay on the western side of Coromandel Peninsula, which was surveyed for the first time. Across these sites, pipi populations varied in abundance and densities: total population sizes were relatively small at Ōhiwa Harbour and Whangamatā Harbour, contrasting with the highest abundance estimate of 49.01 million (CV: 7.34%) pipi at Otūmoetai (Tauranga Harbour). The associated CV of the population estimates was less than 20% at all sites.

Corresponding density estimates showed similar variation to the population sizes, with the highest density of 1284 pipi per m^2 at Te Mata Bay, followed by 752 pipi per m^2 at Otūmoetai (Tauranga Harbour). At the remaining sites, pipi densities were markedly lower (i.e., less than 300 individuals per m^2), with the lowest density estimate at Whangamatā Harbour (95 pipi per m^2).

All of the surveyed populations included few large pipi ($\geq$50 mm shell length), and this size class was particularly scarce at Otūmoetai and Whangapoua Harbour. Across sites, abundance estimates ranged from 0.13 million large pipi at Otūmoetai to 1.79 million pipi at Whangamatā Harbour. The corresponding densities were also low, and the only site with a relatively high density of large pipi was Te Mata Bay, where this size class occurred at 119 large pipi per m^2.

All of the four sites with time series data (i.e., except Te Mata Bay), total pipi densities showed some decline over time, although its timing varied, depending on the site (Figure 36). At Ōhiwa Harbour, pipi densities increased steadily up to 2012–13, and then decreased to the lowest estimates in the current assessment. There was a similar temporal trend at Otūmoetai (Tauranga Harbour), albeit with more fluctuation and with higher current pipi densities than at the start of the assessment period. At both of the Coromandel Peninsula sites, there was a marked drop in population densities at the start of the survey series, and estimates have remained relatively low since then, with some small increases in recent surveys.

Comparing the combined pipi length-frequency distributions at the northern sites over time highlighted a general change in the population size structure towards a smaller size (Figure 37). Although large pipi ($\geq$50 mm shell length) were present in most years, there was an overall reduction in the strength of this size class across surveys. In early assessments, the single cohort was centred on the cut-off length of the large size class, which subsequently shifted to the higher end and centre of medium pipi size class. Any bimodal size structure in some of the surveys was determined by a second strong cohort of recruits ($\leq$20 mm shell length), generally associated with the Bay of Plenty sites Ōhiwa Harbour and Otūmoetai (Tauranga Harbour).

At both of these sites, the large pipi size class diminished markedly over time, although with some fluctuation at Ōhiwa Harbour (Figure 38). A consistent decline in large pipi over time was also evident at Whangamatā and Whangapoua harbours.

Table 38: Estimates of pipi abundance for all sites where more than ten pipi were sampled in the 2020–21 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 ($\geq$50 mm shell length).

Survey site	Population estimate			Population $\geq$50 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Ōhiwa Harbour	7.15	270	10.26	0.86	33	21.48
Otūmoetai	49.01	752	7.34	0.13	2	48.62
Te Mata Bay	12.46	1 284	7.31	1.16	119	14.38
Whangamatā Harbour	7.79	95	8.64	1.79	22	18.97
Whangapoua Harbour	5.50	104	13.42	0.41	8	18.90

