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Intertidal shellfish monitoring in the northern North Island region, 2016–17

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K. Berkenbusch
P. Neubauer

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PO Box 2526
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EXECUTIVE SUMMARY

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Coastal environments throughout New Zealand support bivalve populations that are targeted in recreational and customary fisheries. In northern North Island, the main fisheries species in sheltered, sedimentary habitats are cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*). Populations of both species are often easily accessible in intertidal areas, and occur close to urban centres, exposing them to considerable fishing pressure at some locations. The latter has prompted concerns about population declines and local depletion of some northern North Island cockle and pipi populations. To monitor their populations, the Ministry for Primary Industries (MPI) commissions regular (usually annual) surveys, which focus on a range of estuaries, harbours and inlets in the wider Auckland region, Northland, Waikato, and Bay of Plenty. The present assessment presents the most recent data in this monitoring series, including the 2016–17 fishing year. The sites included in this survey were (in alphabetical order) Aotea Harbour, Eastern Beach, Grahams Beach, Kawakawa Bay (West), Mangawhai Harbour, Ngunguru Estuary, Ruakaka Estuary, Otumoetai (Tauranga Harbour), Te Haumi Beach, Waiōtahe Estuary, Whangamata Harbour, and Whangapoua Harbour.

All of the 12 survey sites contained cockle populations, which varied in abundance and density across sites. The smallest population was at Grahams Beach, with an estimated 17.09 million (CV: 21.82%) cockles, compared with the highest population abundance at Kawakawa Bay (West) of 261.21 million (CV: 13.84%) individuals. The cockle population was also relatively large at Eastern Beach, with the current estimate of 176.91 million (CV: 13.05%) individuals at this site. The corresponding population densities ranged from 64 cockles per m^2 at Grahams Beach to high densities at Ngunguru Estuary and Whangamata Harbour of 1461 cockles per m^2 and 1125 cockles per m^2, respectively. Cockle densities were also comparatively high at the remaining sites, with most sites supporting populations densities of over 400 individuals per m^2.

The cockle populations included few large individuals ($\geq$30 mm shell length), and this size class was absent at three sites, including Aotea Harbour, Grahams Beach, and Ruakaka Estuary. At the other sites, large cockles were present but only a small part of the total population. Their highest abundance estimate was 18.33 million (CV: 36.42%) large cockles at Kawakawa Bay (West), followed by 15.07 million (CV: 17.38%) large cockles at Eastern Beach. At the remaining sites, abundance estimates of this size class were 4.00 million (CV: 24.6%) individuals or less. Their highest density was 67 large individuals per m^2 at Eastern Beach.

Ten of the northern survey sites supported pipi populations, with no pipi beds at Aotea Harbour or Eastern Beach. Their population estimates varied, with the highest abundance estimates at Waiōtahe Estuary and Te Haumi Beach, including 166.25 million (CV: 18.36%) and 101.49 million (CV: 24.80%) million pipi, respectively. A number of sites supported high-density populations, with particularly high estimates of 1388 pipi per m^2 at Waiōtahe Estuary, and 1008 pipi per m^2 at Ruakaka Estuary. Densities were also high at Ngunguru Estuary, Te Haumi Beach, and Otumoetai (Tauranga Harbour), ranging from 453 pipi per m^2 to 889 pipi per m^2. Pipi densities were lowest at Kawakawa Bay (West) with an estimated mean of 6 pipi per m^2, and ranged from 33 to 99 pipi per m^2 at the remaining sites.

Eight of the populations included large pipi ($\geq$50 mm shell length), but their numbers and densities were generally low (about one million individuals or less), with the highest abundance estimate at Whangamata Harbour of 3.87 million (CV: 20.49%) individuals in this size class. Their corresponding density at this site was 50 pipi per m^2, with only one higher density estimate of 89 large pipi per m^2 at Whangapoua Harbour. Their densities were markedly lower at the other sites. Owing to their low abundance, large pipi contributed few individuals to the population, except at Whangamata Harbour, where they constituted about half of the present population.

Sediment sampling in areas inhabited by cockles provided baseline information of sediment properties, including the organic content and grain size composition.

1. INTRODUCTION

Intertidal habitats throughout New Zealand support bivalve species that are important for recreational and customary fisheries. Two of the main target species in these fisheries are cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*), which inhabit a range of sheltered, sedimentary environments throughout the country. Both species frequently form extensive beds and high-density patches, with abundances of over 1000 individuals per m^2 (Morton & Miller 1973, Hooker 1995).

Cockles and pipi often co-occur in estuaries, inlets and harbours, but show differences in habitat preferences at these different environments. Cockles are most commonly found in the intertidal zone, including sand- and mudflats across a range of sediment types. This species shows some tolerance to changes in sediment properties, but is sensitive to increases in sediment fines (silt and clay, <63 μm grain size), such as caused by terrestrial runoff. Pipi are associated with high-flow areas, close to tidal currents, and their high-density beds are usually in the low intertidal, extending into subtidal waters. Pipi show a preference for coarse, clean sands, which makes them vulnerable to sedimentation impacts.

Coastal bivalve populations are also exposed to a number of other factors that may adversely affect their distribution and abundance. Identified threats to cockle and pipi populations include pollution (e.g., heavy metals, organochlorines), nutrient enrichment, diseases, parasites, and also fishing (e.g., see review by Grant & Hay 2003). Both species have featured in recent mortality events, including populations that are part of the northern North Island survey programme. For example, the mass mortality of cockles in Whangateau Harbour (Northland) in 2009 was attributed to infections by bacteria and a parasite, leading to a population decline of over 50% at this site (Ministry for Primary Industries 2015). Similarly, pipi mass mortalities were documented at Te Haumi Beach in 2014 and Ngunguru Estuary in 2015, with suggested causes including bacterial infections and environmental stress (Berkenbusch & Neubauer 2015, Ministry for Primary Industries 2015).

In addition, cockle and pipi populations experience considerable fishing pressure in some regions, such as northern North Island. Their common occurrence in coastal habitats means that they are easily accessible to recreational and customary fisheries, making cockles and pipi the main target species across different sheltered environments during periods of low tide (Hauraki Māori Trust Board 2003, Hartill et al. 2005). Recognition of this fishing pressure has led to a number of initiatives to assess cockle and pipi populations at northern sites. Monitoring efforts include regular surveys as part of the Hauraki Gulf Forum Community Shellfish Monitoring Programme (Auckland Council 2013) and regular surveys commissioned by the Ministry for Primary Industries (MPI).

The MPI surveys commenced in 1992 and focus on cockle and pipi populations at northern North Island sites. The sites were initially restricted to the wider Auckland metropolitan area, but have since then expanded across the Auckland Fisheries Management Area (FMA 1) (see information about the surveys in Appendix A). At each site, the monitoring focuses on particular cockle and pipi populations that are considered to be important for non-commercial fisheries. For this reason, it generally does not provide population estimates of the entire cockle and pipi populations at each site (Pawley & Ford 2007). The surveys collect data on the population abundance, density and size structure of cockle and pipi populations, and recent surveys have also included sediment variables in the data collection (see Berkenbusch & Neubauer 2016). The latter include sediment organic content and grain size composition to provide baseline information that may help explain the distribution and abundance of cockles at the survey sites (Neubauer et al. 2015).

The present report documents the most recent survey in the series of MPI assessments of infaunal bivalve abundance and population structure at selected sites in the northern North Island region. The overall objective of this project was "to determine the distribution, abundance and size frequency of selected intertidal shellfish" for the 2016–17 fishing year. The sites included in this survey were (in alphabetical order): Aotea Harbour, Eastern Beach, Grahams Beach, Kawakawa Bay (West), Mangawhai Harbour, Ngunguru Estuary, Ruakaka Estuary, Otumoetai (Tauranga Harbour), Te Haumi Beach, Waiōtahe Estuary, Whangamata Harbour, and Whangapoua Harbour (Figure 1).

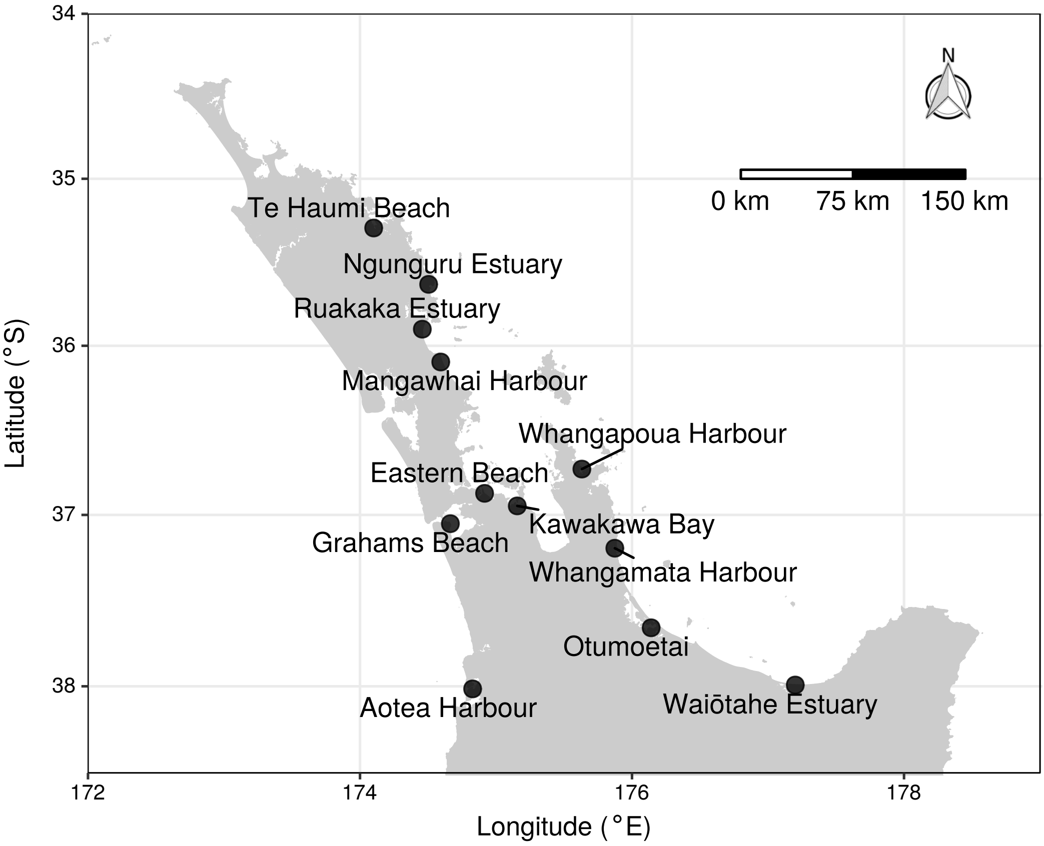


Figure 1: Sites included in the northern North Island intertidal bivalve surveys in 2016–17.

2. METHODS

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

2.1 Survey methods

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

Preliminary analyses of cockle density data from previous surveys (2013–14 to 2015–16) 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 each phase, a fixed number of sampling points was then allocated over all cells, with a probability proportional to the area of the cell over the maximum area of any of the cells in the grid. The position of the point within the cell was randomly allocated. With this procedure, not all the cells that were clipped by the boundary had sampling points allocated to them. The expected density of sampling points across the stratum was uniform. All sampling points were pre-calculated for two phases before the sampling began. All phase-1 points were sampled, whereas sampling of phase-2 points was only carried out when the coefficient of variation (CV) of the total abundance estimate after first-phase sampling exceeded the target value of 20% for either cockle or pipi (i.e., at two sites in 2016–17).

Owing to the importance of sediment properties for infaunal bivalves, recent previous surveys included a sediment sampling programme to determine the sediment organic content and grain size at each site (see Berkenbusch et al. 2015, Berkenbusch & Neubauer 2015). The sediment sampling provided general baseline information, but the small number of sediment samples and the non-random allocation of sediment sampling points prevented formal analyses of sediment variables. For this reason, the sediment sampling design was improved in 2015–16 to allow the analysis of spatial patterns in sediment variables, and to assess gradients in cockle abundance in relation to sediment properties (Neubauer et al. 2015, Berkenbusch & Neubauer 2016).

The sediment sampling was restricted to cockles, as pipi populations frequently extend into subtidal waters deeper than 0.5 m, so that only parts of the population are sampled. Following the re-stratification of sites, a total of 24 sediment sampling points was allocated at each site. The sediment sampling point allocation was based on a subset of at least six sediment sampling points that was randomly allocated within each cockle stratum, corresponding with a randomly-allocated cockle sampling point. Data from the sediment sampling were used to provide baseline information of current sediment properties, and to build a data set that allows spatial and temporal comparisons in future analyses.

2.2 Field sampling–bivalves

The field survey of the northern North Island sites was conducted in February 2017, when bivalve populations at each site were sampled during periods of low tide (see sampling dates for the present and previous surveys in Appendix A, Tables A-1, A-2).

Bivalves were sampled using the same sampling unit as in previous surveys, consisting of a pair of benthic cores that were 15 cm diameter each; the combined cores sampled a surface area of 0.035 m^2. The cores were sampled to 15 cm sediment depth, and this sampling depth included the maximum burrowing depths of cockles and pipi, which reside in the top 10 cm of the sediment (i.e., 1–3 cm for cockles, Hewitt & Cummings 2013; and 8–10 cm for pipi; Morton & Miller 1973).

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

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

2.3 Field sampling–sediment

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

The grain size analysis was based on wet sieving to ascertain the proportion of different size classes, ranging from sediment fines (silt and clay, <63 µm grain size) to different sand fractions of very fine to very coarse sands and gravel (i.e., 125 to 2000 µm grain size) (Eleftheriou & McIntyre 2005). Each sample was homogenised before processing using a stack of sieves to determine the proportion in each sediment grain size fractions (i.e., >63, >125, >250, >500, and >2000 µm). Each sediment fraction retained on the sieves was subsequently dried to constant weight at 60°C before weighing it (accuracy $\pm$ 0.0001 g).

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

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

2.4 Data analysis–bivalves

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

The data analysis followed the previous approach (e.g., Berkenbusch et al. 2015). Consistent with previous surveys, the two cores within each grid cell were considered a single sampling unit. Bivalve abundance within the sampled strata at each site was estimated by extrapolating local density (individuals per m^2), calculated from the number of individuals per sampling unit, to the stratum size:

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

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

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

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

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

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

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

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

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

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

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

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

2.5 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 in the Waikato region, where it is situated on the west coast. This site was sampled in three previous bivalve surveys, in 2005–06, 2009–10, and 2014–15 (see Appendix A, Tables A-1, A-2). The bivalve surveys have focused on cockles at this site, as there are currently no notable pipi beds in Aotea Harbour.

The present survey included the same sampling extent as the preceding survey in 2014–15, in an area directly adjacent to the main road to Aotea township (Figure 2). The sampling area extended across an intertidal mudflat that contained seagrass in low-tide areas. Based on previous sampling data with geo-referenced samples in 2014–15, this area was re-stratified into four strata, A to D, with a total of 81 sampling points across these strata (Table 1).

Sediment samples at Aotea Harbour were low in organic content (less than 2.5%) (Figure 2, and see details in Appendix B, Table B-3). The sediment grain size composition was dominated by fine (>125 µm grain size) and very fine (>63 µm grain size) sands, with a varying proportion of fines (<63 µm grain size) across samples, ranging between 4 and 14%. Similarly, the proportion of gravel (>2000 µm grain size) was variable, with a maximum of 12.8% of sediment in this grain size fraction.

Cockles were distributed across the entire sampling extent, although densities were low at both the upper shore and in the low tide area, in stratum A (Figure 3, Table 1). The total population size was estimated at 76.41 million (CV: 11.05%) cockles in the current survey, and the corresponding population density was 393 cockles per m^2 (Table 2). The current abundance and density estimates were similar to estimated values in the preceding survey in 2014–15. These estimates indicate that there has been no further decline in the cockle population following the marked decreases in total abundance and density between 2009–10 and 2014–15.

In contrast, the population estimate for large cockles (≥30 mm shell length) revealed a continued decrease of this size class, and there were no large individuals in 2016–17 (Table 2). The lack of large cockles in the current survey followed a substantial reduction in their abundance in 2014–15, from an estimated 3.46 million (CV: 27.88%) large cockles in 2009–10 to 0.55 million (CV: 45.13%) large individuals.

While the proportion of large cockles has been consistently small in recent surveys, the proportion of recruits (≤15 mm shell length) remained relatively similar, with 32.93% of cockles in this size class in 2016–17 (Table 3, Figure 4). The prevalence of small and medium-sized cockles in the population was evident in the mean and modal shell lengths, with only a slight reduction in these sizes to 17.06-mm and 17-mm shell lengths in 2016–17, respectively. The consistently unimodal population of predominantly medium-sized cockles at this site was evident in length-frequency distributions of the population over time. Large cockles were scarce, while recruits and medium-sized cockles dominated the population.

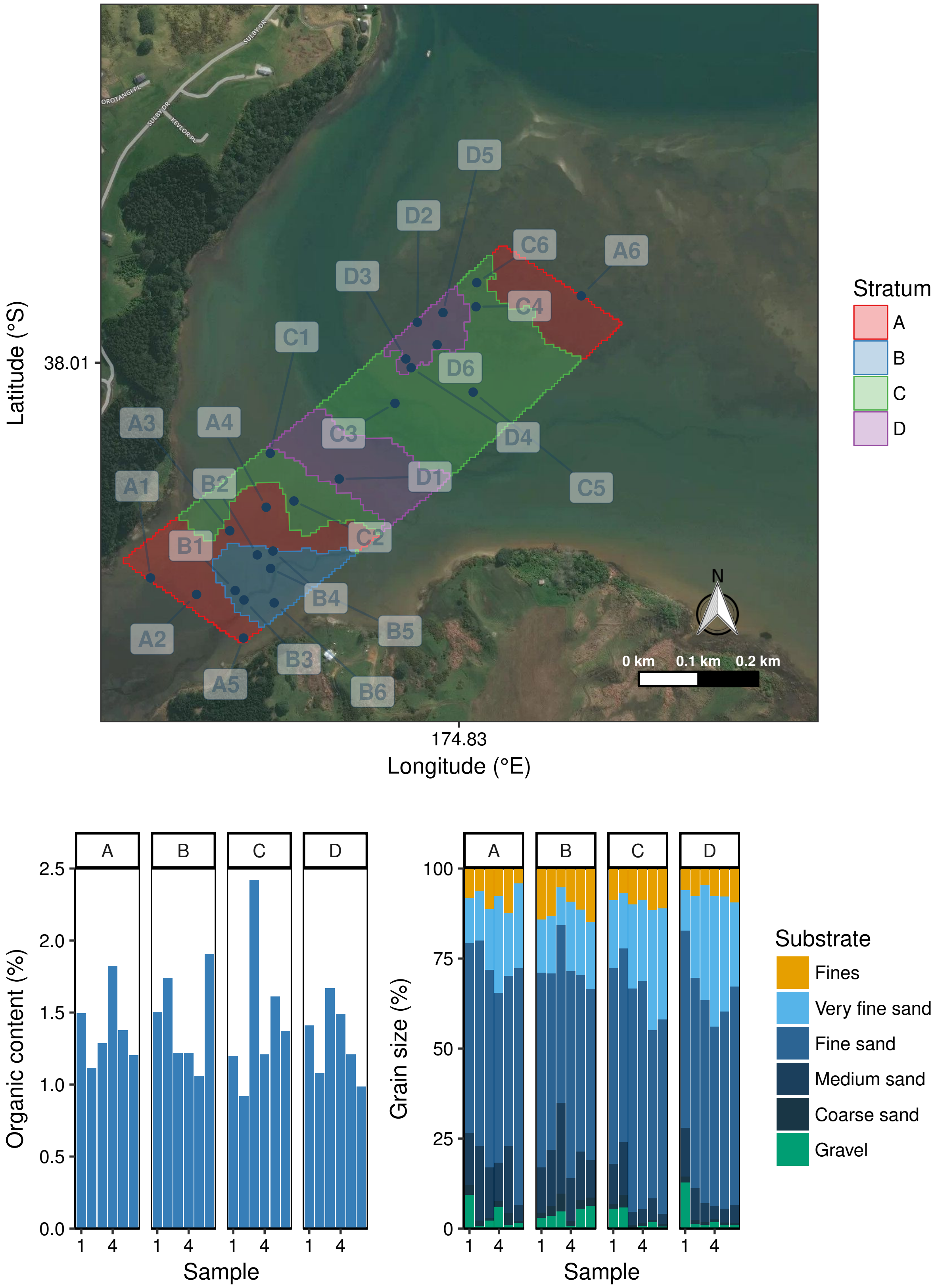


Figure 2: Sediment sample locations and characteristics at Aotea Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125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

3.1.1 Cockles at Aotea Harbour

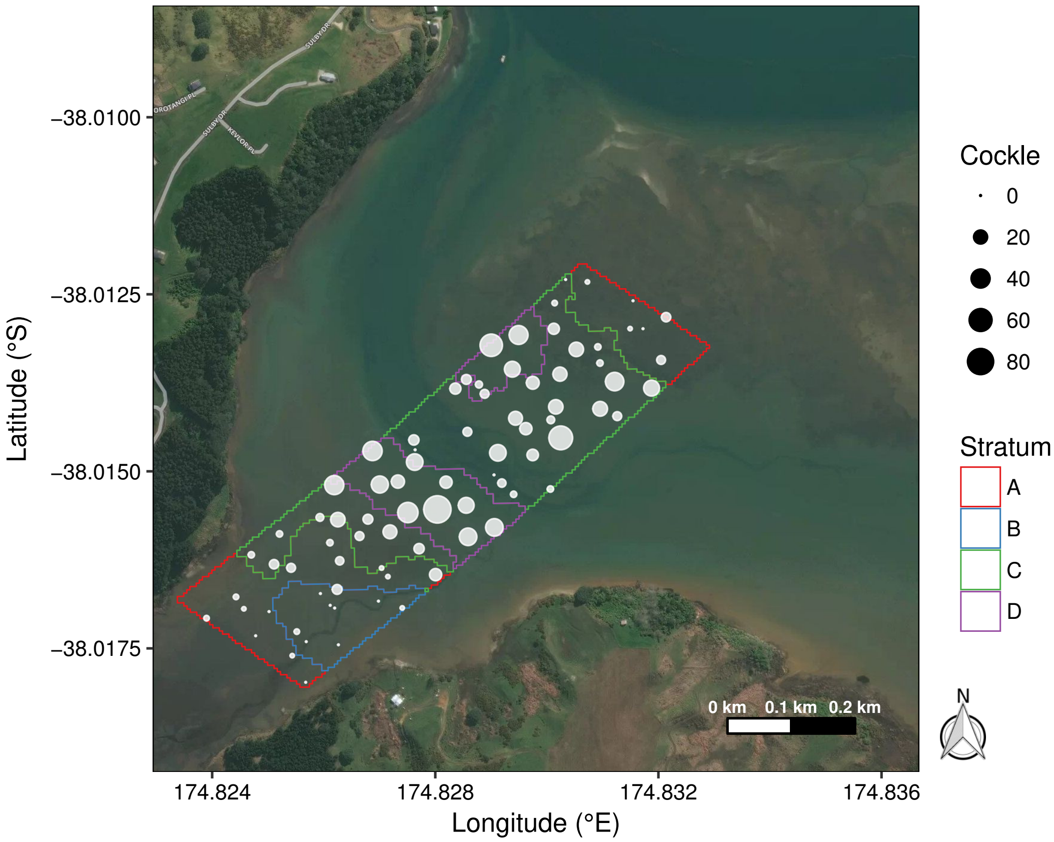


Figure 3: Map of sample strata and individual sample locations for cockles at Aotea Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Aotea Harbour, by stratum, for 2016–17. 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	5.4	20	82	6.27	117	31.10
B	1.9	9	12	0.71	38	73.95
C	8.6	38	530	34.33	398	16.12
D	3.6	14	475	35.10	969	17.25

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	18	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	

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 (%)
2009–10	18.19	15	4–37	33.29	2.52
2014–15	18.40	19	6–32	24.91	0.74
2016–17	17.06	17	2–29	32.93	0.00

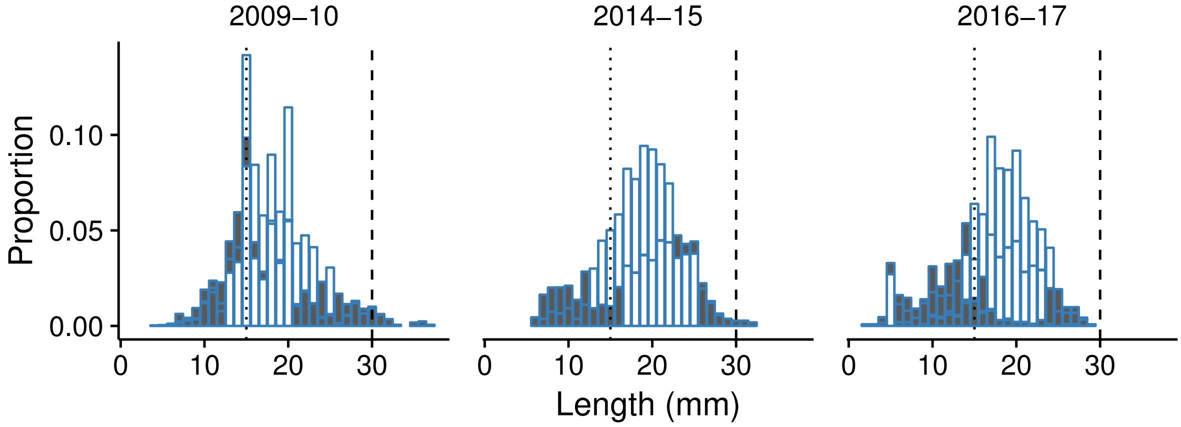


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Aotea Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.2 Eastern Beach

Eastern Beach is one of the Auckland metropolitan survey sites, and situated within Hauraki Gulf, at the eastern side of the city. The current assessment was the fourth survey within the series, with previous surveys in 1999–2000, 2001–02, and most recently in 2014–15 (see Appendix A, Tables A-1, A-2). Eastern Beach was permanently closed to fishing in 1993 (Morrison et al. 1999).

The sampling extent at Eastern Beach was parallel to the shore, and bounded by headlands and rocky platforms at the northwestern and southeastern ends (Figure 5). Based on geo-referenced samples from the preceding survey in 2014–15, the sampling extent was re-stratified, resulting in three strata, A to C (Table 4). The re-stratification included reducing the low-tide extent of the area sampled, and also omitting a small area at the southeastern end (previous stratum C). These areas contained no bivalves, and the southeastern area had changed from a sedimentary site to rocky outcrops and platforms containing little sediment. Across the sampling extent, the current survey included a total of 87 bivalve sampling points (Table 4). There were only two pipi sampled in this survey, and this species is not further reported on here.

The sediment at Eastern Beach was characterised by a low organic content that was generally less than 2% (Figure 5, and see details in Appendix B, Table B-3). Similarly, there was a small proportion of fines (grain size <63 µm) across samples, with a maximum of 2.5% of sediment in this grain size, except for one sample that contained 22.4% of sediment fines. Most samples were dominated by fine sand (>125 µm grain size), with a smaller proportion of very fine sand (>63 µm grain size). Several samples also contained relatively high proportions of coarse particles, i.e., coarse sand (>500 µm) and gravel (>2000 µm grain size).

The cockle population at Eastern Beach showed high densities in the southern part of the sampling extent, with fewer cockles towards the northern area, particularly in stratum C (Figure 6, Table 4). The total population estimate for the Eastern Beach cockle population was 176.91 million (CV: 13.05%) individuals in 2016–17, with an estimated population density of 784 cockles per m^2 (Table 5). The current population estimates were marked increases from previous assessments, particularly in view of the smaller sampling extent in 2016–17; the current abundance and density estimates reflected more than six-fold and ten-fold increases from the preceding survey in 2014–15, respectively. Considering population estimates over time, the cockle population showed a continued increase since the initial survey in 1999–2000.

Similarly, the population of large cockles ($\geq$30 mm shell length) showed a slight increase in the current assessment, with an estimated 15.07 million (CV: 17.38%) individuals in 2016–17, and a corresponding density of 67 large cockles per m^2. In 2014–15, there were an estimated 12.84 million (CV: 26.54%) large individuals at a density of 31 cockles per m^2 included in the population. These findings show that the small population of large cockles seemed to persist at this site.

Considering the proportion of large individuals within the total population, however, highlighted a marked decrease in their contribution overall. Large cockles constituted 8.52% of the total population, compared with 45.61% in 2014–15. While medium-sized individuals made up the bulk of the population, the proportion of recruits ($\leq$15 mm shell length) also showed a recent increase to 7.66% of the total population (Table 6, Figure 7).

The influence of recruits was evident in the concomitant decreases in mean and modal sizes (Table 6, Figure 7). The 17-mm modal confirmed the dominance of recruits, and the current length-frequency distribution revealed a shift towards this smaller modal shell length in 2016–17. At the same time, large and medium-sized cockles made up a smaller part of the population, compared with previous length-frequency distributions.

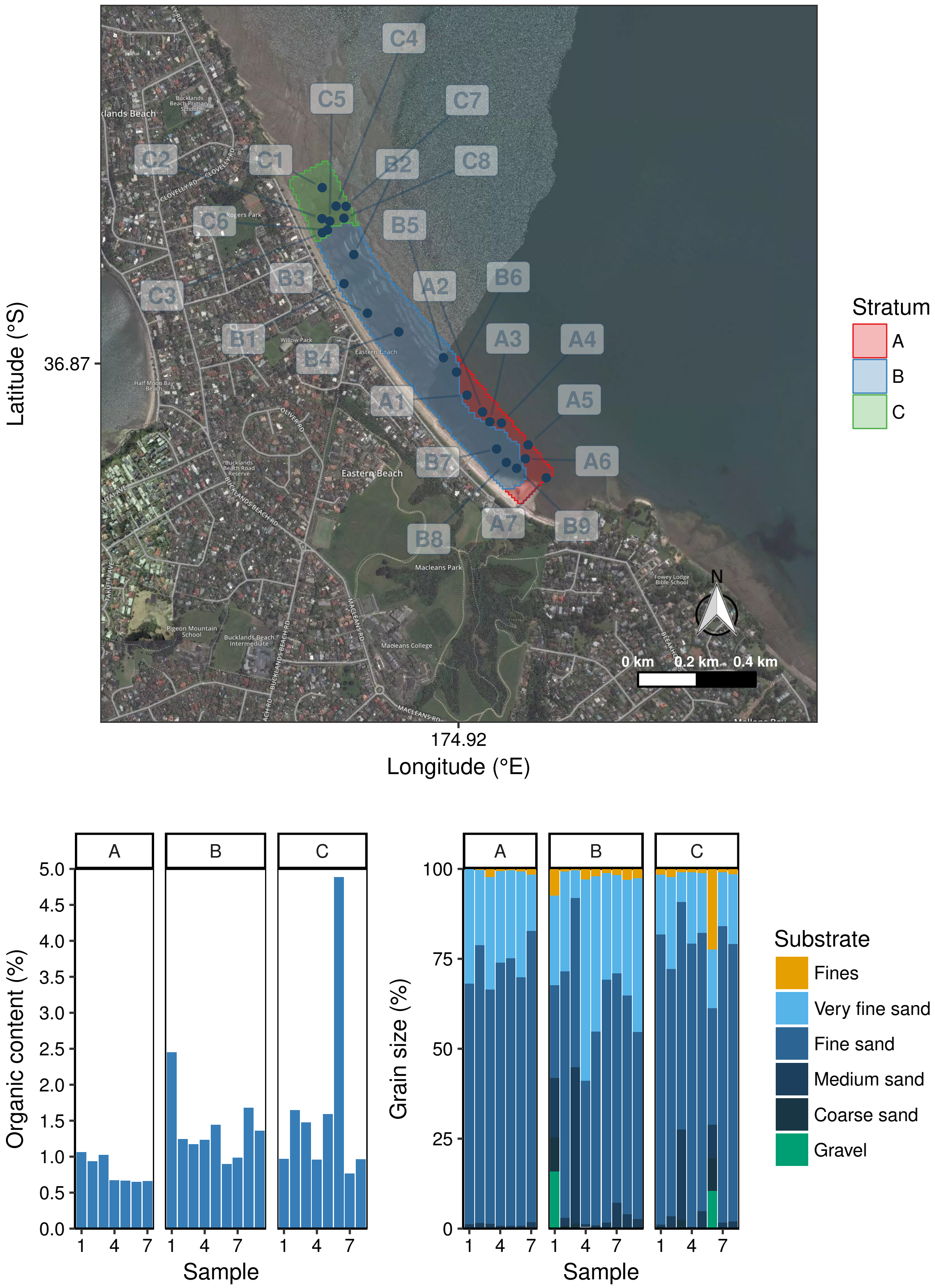


Figure 5: Sediment sample locations and characteristics at Eastern Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.2.1 Cockles at Eastern Beach

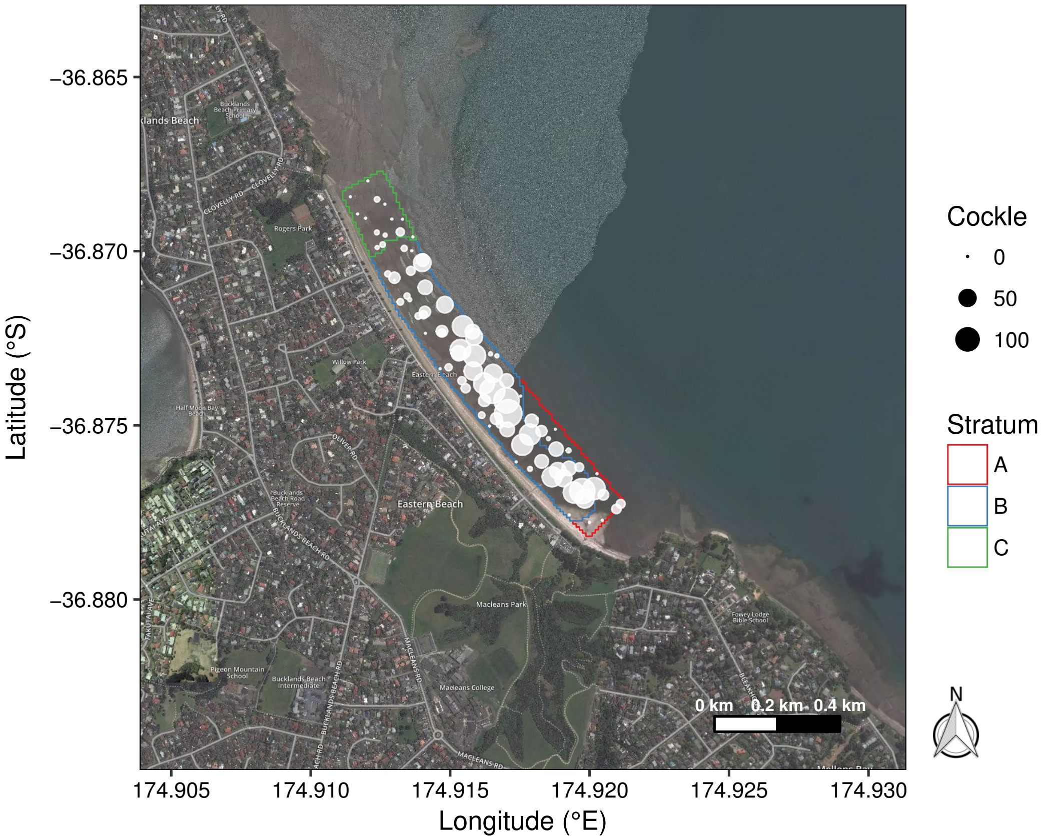


Figure 6: Map of sample strata and individual sample locations for cockles at Eastern Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 4: Estimates of cockle abundance at Eastern Beach, by stratum, for 2016–17. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	3.5	15	227	15.02	432	40.41
B	15.7	58	2 080	160.56	1 025	13.87
C	3.4	14	19	1.33	39	48.61

Table 5: Estimates of cockle abundance at Eastern Beach for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	48.0	6.39	13	17.17	0.00	0	
2001–02	43.4	13.07	30	17.58	3.00	21	29.93
2014–15	41.4	28.16	68	16.59	12.84	31	26.54
2016–17	22.6	176.91	784	13.05	15.07	67	17.38

Table 6: Summary statistics of the length-frequency (LF) distribution of cockles at Eastern Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2001–02	25.52	24	7–38	2.94	22.96
2014–15	28.87	30	7–43	0.12	45.61
2016–17	21.54	17	8–42	7.66	8.52

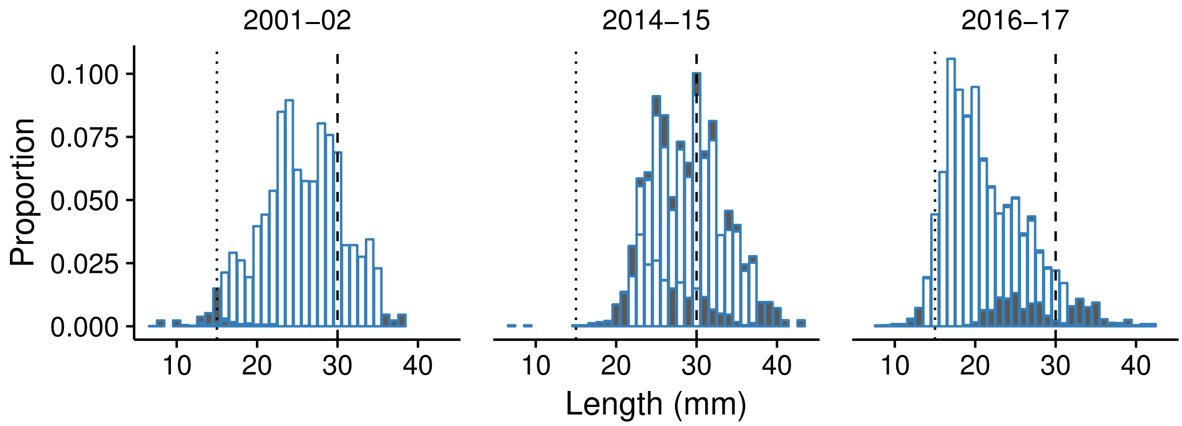


Figure 7: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Eastern Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3 Grahams Beach

Grahams Beach is within Manukau Harbour, on Awhitu Peninsula. Surveys at this site have included four previous bivalve assessments, most recently in 2013–14 (see Appendix A, Tables A-1, A-2). The current study surveyed the same sampling extent as previous surveys, which extended along the length of the beach (Figure 8). Using spatial data from the 2013–14, the sampling extent was re-stratified resulting in three strata. Across these strata, bivalves were sampled in a total of 162 sampling points, with half the number of points each in phases 1 and 2 (Table 7).