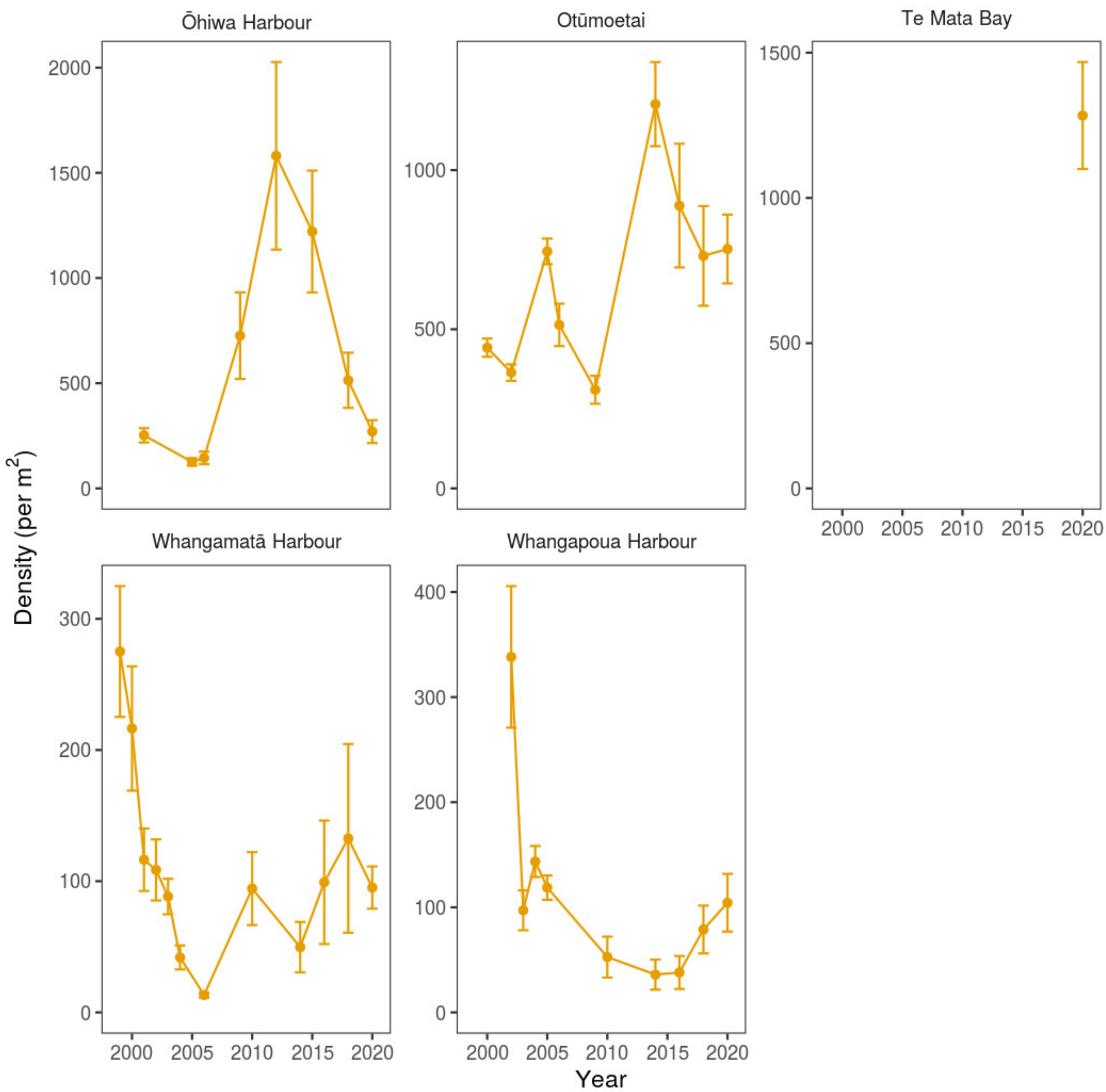


Figure 36: Estimated density of pipi for all sites included in the 2020–21 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

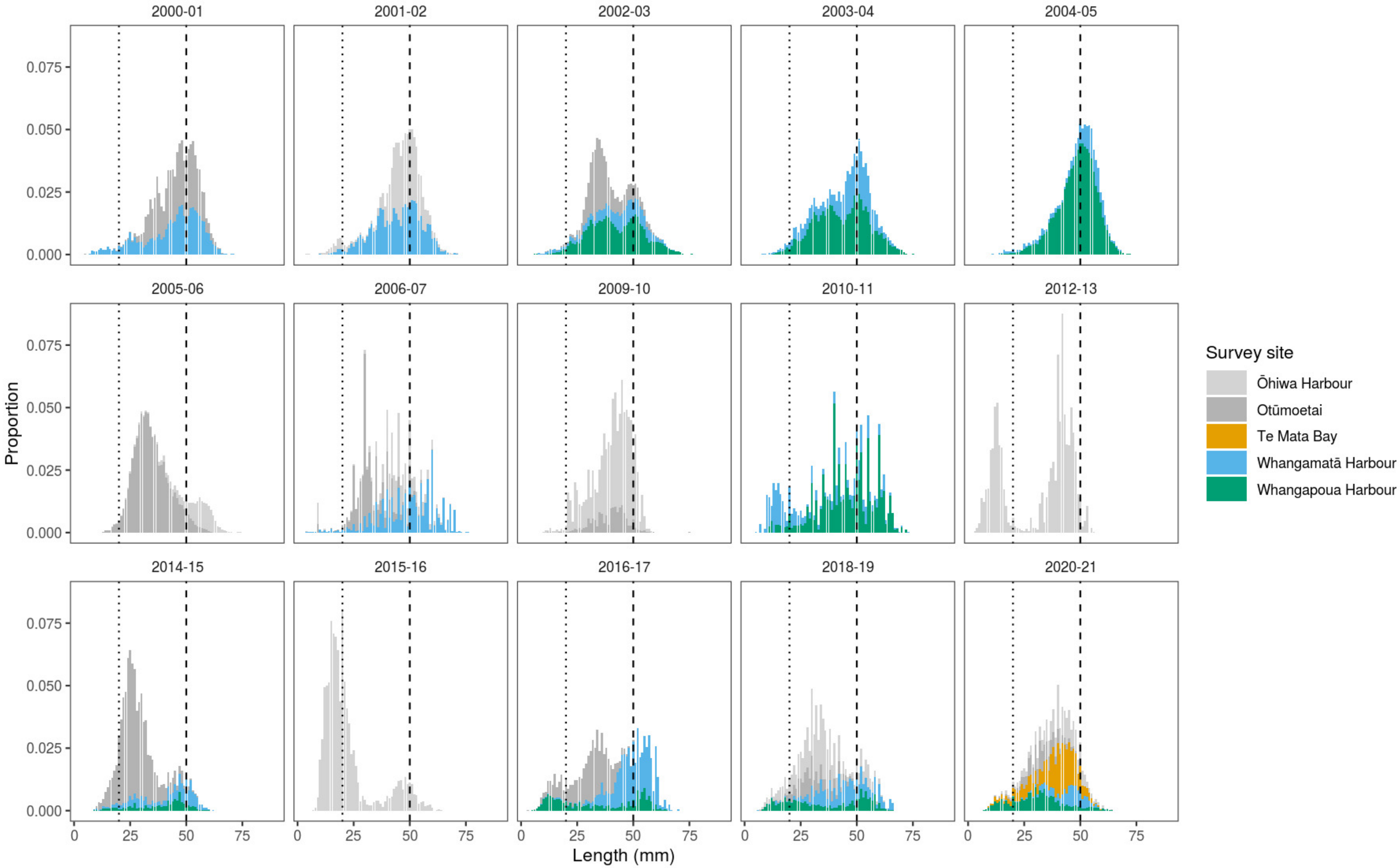


Figure 37: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2020–21 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