Sediment characteristics at Grahams Beach included a generally low organic content of less than 2.4%, and a low proportion of fines (grain size <63 μm), with a maximum of 2.5% of sediment in this grain size fraction (see details in Appendix B, Table B-3). Most of the sediment was medium sand (grain size >500 μm) and, to a lesser extent, fine sand (>125 μm).

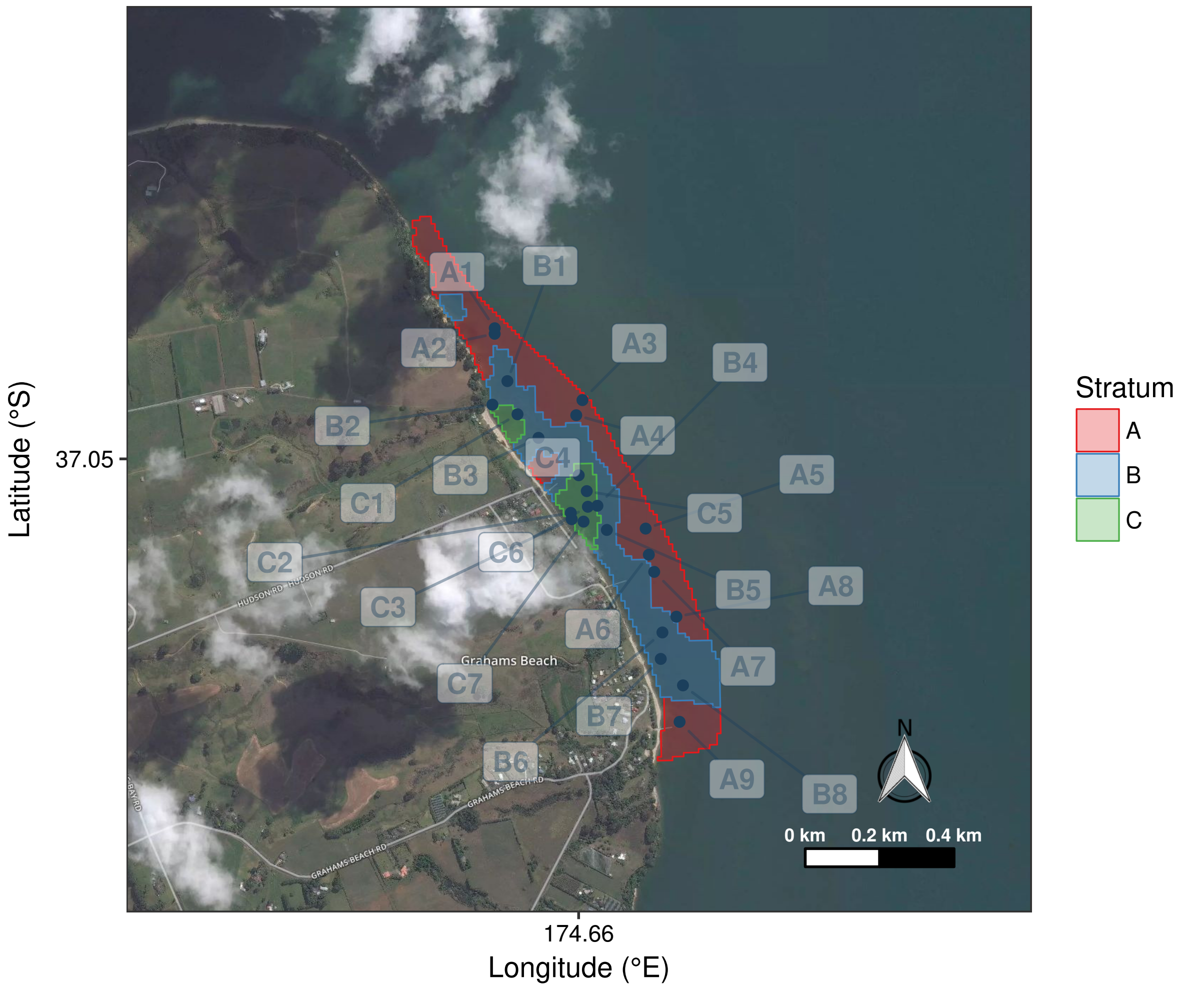
In the 2016–17 survey, the cockle population was largely concentrated in the upper shore area along the beach, with highest densities in stratum C (Figure 9, Table 7). The total population abundance was estimated at 17.09 million (CV: 21.82%) cockles (Table 8), and the estimated population density was 64 cockles per m^2. Although sampling at this site included a second phase, owing to the variability in the cockle population, the CV remained just above 20%. The current estimates reflected a substantial increase in the total cockle population from the two preceding assessments, including the most recent survey in 2013–14, when abundance and density estimates were 4.70 million (CV: 19.10%) cockles at this site, with a corresponding population density of 18 cockles per m^2.

There were no large cockles (≥30 mm shell length) in the population in 2016–17. This finding is consistent across surveys, with only few or no large cockles included in the Grahams Beach population. While large cockles contributed no or few individuals, the proportion of recruits (≤15 mm shell length) dominated the cockle population at this site, increasing from about a third of the population in 2012–13 to 84.33% in the present study (Table 9, Figure 10).

The increase in small cockles was reflected in decreases in mean and modal shell lengths. For example, the modal size decreased from 22-mm to 9-mm shell length in 2016–17. This decrease in medium- to large-sized cockles was illustrated in length-frequency distributions across surveys; the previously bimodal cockle population changed to a unimodal population of small-sized individuals.

Pipi at Grahams Beach were also predominantly in areas close to the shore, particularly in the southern part of the sampling extent (Figure 11, Table 10). The sampling returned a low number of individuals, and the total population estimate for this species was 8.77 million (CV: 25.66%) pipi, with an estimated density of 33 pipi per m^2 (Table 11). These estimates reflect a slight decrease in the pipi population at Grahams Beach.

The population contained no large pipi (≥50 mm shell length), and this size class has been scarce across surveys (Table 12, Figure 12). It consistently contributed few or no pipi to the population, which has been dominated by small pipi (recruits, ≤20 mm shell length). Recruits showed a continuous increase over time, constituting most (81.21%) of the pipi population in 2016–17 (Table 12, Figure 12). Their dominance was evident in the decrease in shell lengths, with a current modal size of 8-mm. Although the population remained bimodal over time, it consisted of one strong mode of small pipi and a considerably smaller second mode in the current study.



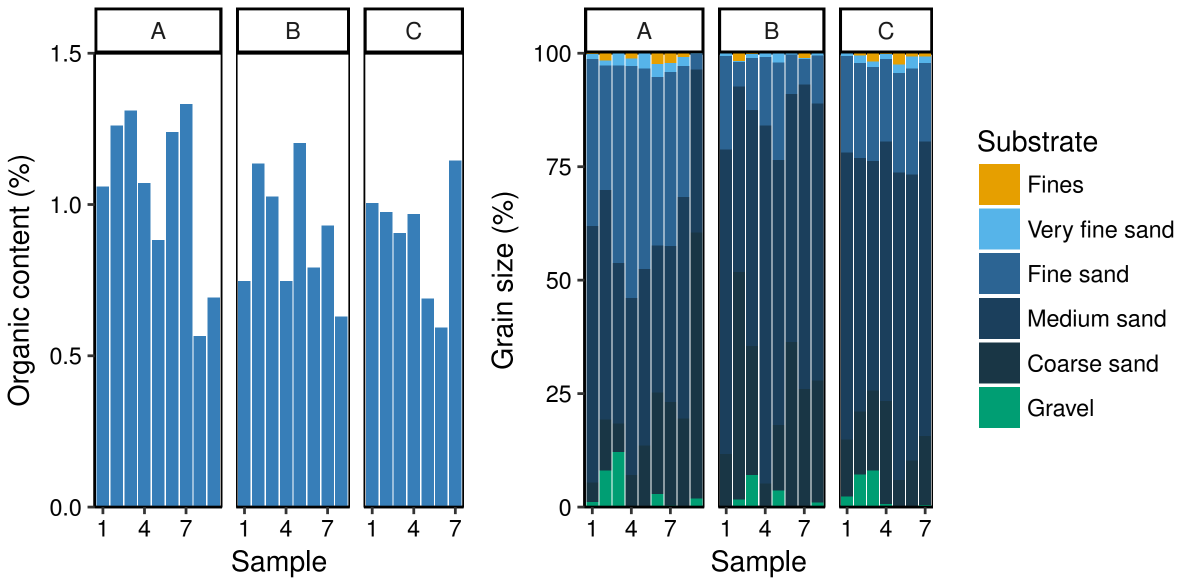


Figure 8: Sediment sample locations and characteristics at Grahams Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.3.1 Cockles at Grahams Beach

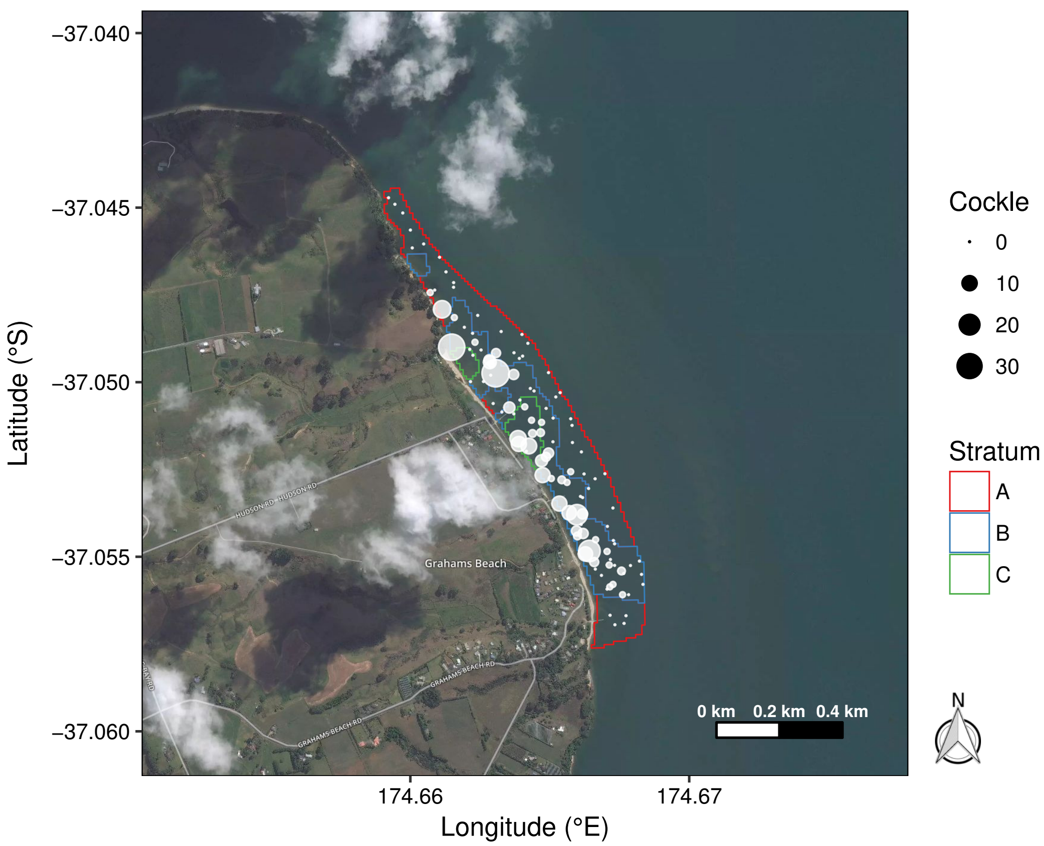


Figure 9: Map of sample strata and individual sample locations for cockles at Grahams Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 7: Estimates of cockle abundance at Grahams Beach, by stratum, for 2016–17. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	13.9	40	19	1.88	14	75.00
B	10.8	85	233	8.42	78	25.48
C	2.2	37	404	6.79	312	39.86

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2010–11	25.1	25.22	100	20.39	0.02	<1	>100
2012–13	20.1	4.23	21	21.00	0.00	0	
2013–14	26.8	4.70	18	19.10	0.12	<1	>100
2016–17	26.8	17.09	64	21.82	0.00	0	

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	18.69	22	6–28	31.68	0.00
2013–14	16.27	10	5–31	52.56	2.56
2016–17	11.13	9	5–25	84.33	0.00

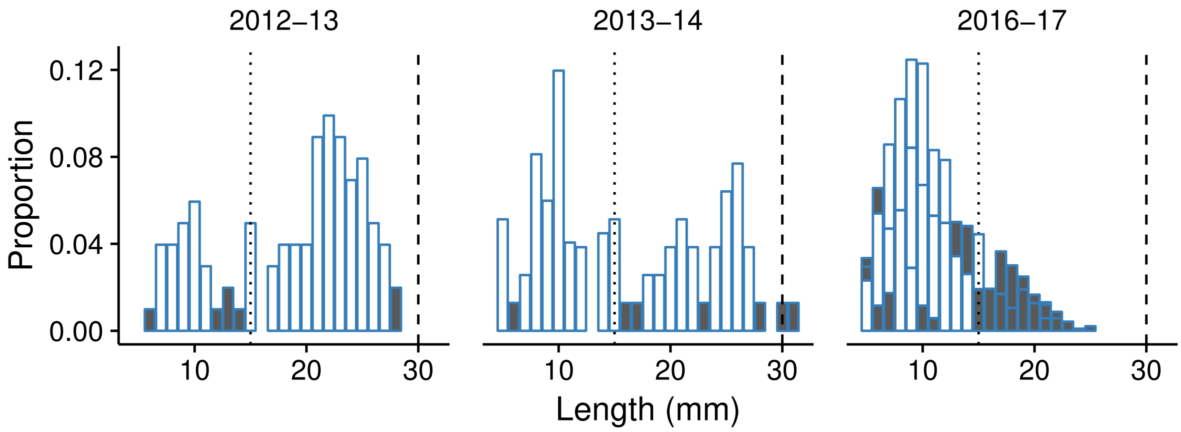


Figure 10: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Grahams Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3.2 Pipi at Grahams Beach

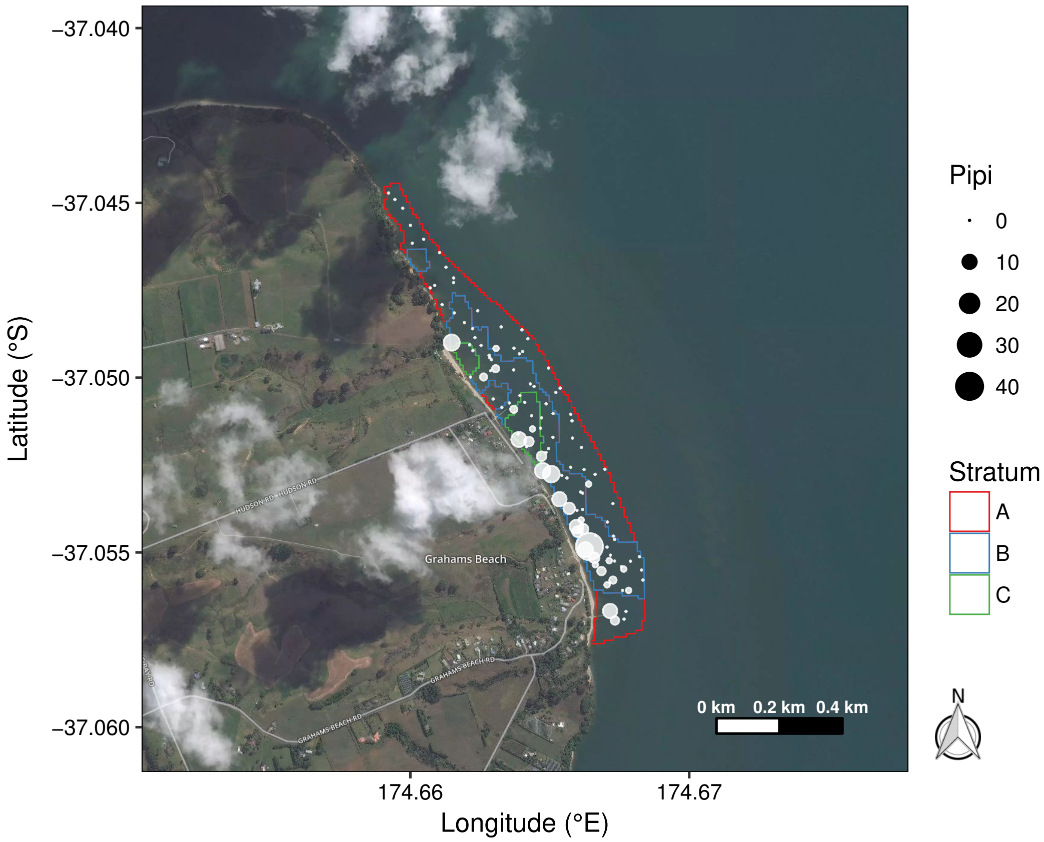


Figure 11: Map of sample strata and individual sample locations for pipi at Grahams Beach, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 10: Estimates of pipi abundance at Grahams Beach, by stratum, for 2016–17. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	13.9	40	15	1.48	11	69.31
B	10.8	85	170	6.15	57	32.16
C	2.2	37	68	1.14	53	27.69

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2010–11	25.1	3.75	15	27.65	0.00	0	
2012–13	20.1	2.93	15	35.01	0.00	0	
2013–14	26.8	12.34	46	21.63	0.06	<1	>100
2016–17	26.8	8.77	33	25.66	0.00	0	

Table 12: Summary statistics of the length-frequency (LF) distribution of pipi at Grahams Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	18.13	12	10–35	65.71	0.00
2013–14	25.00	11	4–53	40.27	0.49
2016–17	13.93	8	2–48	81.21	0.00

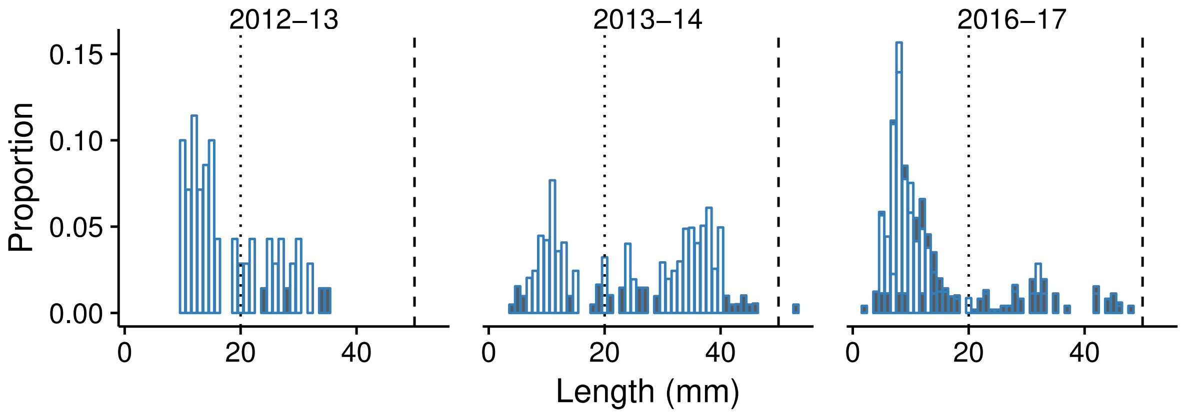


Figure 12: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Grahams Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4 Kawakawa Bay (West)

Kawakawa Bay (West) is one of the survey sites in the (wider) Auckland metropolitan area, and is located in Tamaki Strait within Hauraki Gulf. There have been three previous bivalve assessments at this site, which were conducted in 2004–05, 2006–07, and 2014–15 (see Appendix A, Tables A-1, A-2). Earlier assessments were carried out in 1992–93 and 1993–94, and the site is regularly monitored as part of the Hauraki Gulf Forum community monitoring (e.g., Auckland Council 2013). Consistent with previous MPI surveys, the sampling extent in the present study included the entire western bay (Figure 13). This area was re-stratified using spatial information from the 2014–15 survey, dividing it into three strata (Table 13). Across these strata, there were 92 sampling points in 2016–17.

Sediment samples at Kawakawa Bay (West) were low in organic content, with a maximum value of 4.3%, and showed greatly variability in the grain size composition (Figure 13, and see details in Appendix B, Table B-3). For example, the proportion of sediment fines (grain size <63 μm) was less than 15% in most samples, but varied overall between 0.0 and 70.7%. The prevalent grain size fractions varied dependent on the sample, primarily in the proportions of very fine and fine sands (grain sizes >63 μm) and >125 μm). A number of samples also contained a relatively high proportion of gravel (>2000 μm).

Cockles at this site were distributed across the bay, with comparatively high densities in the eastern area, included in stratum C (Figure 14, Table 13). The 2016–17 estimates for the total cockle population were 261.21 million (CV: 13.84%) cockles, with a population density of 429 individuals per m^2 (Table 14). The current estimates were marked increases from the preceding surveys, which estimated total cockle abundance at less than 90 million cockles and the population density at less than 150 individuals per m^2. The population contained a number of large cockles (≥30 mm shell length), with an estimated 18.33 million (CV: 36.42%) individuals in this size class, at a mean density of 30 large cockles per m^2. Both the abundance and density estimates of large cockles remained similar throughout recent surveys. When considering their contribution to the total population, however, there was a marked drop in the proportion of large cockles in the current survey (Table 15). This size class contributed about a quarter of the population in preceding surveys, compared with 7.02% of all individuals in 2016–17. There was a concomitant increase in the proportion of small cockles (recruits, ≤15 mm shell length) in 2016–17, from 18.04% in 2014–15 to 45.05% of the total population in the current assessment.

The prevalence of small cockles in the current population was reflected in the decrease in mean and modal sizes to 17.75 mm and 15 mm shell lengths, respectively. Although medium-size cockles dominated the unimodal population in previous surveys at this site, individuals in the small size class determined the length-frequency distribution in 2016–17, while large cockles became scarce (Figure 15). Cockles at Kawakawa Bay (West) are also included in the Hauraki Gulf Forum community monitoring programme, with the most recent data including a survey in 2013 (Auckland Council 2013). These data revealed a mean population density of about 258 cockles per m^2 across surveys, and a cohort at 20 to 25 mm shell length. These population data are lower than the current estimates, but differences are likely to be due to the different survey times, and possibly the different survey methods used.

There were few pipi at Kawakawa Bay (West), with only 19 individuals sampled across all sampling points (Figure 16, Table 16). Pipi were mostly present in the upper intertidal area in the eastern part of the bay. The total abundance estimate for this species was 3.72 million (CV: 34.77%) pipi (Table 17). The population density was estimated at 6 individuals per m^2. The small number of pipi sampled was reflected in the high uncertainty (CV) associated with the estimates. Across surveys, the pipi population at Kawakawa Bay (West) has been consistently small, albeit with some variation in abundance and density.

There were no large pipi (≥50 mm shell length) at this site, and this finding was consistent with previous surveys that highlighted the lack of this size class (Table 18, Figure 17). Instead, the population consisted of recruits (≤20 mm shell length), which made up 49.67% of the total pipi population in 2016–17. Although medium-sized pipi were also present in the population, the dominance of recruits was reflected in the mean and modal sizes of 20.44 mm and 10 mm shell lengths. Overall, the pipi population was too small to reveal distinct length-frequency distributions.

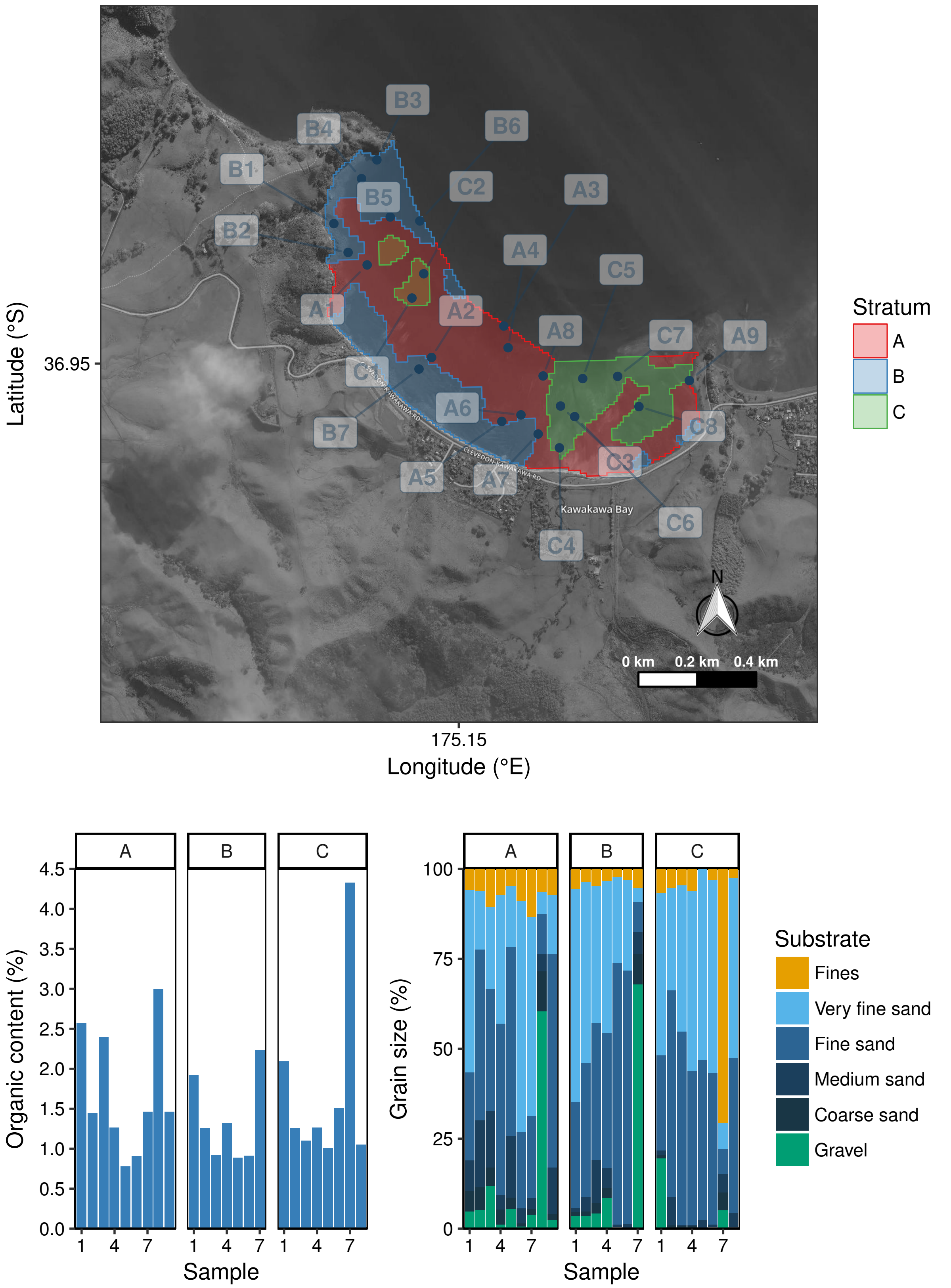


Figure 13: Sediment sample locations and characteristics at Kawakawa Bay (West). Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.4.1 Cockles at Kawakawa Bay (West)

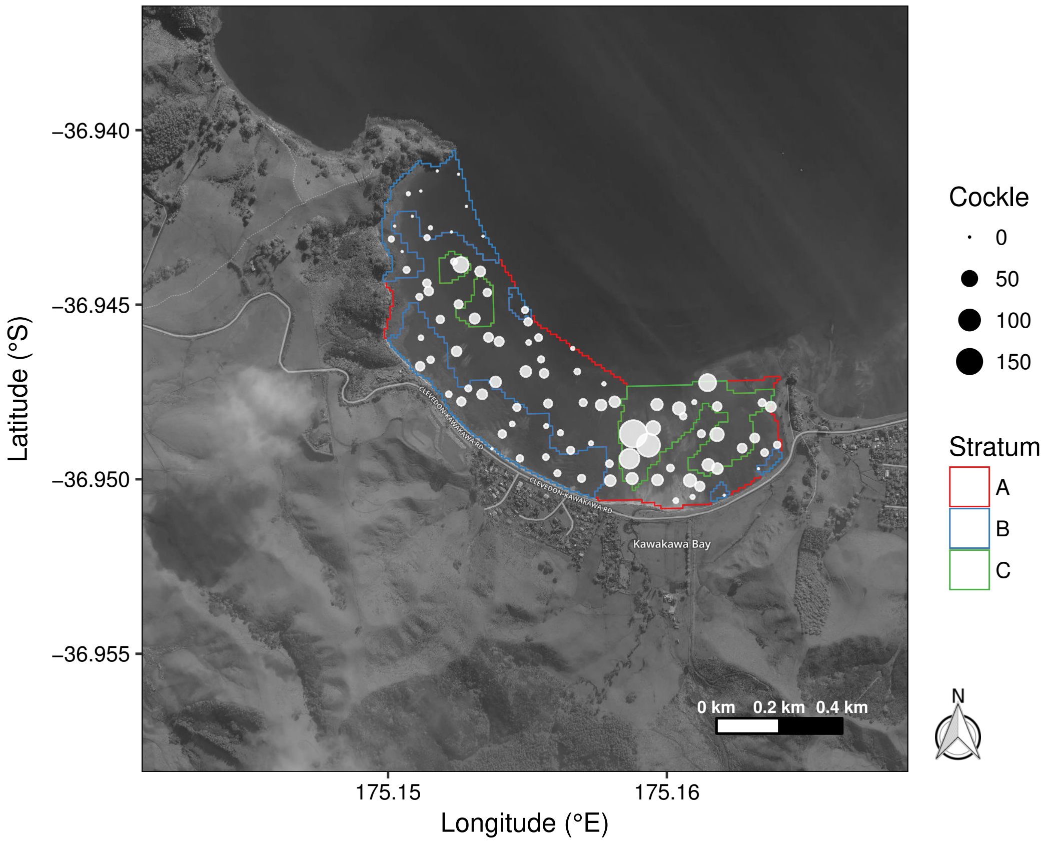


Figure 14: Map of sample strata and individual sample locations for cockles at Kawakawa Bay (West), with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of cockle abundance at Kawakawa Bay, by stratum, for 2016–17. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	30.2	42	475	97.42	323	10.84
B	18.9	30	136	24.49	130	19.84
C	11.8	20	824	139.29	1 177	24.58

Table 14: 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

Table 15: Summary statistics of the length-frequency (LF) distribution of cockles at Kawakawa 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 (%)
2006–07	25.12	25	2–48	8.48	24.58
2014–15	24.05	26	6–46	18.04	26.64
2016–17	17.75	15	6–46	45.05	7.02

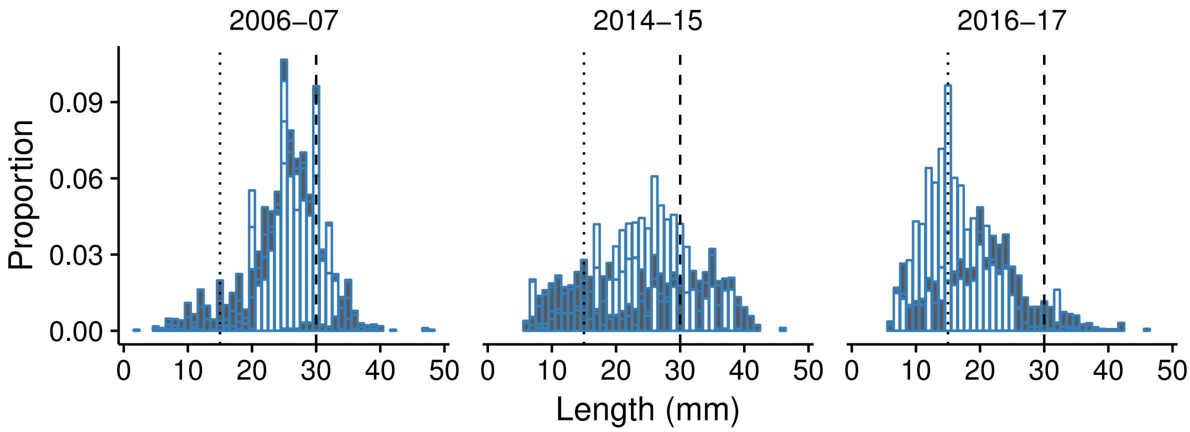


Figure 15: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Kawakawa Bay (West). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4.2 Pipi at Kawakawa Bay (West)

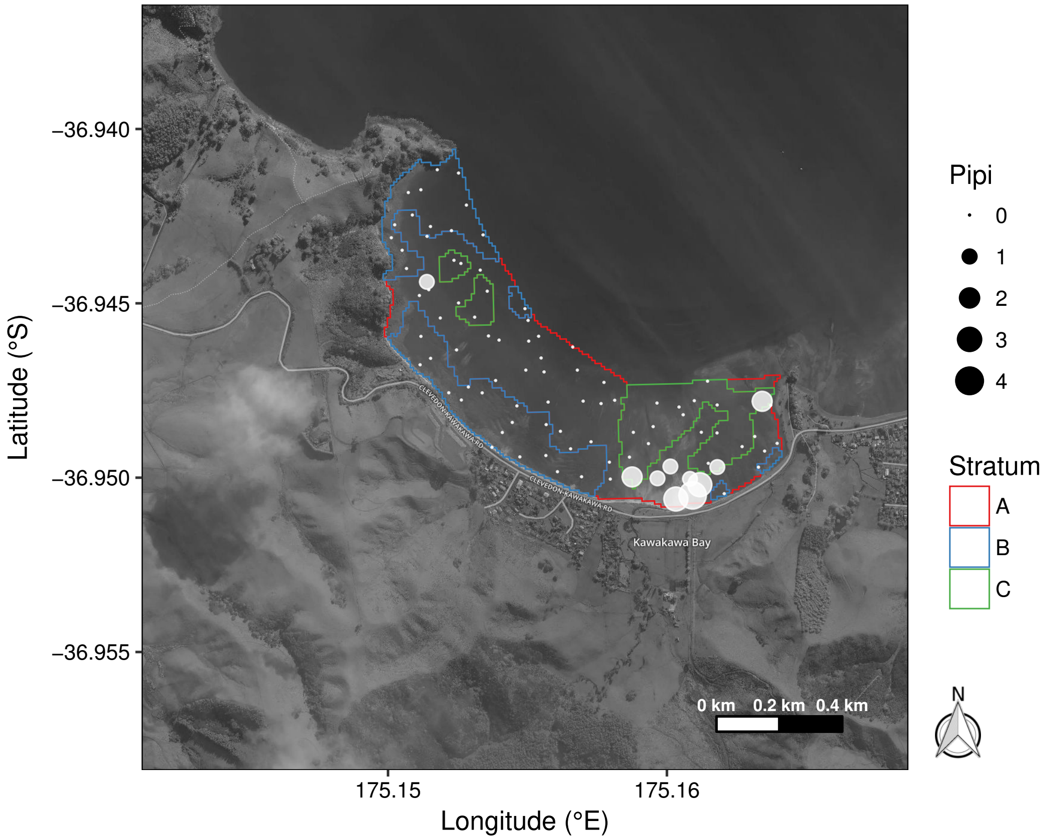


Figure 16: Map of sample strata and individual sample locations for pipi at Kawakawa Bay (West), with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 16: Estimates of pipi abundance at Kawakawa Bay, by stratum, for 2016–17. 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	30.2	42	14	2.87	10	41.74
B	18.9	30	0	0.00	0	
C	11.8	20	5	0.85	7	57.12

Table 17: Estimates of pipi abundance at Kawakawa Bay (West) 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 (%)
2004–05	60.4	1.04	2	14.88	0.00	0	
2006–07	62.9	0.13	<1	100.00	0.00	0	
2014–15	60.9	6.17	10	19.19	0.00	0	
2016–17	60.9	3.72	6	34.77	0.00	0	

Table 18: Summary statistics of the length-frequency (LF) distribution of pipi at Kawakawa 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 (%)
2006–07	19.00	18	18–20	100.00	0.00
2014–15	21.44	19	10–40	51.57	0.00
2016–17	20.44	10	10–41	49.67	0.00

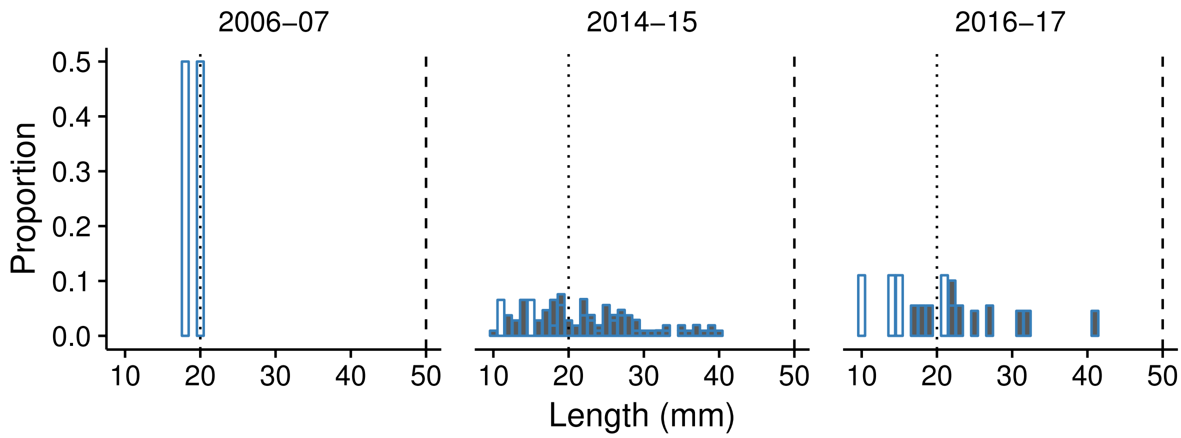


Figure 17: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Kawakawa Bay (West). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5 Mangawhai Harbour

Mangawhai Harbour is situated on Northland's east coast. Bivalves at this site have been regularly assessed in seven previous surveys, including the preceding study in 2014–15 (see Appendix A, Tables A-1, A-2). Throughout the survey series, the bivalve assessments have focused on separate areas within the harbour, including the harbour entrance, the intertidal mudflat in the lower harbour, and high-flow areas associated with the main channel (Figure 18). The present survey focused on the same areas as previous assessments, and the sampling extent was re-stratified based on information from the 2014–15 survey. The field survey sampled four strata, including a pipi bed on the eastern side of the main channel. Previous surveys also included a pipi bed within the main channel (previous stratum E), but this pipi bed has become inaccessible with water depths exceeding 1 m at low tide. Across the four strata, the current survey targeted bivalves in a total of 107 sampling points across all strata (Table 19).

Sediment in Mangawhai Harbour had a low organic content ($<1\%$), with only one sample exceeding 7.0% (Figure 18, and see details in Appendix B, Table B-3). The grain size composition was predominantly fine sand (grain size >125 µm), with varying proportions of medium sand (>250 µm). Samples in stratum A also contained a comparatively high proportion of gravel (>2000 µm), with up to 30.8% of sediment in this coarse grain size fraction.

Cockles were present in all strata, but were most abundant in strata B and D (Figure 19, Table 19). The 2016–17 population estimates for this species included a total abundance of 58.97 million (CV: 13.89%) cockles, and a mean density of 794 cockles per m^2 (Table 20). Overall, the total cockle population showed little variation since 2001–02, although the current estimates indicated a slight increase in population size from the previous survey in 2014–15. The current population included a small number of large cockles ($\geq$30 mm shell length), with an estimated 1.46 million (CV: 28.67%) large individuals in 2016–17. Their population density was 20 cockles per m^2. Over time, cockles in the large size class experienced declines in abundance and density, from initially relatively high estimates in 2000–01 to the lowest values in this survey.

Owing to their low abundance, large cockles only contributed a small proportion (2.48%) to the total population (Table 21). In contrast, small recruits ($\leq$15 mm shell length) made up 29.01% of the population, showing a slight increase from the previous assessment. The dominance of small and also medium-sized cockles was highlighted in the mean and modal sizes of 19.19 mm and 22 mm shell lengths. Medium-sized cockles determined the unimodal length-frequency distribution of the population in 2016–17, indicating that the second mode of small cockles in the previous survey had grown to larger sizes in the meantime, augmenting this cohort in the current population (Figure 20).

The pipi population at Mangawhai Harbour was concentrated in two areas, close to the harbour entrance and on the eastern fringe of the main channel (Figure 21, Table 22). Both abundance and densities of this species were highest in stratum F. For the total pipi population, the current abundance estimate was 2.51 million (CV: 16.18%) pipi at this site, with an estimated density of 34 pipi per m^2 (Table 23). These estimates indicated a smaller pipi population than in 2014–15, but reflected a smaller sampling extent, owing to the inaccessible pipi bed in the main channel.

Large pipi ($\geq$50 mm shell length) have been consistently scarce at Mangawhai Harbour. The current survey revealed similar estimates of the number and density of this size class as previous surveys, with 0.01 million (CV: >100%) large pipi and <1 pipi per m^2. While there were few (0.41%) large pipi within the population , there was a substantial increase in small pipi ($\leq$20 mm shell length) in this survey (Table 24, Figure 22). Pipi in this size class made up 85.55% of the current pipi population, after previously contributing about 40% of all individuals.

The increase in small pipi led to a 10-mm decrease in mean shell length (to 15.61 mm), although the modal size remained the same at 11 mm. There was a distinct, strong mode of small individuals, with few pipi exceeding 20 mm shell length. This population structure was different to previous length-frequency patterns, which were characterised by two cohorts, including small and also medium to large pipi.

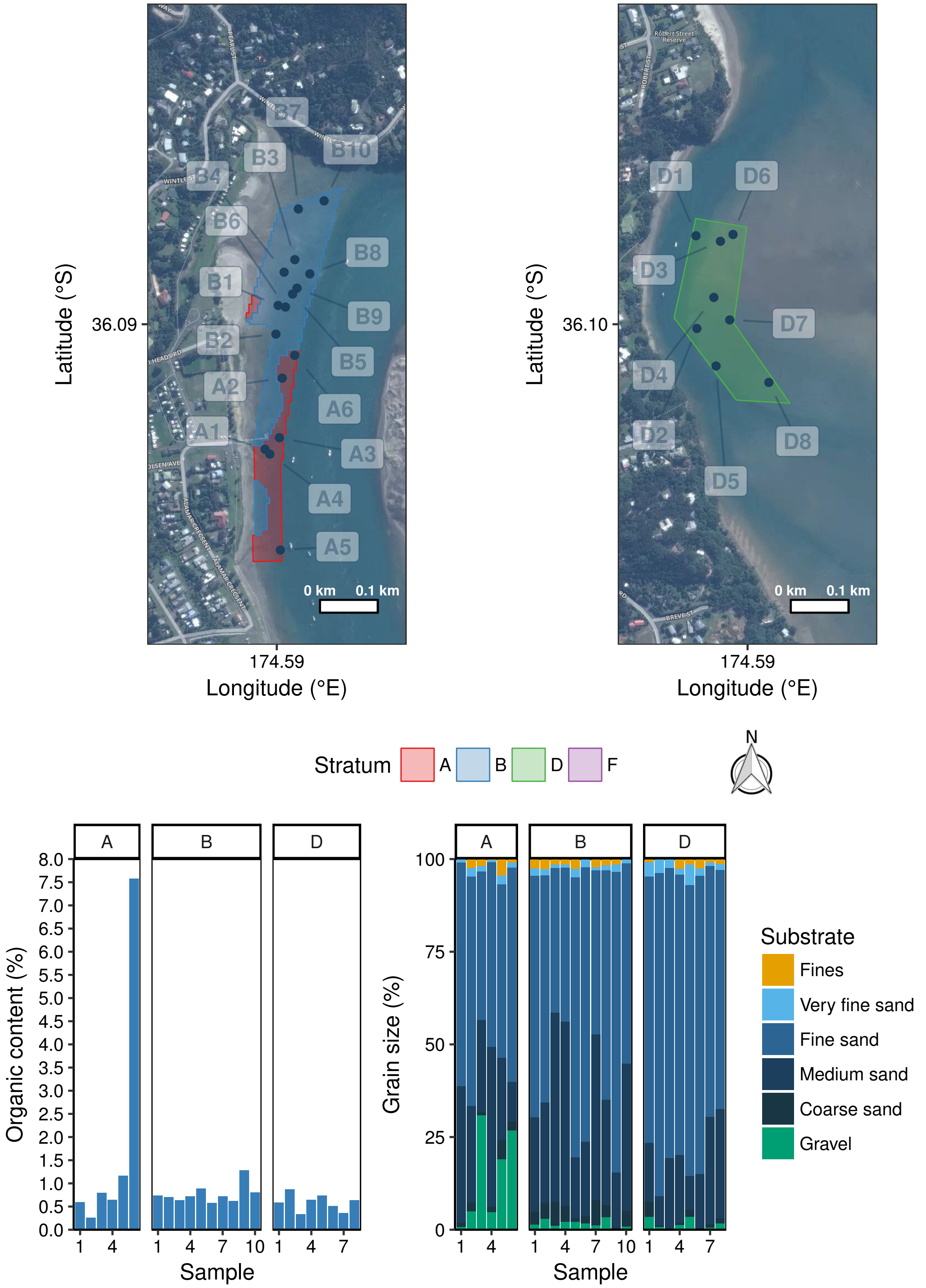


Figure 18: Sediment sample locations and characteristics at Mangawhai Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.5.1 Cockles at Mangawhai Harbour

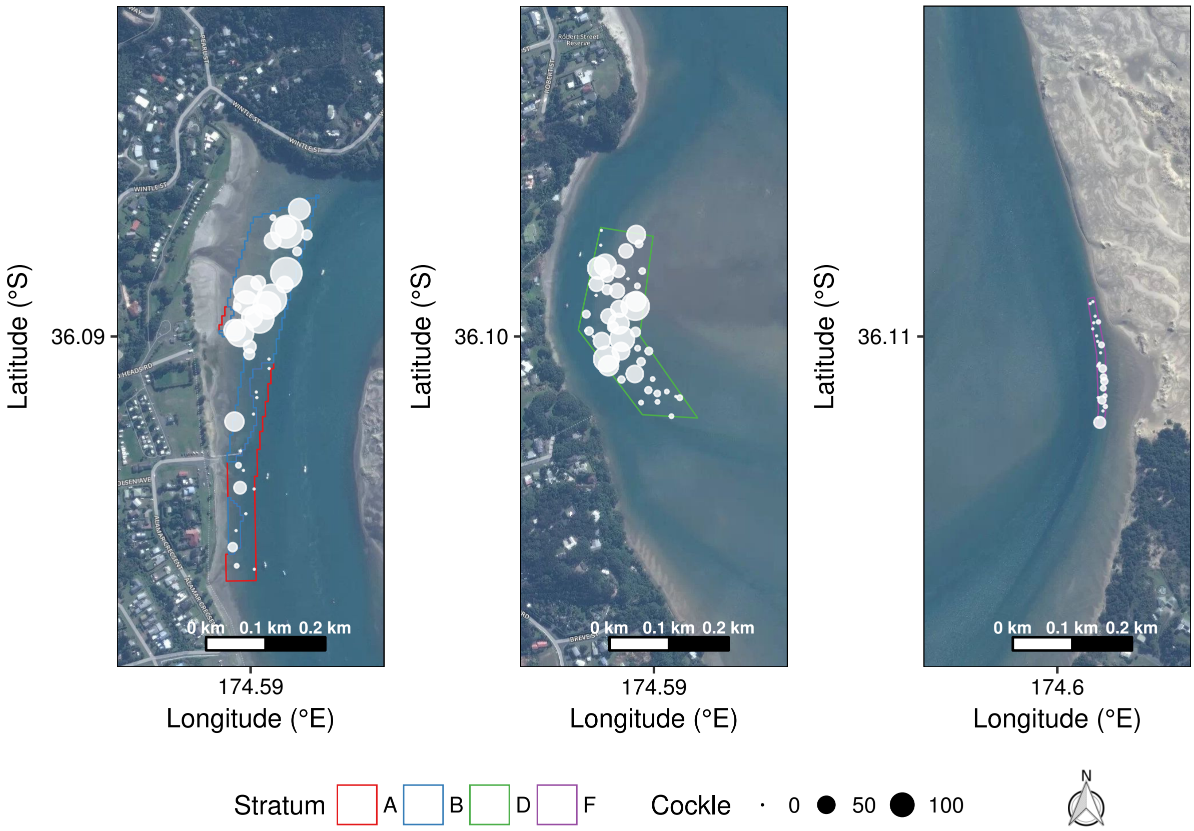


Figure 19: Map of sample strata and individual sample locations for cockles at Mangawhai Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of cockle abundance at Mangawhai Harbour, by stratum, for 2016–17. 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	10	20	0.69	57	84.00
B	3.0	27	1 296	40.72	1 371	18.39
D	3.0	46	943	17.37	586	18.76
F	0.3	24	55	0.19	65	41.57

Table 20: Estimates of cockle abundance at Mangawhai 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	9.4	98.71	1 050	4.54	28.56	304	7.17
2000–01	8.4	76.61	912	4.35	45.27	539	4.35
2001–02	8.4	28.54	340	5.80	8.75	104	7.48
2002–03	8.4	46.14	549	5.46	20.46	256	6.47
2003–04	8.4	50.77	604	4.71	17.43	207	6.24
2010–11	9.0	61.78	686	9.15	8.28	92	17.41
2014–15	8.6	52.73	617	7.58	2.05	24	15.95
2016–17	7.4	58.97	794	13.89	1.46	20	28.67

Table 21: Summary statistics of the length-frequency (LF) distribution of cockles at Mangawhai Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	21.62	20	5–39	19.17	13.40
2014–15	19.68	25	4–37	25.45	3.89
2016–17	19.19	22	5–47	29.01	2.48

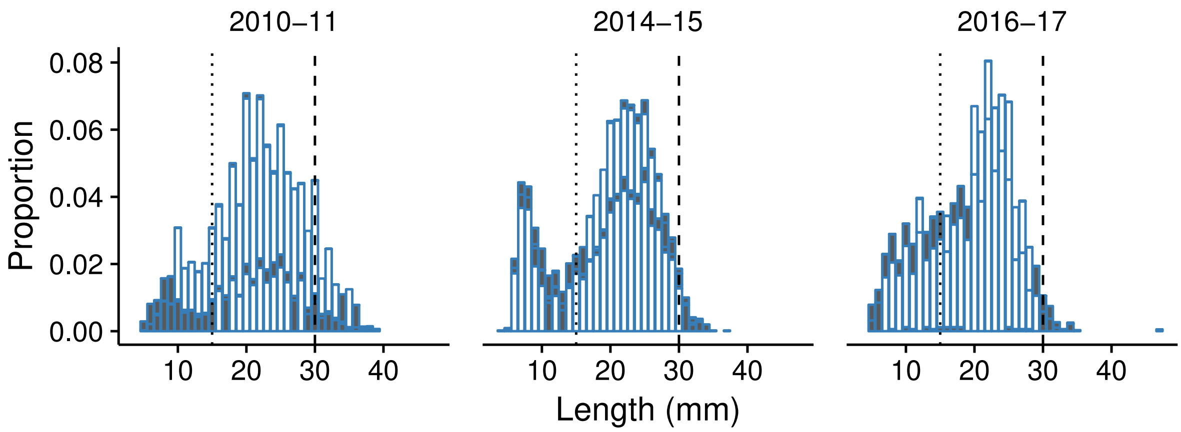


Figure 20: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mangawhai Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5.2 Pipi at Mangawhai Harbour

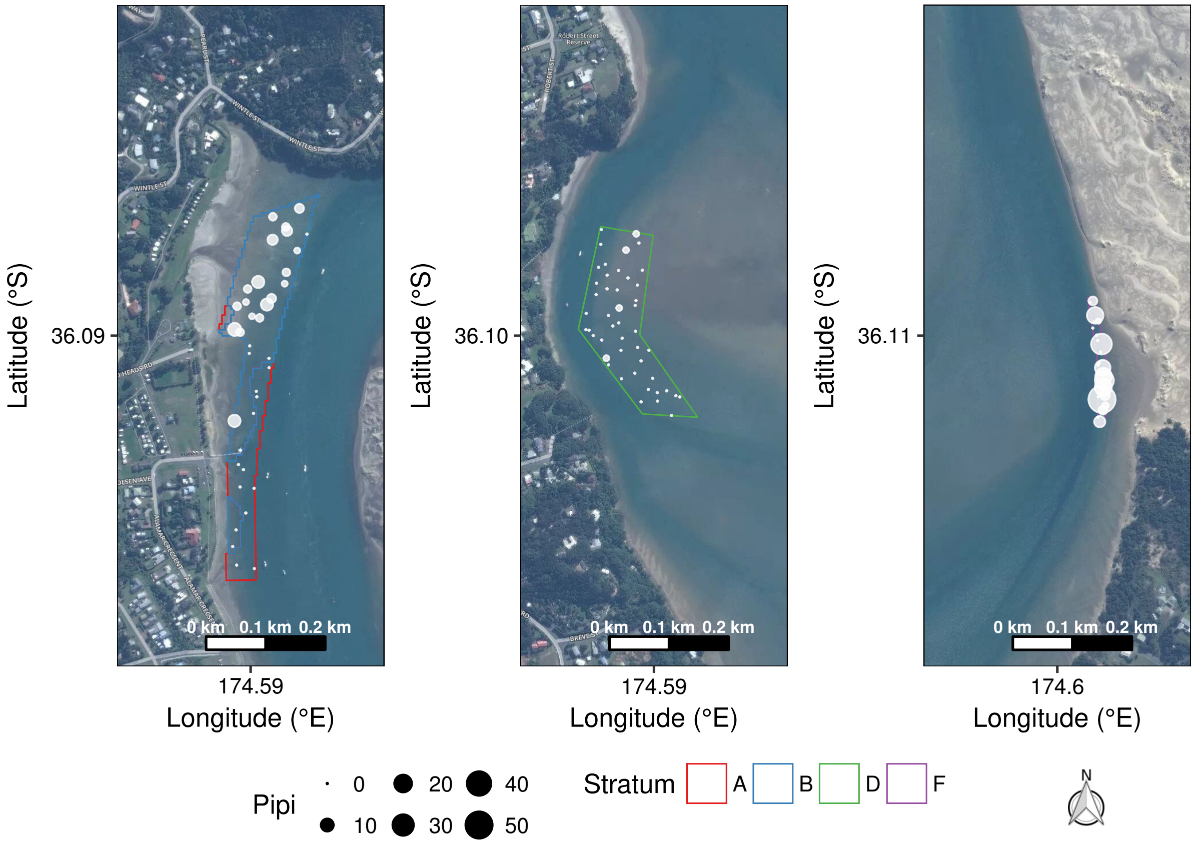


Figure 21: Map of sample strata and individual sample locations for pipi at Mangawhai Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 22: Estimates of pipi abundance at Mangawhai Harbour, by stratum, for 2016–17. 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	10	0	0.00	0	
B	3.0	27	57	1.79	60	19.48
D	3.0	46	4	0.07	2	48.30
F	0.3	24	191	0.65	227	31.78

Table 23: Estimates of pipi abundance at Mangawhai 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	9.4	4.78	51	15.88	1.54	16	15.23
2000–01	8.4	1.96	23	9.81	1.26	17	9.35
2001–02	8.4	0.78	9	9.56	0.51	7	9.55
2002–03	8.4	1.44	17	11.63	0.37	6	9.27
2003–04	8.4	1.18	14	11.00	0.44	7	9.65
2010–11	9.0	4.21	47	19.57	0.08	<1	33.76
2014–15	8.6	6.00	70	21.28	0.03	<1	72.74
2016–17	7.4	2.51	34	16.18	0.01	<1	>100

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	26.26	12	6–57	36.48	1.82
2014–15	25.27	11	8–53	37.53	0.47
2016–17	15.61	11	7–54	85.55	0.41

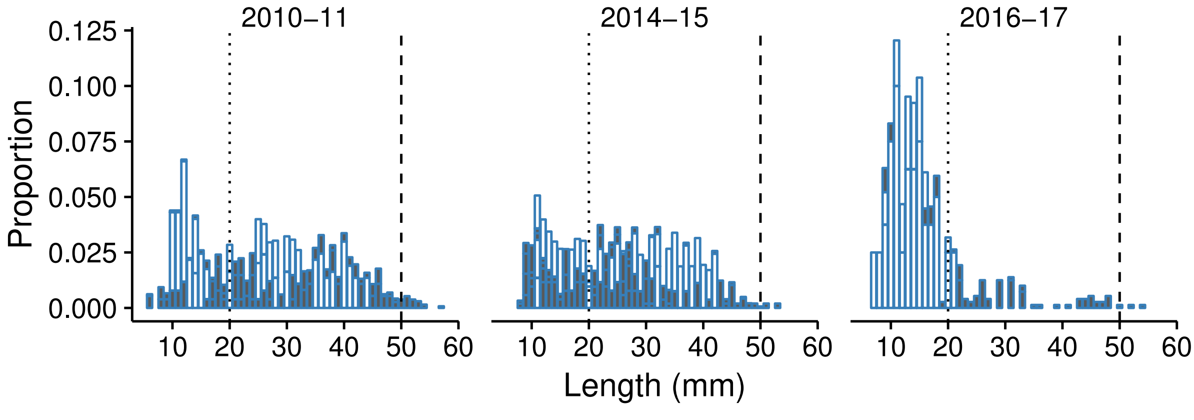


Figure 22: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Mangawhai Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Ngunguru Estuary

Ngunguru Estuary is a relatively small estuary in Northland, north of Whangarei. The estuary was included in four previous surveys, with the most recent preceding survey in 2014–15 (see Appendix A, Tables A-1, A-2). The current field survey included a similar sampling extent as the 2014–15 survey, with the exception of the pipi stratum in the middle of the main channel (stratum D) (Figure 23). This stratum was shifted further downstream, in part due to the deepening of the channel at the previous location of this pipi bed, which made different parts of the pipi population accessible. Strata dominated by cockles were re-stratified using information from the preceding survey, resulting in four strata. Across these strata, cockles and pipi were targeted in a total of 118 sampling points (Table 25).

Sediment at Ngunguru Estuary was low in organic content (less than 3%), and in the proportion of sediment fines (grain size <63 µm) (Figure 23, and see details in Appendix B, Table B-3). The latter made up less than 5% of the sediment across samples, with one exception of 26% of sediment fines. Overall, the dominant grain size fraction was consistently fine sand (grain size >125 µm), followed by a considerably smaller proportion of very fine sand (>63 µm). There was a small amount of gravel (>2000 µm) in some of the samples.

Cockles were present in most areas, but were scarce in the pipi bed in stratum D (Figure 24, Table 25). Their highest abundance and density were mid-estuary, on the intertidal mudflat. Across the entire sampling extent, the total population size was estimated at 91.81 million (CV: 7.19%) cockles, and their estimated mean density was 1461 individuals per m^2 (Table 26). Similar to previous assessments, there were few large cockles (≥30 mm shell length) in the population, and their estimated abundance was 0.22 million (CV: 48.15%) cockles in 2016–17. The corresponding density estimate was 4 large cockles per m^2, reduced from 8 large cockles per m^2 in 2014–15.

Throughout the survey series, the number of large individuals was small, and this size class played a minor role in the population overall; in 2016–17, the proportion of large cockles was 0.24% (Table 27, Figure 25). In comparison, recruits (≤15 mm shell length) made up 27.30% of the population. These findings confirmed previous observations that the cockle population largely consists of medium-sized cockles (modal shell length of 20 mm) that determine the single, strong cohort in the unimodal population.

The pipi population at Ngunguru Estuary was predominantly in stratum D, with few individuals in other areas (Figure 26, Table 28). Pipi abundance and density were high in this stratum, and the entire population size was determined by this pipi bed. The total estimate for the pipi population was 28.43 million (CV: 6.03%) pipi in the current study, reflecting a considerably increase from previous surveys (Table 29). This increase was also evident in the population density, which was estimated at 453 pipi per m^2, compared with 14 individuals per m^2 in 2014–15. The observed increases were accompanied by the increase in sampling extent and the different part of the pipi bed that was sampled.

Although there were no large pipi (≥50 mm shell length) in the previous survey in 2014–15, they were present in small numbers in 2016–17. There were an estimated 0.23 million (CV: 31.61%) pipi in this size class, at a density of 4 individuals per m^2.

The large pipi size class made up a small proportion (0.79%) of the total population. At the same time, recruits (≤20 mm shell length) only constituted 7.72% of the pipi population, and the modal shell length of 42 mm highlighted the prevalence of medium-sized pipi at this site (Table 30, Figure 27). The increasing importance of medium-sized pipi was highlighted in the length-frequency distributions over time. In 2010–11, the population was bimodal, consisting of a cohort each of large and medium-sized pipi, whereas is was largely unimodal, dominated by medium-sized pipi in 2016–17.

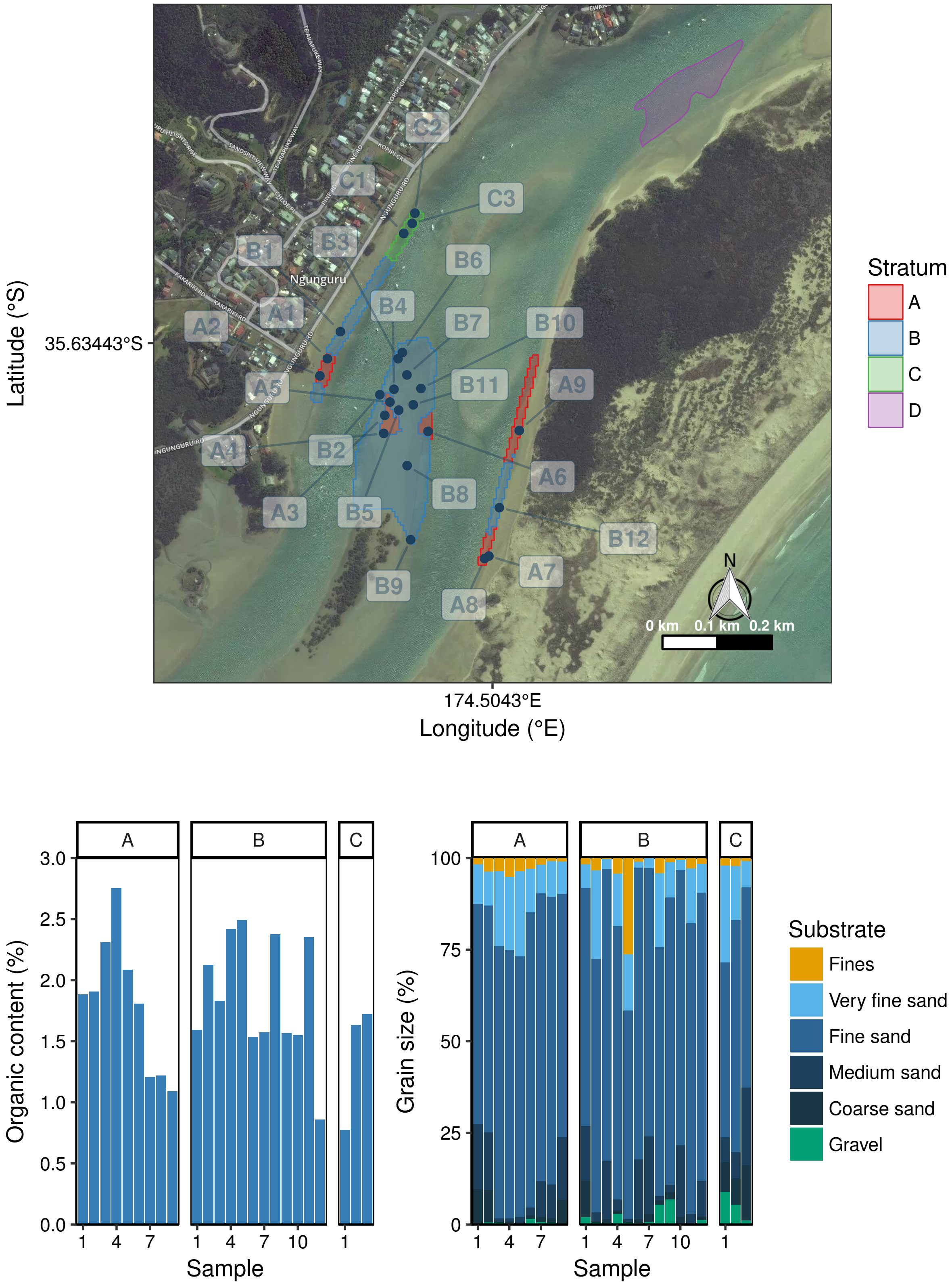


Figure 23: Sediment sample locations and characteristics at Ngunguru Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.6.1 Cockles at Ngunguru Estuary

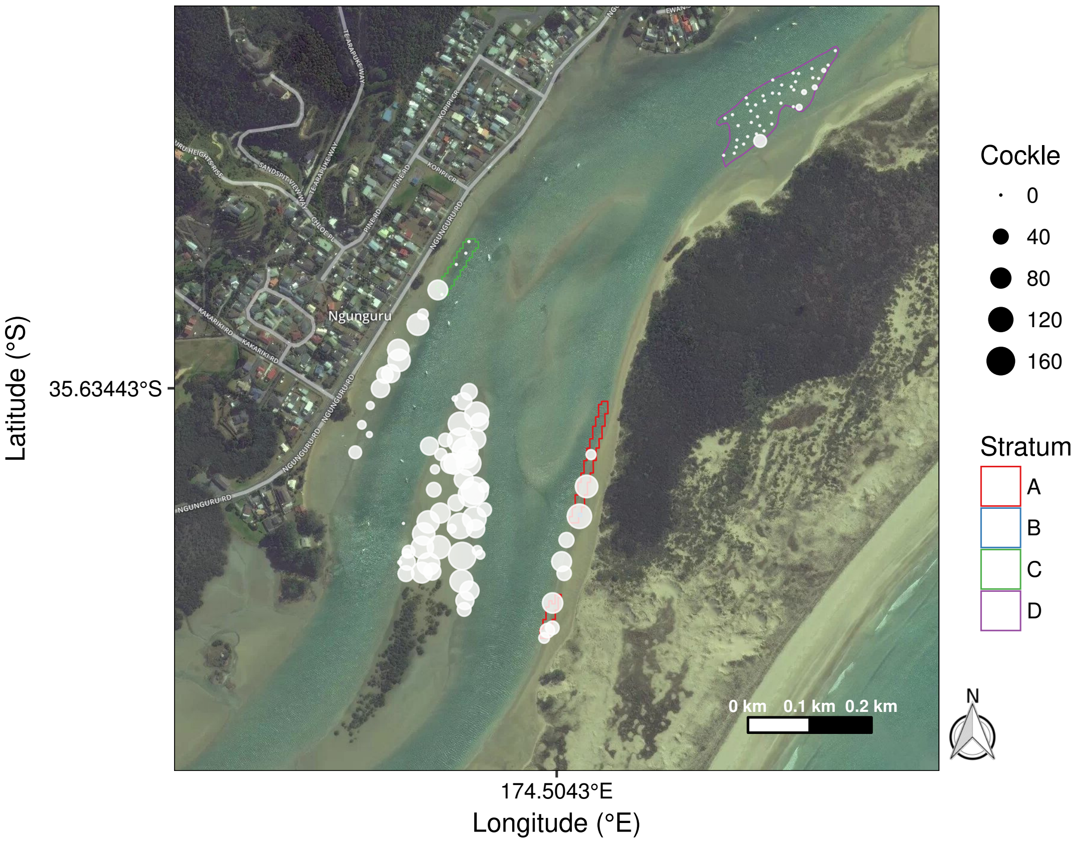


Figure 24: Map of sample strata and individual sample locations for cockles at Ngunguru Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 25: Estimates of cockle abundance at Ngunguru Estuary, by stratum, for 2016–17. 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	0.8	12	334	6.13	795	28.29
B	4.1	60	4 415	85.37	2 102	7.45
C	0.2	3	0	0.00	0	
D	1.2	43	38	0.32	25	76.82

Table 26: Estimates of cockle abundance at Ngunguru Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2003–04	1.7	8.63	508	6.71	0.64	38	11.70
2004–05	1.8	9.79	544	7.77	0.34	25	18.85
2010–11	1.8	19.55	1 086	10.72	0.07	5	35.49
2014–15	5.5	92.67	1 696	7.53	0.38	8	32.11
2016–17	6.3	91.81	1 461	7.19	0.22	4	48.15