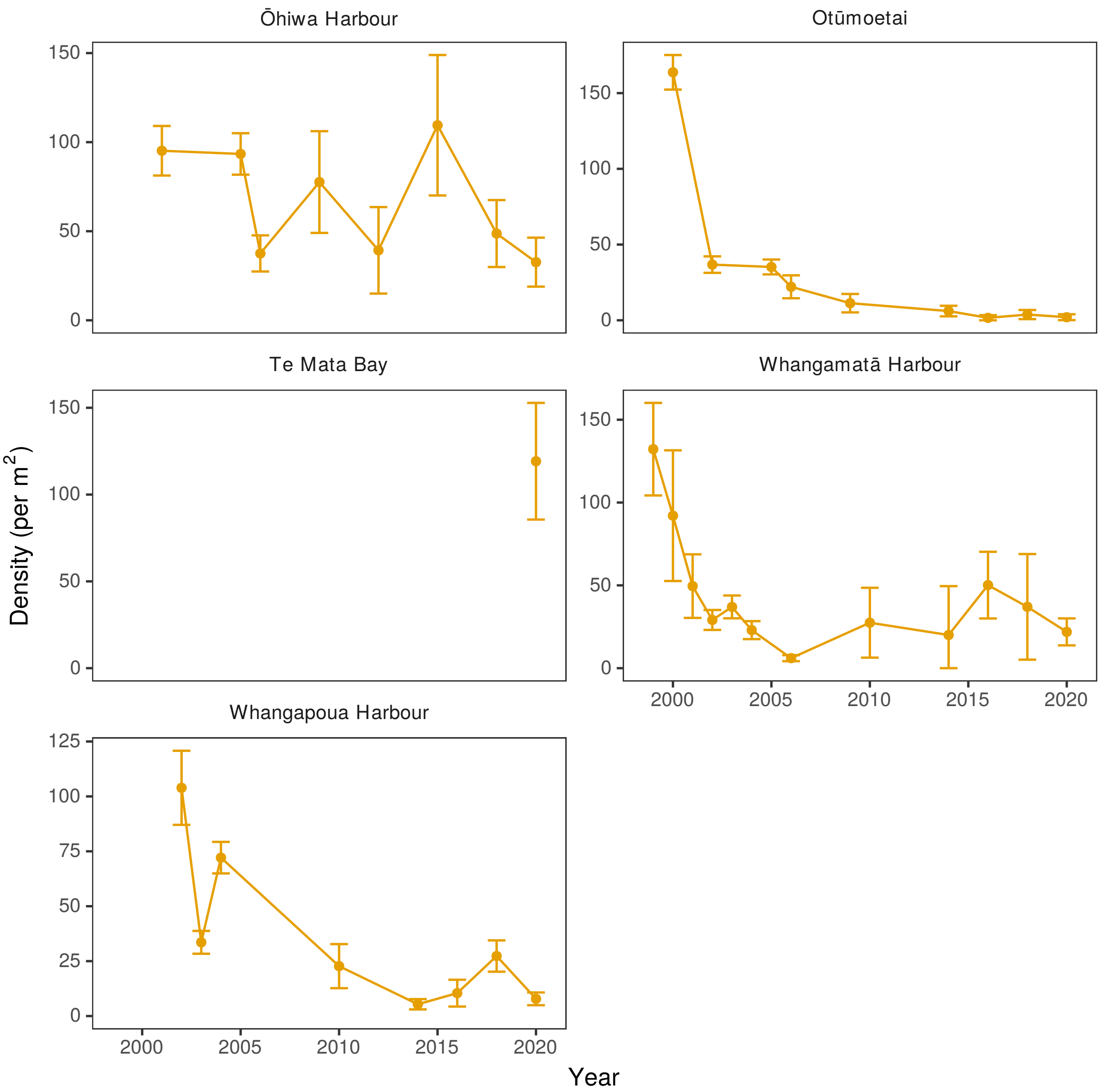


Figure 38: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.3 Sediment data

The sediment sampling across the different northern sites documented that the intertidal cockle strata were generally low in sediment organic content, with average values below 2.5% at all of the sites (Figure 39). Sediment grain size compositions were largely dominated by fine and very fine sands (grain sizes >125 µm and >63 µm), with varying contributions from other sediment grain size fractions. At four of the seven sites with cockle populations, the proportion of fines (grain size <63 µm) exceeded 10% in some of the 2020–21 samples; however, the average proportion of fines remained low at these sites, at Aotea Harbour, Kawakawa Bay (West), Ōhiwa Harbour, and Okoromai Bay. Several samples at Kawakawa Bay (West) also contained a high proportion of gravel, with over 40% in this grain size fraction in two of the samples.

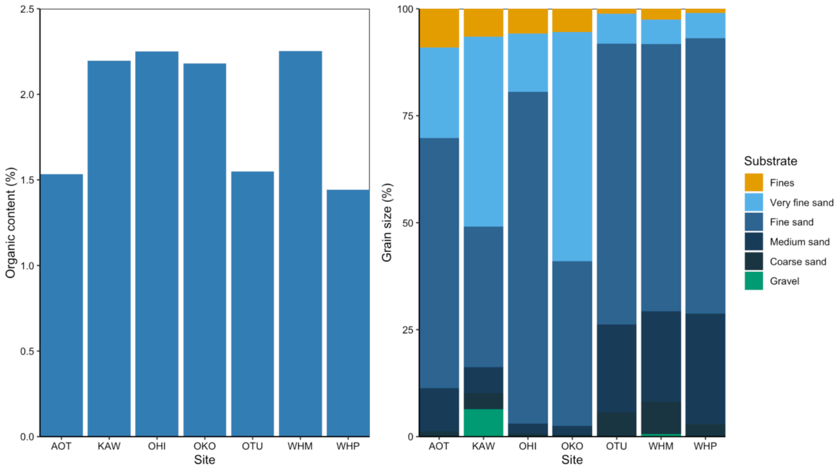


Figure 39: Sediment organic content and grain size composition (averages per site) at the 2020–21 northern survey sites with cockle strata. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand >63 µm, fine sand >125 µm, medium sand >250 µm, coarse sand >500 µm, and gravel >2000 µm.

5. DISCUSSION

This study represents the most recent assessment in the northern bivalve monitoring series, with survey sites in Auckland (Kawakawa Bay (West), Okoromai Bay), Waikato (Aotea Harbour, Te Mata Bay, Whangamatā Harbour, Whangapoua Harbour), and Bay of Plenty (Otūmoetai (Tauranga Harbour), Ōhiwa Harbour). Four sites in Northland could not be surveyed, because of the difficulty of accessing this region, caused by Auckland travel restrictions in February and March 2021 (to counter the spread of COVID-19).