Table 27: Summary statistics of the length-frequency (LF) distribution of cockles at Ngunguru Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	17.46	20	5–32	33.21	0.38
2014–15	19.07	20	4–34	18.71	0.41
2016–17	17.88	20	4–34	27.30	0.24

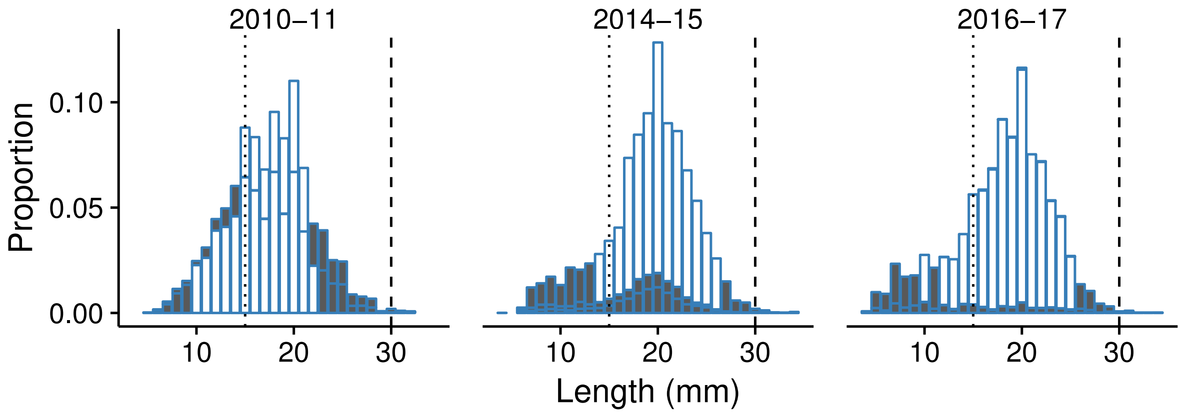


Figure 25: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ngunguru Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6.2 Pipi at Ngunguru Estuary

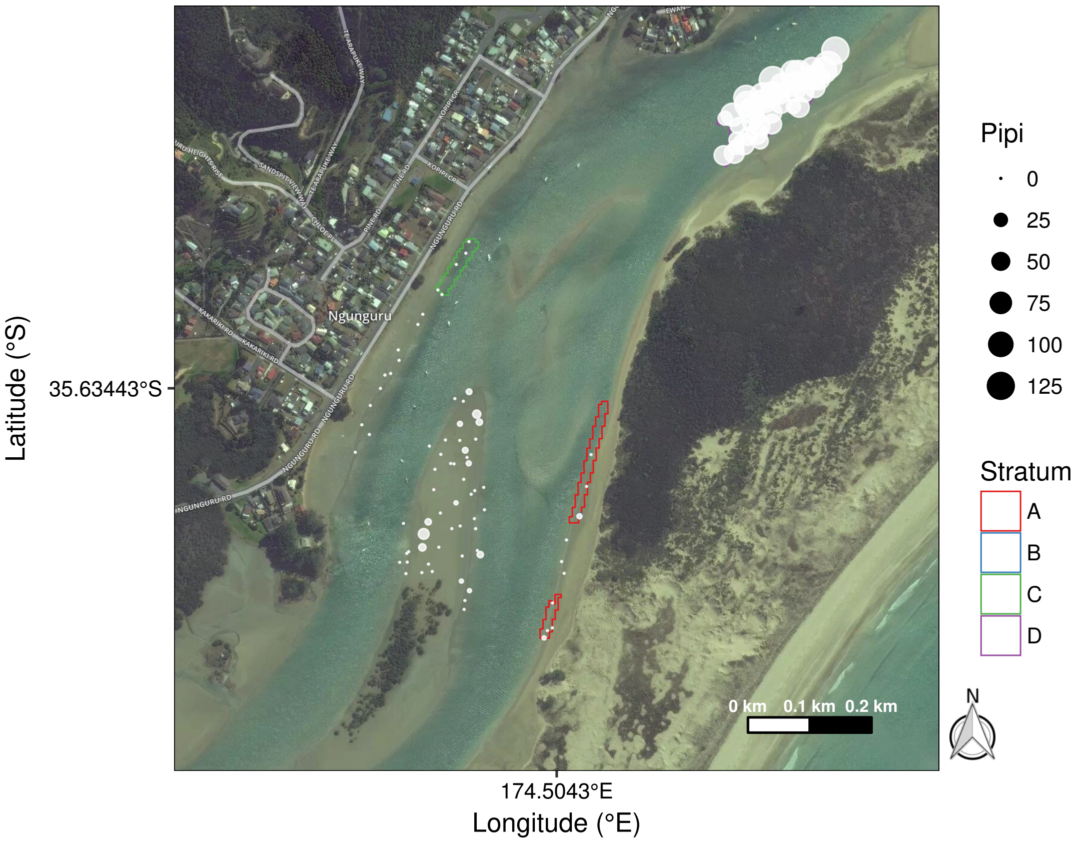


Figure 26: Map of sample strata and individual sample locations for pipi at Ngunguru Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 28: Estimates of pipi abundance at Ngunguru Estuary, by stratum, for 2016–17. 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	0.8	12	1	0.02	2	>100
B	4.1	60	57	1.10	27	34.62
C	0.2	3	0	0.00	0	
D	1.2	43	3 291	27.31	2 187	6.11

Table 29: Estimates of pipi abundance at Ngunguru Estuary for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2003–04	1.7	1.87	110	8.73	0.87	51	9.04
2004–05	1.8	2.23	124	5.37	0.95	53	7.83
2010–11	1.8	0.73	40	16.60	0.25	14	19.25
2014–15	5.5	0.74	14	34.26	0.00	0	
2016–17	6.3	28.43	453	6.03	0.23	4	31.61

Table 30: Summary statistics of the length-frequency (LF) distribution of pipi at Ngunguru Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	42.10	50	7–67	7.65	38.86
2014–15	34.31	40	8–49	14.84	0.00
2016–17	38.61	42	4–56	7.72	0.79

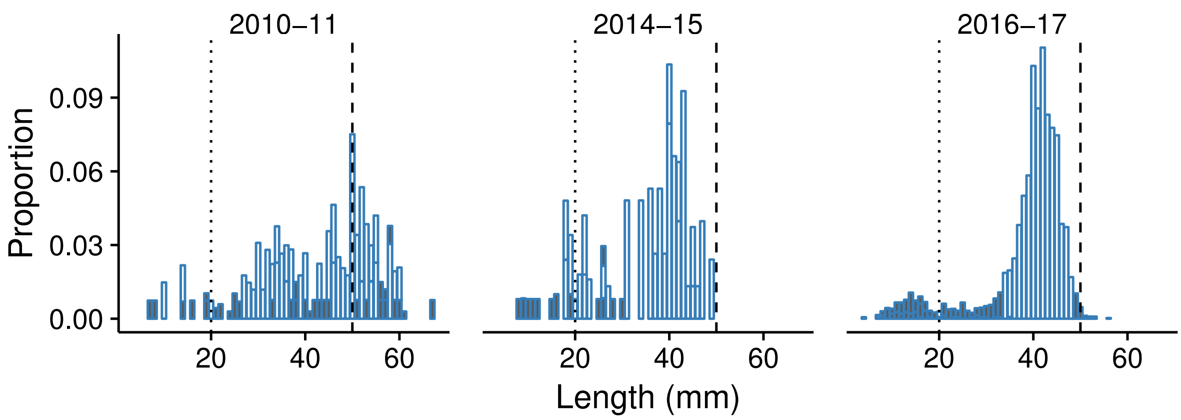


Figure 27: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ngunguru Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7 Otumoetai (Tauranga Harbour)

Otumoetai is one of the Bay of Plenty sites, and situated in Tauranga Harbour, opposite the main harbour entrance. Bivalves at this site have been assessed in six previous surveys (see Appendix A, Tables A-1, A-2). The most recent survey preceding the present study was in 2014–15. The current assessment focused on the same sampling extent as previous surveys, with small amendments to the pipi bed. The field survey included a total of 86 sampling points for cockles and pipi.

The sediment in the cockle strata at Otumoetai was consistently low in organic content, with a maximum of 2.0% across all samples (Figure 28, and see details in Appendix B, Table B-3). The grain size composition was also similar across samples, with a low proportion of fines (grain size <63 µm; maximum of 4.2%). The bulk of the sediment consisted of fine sand (>125 µm), and this grain size fraction made up a maximum of 82.4% of sediment. In comparison, medium sand (>250 µm) constituted between 11% and 23.4% of the sediment across all samples. Some of the samples also contained a small proportion of gravel (>2000 µm).

Cockles were relatively abundant in both areas of the sampling extent, with high numbers and densities in strata A and C (Figure 29, Table 31). Their total abundance was estimated at 40.11 million (CV: 14.56%) cockles, with an estimated mean density of 496 individuals per m^2 (Table 32). These estimates revealed a stable population, with little change in its size and density since 2014–15. Although there was only a small number of large cockles ($\geq$30 mm shell length), both their population size and density of 0.34 million (CV: >100%) cockles at a density of 4 large cockles per m^2 signified increases from previous surveys, but the uncertainty (CV) surrounding these estimates was large.

While large cockles were only a minor proportion (0.85%), recruits ($\leq$15 mm shell length) constituted about half of the current population 52.88% (Table 33, Figure 30). This finding was consistent across surveys. Similarly, the modal size of 15 mm shell length remained close to previous modal lengths, indicating little change in the size-frequency distribution of the cockle population at Otumoetai over time. The population was consistently unimodal, with a strong cohort around this modal size.

The pipi population at Otumoetai was highly abundant throughout stratum C, with only three pipi in the other strata (Figure 31, Table 34). The current population estimates for this bivalve species were 71.90 million (CV: 11.16%) individuals, which were present at an estimated mean density of 889 pipi per m^2 (Table 35). Although the adjustment to the pipi stratum resulted in a slightly larger sampling extent in the current study, these estimates were lower than values in 2014–15 (i.e., 92.59 million (CV: 5.59%) pipi and 1207 pipi per m^2). Nevertheless, both the current and the preceding survey documented the largest pipi population in the survey series.

Decreases in abundance and density estimates were also evident in the reduction of the population of large pipi ($\geq$50 mm shell length). This size class underwent a continued decline since 2000–01, and the current estimates were the lowest values in the survey series; there were 0.13 million (CV: 56.94%) large pipi, and their density was 2 large individuals per m^2.

The general absence of large pipi (0.18% of the total population) was in contrast to the proportion of recruits ($\leq$20 mm shell length), which made up 17.23% of the pipi population (Table 36). Instead, medium-sized individuals determined the population structure, with a modal size of 34-mm shell length. Length-frequency distributions confirmed the predominance of medium-sized pipi across surveys, although their strong cohort was accompanied by a smaller cohort of recruits in the current population (Figure 32).

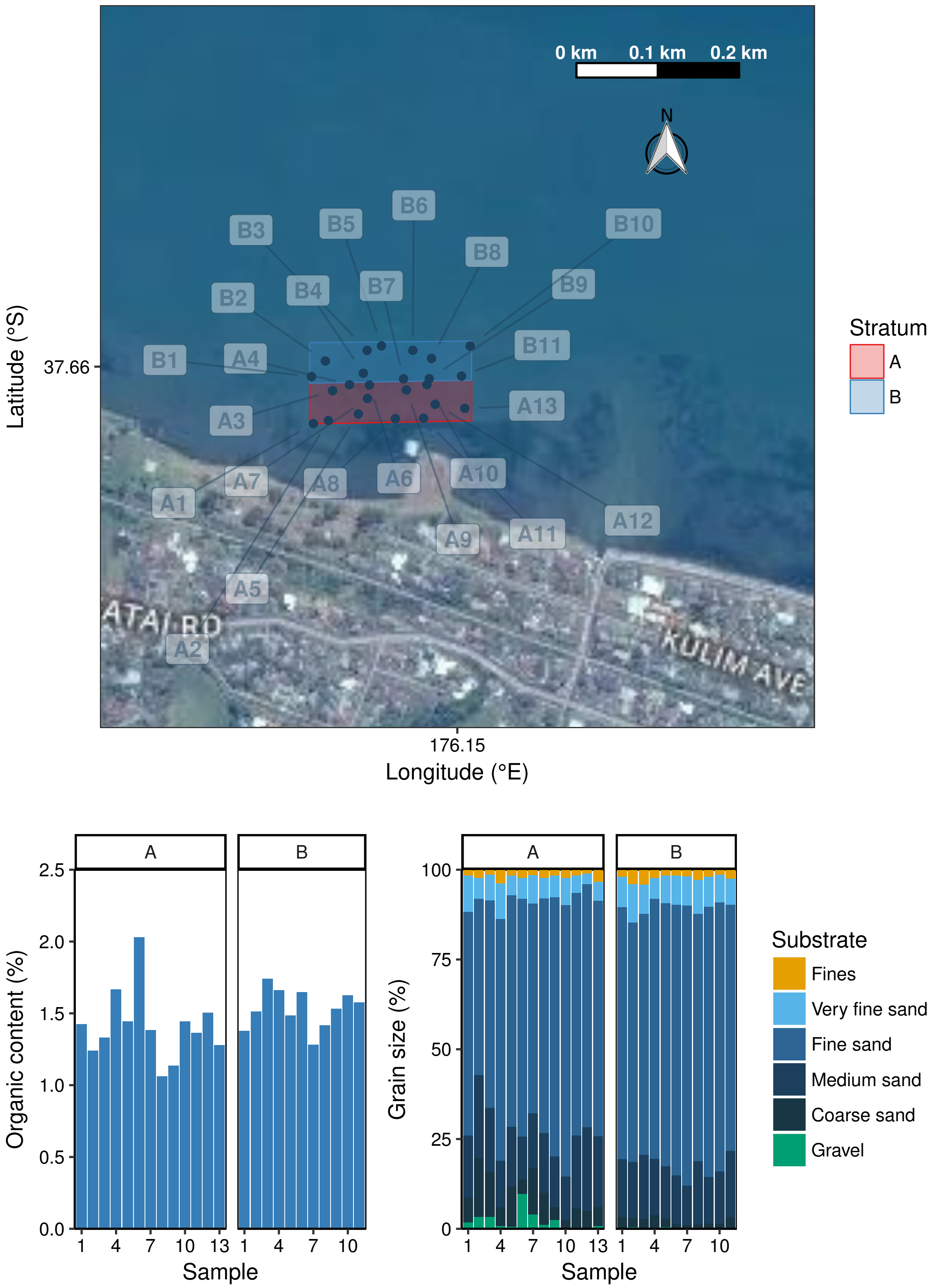


Figure 28: Sediment sample locations and characteristics at Otumoetai (Tauranga Harbour). Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.7.1 Cockles at Otumoetai (Tauranga Harbour)

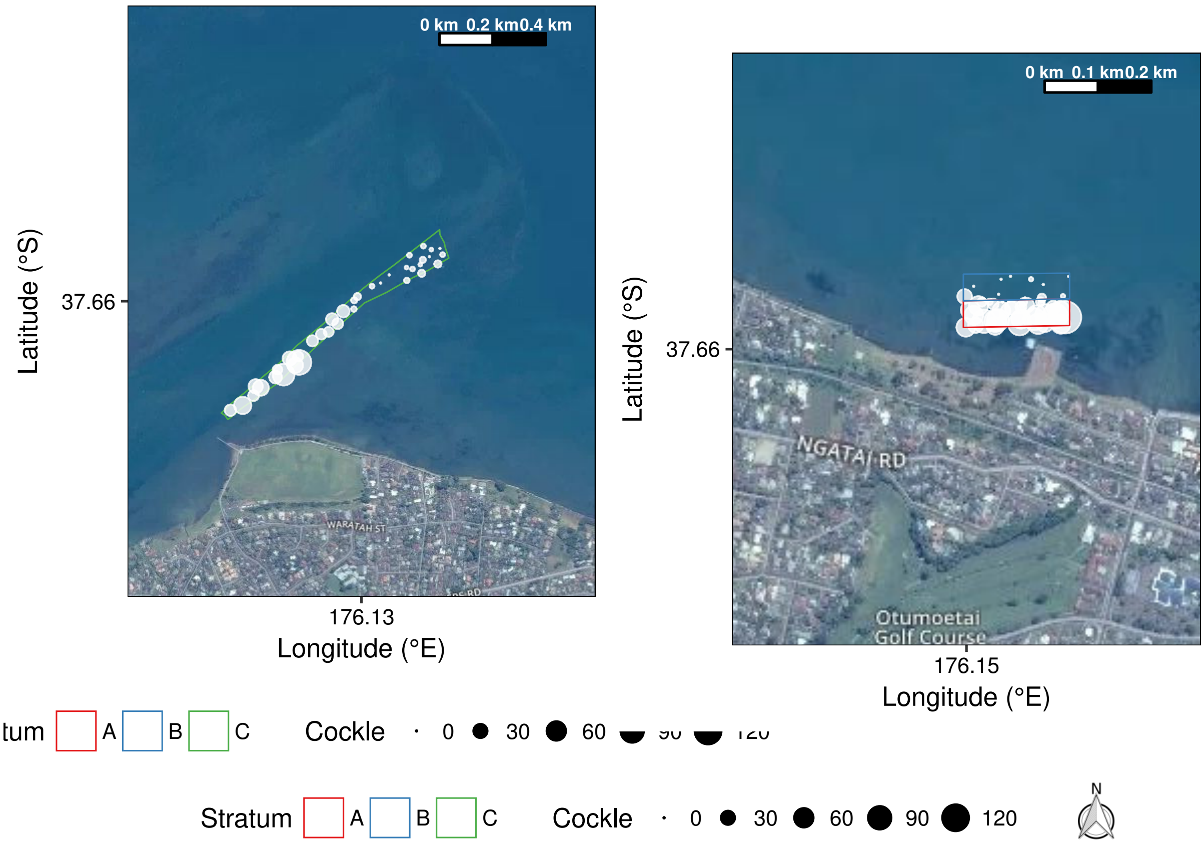


Figure 29: Map of sample strata and individual sample locations for cockles at Otumoetai (Tauranga Harbour), with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of cockle abundance at Otumoetai, by stratum, for 2016–17. 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	34	1 201	10.09	1 009	12.76
B	1.0	11	30	0.76	78	73.35
C	6.1	41	687	29.25	479	19.38

Table 32: Estimates of cockle abundance at Otumoetai (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

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	16.28	15	4–39	45.13	1.62
2014–15	15.73	17	5–32	47.56	0.05
2016–17	15.49	15	5–39	52.88	0.85

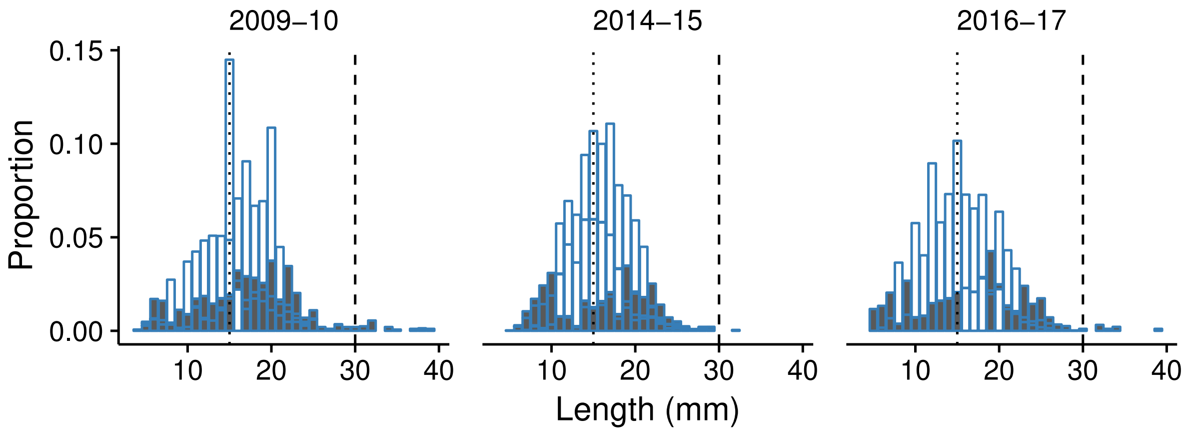


Figure 30: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Otumoetai (Tauranga Harbour). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7.2 Pipi at Otumoetai (Tauranga Harbour)

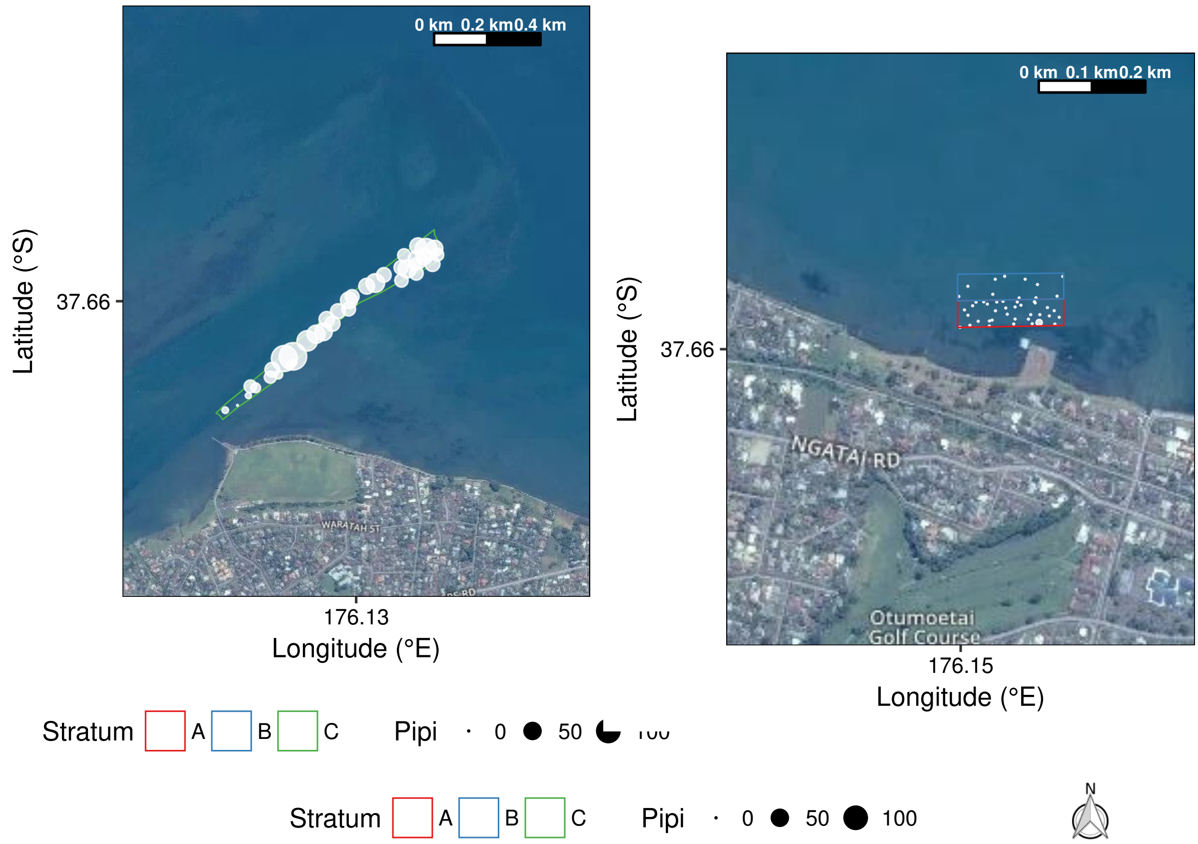


Figure 31: Map of sample strata and individual sample locations for pipi at Otumoetai (Tauranga Harbour), with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of pipi abundance at Otumoetai, by stratum, for 2016–17. 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	34	3	0.03	3	>100
B	1.0	11	0	0.00	0	
C	6.1	41	1 688	71.88	1 176	11.16

Table 35: Estimates of pipi abundance at Otumoetai (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	255	3.56
2002–03	5.6	20.37	364	3.63	2.06	57	7.56
2005–06	4.6	34.26	745	2.76	1.62	45	7.11
2006–07	4.6	23.63	514	6.61	1.02	28	17.46
2009–10	5.6	17.35	310	7.23	0.63	18	27.44
2014–15	7.7	92.59	1 207	5.59	0.47	7	29.21
2016–17	8.1	71.90	889	11.16	0.13	2	56.94

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	39.75	45	12–75	0.49	7.35
2014–15	26.62	24	9–55	15.80	0.50
2016–17	29.91	34	3–50	17.23	0.18

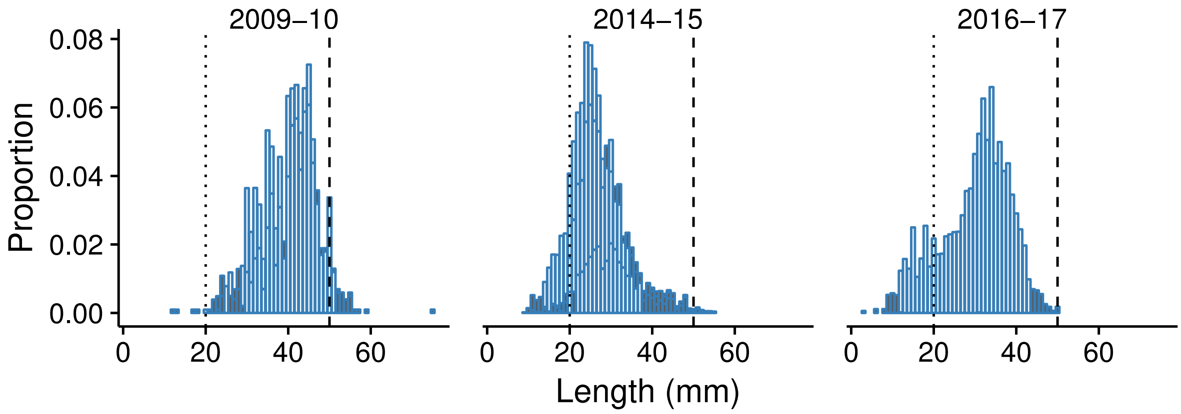


Figure 32: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Otumoetai (Tauranga Harbour). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Ruakaka Estuary

Ruakaka Estuary is a relatively small estuary, south of Whangarei in Northland. Bivalves at this site have been assessed in three previous surveys, with the immediately preceding survey in 2014–15 (see Appendix A, Tables A-1, A-2). The sampling extent in this estuary is largely influenced by the main tidal channel, which has changed course between surveys, particularly in the area close to the estuary entrance (Figure 33). The movement of the channel has affected resident pipi populations, requiring adjustment to the location and size of the sampling extent in individual surveys at this site. In 2016–17, changes in the course of the channel were restricted to an area close to the estuary entrance, and also included two side channels reaching into the northern part of the estuary. The sampling extent remained relatively unaffected, and only included small changes that resulted in a smaller area. The current field sampling included a total of four strata, which were surveyed in 84 sampling points.

The sediment samples at Ruakaka Estuary were similar in organic content and sediment grain composition (Figure 33, and see details in Appendix B, Table B-3). Sediment organic content was low at a maximum of 1.7%, and there was only a small proportion of sediment fines (grain size <63 µm), with a maximum of 3.7%. The sediment consisted primarily of fine and medium sands (grain sizes >125 µm and >250 µm), and few samples contained coarser grain size fractions, such as coarse sand and gravel.

The cockle population was distributed along both sides of the main channel, with high densities in the northern part and separate stratum B (Figure 34, Table 37). Their estimated total population abundance and density were 13.08 million (CV: 18.38%) cockles, and 233 cockles per m^2 (Table 38). Both the current population parameters were markedly lower than in 2014–15. In addition, large cockles ($\geq$30 mm shell length) were lacking in 2016–17, even though this size class was present, albeit in small numbers, in previous assessments.

In contrast to the decline in large cockles, the proportion of recruits ($\leq$15 mm shell length) was consistent to previous surveys, with 52.17% of the total population in this size class (Table 39, Figure 35). Accordingly, mean and modal sizes were small, determining the unimodal population size structure with a strong cohort around the 20 mm modal shell length.

Pipi at Ruakaka Estuary were relatively restricted in their distribution, with the main pipi population residing in the estuary channel, stratum AC (Figure 36, Table 40). Similar to the cockle population, the current population estimates for this species were lower than preceding values, and their total population abundance was 56.53 million (CV: 30.91%) pipi in 2016–17 (Table 41). This species was present at an estimated mean density of 1008 individuals per m^2. Despite the reduction in overall population size, there was an increase in large pipi ($\geq$50 mm shell length), most notably in their density. At an estimated abundance of 1.12 million (CV: 46.67%) large pipi, their density increased to 20 large individuals per m^2, compared with 1 pipi per m^2 in 2014–15.

Nevertheless, large pipi had little influence on the population size structure, containing only 1.97% of the total population (Table 42, Figure 37). Instead, recruits ($\leq$20 mm shell length) and medium-sized individuals determined the pipi population, and 37.25% of all individuals were in the former size class. The increase in recruits led to a reduction in modal size across recent surveys, to 13-mm shell length in 2016–17. Considering the size structure of the pipi population in the three most recent surveys, the increase in recruits resulted in a shift from a unimodal to a bimodal population, with a cohort each of recruits and medium-sized pipi.

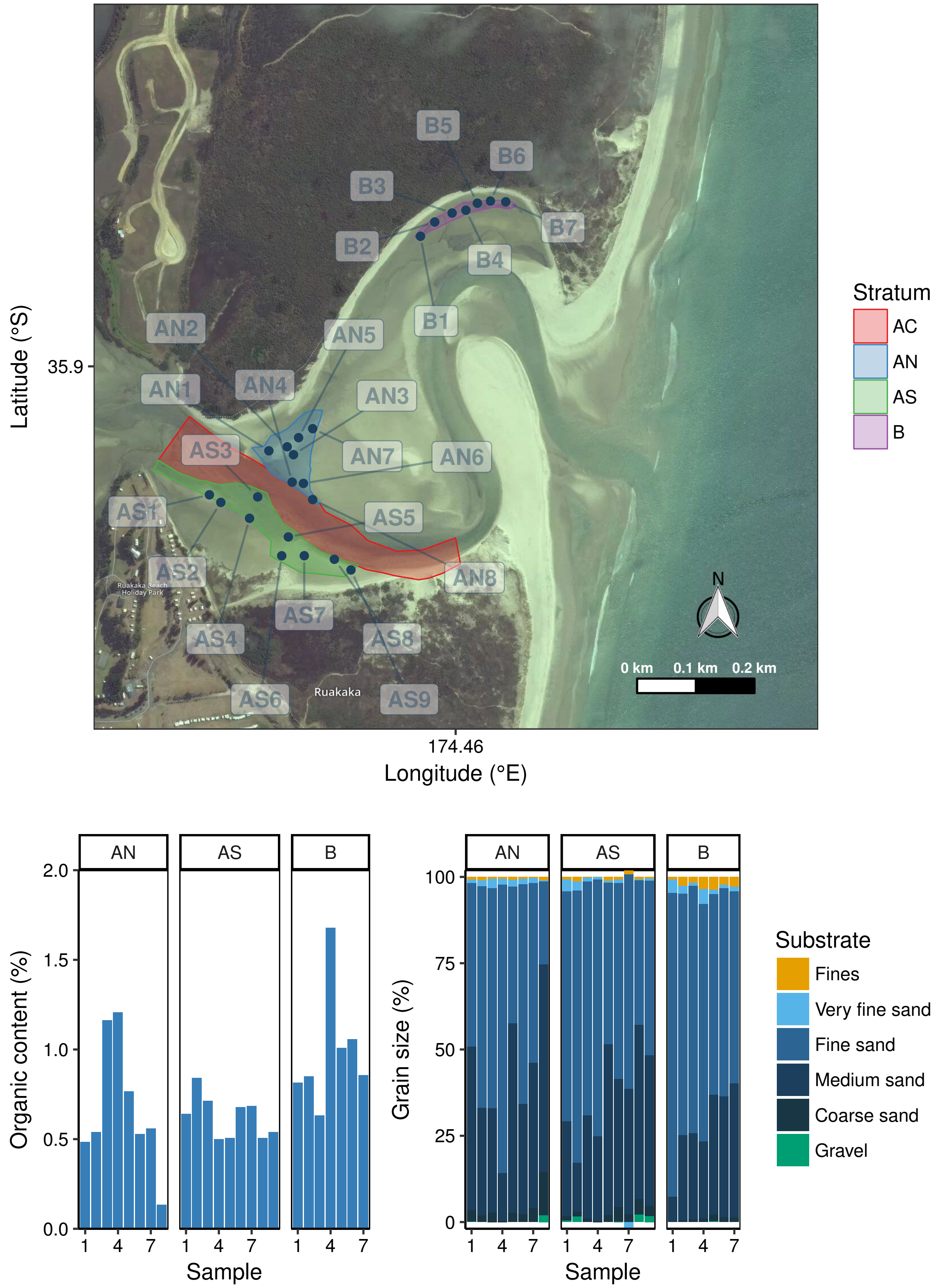


Figure 33: Sediment sample locations and characteristics at Ruakaka Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.8.1 Cockles at Ruakaka Estuary

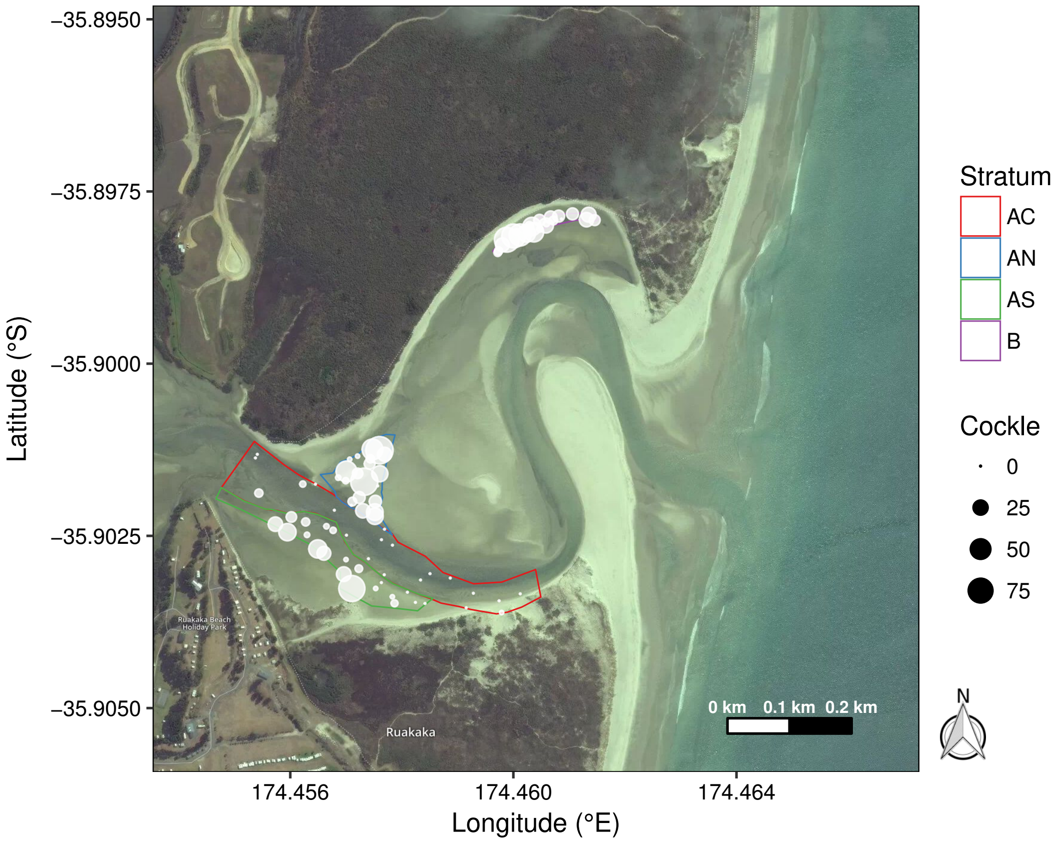


Figure 34: Map of sample strata and individual sample locations for cockles at Ruakaka Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 37: Estimates of cockle abundance at Ruakaka Estuary, by stratum, for 2016–17. 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 (%)
AC	3.1	19	10	0.46	15	65.57
AN	0.9	22	503	5.61	653	25.85
AS	1.4	20	265	5.27	379	35.31
B	0.3	23	531	1.73	660	19.75