All of the 2020–21 sites, except Te Mata Bay, have been regularly surveyed since 1999–2000, with sampling frequencies ranging between 6 and 12 assessments over this period. The current study documented the persistence of bivalve populations at each of the sites, with a general preponderance of medium-sized (or smaller) individuals and unimodal population size structures. There was a universal scarcity of large-sized individuals, which was due to declines in this size class over time, with little or no discernible increases subsequently.

This aspect was evident in both cockle and pipi populations, with the large size class representing only a maximum of 10% in populations of either species. At the same time, there was steady recruitment to these populations, including evidence of strong recruitment events, indicating a consistent supply of cockle and pipi recruits to existing populations. Although length-frequency distributions document the growth of these small-sized individuals into the medium size class over time, there appeared to be a general lack of further growth into the large size class (i.e., exceeding the cut-off lengths of 30 mm for cockles and 50 mm for pipi).

Growth studies to date document variable growth rates for cockles, which mature at about 18 mm shell length in the second year, and grow to 30 mm shell length in 2 to 5 years (Larcombe 1971). Pipi reach sexual maturity at about 30 to 40 mm shell length, grow to 30 mm in just over one year, and attain a maximum size of 55–60 mm shell length within three to four years (Hooker 1995).

Given the persistence of cockle and pipi populations at the northern sites, the reasons for the overall decline and for the lack of a notable comeback of large-sized individuals are unknown. One potential explanation is that large cockles and pipi are removed by fishing activities, because this size class is considered to be preferentially targeted in shellfish gathering. Nevertheless, owing to the lack of information of the number and sizes of bivalves taken in recreational and customary fishing, it is not possible to determine a potential link between fishing pressure and population trends.

In addition, other influences such a biological and environmental factors may prevent the growth of individuals to large sizes. These factors include habitat-specific or density-dependent food limitations, and impediments to the uptake of food particles from the water column through substantial sediment resuspension. For cockles, recent surveys (since 2015–16) have monitored sediment characteristics in cockle strata, providing some information about habitat quality in the form of sediment organic content and grain size composition. Data for neither of these two sediment measures indicated that sites were unsuitable for cockles or that there were marked changes over time (see also Neubauer et al. 2021). Overall, the proportion of organic content and sediment fines (grain size <63 μm) was small at all sites, with no obvious evidence of these sediment properties limiting the cockle populations. For pipi, it is possible that large-sized individuals move to deeper parts of the associated channels (Hooker 1995), with this portion of the population residing in subtidal sediments that are inaccessible to the intertidal sampling.

Regardless of the potential causes, the lack of large cockles and pipi at the current survey sites corresponded with findings at other northern sites that are part of the bivalve monitoring series. For example, this pattern was also evident in cockle and pipi populations surveyed in 2019–20 (Berkenbusch & Neubauer 2020). In this preceding survey, the only documented increases in large cockles were at three of the four sites with fishing restrictions in place; at Cockle Beach, Eastern Beach, and Umupuia Beach (all in the Auckland area).

None of the 2020–21 sites had spatial or temporal fishing restrictions in place, except for Te Mata and Waipatukahu: the two-year closure of shellfish collections at this site came into effect in July 2020 (Department of Internal Affairs 2020). Te Mata and Waipatukahu were included in the survey series for the first time in the current assessment, which provided baseline information about the pipi population at this site. Compared with other northern survey sites, the pipi habitat was unusual in that the pipi beds were in sediment dominated by gravel interspersed with cobble and boulders. Nevertheless, both pipi beds were in physically-dynamic areas in the low-intertidal zone and associated with rivers.

The habitat at Te Mata and Waipatukahu is similar to habitat at another site on the west coast of Coromandel Peninsula, at Waikawau Bay (or Waikawau Beach). This bay is just north of Te Mata and Waipatukahu and was included in earlier surveys, most recently in 2005–06 and in 2013–14 (Walshe et al. 2007, Berkenbusch et al. 2015). The survey in 2005–06 detected only three cockles and few pipi at Waikawau Beach; by 2013–14, the pipi population had disappeared from the established sampling areas at this site, and the habitat seemed to be unsuitable for supporting infaunal bivalve populations. Recent information from Ngāti Tamaterā (L. Ngamane pers. comm.) indicates that local pipi beds still persist at Waikawau Beach, potentially allowing the resumption of surveys at this site, albeit in different areas.

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Aerial imagery data were sourced from the LINZ Data Service. These data are licensed for reuse under the CC BY 4.0 licence.

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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	2021
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					■	■				■			■		■		■		
Ōhiwa Harbour			■				■	■	■		■			■			■		■
Okoromai Bay	■		■	■	■	■		■	■		■	■		■		■			■
Otūmoetai		■		■			■	■	■				■		■		■		■
Papamoa Beach	■																		
Pataua Estuary				■	■		■					■		■		■		■	
Raglan Estuary	■	■		■	■				■		■		■			■		■	
Ruakaka Estuary								■		■			■		■		■		
Tairua Harbour	■	■	■	■			■	■		■		■		■		■		■	
Te Haumi Bay	■	■	■	■				■	■		■		■		■		■		
Te Mata Bay																			■
Umupuia Beach	■	■	■	■	■	■	■	■	■	■	■	■		■		■		■	
Waikawau Beach	■	■				■	■					■							
Waiotahe Estuary				■	■	■	■		■			■			■			■	
Whangamatā Harbour	■	■	■	■	■	■		■		■			■		■		■		■
Whangapoua Harbour				■	■	■	■			■			■		■		■		■
Whangateau Harbour			■		■	■		■	■	■	■	■		■		■		■	
Whitianga Harbour											■			■		■		■	