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2006–07	7.0	1.22	17	16.07	0.23	3	55.99
2010–11	11.0	3.27	30	20.30	0.04	<1	>100
2014–15	6.5	43.97	675	8.77	0.15	2	35.4
2016–17	5.6	13.08	233	18.38	0.00	0	

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	16.18	20	2–35	45.95	1.22
2014–15	15.87	14	5–40	53.82	0.35
2016–17	15.34	20	4–29	52.17	0.00

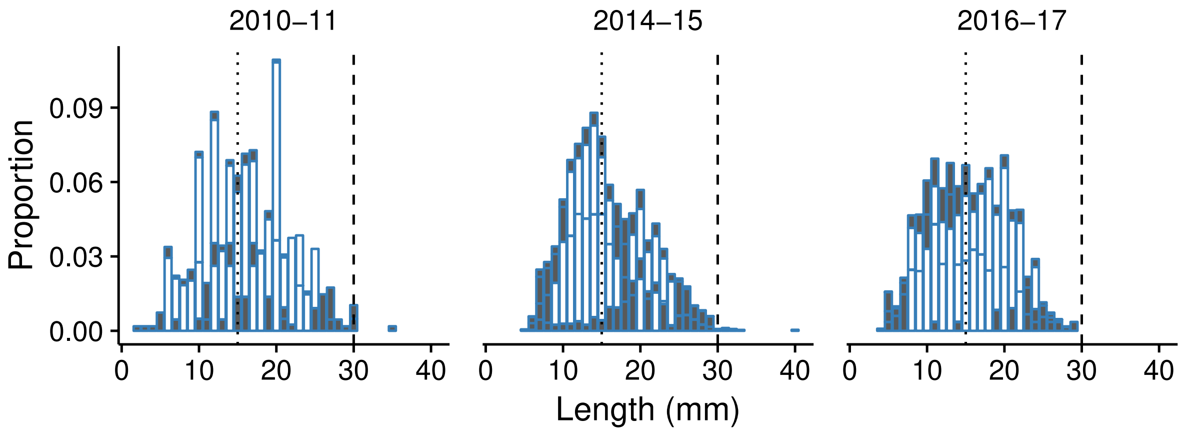


Figure 35: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ruakaka Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8.2 Pipi at Ruakaka Estuary

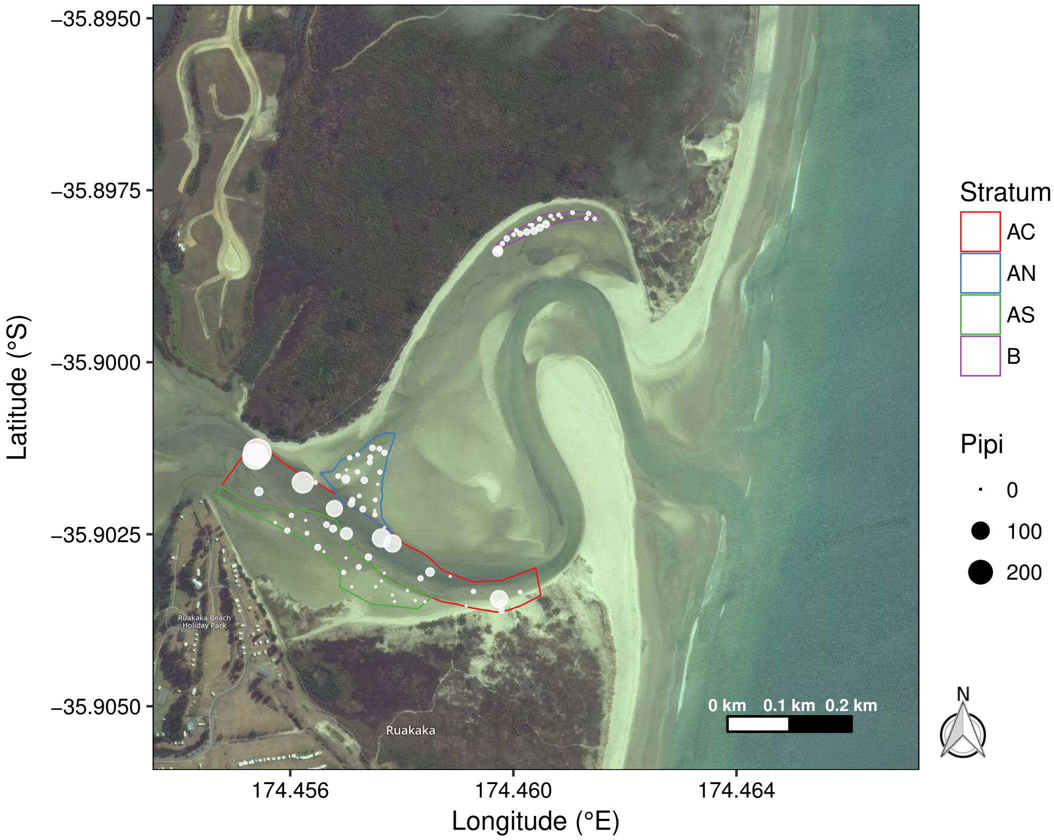


Figure 36: Map of sample strata and individual sample locations for pipi at Ruakaka Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 40: Estimates of pipi abundance at Ruakaka Estuary, by stratum, for 2016–17. 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 (%)
AC	3.1	19	1 177	54.73	1 770	31.92
AN	0.9	22	73	0.81	95	21.39
AS	1.4	20	33	0.66	47	36.86
B	0.3	23	101	0.33	125	30.02

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2006–07	7.0	33.87	484	13.03	1.47	45	21.28
2010–11	11.0	25.93	235	19.84	0.05	<1	100.00
2014–15	6.5	81.23	1 247	16.51	0.08	1	83.35
2016–17	5.6	56.53	1 008	30.91	1.12	20	46.67

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	27.30	30	7–55	22.59	0.20
2014–15	26.52	25	8–51	24.91	0.09
2016–17	27.29	13	5–55	37.25	1.97

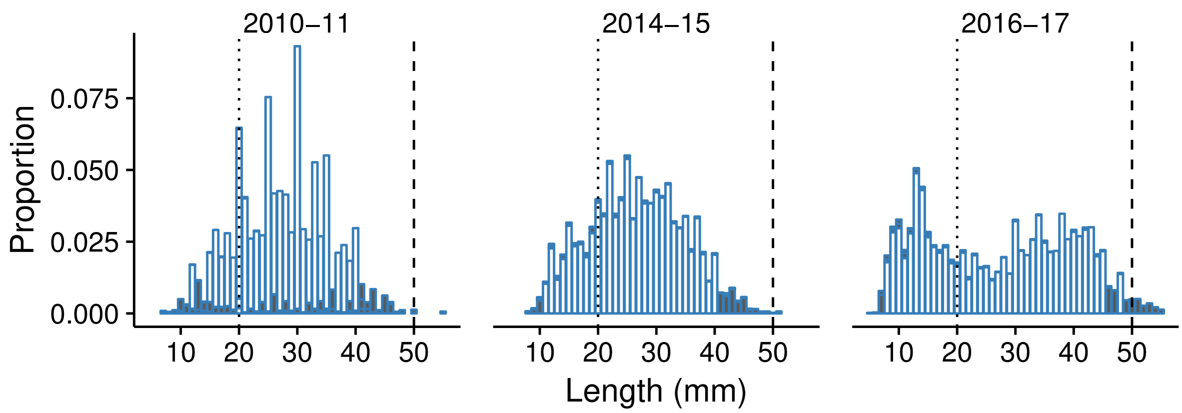


Figure 37: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ruakaka Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9 Te Haumi Beach

Te Haumi Beach is on the east coast of Northland, south of Paihia. This site has been regularly included in the survey series, with a total of nine previous assessments since 1999–2000; the most recent previous survey was in 2014–15 (see Appendix A, Tables A-1, A-2). The current sampling focused on the same two areas as previous studies, an estuarine area west of State Highway 11, and the sand flat on the main beach in the east (Figure 38). Following re-stratification using information from 2014–15, the survey included four strata across both areas, assessing bivalves in a total of 84 sampling points (Table 43).

At Te Haumi Beach, the sediment contained a low organic content, which was less than 3% across all samples (Figure 38, and see details in Appendix B, Table B-3). There was also only a minor proportion of fines (grain size <63 µm; maximum of 0.1%), and most of the sediment consisted of sands. The predominant grain size fractions was fine sand (grain size >125 µm), with samples containing up to 82% of this grain size. There was also a varying proportion of gravel (>2000 µm grain size) in the sediment, ranging between 0.5 and 27.5%.

Cockles were predominantly in the eastern area, on the intertidal sandflat, with highest concentrations in the southern part, in stratum A (Figure 39, Table 43). There were few cockles in the low-intertidal area of the beach or in the western, estuarine area. Based on data from the field survey, the cockle population estimates were 69.91 million (CV: 12.39%) cockles at Te Haumi Beach, and their corresponding mean density was 548 individuals per m^2 (Table 44). These estimates documented an almost doubling of the total cockle population since 2014–15, and the highest population estimates in the survey series. At the same time, estimates of large cockles (≥30 mm shell length) revealed slight decreases, with 2.96 million (CV: 24.82%) individuals at a density of 23 large cockles per m^2 in 2016–17. Although this part of the cockle population has shown some variation over time, estimates have been consistently low since a considerable decline in large cockles in 1999–2000 and 2000–01.

Corresponding with their low abundance, the proportion of large cockles within the population was small (4.24%) in 2016–17, whereas recruits (≤15 mm shell length) dominated the population (Table 45, Figure 40). The latter size class constituted half (49.33%) of the current population, reflecting a notable increase in small cockles since the preceding survey. This influx of recruits was evident in the recent decrease in modal size to 10 mm shell length.

Across the three most recent surveys, the influence of small cockles on the population size structure became increasingly significant, resulting in a progressive change from a unimodal to a bimodal population. Although cockles at medium sizes were a main part of the population, recruits made up the strongest cohort in the present study.

The pipi population at Te Haumi Beach was generally concentrated in the northern and low-intertidal areas of the sandflat, with relatively high densities in the western estuarine area also (Figure 41, Table 46). Similar to the cockle population, this species showed a notable increase in population size and abundance from the previous survey, with an estimated 101.49 million (CV: 24.80%) pipi and a mean density of 795 pipi per m^2 (Table 47).

At the same time, the population included only a small number of large pipi (≥50 mm shell length), and estimates for this size class decreased to 0.55 million (CV: 37.83%) pipi, with a concomitant decrease in their density to 4 individuals per m^2. The observed decline in the number of large pipi may be owing to mortality events that were noted before the 2014–15 survey, which affected large numbers of pipi in both areas of the sampling extent in two separate incidents in 2014.

The small proportion (0.54%) of large pipi was in contrast to the prevalence of recruits (≤20 mm shell length), which made up half (52.71%) of the current pipi population at this site (Table 48, Figure 42). Recruits have consistently been an important size class, evident in the mean and modal sizes across surveys; the modal size in 2016–17 was 18 mm shell length. This modal length reflected the strongest cohort in the bimodal population in recent surveys, with a considerably smaller, second cohort of medium-sized pipi.

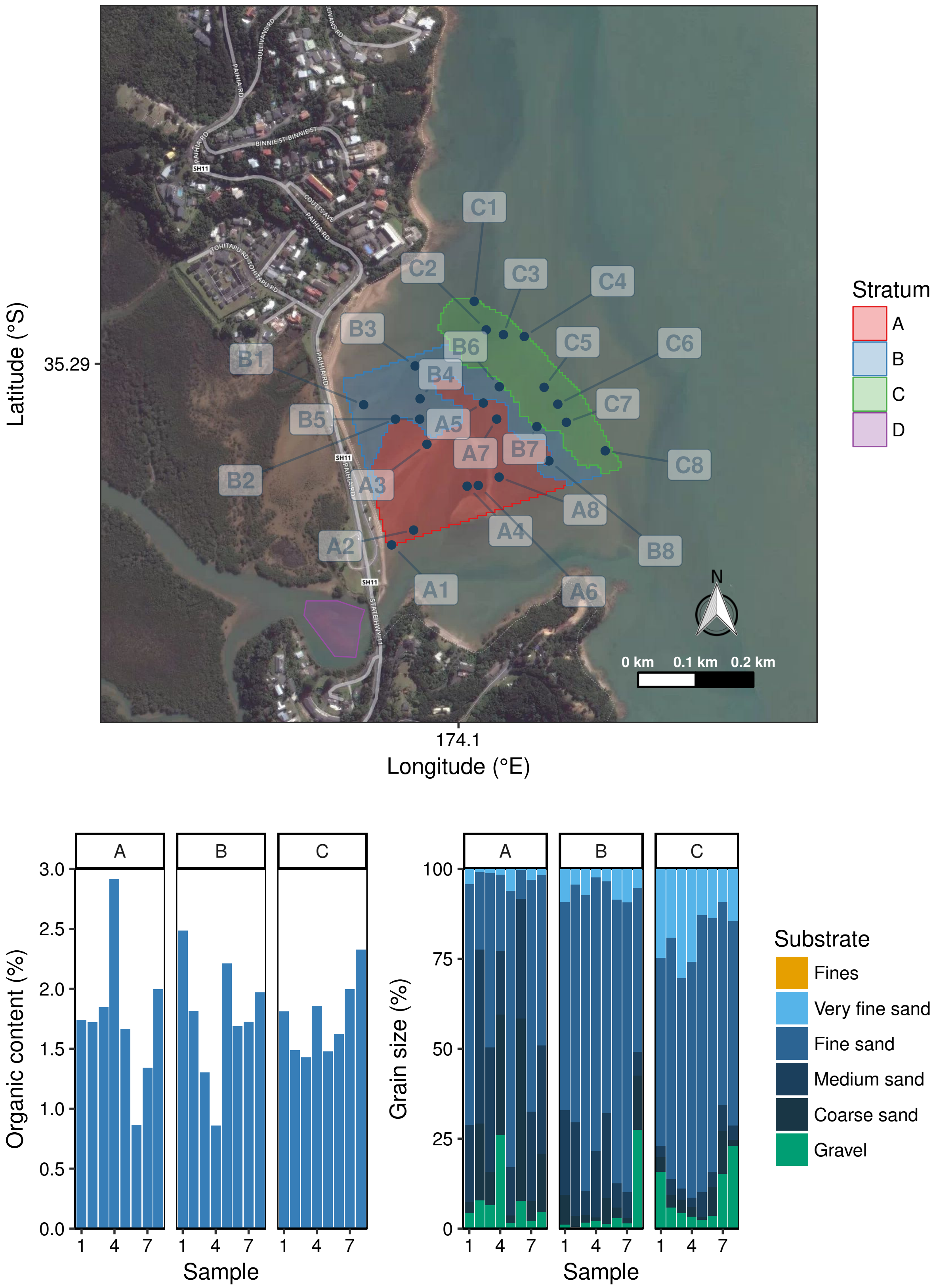


Figure 38: Sediment sample locations and characteristics at Te Haumi Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.9.1 Cockles at Te Haumi Beach

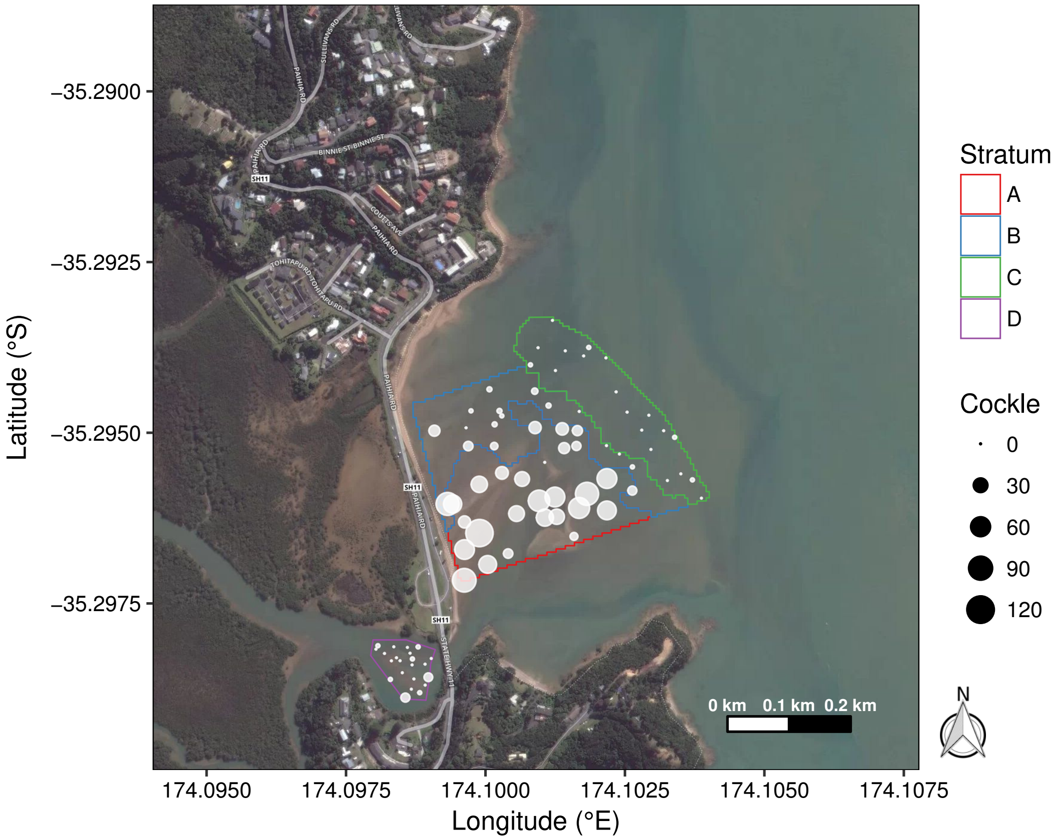


Figure 39: Map of sample strata and individual sample locations for cockles at Te Haumi Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 43: Estimates of cockle abundance at Te Haumi Beach, by stratum, for 2016–17. 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	5.3	27	1 183	65.82	1 252	13.03
B	3.5	16	59	3.67	105	32.06
C	3.3	19	4	0.20	6	45.64
D	0.7	22	24	0.22	31	53.91

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.0	34.73	347	7.95	8.36	84	8.86
2000–01	9.9	17.06	172	11.00	4.11	41	10.27
2001–02	9.9	24.67	249	9.92	1.75	18	11.52
2002–03	9.9	41.77	422	7.97	2.16	31	13.99
2006–07	9.8	15.73	160	12.87	1.98	20	14.53
2009–10	12.1	34.99	290	9.66	2.13	18	26.58
2012–13	12.1	44.67	370	12.28	3.27	27	40.71
2014–15	12.8	35.36	277	11.35	3.42	27	19.75
2016–17	12.8	69.91	548	12.39	2.96	23	24.82

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	18.74	15	5–42	37.95	7.33
2014–15	20.45	18	6–38	21.40	9.67
2016–17	17.01	10	5–39	49.33	4.24

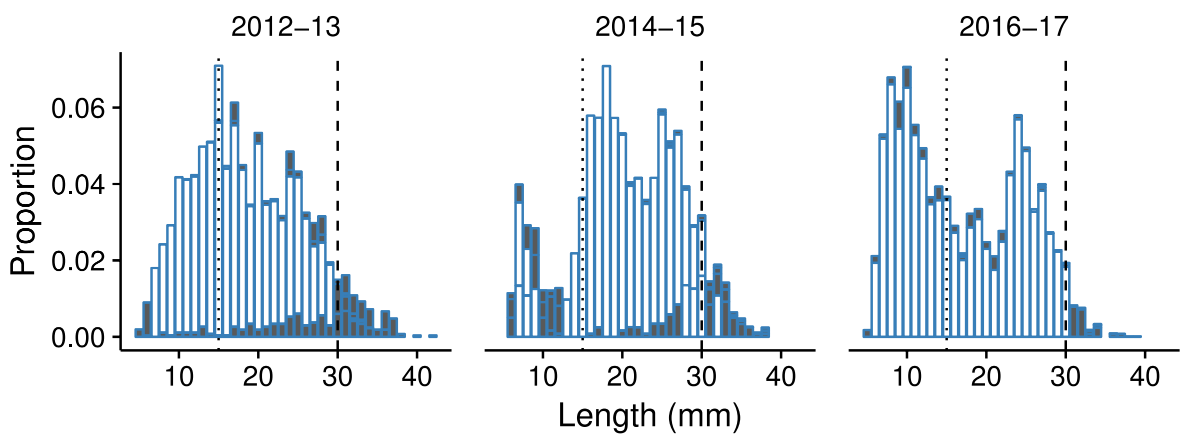


Figure 40: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Te Haumi Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9.2 Pipi at Te Haumi Beach

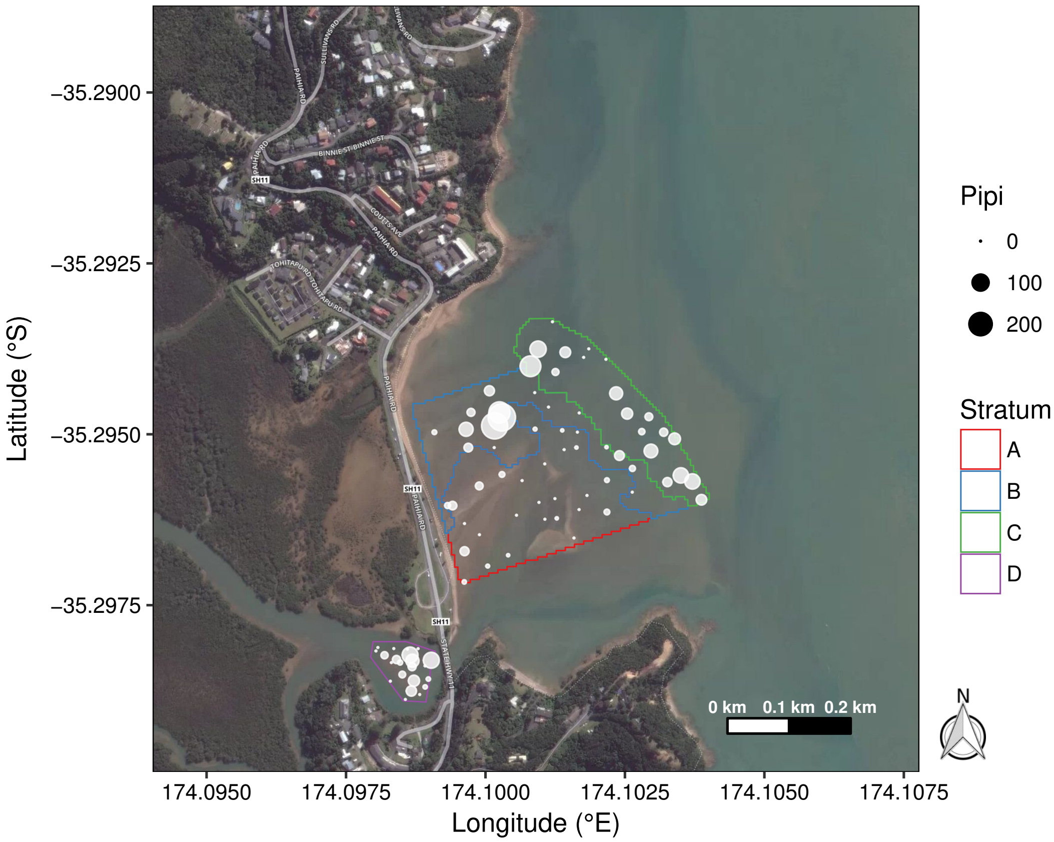


Figure 41: Map of sample strata and individual sample locations for pipi at Te Haumi Beach, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 46: Estimates of pipi abundance at Te Haumi Beach, by stratum, for 2016–17. 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	5.3	27	98	5.45	104	33.67
B	3.5	16	883	54.95	1 577	42.71
C	3.3	19	755	37.60	1 135	23.51
D	0.7	22	376	3.49	488	34.30

Table 47: Estimates of pipi abundance at Te Haumi Beach for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.0	41.70	417	10.97	7.29	73	17.30
2000–01	9.9	62.33	630	9.35	12.17	123	11.94
2001–02	9.9	16.73	169	13.44	1.85	19	16.64
2002–03	9.9	34.04	344	11.17	2.39	24	24.56
2006–07	9.8	31.84	325	13.07	1.14	12	18.85
2009–10	12.1	43.93	364	12.64	0.20	2	33.60
2012–13	12.1	76.45	634	20.73	0.71	6	74.98
2014–15	12.8	55.91	438	18.38	1.16	9	47.92
2016–17	12.8	101.49	795	24.80	0.55	4	37.83

Table 48: Summary statistics of the length-frequency (LF) distribution of pipi at Te Haumi Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	22.19	20	6–54	54.30	0.93
2014–15	28.22	19	8–58	36.92	2.07
2016–17	23.03	18	3–58	52.71	0.54

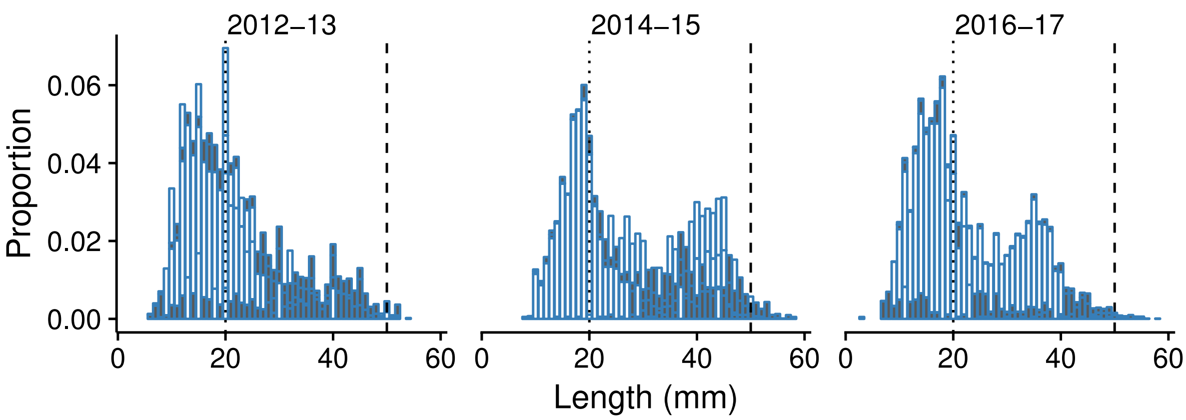


Figure 42: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Te Haumi Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10 Waiōtahe Estuary

Waiōtahe Estuary (formerly Waiotahi Estuary) is a small estuary in eastern Bay of Plenty. Bivalve populations at this site have been assessed in six previous surveys, most recently in 2013–14 (see Appendix A, Tables A-1, A-2). Since January 2017, there have been health warnings in place, advising against the consumption of shellfish from this site, owing to *Escherichia coli* bacteria contamination. Sampling in this estuary has targeted bivalves north and south of the main tidal channel, and the current study surveyed the same sampling extent used previously (Figure 43). Re-stratification based on the 2013–14 survey data resulted in a total of three strata across the sampling extent. Across these strata, cockles and pipi were targeted in 83 sampling points in 2016–17.

The sampling in the cockle strata revealed sediment that was characterised by a low organic content (<4%) (Figure 43, and see details in Appendix B, Table B-3). Similarly, the proportion of fines (grain size <63 µm) was small, except in stratum A, where samples contained up to 14% of this grain size fraction, and also a relatively high proportion of very fine sands (grain size >63 µm). Most of the sediment was fine sand (grain size >125 µm), and this grain size fraction varied between 35 and 93% across all samples.

Cockles at this site were mostly distributed through the western part of the sampling extent, in stratum A (Figure 44, Table 49). The total cockle population consisted of an estimated 48.61 million (CV: 16.66%) cockles, which occurred at an estimated mean density of 406 cockles per m^2 (Table 50). These estimates were comparable to values in the preceding survey, and indicated that the cockle population remained stable, following its increase in 2009–10. Although the population contained no large cockles ($\geq$ 30 mm shell length) in 2013–14, this part of the population showed a slight increase in the present study, with 0.12 million (CV: 80.6%) cockles, at a density of 1 large cockle per m^2.

Comparing the proportions of large cockles and recruits ($\leq$15 mm shell length) showed that the small number of large cockles corresponded with a minor contribution of individuals (0.25%), whereas recruits constituted a third (31.44%) of the population (Table 51, Figure 45). Nevertheless, the proportion of recruits reflected a marked decline (from 84.98% in 2013–14), which was reflected in an increase in the size of the main cohort of the unimodal population. Both mean and modal shell lengths confirmed the prevalence of medium-sized cockles, with a single cohort around the modal size of 20 mm in 2016–17.

The distribution of the pipi population at Waiōtahe Estuary reflected the opposite pattern to that of cockles, with high pipi densities in the northern and eastern parts of the estuary (Figure 46, Table 52. The current population estimates for this species were 166.25 million (CV: 18.36%) pipi, occurring at a mean density of 1388 individuals per m^2 (Table 53). Included in the population was a small number of large pipi ($\geq$50 mm shell length), and there were an estimated 1.05 million (CV: 43.81%) individuals in this size class. Their mean density was also low at 9 large individuals per m^2. While current estimates for the total pipi population were similar to the preceding assessment in 2013–14, the population of large cockles showed a small increase.

Throughout the survey series, the large pipi size class was only a small proportion of the population; in 2016–17, large pipi comprised 0.63% of all individuals (Table 54). Recruits ($\leq$20 mm shell length) were also only a small part of the pipi population in 2016–17, following their decrease from 45.08% of the population in 2013–14 to 12.08% in the present study. As small pipi grew into the medium-size class between surveys, the modal length increased from 20-mm to 35-mm shell length, with a concomitant shift in the unimodal population towards medium-sized pipi (Figure 47).

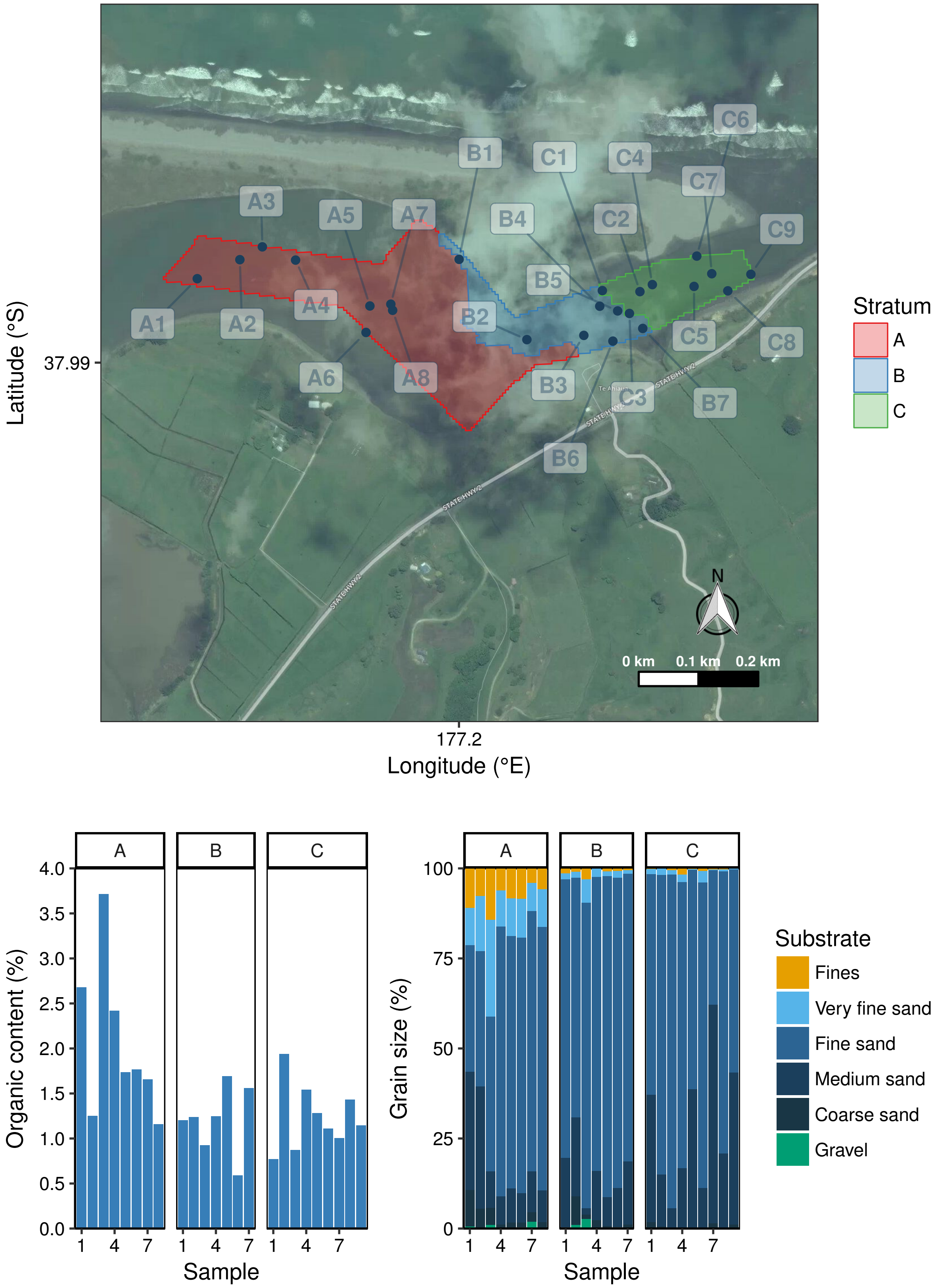


Figure 43: Sediment sample locations and characteristics at Waiōtahe Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine,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

3.10.1 Cockles at Waiōtahe Estuary

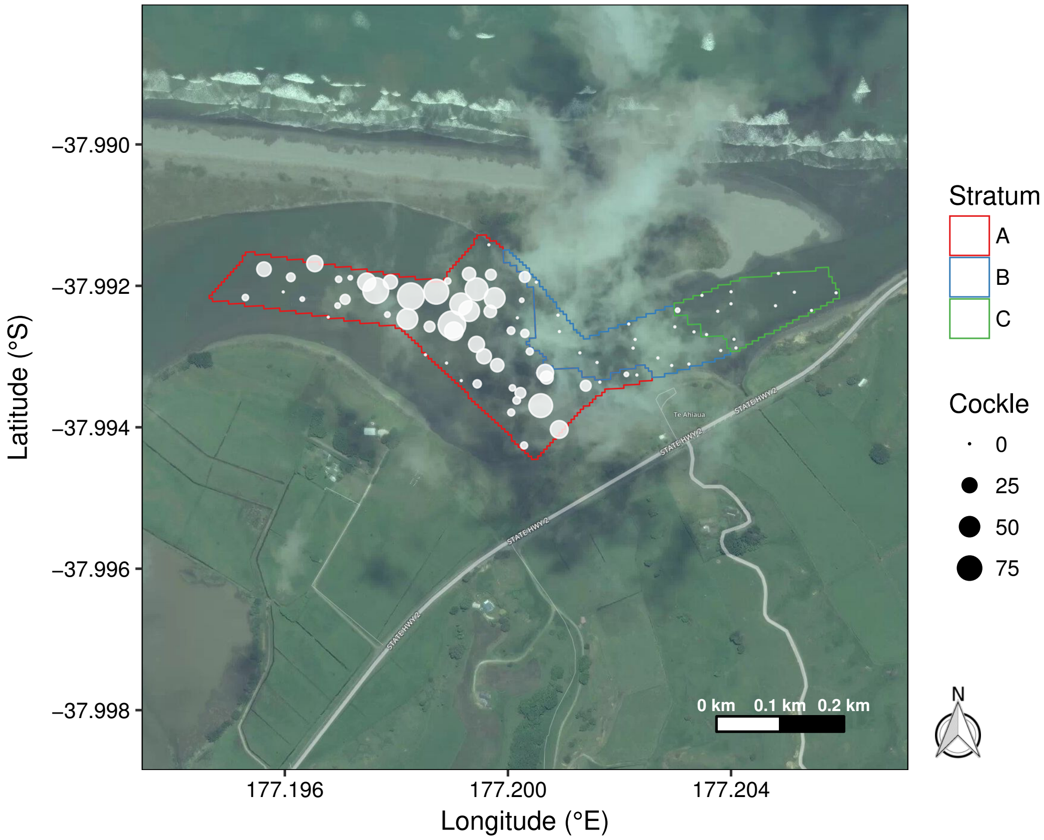


Figure 44: Map of sample strata and individual sample locations for cockles at Waiōtahe Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 49: Estimates of cockle abundance at Waiōtahe Estuary, by stratum, for 2016–17. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	7.7	55	1 206	48.01	626	16.82
B	2.4	15	12	0.56	23	>100
C	1.9	13	1	0.04	2	>100