Table A-2: Sampling dates and size of the sampling extent for sites included in the northern North Island bivalve surveys since 1999–00, including the present survey in 2020–21. 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
	2020–21	26 Feb	19.40	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
	2020–21	10 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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2013–14	19 Mar–20 Mar	17.09	AKI2013-01
	2015–16	8 Feb–11 Feb	18.38	AKI2015-01
	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
Ōhiwa 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
	2020–21	16 Feb–19 Feb	2.65	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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2006–07	20 Mar	20.00	AKI2006-01
	2009–10	17 Feb	20.00	AKI2009-01
	2012–13	30 Jan	20.00	AKI2012-01
	2013–14	31 Mar	19.84	AKI2013-01
	2015–16	11 Jan	19.84	AKI2015-01
	2017–18	6 Feb	19.83	AKI2017-01
	2020–21	27 Feb	19.83	AKI2018-01
Otūmoetai	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
	2020–21	17 Feb	6.52	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 Estuary	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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
Te Haumi Bay	1999–00	7 Mar–30 Mar	10.00	AKI1999-01
	2000–01	12 Mar	13.53	AKI2000-01
	2000–01	15 Jan–26 Jan	9.90	AKI2000-01
	2001–02	15 Mar–15 Apr	9.90	AKI2001-01
	2002–03	21 Jan–22 Apr	9.90	AKI2002-01
	2006–07	22 Mar	9.81	AKI2006-01
	2009–10	18 Feb	12.06	AKI2009-01
	2012–13	13 Dec	12.06	AKI2012-01
	2014–15	24 Jan–26 Jan	12.78	AKI2014-01
	2016–17	12 Feb	12.77	AKI2016-01
	2018–19	21 Feb–24 Feb	11.91	AKI2018-01
Te Mata Bay	2020–21	14 Feb–20 Feb	0.97	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
Waiotahe Estuary	2002–03	7 Feb–10 Feb	8.50	AKI2002-01
	2003–04	21 Jan–24 Jan	8.50	AKI2003-01
	2004–05	21 Jan–25 Jan	9.50	AKI2004-01
	2005–06	10 Feb–12 Feb	9.50	AKI2005-01
	2009–10	4 Mar	9.50	AKI2009-01
	2013–14	17 Mar–20 Mar	11.23	AKI2013-01
	2016–17	22 Feb	11.98	AKI2016-01
	2019–20	26 Feb–27 Feb	11.98	AKI2018-01
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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2016–17	24 Feb–26 Feb	7.71	AKI2016-01
	2018–19	29 Jan–30 Jan	7.55	AKI2018-01
	2020–21	11 Feb	8.18	AKI2018-01
Whangapoua Harbour	2002–03	30 Mar–6 Apr	1.66	AKI2002-01
	2003–04	1 Feb–3 Feb	5.20	AKI2003-01
	2004–05	8 Mar–10 Mar	5.20	AKI2004-01
	2005–06	8 Mar–10 Mar	5.20	AKI2005-01
	2010–11	21 Apr	5.20	AKI2010-01
	2014–15	24 Feb–25 Feb	6.32	AKI2014-01
	2016–17	25 Feb–26 Feb	6.32	AKI2016-01
	2018–19	27 Jan–28 Jan	5.28	AKI2018-01
	2020–21	12 Feb–13 Feb	5.27	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 2020–21 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
Aotea Harbour	A	1	-38.01739	174.82453	1.6	12.4	11.3	53.6	19.8	2.8	0.2
	A	2	-38.01630	174.82421	1.5	13.6	14.3	53.3	16.3	2.5	0.0
	A	4	-38.01633	174.82496	0.9	5.6	14.3	63.0	15.7	1.4	0.0
	A	7	-38.01244	174.83018	1.2	5.7	22.7	66.4	4.8	0.4	0.0
	A	9	-38.01234	174.83072	1.6	9.0	29.4	57.1	3.9	0.6	0.0
	A	8	-38.01280	174.83022	1.6	8.0	26.6	60.2	4.4	0.7	0.0
	A	3	-38.01769	174.82553	1.9	14.5	18.3	55.8	10.1	1.3	0.0
	A	11	-38.01359	174.83220	1.6	11.7	20.9	62.2	4.6	0.5	0.0
	A	5	-38.01687	174.82584	1.7	14.6	14.1	50.9	17.1	3.3	0.0
	A	6	-38.01615	174.82589	1.5	11.3	29.0	49.0	9.9	0.9	0.0
	A	10	-38.01287	174.83133	1.2	6.6	28.3	60.5	3.9	0.6	0.0
	B	2	-38.01590	174.82669	2.1	11.8	19.4	53.8	14.0	1.0	0.0
	B	3	-38.01514	174.82708	1.6	5.6	28.2	60.7	4.8	0.7	0.0
	B	9	-38.01318	174.82982	1.8	10.5	7.6	41.6	36.2	3.6	0.6
	B	4	-38.01590	174.82840	1.4	7.3	17.3	71.2	3.7	0.4	0.0
	B	13	-38.01400	174.83174	1.6	10.8	21.6	63.4	3.9	0.3	0.0
	B	12	-38.01397	174.83149	1.9	11.2	31.2	49.0	7.8	0.7	0.0
	B	10	-38.01417	174.83071	1.5	7.7	15.4	71.8	4.7	0.5	0.0
	B	8	-38.01487	174.82957	1.0	7.9	15.6	59.0	15.9	1.6	0.0
	B	1	-38.01624	174.82638	1.2	7.3	22.5	57.2	11.2	1.7	0.0
	B	11	-38.01328	174.83040	1.1	6.6	22.7	65.7	4.1	1.0	0.0
	B	7	-38.01416	174.82866	2.5	9.6	47.2	41.9	1.0	0.3	0.0