Table 50: Estimates of cockle abundance at Waiōtahe Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	8.5	36.66	431	8.08	0.51	6	16.53
2002–03	8.5	36.67	431	8.08	0.52	6	16.42
2003–04	8.5	5.77	68	9.16	0.09	1	34.2
2004–05	9.5	1.13	12	12.12	0.04	<1	>100
2005–06	9.5	5.88	62	10.53	0.09	1	52.32
2009–10	9.5	20.17	212	15.50	0.06	<1	70.81
2013–14	11.2	47.37	422	10.10	0.00	0	
2016–17	12.0	48.61	406	16.66	0.12	1	80.6

Table 51: Summary statistics of the length-frequency (LF) distribution of cockles at Waiōtahe Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	18.13	20	5–35	20.52	0.33
2013–14	11.70	10	2–28	84.98	0.00
2016–17	17.71	20	5–30	31.44	0.25

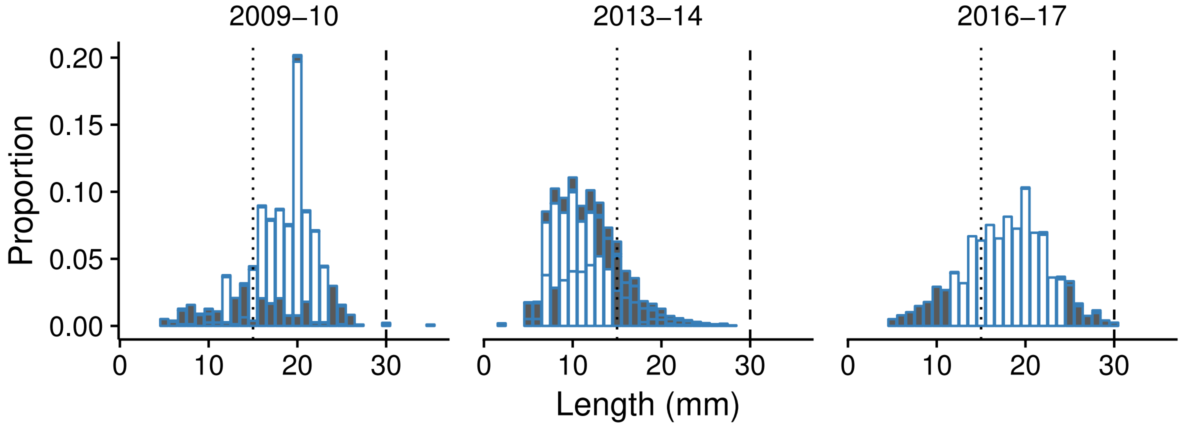


Figure 45: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Waiōtahe Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10.2 Pipi at Waiōtahe Estuary

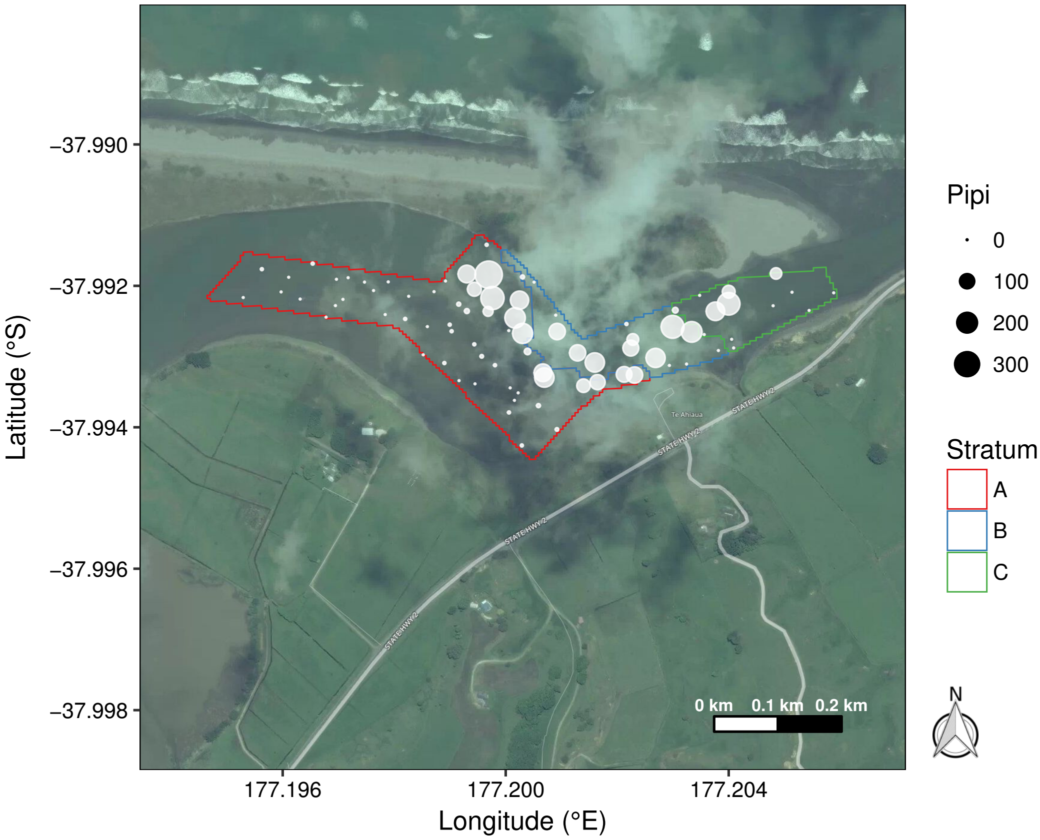


Figure 46: Map of sample strata and individual sample locations for pipi at Waiōtahe Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 52: Estimates of pipi abundance at Waiōtahe Estuary, by stratum, for 2016–17. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	7.7	55	2 204	87.73	1 145	26.59
B	2.4	15	1 213	56.36	2 310	28.42
C	1.9	13	537	22.15	1 180	51.59

Table 53: Estimates of pipi abundance at Waiōtahe Estuary for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	8.5	183.91	2 164	5.14	1.46	17	15.83
2002–03	8.5	183.91	2 164	5.14	1.46	17	15.83
2003–04	8.5	47.91	564	5.70	0.20	2	19.63
2004–05	9.5	41.41	436	5.00	0.81	23	12.10
2005–06	9.5	40.61	427	9.30	1.24	19	19.83
2009–10	9.5	96.71	1 018	12.48	3.56	38	23.71
2013–14	11.2	150.21	1 338	12.57	0.09	<1	65.16
2016–17	12.0	166.25	1 388	18.36	1.05	9	43.81

Table 54: Summary statistics of the length-frequency (LF) distribution of pipi at Waiōtahe Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	29.68	40	3–63	26.09	3.93
2013–14	23.00	20	4–112	45.08	0.06
2016–17	30.73	35	7–54	12.08	0.63

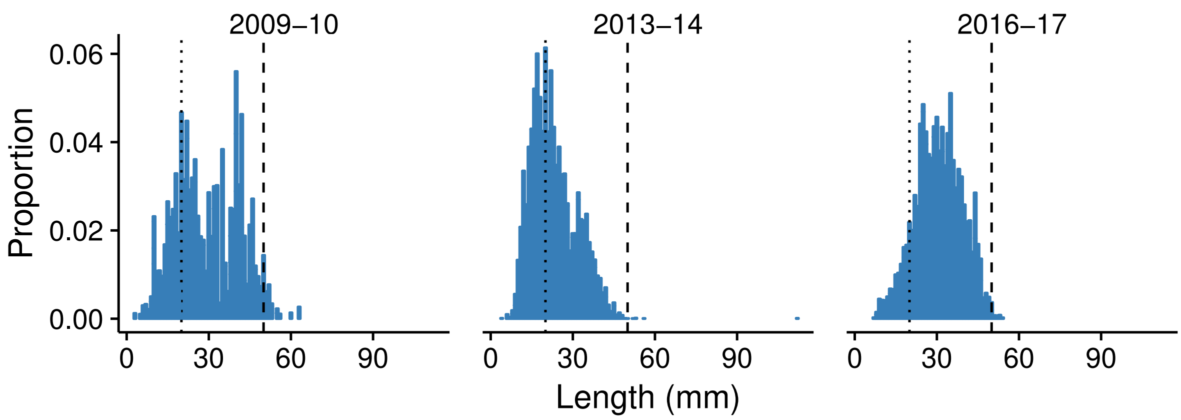


Figure 47: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Waiōtahe Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Whangamata Harbour

Whangamata Harbour is a relatively large Waikato estuary on the eastern side of Coromandel Peninsula. The harbour has been surveyed in nine previous bivalve assessments, with the immediately preceding study in 2014–15 (see Appendix A, Tables A-1, A-2). The sampling extent in the harbour has consistently included two separate areas, which are divided by the channel from Moanaanuanu Estuary (Figure 48). Information from the 2014–15 survey was used to re-stratify the sampling area, and the 2016–17 sampling extent included an additional pipi bed. The latter was in a shallow area characterised by high tidal flow, alongside the main channel. Including this pipi bed, there were five strata in the 2016–17 field survey, and a total of 152 sampling points.

Sediment in the cockle strata had little organic content, with a maximum of 4% across all samples (Figure 48, and see details in Appendix B, Table B-3). The sediment grain size distribution was variable, and generally contained a small proportion of sediment fines (grain size <63 µm) of 2% or less, with the exception of two samples that contained 16 and 43% of sediment fines, respectively. The main grain size fractions were fine (>125 µm) and medium (>250 µm) sands, with some samples containing varying proportions of coarser sediment and gravel also.

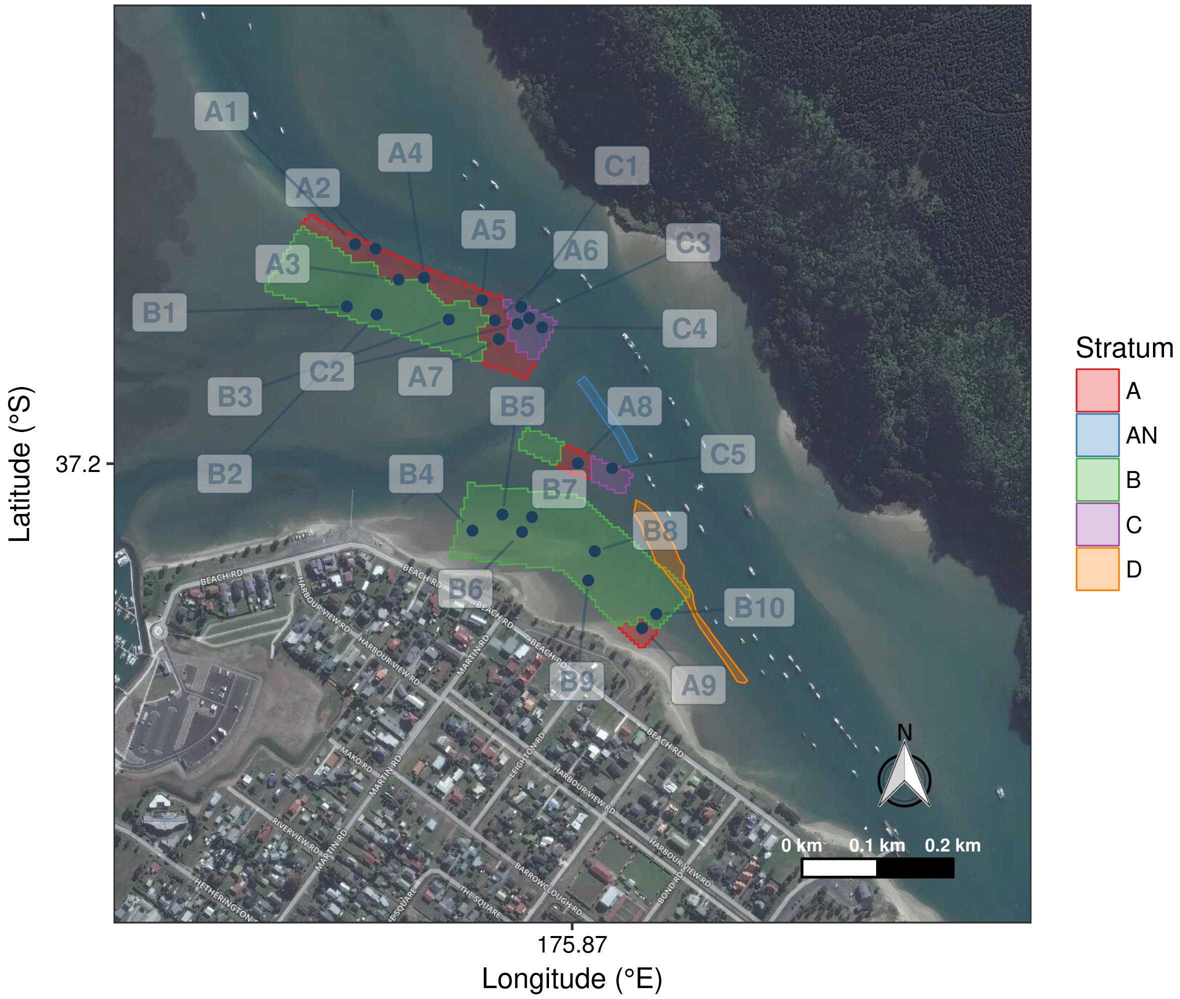
Cockles at Whangamata Harbour were spread throughout the sampling extent, and were concentrated in stratum B (Figure 49, Table 55). The 2016–17 estimate for the total population was 86.78 million (CV: 7.86%) cockles, and the corresponding population density was 1125 cockles per m^2 (Table 56). These estimates were indicative of a recent decrease in the cockle population, although the population abundance was similar to the earlier estimate in 2010–11. For large cockles (≥30 mm shell length), both the abundance and density estimates were higher than in the previous survey, indicating a small, but continuing increase in their population. Nevertheless, this size class was only present in low numbers with an estimated 4.00 million (CV: 24.60%) large cockles, and a mean density of 52 individuals per m^2.

The low abundance of large cockles meant that they constituted only a small proportion (4.61%) of the population (Table 57, Figure 50). At the same time, recruits (≤15 mm shell length) also played only a small role, with 15.55% of all cockles in this size class. Instead, the population structure was determined by medium-sized cockles, with a current modal length of 24 mm. This finding was consistent with previous surveys, which also documented the pre-dominance of medium-sized cockles in the Whangamata Harbour population.

Pipi in Whangamata Harbour were largely restricted to areas associated with channels, and particularly abundant in a shallow area adjacent to the main channel, stratum D (Figure 51, Table 58). This stratum was added as changes to the main channel seemed to have resulted in a shift of the pipi bed from the deeper channel area to this relatively shallow, but high-flow location. The estimated population abundance for 2016–17 was 7.65 million (CV: 24.21%) pipi, which were present at a mean density of 99 individuals per m^2 (Table 59). Based on a similar sampling extent, the current estimates indicated a pipi population that almost doubled in size since 2014–15.

Similar increases in abundance and density were also evident in the population of large pipi (≥50 mm shell length), and their estimated abundance was 3.87 million (CV: 20.49%) individuals in 2016–17, with an estimated density of 50 large individuals per m^2. In view of the small total population size, large pipi contributed a substantial proportion of individuals, with 50.90% of the population larger than 50-mm shell length (Table 60, Figure 52). In contrast, there were few recruits (≤20 mm shell length), which constituted only 6.30% of the population.

Across the three most recent surveys, the pipi population was largely influenced by individuals that exceeded 50 mm shell length, with a recent increase in the modal size from 51-mm to 60-mm shell length between 2014–15 and 2016–17. The increase in large pipi, and the concomitant decrease in the proportion of recruits, resulted in a distinct shift from a bimodal to a unimodal population that predominantly consisted of medium-sized and large pipi.



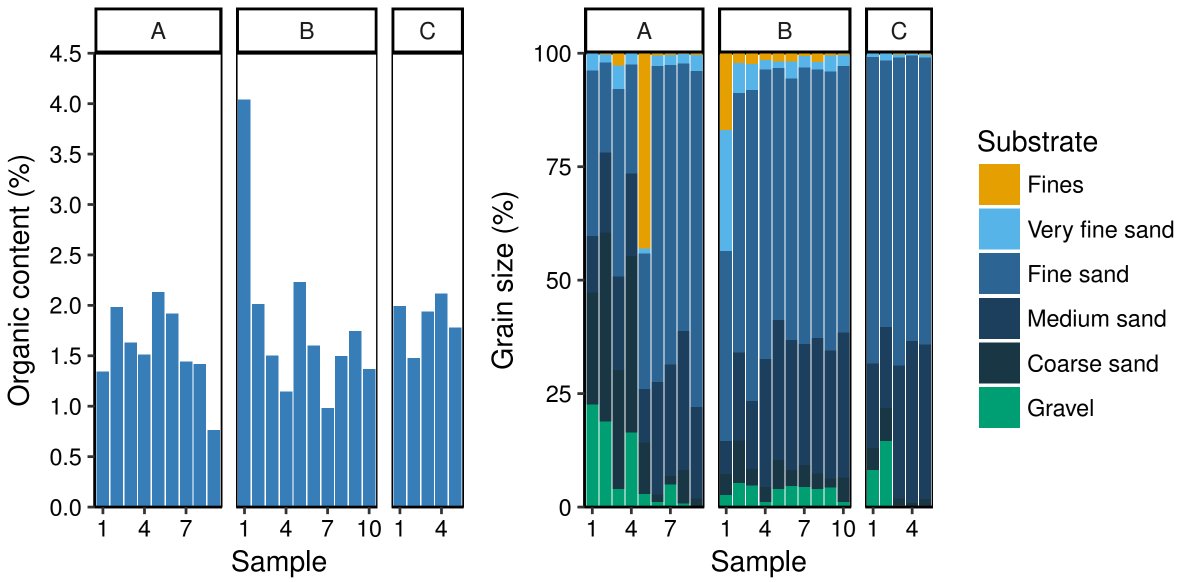


Figure 48: Sediment sample locations and characteristics at Whangamata Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine,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

3.11.1 Cockles at Whangamata Harbour

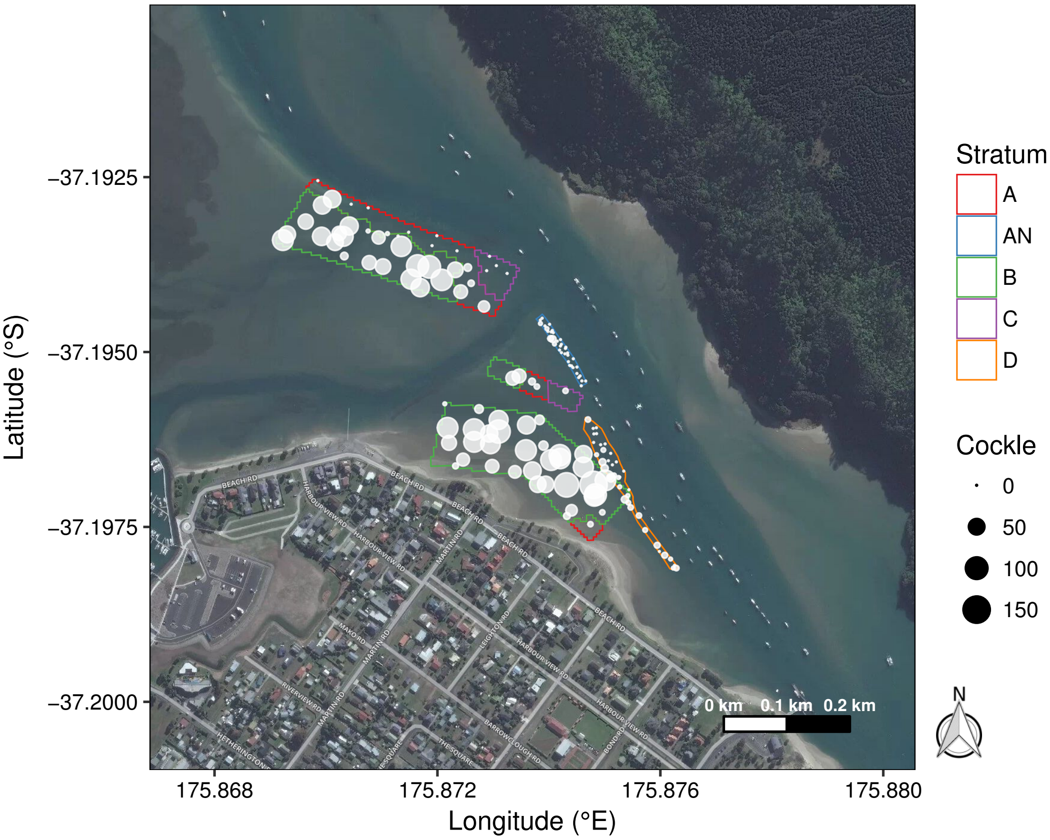


Figure 49: Map of sample strata and individual sample locations for cockles at Whangamata Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 55: Estimates of cockle abundance at Whangamata Harbour, by stratum, for 2016–17. 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	16	137	3.29	245	46.16
AN	0.2	36	13	0.02	10	55.33
B	5.3	59	3 246	83.19	1 572	8
C	0.5	5	3	0.08	17	>100
D	0.4	36	59	0.20	47	23.21

Table 56: Estimates of cockle abundance at Whangamata 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	52	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

Table 57: Summary statistics of the length-frequency (LF) distribution of cockles at Whangamata Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	17.50	20	4–40	35.92	1.62
2014–15	19.92	20	5–35	21.27	2.61
2016–17	21.21	24	5–58	15.55	4.61

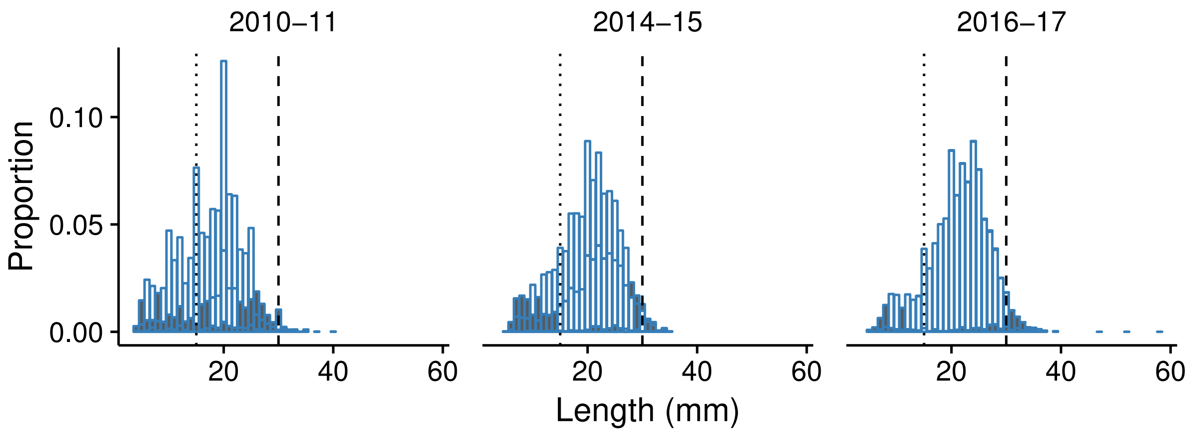


Figure 50: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangamata Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11.2 Pipi at Whangamata Harbour

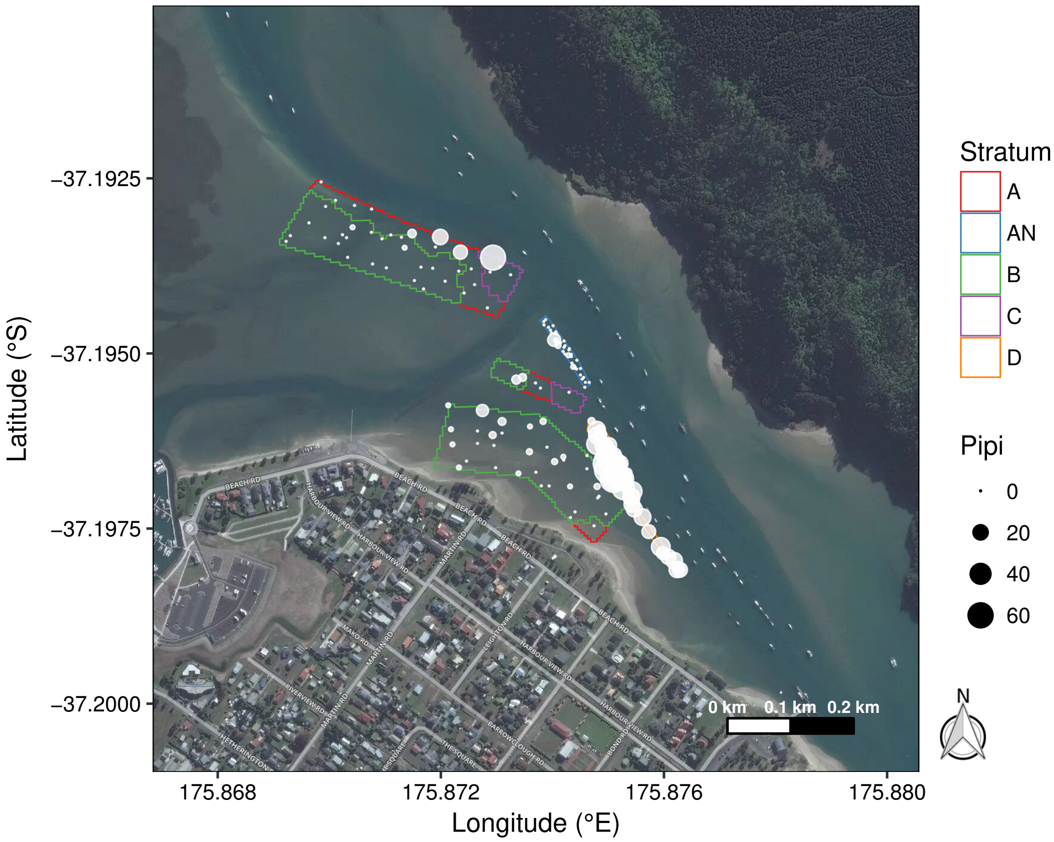


Figure 51: Map of sample strata and individual sample locations for pipi at Whangamata Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 58: Estimates of pipi abundance at Whangamata Harbour, by stratum, for 2016–17. 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	16	43	1.03	77	60.74
AN	0.2	36	19	0.02	15	74.15
B	5.3	59	48	1.23	23	30.37
C	0.5	5	60	1.66	343	>100
D	0.4	36	1 074	3.70	852	10.28

Table 59: Estimates of pipi abundance at Whangamata 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	26	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

Table 60: Summary statistics of the length-frequency (LF) distribution of pipi at Whangamata Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2010–11	35.00	52	5–73	31.67	29.97
2014–15	41.81	51	9–62	10.71	40.59
2016–17	46.71	60	7–70	6.30	50.90

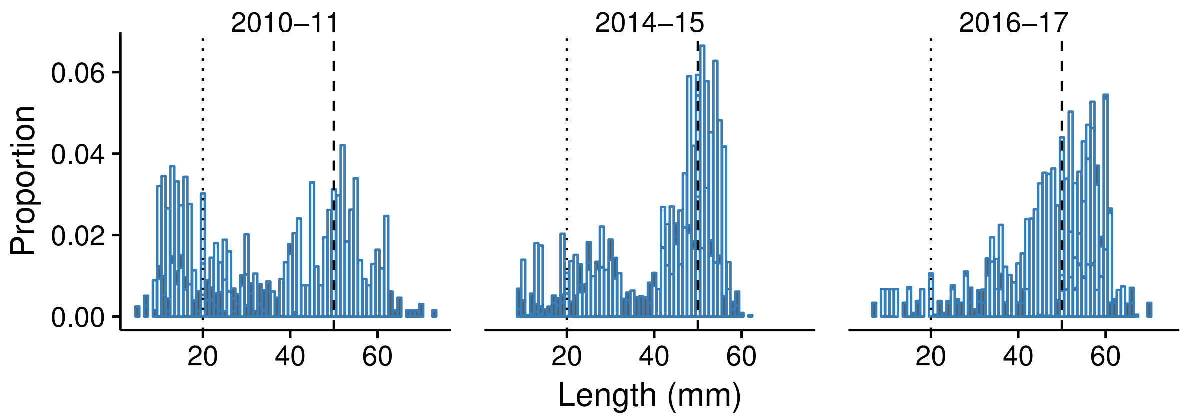


Figure 52: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangamata Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12 Whangapoua Harbour

Whangapoua Harbour is in the Waikato region, on the east coast of Coromandel Peninsula. This large inlet was included in six previous assessments, and the most recent bivalve survey was in 2014–15 (see Appendix A, Tables A-1, A-2). In this inlet, the sampling extent has consistently been split between two main areas, on either side of the harbour channel (Figure 53). The current study used a similar sampling extent to the 2014–15 survey, except for the omission of one pipi stratum (previous stratum D) that did not contain any bivalves. The sampling extent covered four separate strata, with a total of 149 sampling points in phase 1, and 28 sampling points in phase 2 (restricted to stratum B only).

Sediment samples from Whangapoua Harbour showed some differences between cockle strata (Figure 53, and see details in Appendix B, Table B-3). In general, the sediment had a low organic content and a low proportion of fines (grain size $<$63 µm) across all samples, with values of 2.5% or less for both parameters. The main grain size fractions were fine and medium sands (grain sizes $>$125 µm and $>$250 µm), but their proportions varied between stratum A and the other two strata. Sediment in the former stratum was predominantly medium sand with a smaller proportion of fine sand, whereas fine sand determined the sediment composition in the other strata, with a maximum of 86% of sediment at this grain size.

Cockles were present in all strata, with high numbers in stratum B, and also stratum C (Figure 54, Table 61). The estimated total population size of this species was 43.80 million (CV: 16.02%) cockles in 2016–17 (Table 62). Their estimated population density was 827 cockles per m^2. While estimates for the total population reflected increases from previous surveys and the highest values in the survey series, the population of large cockles ($\geq$30 mm shell length) remained small, with a slight decrease in estimated abundance and density. These two population parameters were 1.08 million (CV: 16.30%) large cockles, and 20 large individuals per m^2 in 2016–17.

The small size of the population of large cockles was highlighted in their minor contribution (2.47%) to the overall population (Table 63, Figure 55). In contrast, the recent increase in the proportion of recruits ($\leq$15 mm shell length) from 10.55% in 2014–15 to 32.84% in 2016–17 indicated a recruitment event. The length-frequency distributions from the three most recent surveys illustrated the influence of recruits, as the previously unimodal population of predominantly medium-sized cockles changed to a bimodal size structure with a second, smaller cohort of small-sized individuals. This change was also evident in the drop in mean and modal sizes in 2016–17 to 17.92 mm and 20 mm shell length, compared with 21.83 mm and 25 mm mean and modal shell lengths in the preceding assessment.

Pipi in Whangapoua Harbour were only found close to the harbour entrance in the main tidal channel in stratum E; there were only two individuals in other strata (Figure 56, Table 64). This pipi bed supported a small population of an estimated 2.01 million (CV: 21.05%) pipi, and their density was 38 individuals per m^2 (Table 65). The population included a small number of large pipi ($\geq$50 mm shell length), which consisted of 0.66 million (CV: 29.84%) individuals, and occurred at a relatively high density of 89 large pipi per m^2 compared with the total population.

The large-pipi size class made up about a third (33.19%) of the population and recruits ($\leq$20 mm shell length) constituted a similar proportion (34.36%) in this survey (Table 66, Figure 57). The influence of large pipi was highlighted in the modal size of 55-mm shell length, reflecting a strong cohort around this size in the current population. Recruits made up a second cohort in the bimodal population, with medium-sized pipi between these two cohorts as individuals grow over time.

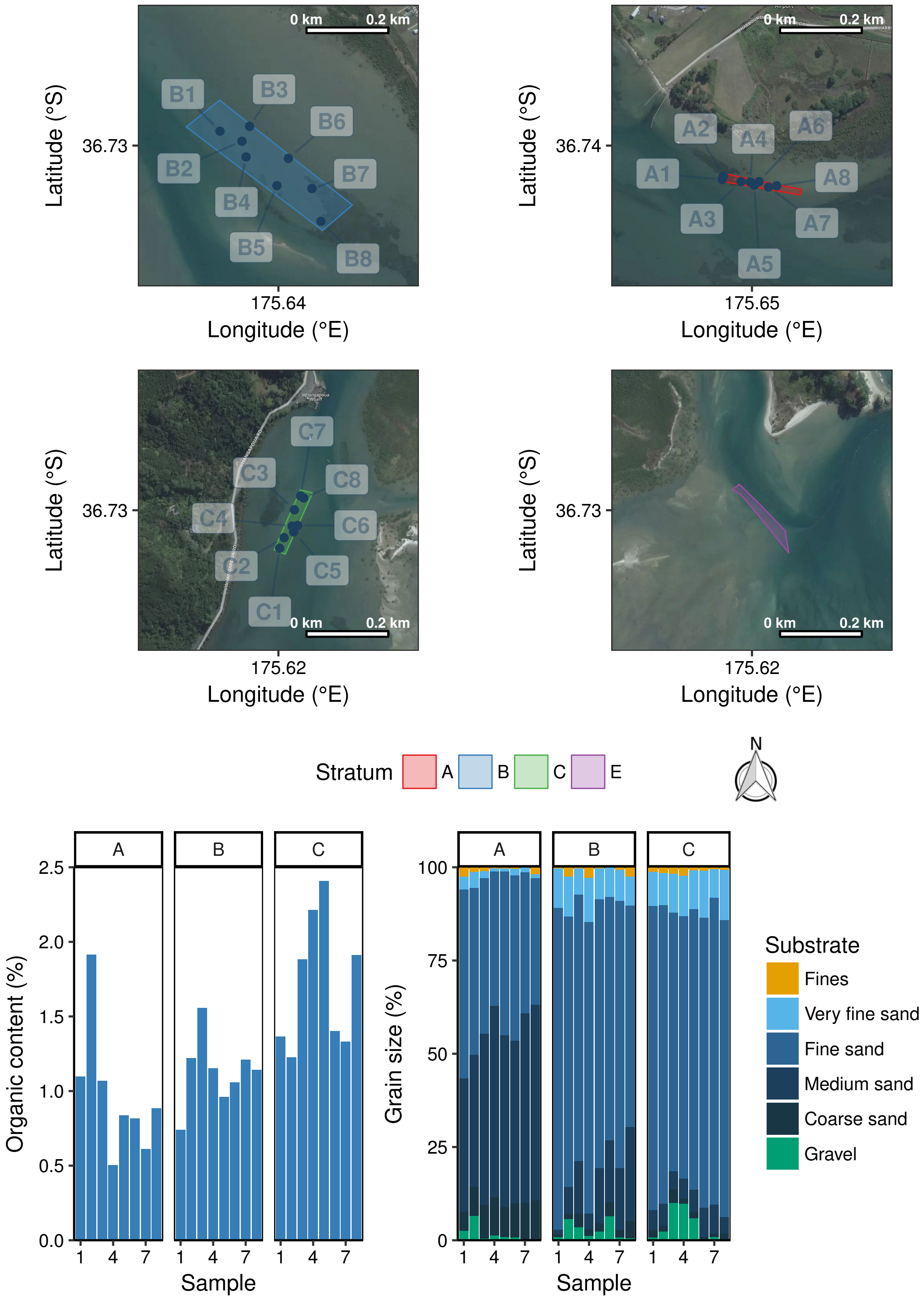


Figure 53: Sediment sample locations and characteristics at Whangapoua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.12.1 Cockles at Whangapoua Harbour

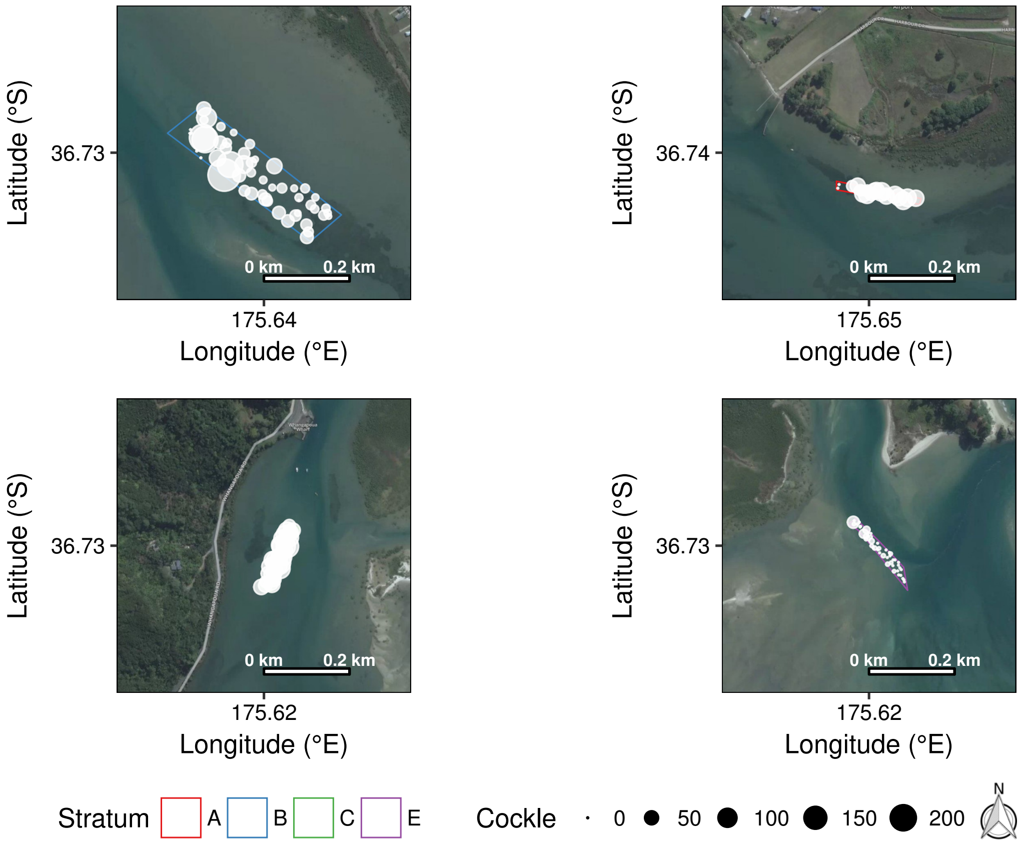


Figure 54: Map of sample strata and individual sample locations for cockles at Whangapoua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 61: Estimates of cockle abundance at Whangapoua Harbour, by stratum, for 2016–17. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	21	750	3.46	1 020	12.96
B	4.1	52	1 476	33.11	811	21.05
C	0.5	30	1 539	7.02	1 466	9.59
E	0.4	46	86	0.21	53	47.19

Table 62: Estimates of cockle abundance at Whangapoua Harbour for all sizes and large size ($\geq$30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population $\geq$ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
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	133	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	20	16.30

Table 63: 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 (%)
2010–11	20.76	20	2–45	20.74	8.82
2014–15	21.83	25	6–40	10.55	4.25
2016–17	17.92	20	5–58	32.84	2.47

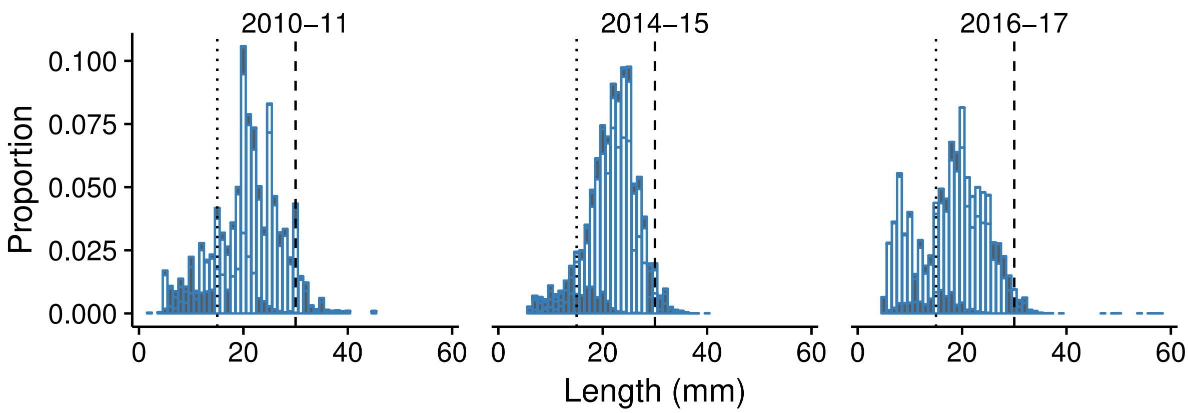


Figure 55: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangapoua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12.2 Pipi at Whangapoua Harbour

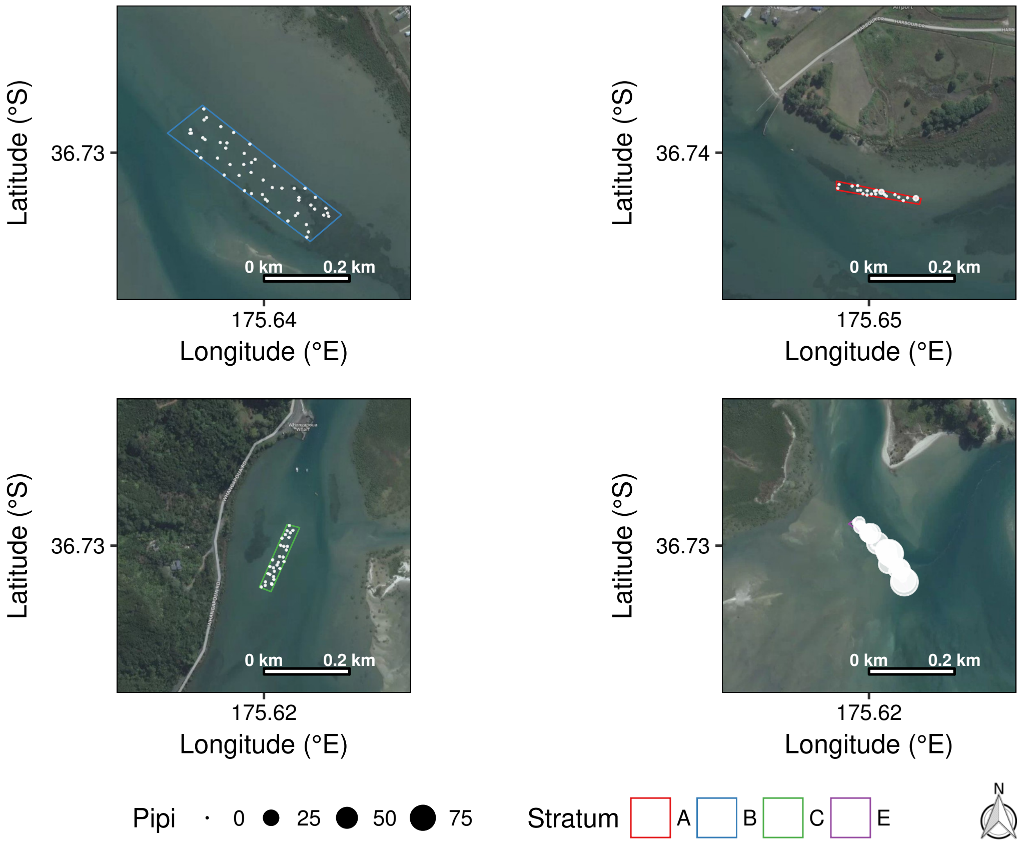


Figure 56: Map of sample strata and individual sample locations for pipi at Whangapoua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 64: Estimates of pipi abundance at Whangapoua Harbour, by stratum, for 2016–17. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	21	2	0.01	3	68.92
B	4.1	52	0	0.00	0	
C	0.5	30	0	0.00	0	
E	0.4	46	808	2.00	502	21.14

Table 65: 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	432	8.28
2003–04	5.2	5.05	97	9.98	1.75	218	7.90
2004–05	5.2	7.47	144	5.25	3.75	469	5.08
2010–11	5.2	2.74	53	18.82	1.18	98	22.54
2014–15	6.3	2.27	36	20.24	0.34	18	22.32
2016–17	5.3	2.01	38	21.05	0.66	89	29.84

Table 66: 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 (%)
2010–11	45.60	40	11–72	4.13	43.14
2014–15	38.42	47	9–60	10.78	14.90
2016–17	34.19	55	5–65	34.36	33.19

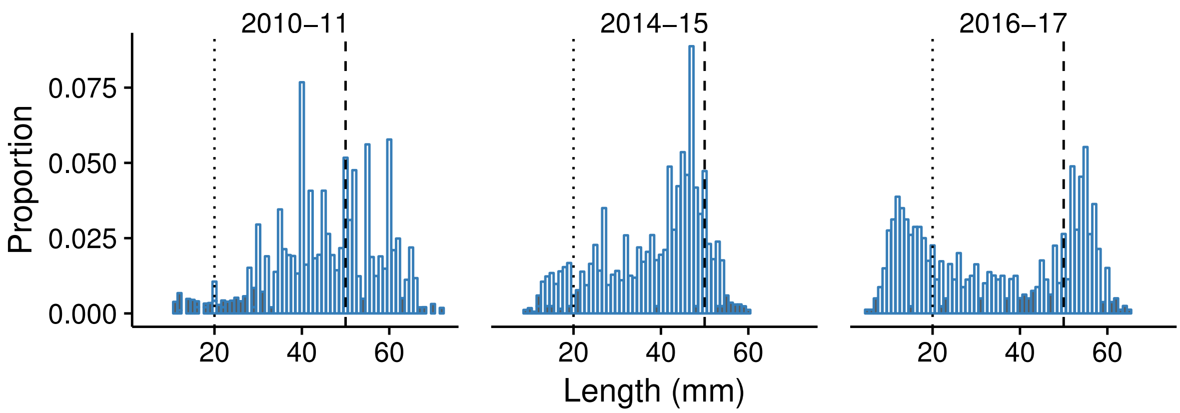


Figure 57: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangapoua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

All of the 2016–17 survey sites contained notable cockle populations, and data from the field sampling were sufficient to provide cockle population estimates with relatively low uncertainty, i.e., with a CV of less than 20%. The only exception was Grahams Beach, where additional phase-2 sampling did not achieve a lowering of the CV to below 21.82% (Table 67). The combination of a small population size and an uneven distribution of cockles at this site meant that increased sampling effort did not achieve a lowering of the uncertainty to the target CV.

Across the survey sites, cockle population estimates ranged from a small total abundance of 13.08 million (CV: 18.38%) cockles at Ruakaka Estuary to 261.21 million (CV: 13.84%) cockles at Kawakawa Bay (West). While these abundance estimates provide information about the overall size of cockle populations, differences across sites prevent direct comparisons. For the latter, population density is a more meaningful parameter to compare cockle populations across sites or regions.

In 2016–17, most (10) sites had relatively high population densities, where estimates exceeded 400 individuals per m^2. There were two sites with particularly high density estimates (> 1000 individuals per m^2), Ngunguru Estuary in Northland and Whangamata Harbour on Coromandel Peninsula. At these two sites, cockle densities were 1461 individuals per m^2 and 1125 individuals per m^2, respectively. In contrast, the lowest density estimate was at Grahams Beach, where cockles occurred at an estimated 64 individuals per m^2.

An important aspect of the population assessment is the population size structure, including the number and density of large cockles ($\geq$30 mm shell length). Comparisons across sites highlighted the general scarcity of individuals in this size class, and large cockles were absent at three of the 12 sites; their population abundance was low (i.e., less than 1 million individuals) at another three sites. The biggest populations of large cockles were at Kawakawa Bay (West) and Eastern Beach; however, even at these two sites, large cockles were only a minor proportion of the total population.

Density estimates of large cockles highlighted their rareness in the northern populations, with values well below the density estimates for the total cockle population at each site. For example, at Ngunguru Estuary, which had the highest estimated density of all cockles, the density of large individuals was 4 cockles per m^2. The highest estimated density of large cockles was at Eastern Beach, with 67 individuals per m^2 (CV: 17.38%). It is worth noting that this beach has had a permanent fishing closure in place since 1993, even though available data are insufficient to directly assess the role of fishing pressure and population trends at this or any other site.

Considering total population trends over time revealed a number of sites with recent increases in cockle population densities (Figure 58). These increases were discernible at Eastern Beach, Grahams Beach, Kawakawa Bay (West), and Te Haumi Beach, and occurred to a lesser extent at Mangawhai and Whangapoua harbours. There was a notable decline in cockle density at Ruakaka Estuary in 2016–17, while observed decreases at remaining sites were relatively small.

Putting these trends into the context of the population structures, the universal shift towards smaller cockle sizes across surveys indicated that the population increases were determined by recruitment events of small-sized individuals (Figure 59). Most of the cockle populations in the 2016–17 survey changed from supporting a range of cockle sizes to population structures largely determined by recruits and medium-sized cockles. This change was evident in the length-frequency distributions, in the shift towards smaller sizes between earlier surveys and the current assessment.

The time-series of large cockle densities at the survey sites confirmed the decline of this size class in most populations over the reporting period (Figure 60). In general, there was a relatively sudden drop in the density of large individuals early in the period, and subsequent lack of recovery. Two sites that differed from this pattern were Eastern Beach and Kawakawa Bay (West). At Eastern Beach, large cockles (and cockles at other sizes) were absent at the start of the reporting period (1999–2000), but increased to relatively high densities over time. At Kawakawa Bay (West), the large cockle population was small, but appeared stable across surveys, with relatively little change in density across surveys. These data indicate that the loss of large individuals from cockle populations was seldom reversed.

Table 67: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2016–17 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	76.41	393	11.05	0.00	0	
Eastern Beach	176.91	784	13.05	15.07	67	17.38
Grahams Beach	17.09	64	21.82	0.00	0	
Kawakawa Bay	261.21	429	13.84	18.33	30	36.42
Mangawhai Harbour	58.97	794	13.89	1.46	20	28.67
Ngunguru Estuary	91.81	1 461	7.19	0.22	4	48.15
Otumoetai	40.11	496	14.56	0.34	4	>100
Ruakaka Estuary	13.08	233	18.38	0.00	0	
Te Haumi Beach	69.91	548	12.39	2.96	23	24.82
Waiōtahe Estuary	48.61	406	16.66	0.12	1	80.6
Whangamata Harbour	86.78	1 125	7.86	4.00	52	24.6
Whangapoua Harbour	43.80	827	16.02	1.08	20	16.3

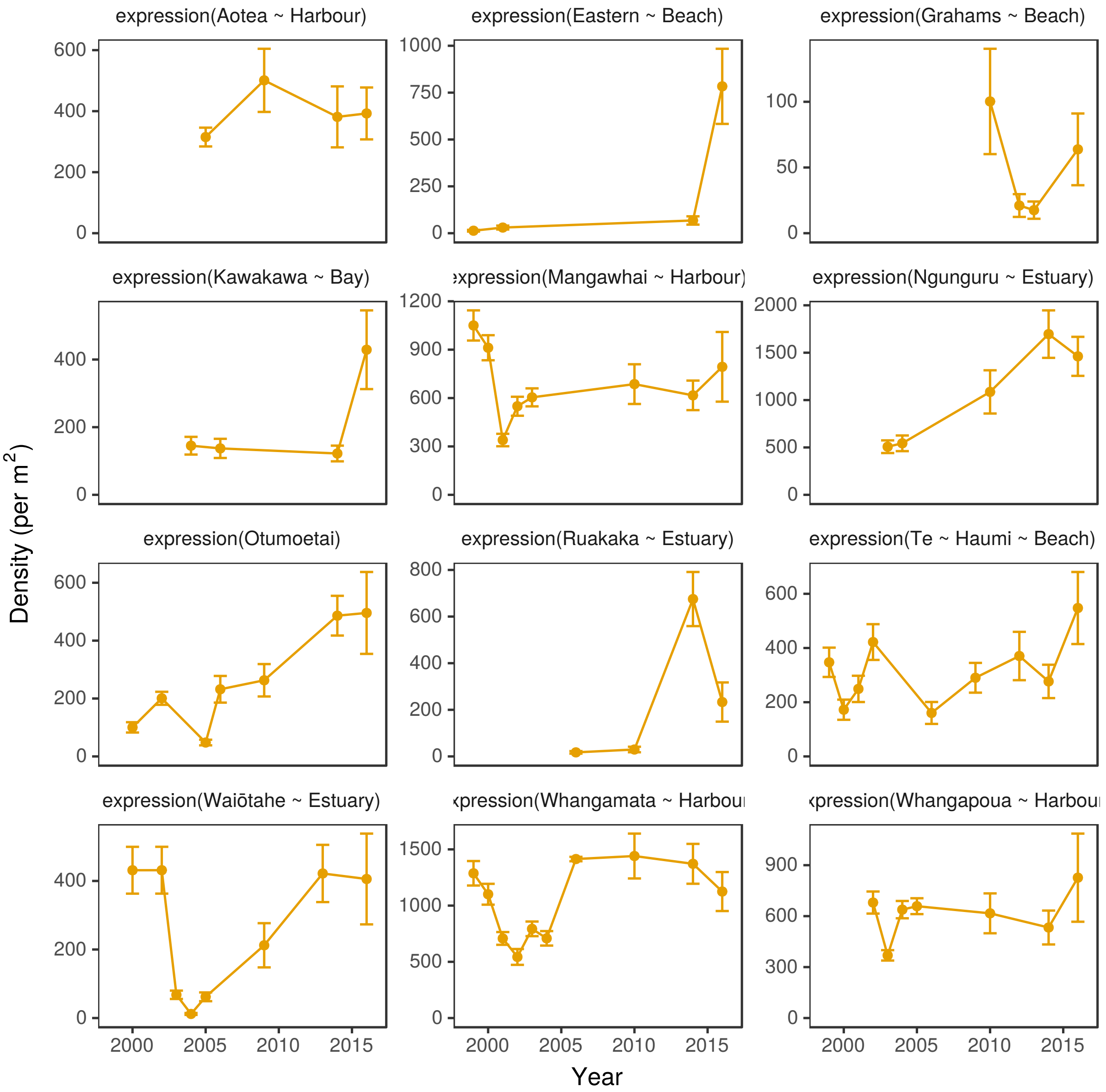


Figure 58: Estimated density of cockles for all sites included in the 2016–17 survey. Shown are the mean estimated densities across years, with bars indicating the 95% credible interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

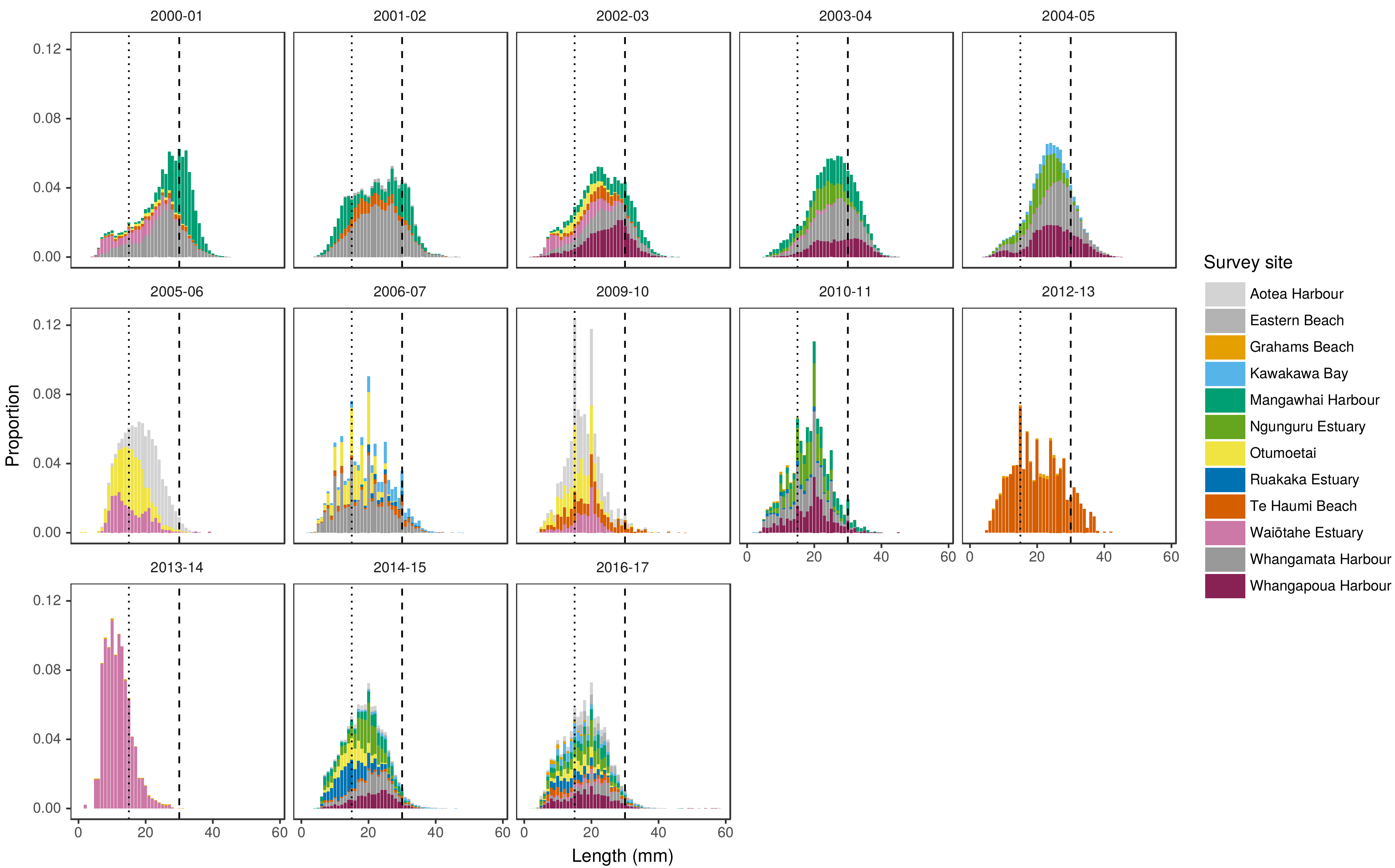


Figure 59: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2016–17 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

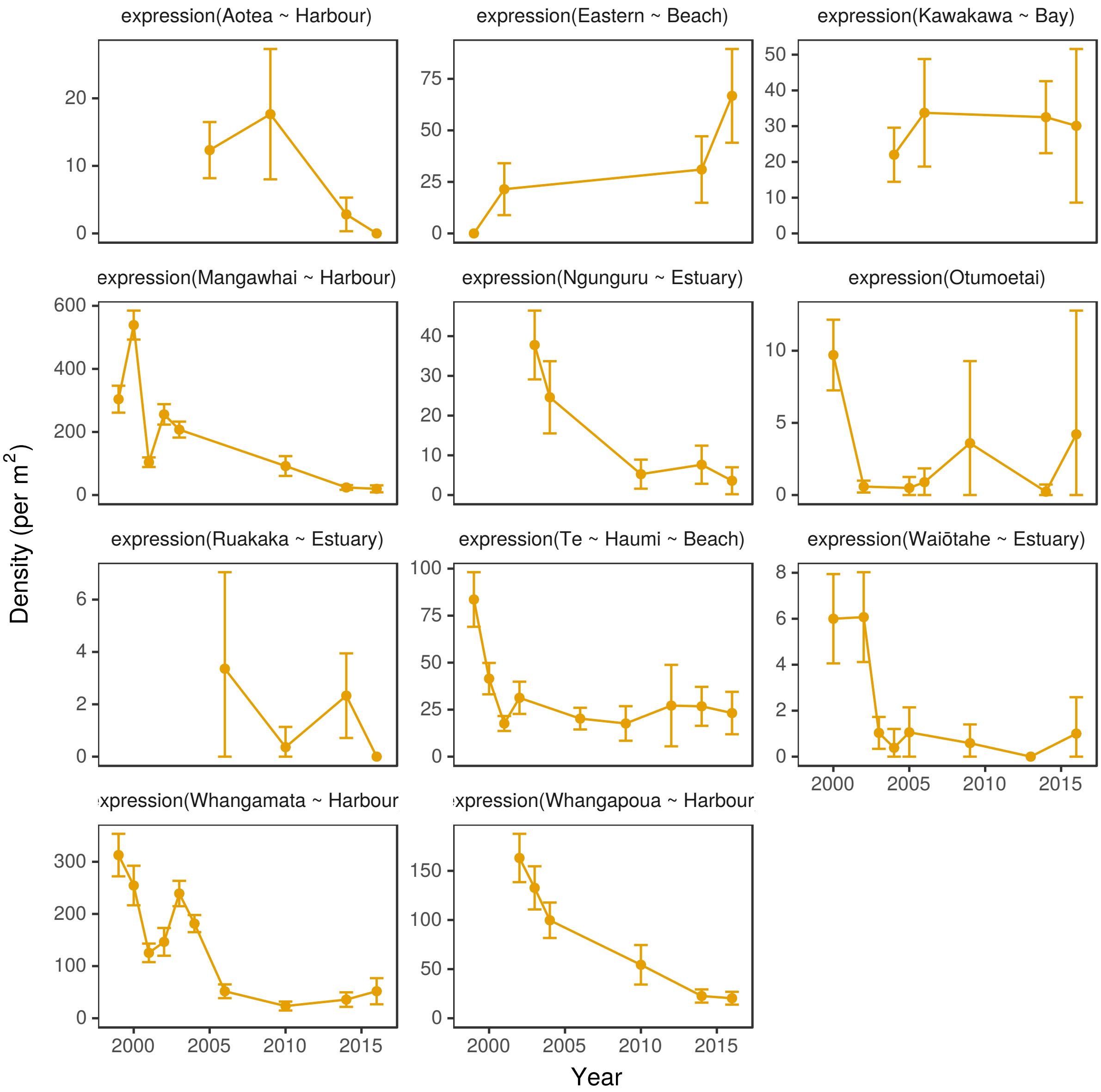


Figure 60: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% credible interval. (Note different scales on the y-axes.)

4.2 Pipi populations

Pipi populations were present at ten of the sites included in the 2016–17 survey (Table 68). The largest populations in the present study were at Waiōtahe Estuary and Te Haumi Beach. Pipi abundances at these two sites were 166.25 million (CV: 18.36%) pipi and 101.49 million (CV: 24.80%), respectively. The pipi population at Waiōtahe Estuary had also at the highest population density at 1388 pipi per m^2, followed by 1008 pipi per m^2 at Ruakaka Estuary. Density estimates were also relatively high (> 400 pipi per m^2) at Otumoetai (Tauranga Harbour), Te Haumi Beach, and Ngunguru Estuary. The lowest density estimate was at Kawakawa Bay (West), with six pipi per square metre.

At a number of sites, the population estimates had an associated uncertainty above the target CV of 20%. The reason for the relatively high uncertainty at these sites was due to low numbers or patchy distributions of pipi across the entire sampling extent. The pipi sampling generally focused on high-density beds, but the occurrence of some pipi (frequently recruits) in areas dominated by cockles affected the overall population estimates. In addition, the 0.5 m depth limit (at low tide) of the field sampling meant that parts of the pipi populations were inaccessible, further augmenting their patchy distribution. At the same time, the stratification of the sampling extent was primarily focused on ensuring that the CV values of the cockle population estimates were low. These strata may not be appropriate for pipi, especially given their subtidal distribution.

Similar to cockle populations at the northern sites, there were few large pipi (≥50 mm shell length) recorded in the 2016–17 survey, and this finding was consistent across sites and regions. Owing to their scarcity, large pipi were only a small part of the total population at most sites. The exception was at Whangamata Harbour, where individuals in this size class had the highest estimated abundance (3.87 million (CV: 20.49%) individuals) and made up about half of the total population.

The corresponding densities of large pipi were also low at most sites, and the maximum density in the current survey was 89 large pipi per m^2 at Whangapoua Harbour. Other comparatively high estimates included the populations at Whangamata Harbour of 50 large pipi per m^2, followed by Ruakaka Estuary with an estimated density of 20 large pipi per m^2. All other populations that contained large pipi had low estimates of less than ten large individuals per m^2.

Throughout the survey series, pipi showed a considerable decrease in density at each site, although the timing of this decline varied depending on the site (Figure 61). Most populations have had subsequent increases following the decline, with some populations returning to similar or higher densities than before the decline, such as at Ngunguru Estuary and Otumoetai (Tauranga Harbour). At Whangamata and Whangapoua harbours, pipi density estimates remained low in recent surveys, showing little sign of recovery.

The time-series of combined length-frequency distributions for the 2016–17 survey illustrated a generally consistent pattern over time, with medium-sized pipi determining the population size structure (Figure 62). In 2016–17, there was reduction in this cohort, accompanied by the presence of a second, smaller cohort of recruits at some sites. While early length-frequency distributions included large pipi, large-sized individuals have become fewer, as medium-sized pipi seem to fail to contribute to this size class over time.

This finding is highlighted in the time-series of density estimates of large pipi at the different sites (Figure 63). Although population densities of large pipi varied across sites at the start of the survey series, they showed a universal decline at all sites throughout the survey series. At some of the sites, the current assessment recorded an increase in the density of large pipi, but these increases were relatively small and generally not significant. Similar to the cockle populations at the current survey sites, the bivalve assessments highlight that large pipi show no little sign of recovery following marked decreases.

Table 68: Estimates of pipi abundance for all sites on which more than ten pipi were found in the 2016–17 survey. For each site, the table includes the estimated mean number, the mean density, and coefficient of variation (CV) for all pipi (Total) and for large pipi (≥50 mm shell length).