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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	5	-38.01485	174.82808	1.3	3.5	15.4	71.4	8.3	1.3	0.0
	B	6	-38.01448	174.82812	1.5	5.1	14.6	63.5	14.9	1.8	0.0
Kawakawa Bay (West)	A	1	-36.94283	175.15139	2.0	5.0	68.4	23.6	2.5	0.6	0.0
	A	3	-36.94980	175.16293	3.8	14.6	11.7	17.2	5.6	5.7	45.1
	A	4	-36.95031	175.16213	2.2	7.5	16.2	33.2	17.6	11.9	13.5
	A	2	-36.94825	175.15320	3.0	13.5	64.9	16.8	3.0	1.8	0.0
	B	6	-36.94681	175.15150	2.7	18.0	61.0	16.0	3.8	1.2	0.0
	B	5	-36.94596	175.15212	2.6	8.8	60.5	28.1	2.0	0.6	0.0
	B	7	-36.94630	175.15305	2.1	6.1	74.3	18.9	0.5	0.3	0.0
	B	8	-36.94720	175.15228	2.9	6.6	72.9	14.9	3.4	2.3	0.0
	B	4	-36.94477	175.15225	1.8	6.5	63.1	29.3	1.0	0.2	0.0
	B	2	-36.94343	175.15189	1.9	3.5	64.6	30.8	1.0	0.2	0.0
	B	1	-36.94334	175.15278	1.7	2.9	53.6	43.1	0.4	0.0	0.0
	B	3	-36.94362	175.15270	1.9	3.7	51.4	44.1	0.6	0.2	0.0
	B	18	-36.94983	175.16111	2.5	4.6	15.8	38.8	16.4	11.9	12.6
	B	16	-36.94989	175.15897	2.5	6.2	4.4	15.5	13.4	11.9	48.6
	B	17	-36.94943	175.15997	2.1	5.6	7.7	35.3	20.0	14.5	17.0
	B	15	-36.94913	175.15973	2.4	8.7	10.3	30.1	21.5	15.0	14.4
	B	10	-36.94719	175.15341	2.4	8.1	64.1	25.6	1.7	0.6	0.0
	B	9	-36.94603	175.15445	1.5	3.3	38.8	57.4	0.4	0.1	0.0
	B	11	-36.94700	175.15589	1.2	3.0	29.2	66.6	1.0	0.2	0.0
	B	12	-36.94710	175.15693	2.5	3.2	36.4	59.4	0.8	0.2	0.0
	B	14	-36.94855	175.15937	2.0	6.9	15.9	47.3	18.6	8.1	3.2
	B	13	-36.94853	175.15801	1.4	3.3	38.4	49.1	8.2	1.1	0.0
	C	1	-36.94213	175.15148	2.0	4.4	76.4	16.6	1.3	0.9	0.4
	C	2	-36.94262	175.15225	1.8	2.6	65.8	30.9	0.6	0.0	0.0

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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
Ōhiwa Harbour	A	10	-38.00952	177.13947	2.3	9.6	16.4	71.5	1.6	0.9	0.0
	A	9	-38.00926	177.13957	2.4	3.5	13.0	77.0	4.1	2.3	0.0
	A	8	-38.00892	177.13935	2.3	7.4	18.1	72.5	1.3	0.7	0.0
	A	7	-38.00870	177.13943	2.4	3.8	10.0	82.4	2.6	1.3	0.0
	A	6	-38.00855	177.13929	2.1	8.8	15.4	74.0	1.4	0.4	0.0
	A	5	-38.00802	177.13925	2.1	2.7	8.4	86.7	1.6	0.6	0.0
	A	3	-38.00933	177.13937	2.2	6.2	19.4	69.8	2.7	2.0	0.0
	A	12	-38.00877	177.13951	2.5	5.7	13.4	76.9	2.5	1.6	0.0
	A	11	-38.00847	177.13950	2.2	6.5	10.4	81.2	1.4	0.5	0.0
	A	4	-38.00660	177.13896	1.8	1.5	4.0	84.0	8.2	2.2	0.0
	A	1	-38.00780	177.13907	2.2	5.5	13.0	79.6	1.1	0.8	0.0
	A	2	-38.00792	177.13916	2.0	5.7	10.5	82.0	1.3	0.6	0.0
	B	2	-38.01328	177.13909	1.8	2.4	7.4	86.7	3.3	0.2	0.0
	B	3	-38.01336	177.13897	1.8	2.0	9.4	86.3	2.2	0.1	0.0
	B	9	-38.01364	177.13888	2.5	7.7	14.3	75.5	2.2	0.3	0.0
	B	10	-38.01385	177.13874	2.5	9.6	14.4	73.2	2.5	0.3	0.0
	B	5	-38.01375	177.13876	2.1	7.4	13.3	76.9	2.1	0.3	0.0
	B	4	-38.01355	177.13890	2.3	5.9	11.5	79.8	2.5	0.3	0.0
	B	11	-38.01450	177.13824	2.3	6.7	16.4	75.1	1.6	0.2	0.0
	B	12	-38.01484	177.13802	2.4	4.5	15.7	78.1	1.5	0.3	0.0
	B	8	-38.01476	177.13794	2.1	1.6	9.1	87.2	1.8	0.3	0.0
	B	7	-38.01471	177.13803	2.8	7.4	21.7	68.8	1.9	0.2	0.0
	B	6	-38.01429	177.13832	3.1	13.1	29.8	54.4	2.1	0.6	0.0
	B	1	-38.01429	177.13819	2.0	3.2	12.9	80.9	2.2	0.8	0.0
Okoromai Bay	A	6	-36.60868	174.80864	2.3	5.5	49.5	43.0	1.9	0.2	0.0
	A	1	-36.61096	174.80788	2.9	3.8	45.9	43.1	6.5	0.7	0.0

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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	2	-36.61192	174.80793	2.4	3.9	47.3	44.5	3.9	0.3	0.0
	A	3	-36.61178	174.80806	2.5	4.9	45.7	47.7	1.5	0.1	0.0
	A	4	-36.61113	174.80837	2.4	5.8	55.9	36.1	2.1	0.1	0.0
	A	7	-36.61179	174.80880	2.4	2.8	42.1	53.5	1.4	0.2	0.0
	A	5	-36.61219	174.80841	2.1	3.6	38.1	54.8	3.2	0.2	0.0
	A	8	-36.61034	174.81145	1.9	4.2	47.4	47.3	0.9	0.2	0.0
	A	9	-36.61118	174.81137	2.0	3.1	34.7	61.7	0.5	0.1	0.0
	A	10	-36.61190	174.81126	1.8	3.6	31.5	63.8	0.8	0.3	0.0
	B	1	-36.61016	174.80840	2.7	2.8	65.7	29.9	1.4	0.1	0.0
	B	10	-36.60767	174.81159	3.1	15.1	39.0	30.4	8.8	6.7	0.0
	B	13	-36.60886	174.81188	2.1	10.2	59.1	27.7	2.3	0.6	0.0
	B	11	-36.60882	174.81172	2.2	8.2	65.7	24.4	1.1	0.6	0.0
	B	14	-36.60896	174.81210	2.1	8.1	59.9	29.2	2.1	0.7	0.0
	B	12	-36.60937	174.81177	2.0	5.6	54.9	38.1	1.2	0.3	0.0
	B	6	-36.60790	174.81070	2.4	8.9	78.8	11.1	0.8	0.4	0.0
	B	8	-36.60830	174.81097	1.8	7.2	64.1	26.3	1.7	0.7	0.0
	B	2	-36.60815	174.80917	2.1	5.5	84.3	9.7	0.3	0.1	0.0
	B	3	-36.60877	174.80980	2.1	5.6	64.9	28.8	0.6	0.1	0.0
	B	7	-36.60931	174.81056	1.8	2.8	60.2	35.5	1.1	0.3	0.0
	B	9	-36.60957	174.81086	1.8	4.6	60.7	33.5	0.9	0.3	0.0
	B	4	-36.61059	174.80996	1.7	2.6	48.4	48.2	0.7	0.1	0.0
	B	5	-36.61136	174.81031	2.0	3.0	39.7	56.6	0.6	0.1	0.0
Otūmoetai (Tauranga Harbour)	A	2	-37.66432	176.15035	1.8	0.9	9.0	59.7	18.5	11.8	0.2
	A	3	-37.66452	176.15036	1.7	1.5	7.7	65.3	15.3	10.2	0.0
	A	5	-37.66447	176.15049	1.3	2.1	7.8	54.5	27.0	8.5	0.1
	A	4	-37.66431	176.15041	1.4	1.4	5.7	45.6	28.5	18.1	0.6

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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	14	-37.66417	176.15214	1.5	1.2	6.5	73.7	16.5	2.1	0.0
	A	13	-37.66427	176.15204	1.3	1.0	5.5	61.7	22.3	9.4	0.0
	A	10	-37.66426	176.15173	1.6	1.4	7.1	66.7	17.8	7.1	0.0
	A	9	-37.66425	176.15144	1.3	1.7	5.9	63.7	23.4	5.2	0.0
	A	11	-37.66439	176.15158	1.2	1.4	6.8	70.1	18.1	3.6	0.0
	A	8	-37.66445	176.15136	1.0	0.2	4.0	73.0	20.3	2.5	0.0
	A	7	-37.66429	176.15096	1.6	1.5	6.0	52.2	30.3	10.0	0.0
	A	12	-37.66453	176.15191	1.3	0.6	4.2	54.1	30.8	10.3	0.0
	A	1	-37.66460	176.15006	1.5	1.5	5.3	58.6	24.0	10.6	0.0
	A	6	-37.66461	176.15076	1.6	1.4	6.1	61.7	23.1	7.5	0.2
	B	2	-37.66417	176.15034	1.6	1.1	8.5	71.8	15.1	3.5	0.0
	B	1	-37.66395	176.15023	1.6	0.8	6.9	66.9	22.2	3.2	0.0
	B	3	-37.66394	176.15071	1.8	1.9	9.6	72.6	14.1	1.8	0.0
	B	4	-37.66379	176.15091	1.8	1.2	8.3	71.2	17.6	1.3	0.3
	B	5	-37.66391	176.15117	1.7	0.9	10.2	74.1	14.0	0.7	0.0
	B	6	-37.66374	176.15136	1.8	0.9	7.0	74.7	15.6	1.7	0.1
	B	8	-37.66377	176.15160	2.0	1.0	6.7	70.7	19.4	2.1	0.0
	B	9	-37.66381	176.15181	1.7	1.3	7.5	70.6	19.3	1.4	0.0
	B	7	-37.66404	176.15154	1.6	0.6	7.4	69.5	21.4	1.1	0.0
	B	10	-37.66414	176.15196	1.4	1.0	7.7	72.1	17.2	2.0	0.0
Whangamatā Harbour	A	5	-37.19561	175.87420	2.0	0.6	2.3	76.9	19.9	0.3	0.0
	A	1	-37.19317	175.87113	2.4	1.1	4.1	33.6	24.4	32.4	4.4
	A	2	-37.19348	175.87226	2.0	1.1	3.5	60.6	14.8	18.4	1.5
	A	4	-37.19388	175.87318	2.5	0.5	1.1	70.0	27.9	0.6	0.0
	A	3	-37.19402	175.87307	2.0	0.9	2.0	72.6	24.1	0.3	0.0
	B	1	-37.19324	175.87098	2.2	3.0	7.2	33.8	14.8	35.1	6.0

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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	3	-37.19448	175.87307	2.5	1.1	2.3	72.5	23.6	0.5	0.0
	B	2	-37.19403	175.87255	2.0	1.4	3.8	76.2	17.8	0.8	0.0
	C	16	-37.19712	175.87527	2.0	0.6	4.4	63.1	27.3	4.5	0.0
	C	15	-37.19694	175.87508	1.6	1.7	4.4	61.8	27.2	5.0	0.0
	C	13	-37.19678	175.87426	1.9	2.5	4.4	58.1	31.2	3.8	0.0
	C	14	-37.19727	175.87496	2.0	3.6	6.4	64.5	22.8	2.7	0.1
	C	12	-37.19657	175.87320	2.0	2.8	4.2	53.5	35.5	4.1	0.0
	C	9	-37.19647	175.87235	2.0	2.9	6.1	62.4	26.0	2.6	0.0
	C	7	-37.19640	175.87208	2.1	3.8	6.0	60.7	26.2	3.3	0.0
	C	11	-37.19610	175.87321	1.3	1.8	3.5	58.3	29.4	6.7	0.2
	C	10	-37.19598	175.87338	1.4	1.2	3.0	30.8	34.6	27.9	2.6
	C	1	-37.19318	175.86971	3.0	7.0	15.7	62.4	8.4	6.5	0.0
	C	2	-37.19368	175.87089	3.0	6.2	12.4	66.5	9.7	5.2	0.0
	C	4	-37.19363	175.87150	2.2	3.0	9.1	62.8	14.2	10.6	0.4
	C	5	-37.19378	175.87155	2.4	3.8	8.2	71.4	13.8	2.8	0.0
	C	3	-37.19383	175.87133	2.8	3.2	9.2	70.5	14.0	3.1	0.0
	C	8	-37.19413	175.87222	3.2	3.6	7.4	79.4	9.3	0.3	0.0
	C	6	-37.19394	175.87166	3.5	3.6	7.6	75.0	11.9	1.9	0.0
Whangapoua Harbour	A	1	-36.73846	175.64851	1.2	0.5	2.2	40.5	49.1	7.7	0.0
	A	8	-36.73867	175.65030	1.2	1.0	1.1	36.6	55.9	5.5	0.0
	A	7	-36.73873	175.64990	0.8	0.4	1.1	40.1	52.5	5.9	0.0
	A	6	-36.73868	175.64962	0.9	0.6	1.0	36.6	56.3	5.5	0.0
	A	5	-36.73862	175.64958	0.9	0.8	0.8	33.6	58.5	6.3	0.0
	A	4	-36.73858	175.64949	0.9	0.9	0.6	26.6	62.4	9.5	0.0
	A	3	-36.73862	175.64934	1.0	0.7	1.0	39.3	54.3	4.6	0.0
	A	2	-36.73859	175.64912	1.3	0.4	1.1	39.7	53.3	5.5	0.0

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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	6	-36.73476	175.64074	1.4	1.0	8.4	68.2	21.3	1.1	0.0
	B	7	-36.73507	175.64051	1.4	1.4	7.2	66.7	22.5	2.2	0.0
	B	8	-36.73509	175.64054	1.5	1.6	6.1	68.4	22.8	1.1	0.0
	B	5	-36.73447	175.63984	1.5	1.9	7.1	73.1	16.5	1.4	0.0
	B	4	-36.73445	175.63918	1.2	0.4	6.7	74.6	16.2	2.1	0.0
	B	1	-36.73333	175.63699	1.3	0.4	5.3	82.2	11.6	0.5	0.0
	B	2	-36.73346	175.63735	1.9	1.5	10.8	83.7	3.6	0.4	0.0
	B	3	-36.73342	175.63777	1.8	1.4	14.1	79.6	4.2	0.8	0.0
	C	1	-36.72539	175.61647	2.0	1.8	11.6	82.0	4.2	0.4	0.0
	C	4	-36.72531	175.61663	1.8	0.5	7.5	85.3	5.5	1.1	0.0
	C	3	-36.72510	175.61668	1.5	0.5	5.0	82.8	10.8	0.9	0.0
	C	6	-36.72553	175.61657	1.9	2.1	7.8	71.8	15.3	3.0	0.0
	C	2	-36.72616	175.61604	1.7	0.6	8.7	86.5	3.3	0.8	0.0
	C	5	-36.72637	175.61603	1.8	1.3	9.6	84.3	3.9	1.0	0.0
	C	8	-36.72608	175.61635	1.6	1.6	7.0	80.7	9.9	0.7	0.0
	C	7	-36.72595	175.61640	1.9	1.2	8.6	82.5	7.2	0.5	0.0

APPENDIX C: Sampling areas at Te Mata Bay and Waipatukahu

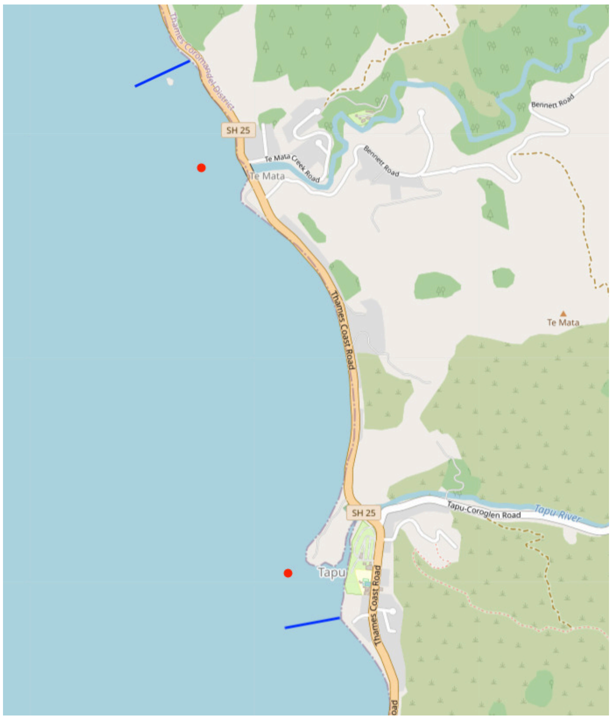

Figure C-1: Sampling areas (red circles) at Te Mata Bay and Waipatukahu, Coromandel Peninsula. Blue lines indicate the northern and southern extents of the area included in the pre-survey reconnaissance.

Figure C-2: Intertidal sampling area at Te Mata and Waipatukahu. General sampling area (left) and close up of the sediment surface (right; length of calipers: 21 cm).