Survey site	Population estimate			Population ≥50 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Grahams Beach	8.77	33	25.66	0.00	0	
Kawakawa Bay	3.72	6	34.77	0.00	0	
Mangawhai Harbour	2.51	34	16.18	0.01	<1	>100
Ngunguru Estuary	28.43	453	6.03	0.23	4	31.61
Otumoetai	71.90	889	11.16	0.13	2	56.94
Ruakaka Estuary	56.53	1 008	30.91	1.12	20	46.67
Te Haumi Beach	101.49	795	24.80	0.55	4	37.83
Waiōtahe Estuary	166.25	1 388	18.36	1.05	9	43.81
Whangamata Harbour	7.65	99	24.21	3.87	50	20.49
Whangapoua Harbour	2.01	38	21.05	0.66	89	29.84

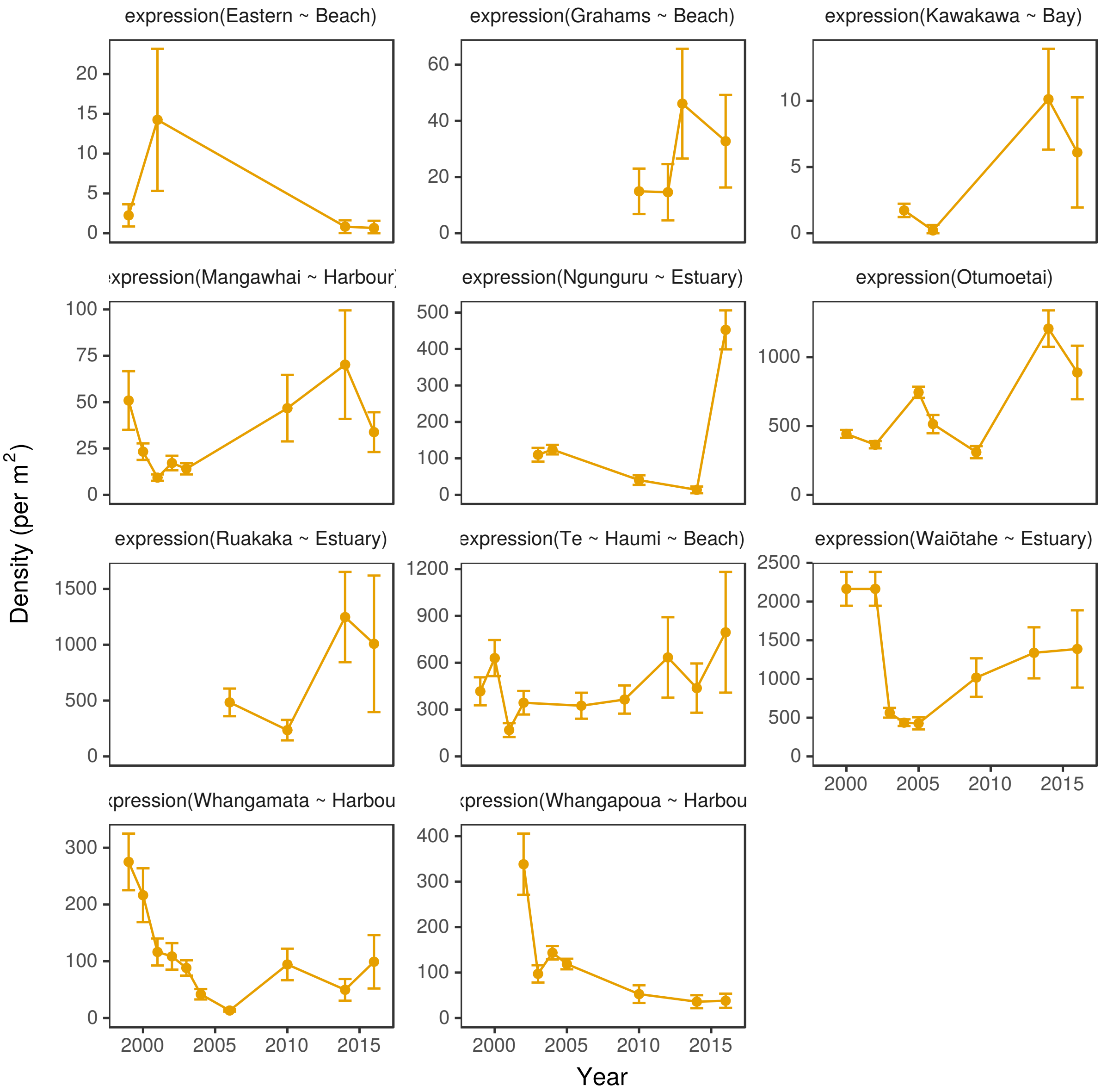


Figure 61: Estimated density of pipi for all sites included in the 2016–17 survey. Shown are the mean estimated densities across years, with bars indicating the 95% credible interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

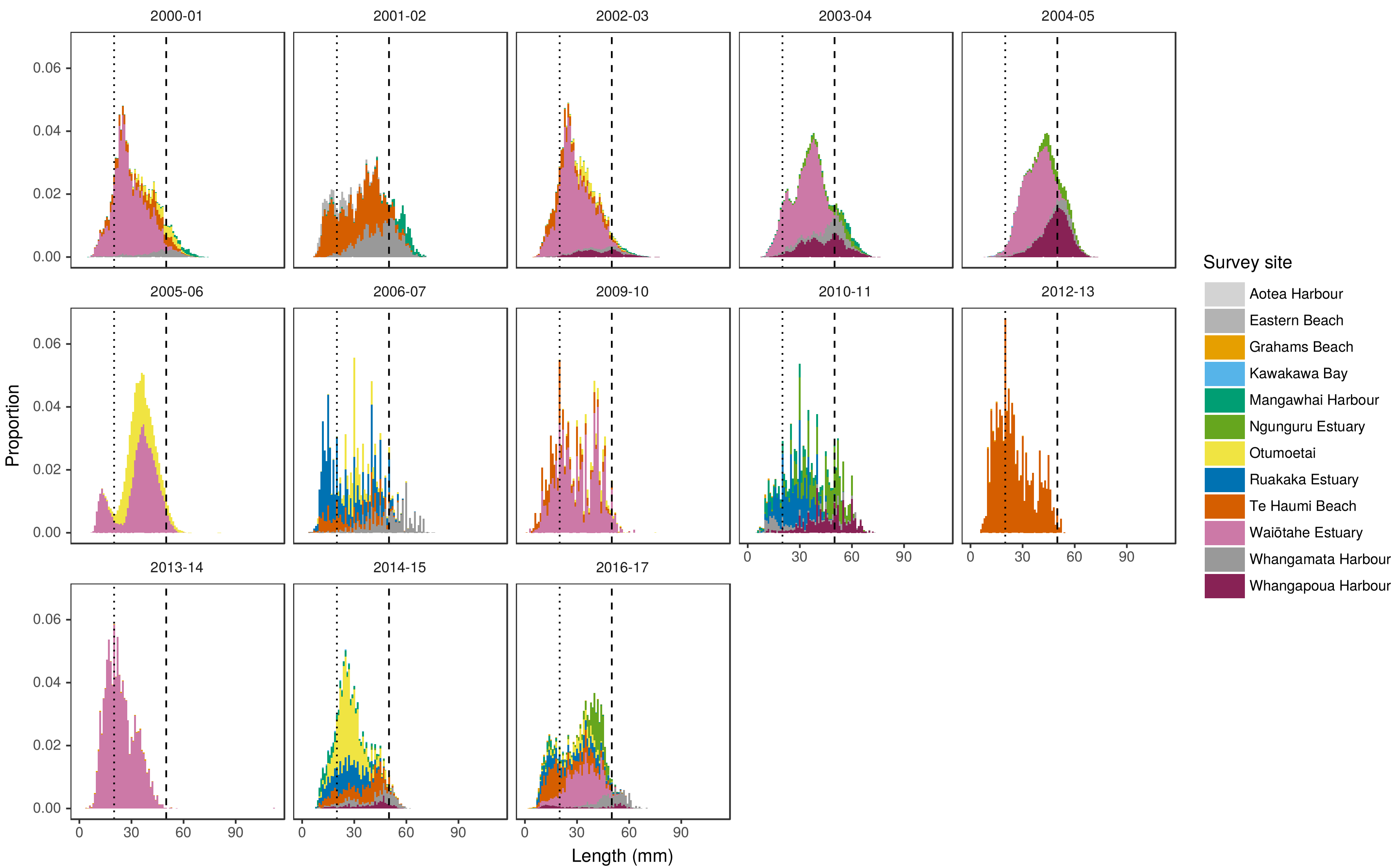


Figure 62: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2016–17 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

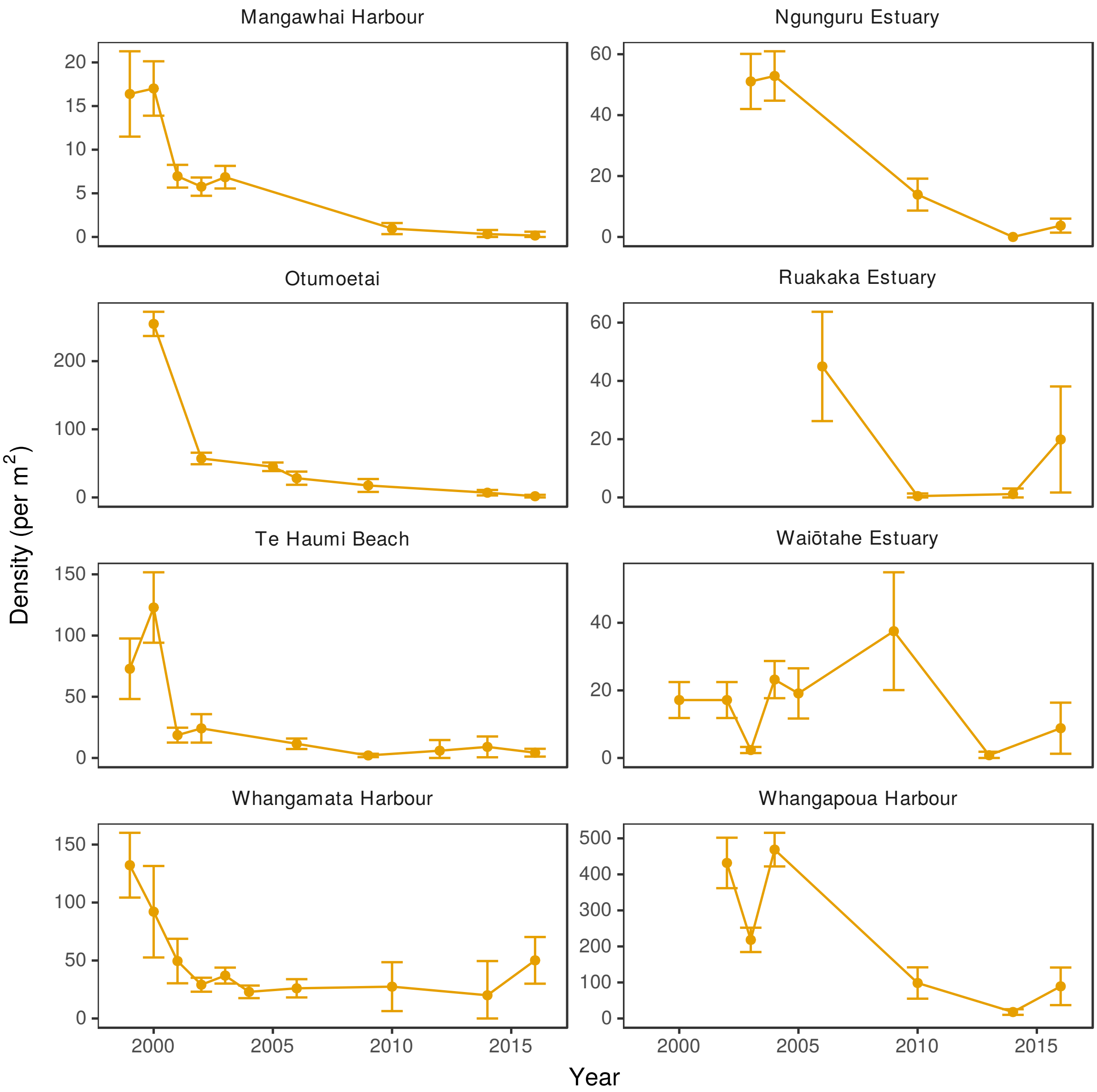


Figure 63: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% credible interval. (Note different scales on the y-axes.)

5. DISCUSSION

The current survey assessed northern North Island cockle and pipi populations across a range of different habitats, including sheltered estuaries, large inlets, and open beaches. It updates the survey series by providing recent population information of cockles and pipi at the selected sites. All of the 2016–17 sites had been surveyed previously, with the sampling frequency ranging from four to ten times since 1999–2000, depending on the site. Although the sampling extent at some of these sites has varied over time, changes in recent surveys (i.e., since 2013–14) have been relatively small, and survey information has included GPS-referenced sampling points.

For cockle populations, this spatial information was used to re-stratify sampling areas to better reflect the distribution and density of cockles, and thereby improve the sampling efficiency and lower the uncertainty of the estimates. Nevertheless, two of the 12 sites, Grahams Beach and Whangapoua Harbour, required phase-2 sampling. At the former site, the additional effort did not achieve a sufficient reduction in the CV to meet the target value of 20%, owing to the patchy distribution and low abundance of cockles at this site.

Other changes to the size and shape of sampling areas were prompted by spatial shifts in pipi populations or changes in their environment at some of the sites. As pipi beds are predominantly in high-flow areas and channels, changes in these dynamic environments sometimes necessitate adjustments to sampling strata to delineate the new boundaries of the pipi populations. For example, movement of the main tidal channel at Whangamata Harbour between 2014–15 and 2016–17 resulted in the upshore shift of the resident pipi bed to a shallow area characterised by considerable tidal movement. At other sites, such as Mangawhai Harbour, deepening of the channel meant that the previously sampled pipi beds was inaccessible (i.e., deeper than 0.5 m water depth at low tide) in 2016–17.

All of the 2016–17 survey sites supported cockle populations, and cockles were present at high densities (i.e., more than 400 individuals per m^2) at ten of the sites. The exceptions were Grahams Beach and Ruakaka Estuary, where cockles were notably less abundant. Although cockle densities were low at Grahams Beach, they reflected a considerable population increase since the previous surveys in 2012–13 and 2013–14. At Ruakaka Estuary, densities were still relatively high, but they reflected a marked reduction in the cockle population since the preceding assessment in 2014–15.

In addition to Grahams Beach, there were significant increases in the cockle populations at Eastern Beach, Kawakawa Bay (West), and Te Haumi. At the latter two sites, previous cockle densities were already relatively high, and the current increases were largely determined by an influx of recruits, which constituted about half of the current cockle populations at these two sites. Eastern Beach was different in that the preceding 2014–15 estimate of the cockle population was small, so that the current estimate reflected a notable increase. At the same time, the Eastern Beach population was dominated by medium-sized cockles, and recruits were only a small part (less than 8%) of the population. This finding indicates that recruits from a previous influx grew into the medium size class in the interim.

Eastern Beach contained a small population of large cockles, and this size class also showed an increase in 2016–17. Early surveys conducted in 1999–2000 and 2001–02 suggested that high mortality affected recruiting cockles at this site, preventing the re-establishment of the adult population after it had declined (Morrison et al. 1999). Data from the two most recent surveys in 2014–15 and 2016–17 indicate that the cockle population is recovering at Eastern Beach, including a number of large cockles. This recovery may have been supported by the permanent closure of Eastern Beach to fishing that was implemented in 1993.

For pipi, the only significant increase in 2016–17 was at Ngunguru Estuary, where low pipi densities preceded the present study. The current estimates were also the highest values throughout the survey series, although they only reflected a small increase in the population of large pipi. Instead, medium-sized individuals were prevalent in the population, and recruits were also only a small part (less than 8%) of it. Previous surveys at this site have focused on the pipi bed in the middle of the main channel (Pawley 2012, Berkenbusch & Neubauer 2015), whereas the current study sampled an area slightly further downstream as the previous pipi bed had become inaccessible. It is possible that the recorded increases at this site were owing to the change in sampling area. Nevertheless, the increase may also be related to the closure of this estuary to shellfish collections; bivalves at Ngunguru Estuary are currently protected through a rāhui that was declared in November 2015. This protection measure was prompted by concerns of population declines caused by fishing, and also by pipi mass mortalities in 2015 at this estuary.

A common occurrence across northern North Island survey sites was the decrease or disappearance of large individuals over time, affecting both cockle and pipi populations. At most sites, this decline occurred over a short period of time (i.e, between two surveys), with its timing dependent on the site. Only a few populations revealed subsequent increases in large individuals that persisted over time, and time-series data suggest that populations of large individuals are unlikely to recover once they have declined.

The exact reasons for the decline and lack of recovery of large cockles and pipi are unknown. Possible factors include the preferential take of large individuals in shellfish collections. Fishing may also impact medium-sized individuals as they become larger, explaining the observed lack of recruitment of these individuals to the large size class over time. Recruits and medium-sized cockles and pipi dominated populations at most of the 2016–17 survey sites, and individuals in the former size class frequently contributed at least 30% of the population.

While the lack of fishing data prevents an assessment of the impact of this activity on bivalve populations, environmental factors and other (human) impacts may also affect cockles and pipi at the survey sites. Examples of these impacts include faecal contaminations of estuaries and inlets as documented at Waiōtahe Estuary in early 2017, and bacterial infections, parasites and environmental stress that have been implicated in recent cockle and pipi mass mortalities at northern sites. In the context of these impacts, data from this survey series allow regular assessments of cockle and pipi populations across the northern North Island region, including comparisons over time.

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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 1999–00.

Survey site	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2009–10	2010–11	2012–13	2013–14	2014–15	2015–16	2016–17
Aotea Harbour							■		■				■		■
Bowentown Beach			■							■	■			■	
Cheltenham Beach														■	
Clarks Beach						■									
Cockle Bay									■	■	■	■		■	
Cornwallis Wharf			■												
Eastern Beach	■		■										■		■
Grahams Beach								■		■	■	■			■
Howick Harbour							■								
Kawakawa Bay (West)						■		■					■		■
Little Waihi Estuary		■		■	■	■		■	■		■	■		■	
Mangawhai Harbour	■	■	■	■	■					■			■		■
Marokopa Estuary							■			■				■	
Marsden Bank									■		■	■			
Mill Bay	■	■	■		■	■	■		■				■		
Ngunguru Estuary					■	■				■			■		■
Ohiwa Harbour			■				■	■	■		■			■	
Okoromai Bay	■		■	■	■	■		■	■		■	■		■	
Otumoetai		■		■			■	■	■				■		■
Papamoa Beach	■														
Pataua Estuary				■	■		■					■		■	
Raglan Harbour	■	■		■	■				■		■		■		
Ruakaka Estuary								■		■			■		■
Tairua Harbour	■	■	■	■			■	■		■		■		■	
Te Haumi Beach	■	■	■	■				■	■		■		■		■
Umupuia Beach	■	■	■	■	■	■	■	■	■	■	■	■		■	
Waikawau Beach	■	■				■	■					■			
Waiōtahe Estuary				■	■	■	■		■			■			■
Whangamata 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 2016–17. Surveys are ordered by site and year.

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
Aotea Harbour	2005–06	17 Jan–18 Jan	9.60	AKI2005-01
	2009–10	26 Mar–13 Jul	28.10	AKI2009-01
	2014–15	19 Feb	19.46	AKI2014-01
	2016–17	9 Feb	19.46	AKI2016-01
Bowentown Beach	2001–02	26 Apr–25 May	1.58	AKI2001-01
	2010–11	18 Mar	1.58	AKI2010-01
	2012–13	8 Feb	1.58	AKI2012-01
	2015–16	20 Jan	1.50	AKI2015-01
Cheltenham Beach	2015–16	14 Jan	31.92	AKI2015-01
Clarks Beach	2004–05	3 Feb–24 Feb	144.71	AKI2004-01
Cockle Bay	2009–10	16 Feb	16.00	AKI2009-01
	2010–11	5 May	16.00	AKI2010-01
	2012–13	31 Jan	16.00	AKI2012-01
	2013–14	29 Mar	15.77	AKI2013-01
	2015–16	18 Jan	15.77	AKI2015-01
Cornwallis Wharf	2001–02	26 Mar–20 Apr	2.65	AKI2001-01
Eastern Beach	1999–00	15 May–30 Jun	48.00	AKI1999-01
	2001–02	14 Mar–16 Apr	43.38	AKI2001-01
	2014–15	27 Jan–18 Feb	41.42	AKI2014-01
	2016–17	16 Feb	22.58	AKI2016-01
Grahams Beach	2006–07	20 Apr	24.75	AKI2006-01
	2010–11	17 May	25.15	AKI2010-01
	2012–13	11 Mar	20.06	AKI2012-01
	2013–14	28 Mar	26.76	AKI2013-01
	2016–17	10 Feb–28 Feb	26.78	AKI2016-01
Howick Harbour	2005–06	23 Dec–24 Jan	6.90	AKI2005-01
Kawakawa Bay (West)	2004–05	5 Feb–8 Apr	60.37	AKI2004-01
	2006–07	19 Apr	62.94	AKI2006-01
	2014–15	17 Feb–25 Feb	60.90	AKI2014-01
	2016–17	27 Feb	60.89	AKI2016-01
Little Waihi Estuary	2000–01	21 Mar–31 Mar	3.00	AKI2000-01
	2002–03	30 Jan–1 Feb	3.00	AKI2002-01
	2003–04	7 Jan–19 Jan	3.12	AKI2003-01
	2004–05	14 Jan–15 Jan	3.75	AKI2004-01
	2006–07	15 Jun–28 Jun	3.16	AKI2006-01
	2009–10	2 Mar	13.92	AKI2009-01
	2012–13	10 Feb	15.42	AKI2012-01
	2013–14	19 Mar–20 Mar	17.09	AKI2013-01
	2015–16	8 Feb–11 Feb	18.38	AKI2015-01
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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2014–15	21 Jan–22 Jan	8.55	AKI2014-01
	2016–17	11 Feb–16 Feb	8.59	AKI2016-01
Marokopa Estuary	2005–06	18 Feb–20 Feb	2.35	AKI2005-01
	2010–11	16 May	2.35	AKI2010-01
	2015–16	12 Feb–13 Feb	2.58	AKI2015-01
Marsden Bank	2009–10	13 Nov	11.51	IPA2009-12
	2012–13	12 Dec	6.31	AKI2012-01
	2013–14	2 Feb	15.43	AKI2013-01
Mill Bay	1999–00	4 May–30 Jun	4.60	AKI1999-01
	2000–01	20 Feb–23 Feb	4.80	AKI2000-01
	2001–02	20 Mar–22 Apr	4.50	AKI2001-01
	2003–04	26 Jan–28 Jan	4.50	AKI2003-01
	2004–05	24 Dec–24 Jan	4.50	AKI2004-01
	2005–06	20 Dec–24 Dec	4.50	AKI2005-01
	2009–10	13 May	4.95	AKI2009-01
	2014–15	26 Feb	4.88	AKI2014-01
Ngunguru Estuary	2003–04	6 Mar–7 Mar	1.70	AKI2003-01
	2004–05	6 Feb–7 Feb	1.80	AKI2004-01
	2010–11	23 Mar	1.80	AKI2010-01
	2014–15	23 Jan–24 Jan	5.46	AKI2014-01
	2016–17	13 Feb–15 Feb	6.28	AKI2016-01
Ohiwa Harbour	2001–02	9 Apr–11 Apr	2.25	AKI2001-01
	2005–06	25 Feb–26 Feb	2.70	AKI2005-01
	2006–07	13 Jun–29 Jun	5.70	AKI2006-01
	2009–10	3 Mar	2.10	AKI2009-01
	2012–13	9 Feb–15 Mar	2.63	AKI2012-01
	2015–16	9 Feb–10 Feb	4.58	AKI2015-01
Okoromai Bay	1999–00	19 Apr–24 Apr	20.00	AKI1999-01
	2001–02	8 Apr–12 Apr	24.00	AKI2001-01
	2002–03	26 Dec–29 Dec	20.00	AKI2002-01
	2003–04	17 Mar–20 Mar	20.00	AKI2003-01
	2004–05	15 Jan–16 Jan	20.00	AKI2004-01
	2006–07	20 Mar	20.00	AKI2006-01
	2009–10	17 Feb	20.00	AKI2009-01
	2012–13	30 Jan	20.00	AKI2012-01
	2013–14	31 Mar	19.84	AKI2013-01
	2015–16	11 Jan	19.84	AKI2015-01
Otumoetai	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
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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2005–06	14 Feb–16 Feb	10.45	AKI2005-01
	2013–14	3 Feb–6 Feb	26.30	AKI2013-01
	2015–16	12 Jan–13 Jan	27.89	AKI2015-01
Raglan Harbour	1999–00	26 May–30 Jun	10.10	AKI1999-01
	2000–01	13 Feb–10 Mar	10.04	AKI2000-01
	2002–03	13 Jan–16 Jan	8.24	AKI2002-01
	2003–04	14 Jan–16 Jan	8.24	AKI2003-01
	2009–10	26 Apr	9.20	AKI2009-01
	2012–13	11 Jan	8.24	AKI2012-01
	2014–15	20 Feb–23 Feb	7.24	AKI2014-01
Ruakaka Estuary	2006–07	21 Mar	7.00	AKI2006-01
	2010–11	22 Mar	11.01	AKI2010-01
	2014–15	25 Jan–26 Jan	6.51	AKI2014-01
	2016–17	14 Feb	5.61	AKI2016-01
Tairua Harbour	1999–00	1 Apr–1 May	3.70	AKI1999-01
	2000–01	15 Feb–16 Feb	3.90	AKI2000-01
	2001–02	23 May–24 May	3.90	AKI2001-01
	2002–03	23 Feb–28 Mar	3.90	AKI2002-01
	2005–06	14 Jan–15 Jan	3.90	AKI2005-01
	2006–07	3 May–1 Aug	4.80	AKI2006-01
	2010–11	20 Apr	5.80	AKI2010-01
	2013–14	13 Mar–22 Mar	9.38	AKI2013-01
	2015–16	6 Feb–7 Feb	8.17	AKI2015-01
Te Haumi Beach	1999–00	7 Mar–30 Mar	10.00	AKI1999-01
	2000–01	12 Mar	13.53	AKI2000-01
	2000–01	15 Jan–26 Jan	9.90	AKI2000-01
	2001–02	15 Mar–15 Apr	9.90	AKI2001-01
	2002–03	21 Jan–22 Apr	9.90	AKI2002-01
	2006–07	22 Mar	9.81	AKI2006-01
	2009–10	18 Feb	12.06	AKI2009-01
	2012–13	13 Dec	12.06	AKI2012-01
	2014–15	24 Jan–26 Jan	12.78	AKI2014-01
	2016–17	12 Feb	12.77	AKI2016-01
Umupuia Beach	1999–00	1 Apr–12 Apr	25.00	AKI1999-01
	2000–01	15 Feb–16 Feb	36.00	AKI2000-01
	2001–02	28 Mar–12 Apr	36.00	AKI2001-01
	2002–03	28 Dec–2 Jan	36.00	AKI2002-01
	2003–04	25 Mar–28 Mar	36.00	AKI2003-01
	2004–05	22 Jan–23 Jan	36.00	AKI2004-01
	2005–06	28 Jan–29 Jan	36.00	AKI2005-01
	2006–07	18 Apr	36.00	AKI2006-01
	2009–10	15 Feb	36.00	AKI2009-01
	2010–11	4 May	36.00	AKI2010-01
	2012–13	13 Mar	36.00	AKI2012-01
	2013–14	30 Mar–1 Apr	33.86	AKI2013-01
	2015–16	18 Jan–19 Jan	33.90	AKI2015-01
Waikawau Beach	1999–00	20 May–30 Jun	2.90	AKI1999-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2000–01	24 Feb–15 May	2.70	AKI2000-01
	2004–05	18 Jan–10 Mar	3.10	AKI2004-01
	2005–06	15 Feb–27 Feb	3.10	AKI2005-01
	2013–14	21 Mar		AKI2013-01
Waiōtahe Estuary	2002–03	7 Feb–10 Feb	8.50	AKI2002-01
	2003–04	21 Jan–24 Jan	8.50	AKI2003-01
	2004–05	21 Jan–25 Jan	9.50	AKI2004-01
	2005–06	10 Feb–12 Feb	9.50	AKI2005-01
	2009–10	4 Mar	9.50	AKI2009-01
	2013–14	17 Mar–20 Mar	11.23	AKI2013-01
	2016–17	22 Feb	11.98	AKI2016-01
Whangamata Harbour	1999–00	20 May–29 May	5.48	AKI1999-01
	2000–01	15 Feb–16 Feb	5.48	AKI2000-01
	2001–02	9 May–26 May	5.48	AKI2001-01
	2002–03	9 Mar–28 Mar	5.48	AKI2002-01
	2003–04	1 Jan–31 Jan	5.48	AKI2003-01
	2004–05	6 Feb–8 Feb	5.48	AKI2004-01
	2006–07	2 May–2 Aug	24.61	AKI2006-01
	2010–11	19 Apr	5.89	AKI2010-01
	2014–15	28 Jan–30 Jan	7.62	AKI2014-01
	2016–17	24 Feb–26 Feb	7.71	AKI2016-01
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
Whangateau Harbour	2001–02	7 Apr–22 May	64.19	AKI2001-01
	2003–04	17 Dec–2 Mar	64.15	AKI2003-01
	2004–05	2 Feb–26 Mar	64.15	AKI2004-01
	2006–07	19 Mar–2 May	64.15	AKI2006-01
	2009–10	18 Mar–14 Jul	64.51	AKI2009-01
	2010–11	19 May–20 May	64.15	AKI2010-01
	2012–13	14 Dec–17 Dec	64.20	AKI2012-01
	2013–14	29 Jan–6 Feb	110.91	AKI2013-01
	2015–16	15 Jan–17 Jan	110.71	AKI2015-01
Whitianga Harbour	2012–13	7 Feb	7.08	AKI2012-01
	2015–16	5 Feb	6.10	AKI2015-01

APPENDIX B: Sediment properties

Table B-3: Sediment organic content and sediment grain size distributions at sites surveyed in 2015–16 as part of the northern North Island bivalve surveys.Position of the sampling points is indicated in decimal degrees (World Geodetic System 1984). Sediments grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm. Missing cells indicate missing data.

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Aotea Harbour	A	1	-38.01707	174.82390	1.5	8.2	12.5	52.8	14.3	2.7	9.4
	A	2	-38.01732	174.82478	1.1	6.4	13.6	57.1	20.8	1.4	0.8
	A	3	-38.01636	174.82542	1.3	11.3	16.8	54.8	14.1	0.7	2.2
	A	5	-38.01798	174.82568	1.4	12.3	17.5	47.3	18.6	3.4	1.0
	A	4	-38.01601	174.82611	1.8	7.6	26.8	47.2	10.8	1.6	6.0
	A	6	-38.01282	174.83214	1.2	4.2	23.5	65.6	4.5	0.6	1.6
	B	2	-38.01673	174.82594	1.7	13.2	16.0	48.9	15.7	2.6	3.6
	B	5	-38.01693	174.82620	1.1	11.5	18.1	49.0	13.4	2.4	5.6
	B	6	-38.01745	174.82626	1.9	14.9	18.7	47.5	10.3	2.4	6.3
	B	3	-38.01741	174.82569	1.2	5.2	10.5	49.4	25.2	5.0	4.8
	B	4	-38.01667	174.82624	1.2	9.2	19.2	57.6	11.9	1.4	0.7
	B	1	-38.01726	174.82552	1.5	14.2	14.7	54.1	12.6	1.5	3.0
	C	1	-38.01519	174.82619	1.2	8.8	18.9	54.3	11.3	1.2	5.6
	C	2	-38.01591	174.82664	0.9	6.9	15.3	53.7	14.7	3.4	5.9
	C	4	-38.01299	174.83013	1.2	8.7	22.6	63.3	4.1	0.7	0.7
	C	6	-38.01262	174.83014	1.4	11.0	30.9	53.9	2.9	0.6	0.7
	C	5	-38.01427	174.83007	1.6	11.6	33.3	46.7	6.1	0.5	1.8
	C	3	-38.01444	174.82858	2.4	9.9	23.4	62.0	3.8	0.6	0.3
	D	1	-38.01558	174.82751	1.4	6.0	11.2	54.7	13.6	1.7	12.8
	D	4	-38.01391	174.82888	1.5	7.6	36.2	49.9	3.7	0.8	1.8
	D	3	-38.01377	174.82878	1.7	4.5	31.9	56.4	5.3	0.8	1.0
	D	2	-38.01322	174.82900	1.1	7.7	22.6	58.4	8.9	1.0	1.4
	D	6	-38.01356	174.82938	1.0	9.5	23.3	60.6	5.3	0.5	0.9
	D	5	-38.01307	174.82949	1.2	7.8	31.9	54.8	3.8	0.8	1.0

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Eastern Beach	A	6	-36.87682	174.92016	0.6	0.7	29.4	69.1	0.8	0.1	0.0
	A	7	-36.87740	174.92096	0.7	1.6	15.7	80.9	1.5	0.3	0.0
	A	5	-36.87639	174.92027	0.7	0.4	24.4	74.4	0.7	0.1	0.0
	A	4	-36.87572	174.91924	0.7	0.6	25.5	73.1	0.7	0.1	0.0
	A	3	-36.87568	174.91880	1.0	2.3	31.2	65.2	1.0	0.0	0.3
	A	2	-36.87538	174.91852	0.9	0.3	20.9	77.2	1.3	0.3	0.0
	A	1	-36.87487	174.91792	1.1	0.0	31.9	66.9	1.2	0.0	0.0
	B	2	-36.87056	174.91359	1.2	0.7	27.7	68.6	2.2	0.8	0.0
	B	1	-36.87145	174.91321	2.4	7.5	24.8	25.8	16.5	9.5	15.9
	B	9	-36.87711	174.91983	1.4	2.6	42.7	52.0	2.5	0.1	0.0
	B	8	-36.87693	174.91943	1.7	3.1	32.1	60.8	3.9	0.2	0.0
	B	7	-36.87652	174.91906	1.0	1.7	27.3	63.9	6.9	0.3	0.0
	B	6	-36.87416	174.91753	0.9	1.2	29.6	67.6	1.6	0.0	0.0
	B	5	-36.87372	174.91702	1.4	2.1	43.1	53.8	0.9	0.1	0.0
	B	4	-36.87293	174.91531	1.2	3.0	55.9	40.0	0.8	0.1	0.3
	B	3	-36.87236	174.91411	1.2	0.4	7.7	47.0	43.4	1.5	0.0
	C	1	-36.86851	174.91238	1.0	1.6	16.6	80.6	0.7	0.5	0.0
	C	7	-36.86908	174.91329	0.8	1.0	14.9	82.4	1.5	0.2	0.0
	C	4	-36.86908	174.91291	1.0	1.0	19.8	78.8	0.4	0.1	0.0
	C	8	-36.86945	174.91321	1.0	1.5	19.3	77.2	1.7	0.1	0.1
	C	5	-36.86954	174.91267	1.6	1.2	16.6	77.4	4.6	0.3	0.0
	C	2	-36.86946	174.91237	1.6	2.2	25.6	68.6	3.2	0.3	0.0
	C	3	-36.86989	174.91238	1.5	0.9	8.3	63.3	25.1	2.4	0.0
	C	6	-36.86981	174.91258	4.9	22.4	16.4	32.4	9.3	9.0	10.5
Grahams Beach	A	2	-37.04728	174.66155	1.3	1.7	1.1	27.4	50.5	11.3	8.0
	A	1	-37.04715	174.66155	1.1	0.1	1.1	36.8	56.5	4.3	1.1
	A	3	-37.04889	174.66422	1.3	0.0	2.7	43.5	35.4	6.3	12.2

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	4	-37.04925	174.66403	1.1	1.2	1.6	51.2	39.0	7.0	0.1
	A	8	-37.05413	174.66707	0.6	0.8	2.1	28.9	48.7	19.6	0.0
	A	9	-37.05668	174.66716	0.7	0.0	0.2	3.3	36.0	58.6	1.9
	A	7	-37.05304	174.66639	1.3	2.1	2.0	38.4	34.3	22.8	0.4
	A	6	-37.05263	174.66623	1.2	2.4	2.8	37.2	32.4	22.3	2.9
	A	5	-37.05200	174.66613	0.9	0.0	3.3	44.2	38.9	13.4	0.2
	B	2	-37.04900	174.66148	1.1	1.7	0.2	5.4	40.9	50.0	1.8
	B	1	-37.04843	174.66194	0.7	0.0	0.7	20.6	67.1	11.6	0.1
	B	3	-37.04980	174.66288	1.0	0.2	0.8	11.5	52.0	28.4	7.1
	B	7	-37.05515	174.66659	0.9	1.1	0.2	5.6	67.2	25.9	0.1
	B	4	-37.05144	174.66467	0.7	0.0	0.8	15.0	78.9	5.3	0.0
	B	5	-37.05203	174.66496	1.2	0.0	2.0	21.5	58.3	14.5	3.7
	B	8	-37.05579	174.66727	0.6	0.0	0.4	10.7	60.9	26.9	1.1
	B	6	-37.05451	174.66664	0.8	0.0	0.3	8.7	54.6	36.4	0.0
	C	1	-37.04923	174.66225	1.0	0.0	0.6	21.2	63.3	12.6	2.3
	C	2	-37.05162	174.66386	1.0	0.5	1.6	21.0	55.9	13.8	7.2
	C	3	-37.05177	174.66389	0.9	1.8	1.3	20.7	50.5	17.7	8.1
	C	7	-37.05183	174.66425	1.1	0.7	1.4	17.2	65.0	15.2	0.5
	C	6	-37.05147	174.66438	0.6	0.7	2.6	23.4	63.0	10.1	0.2
	C	5	-37.05109	174.66435	0.7	2.5	1.8	21.9	67.8	6.0	0.0
	C	4	-37.05071	174.66410	1.0	0.1	1.1	18.2	57.2	22.8	0.7
Kawakawa Bay	A	1	-36.94438	175.15139	2.6	5.8	50.7	24.6	8.6	5.6	4.8
	A	2	-36.94721	175.15386	1.4	6.1	16.3	47.5	18.6	6.4	5.2
	A	3	-36.94625	175.15662	2.4	10.6	22.8	34.1	15.6	5.1	11.9
	A	4	-36.94692	175.15679	1.3	7.3	35.8	47.5	4.1	4.2	1.2
	A	5	-36.94917	175.15655	0.8	4.8	16.9	52.4	17.1	3.1	5.6
	A	6	-36.94897	175.15728	0.9	9.0	64.1	21.3	4.2	0.8	0.7

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	7	-36.94956	175.15794	1.5	13.4	55.3	22.8	3.1	1.5	3.9
	A	8	-36.94778	175.15813	3.0	6.3	6.2	11.2	4.8	11.1	60.4
	A	9	-36.94792	175.16372	1.5	7.4	16.3	59.3	12.9	1.8	2.3
	B	1	-36.94312	175.15012	1.9	5.6	59.2	29.5	1.1	1.1	3.5
	B	2	-36.94400	175.15066	1.3	3.7	50.3	37.2	4.0	1.3	3.5
	B	3	-36.94117	175.15177	0.9	4.8	38.0	38.1	11.9	3.0	4.2
	B	4	-36.94174	175.15118	1.3	3.4	42.3	37.7	5.3	2.9	8.5
	B	5	-36.94291	175.15228	0.9	2.3	23.8	72.7	0.7	0.4	0.1
	B	6	-36.94304	175.15341	0.9	3.0	25.2	70.4	1.1	0.3	0.0
	B	7	-36.94757	175.15338	2.2	5.2	4.0	8.3	6.0	8.5	68.0
	C	1	-36.94540	175.15311	2.1	6.7	45.2	26.3	1.3	1.0	19.5
	C	2	-36.94465	175.15356	1.3	5.3	28.5	57.3	8.0	0.9	0.0
	C	3	-36.94870	175.15880	1.1	4.6	40.7	53.7	0.4	0.5	0.2
	C	4	-36.94998	175.15875	1.3	6.1	49.9	42.9	0.3	0.6	0.1
	C	5	-36.94786	175.15965	1.0	0.0	53.1	44.5	2.2	0.1	0.0
	C	6	-36.94902	175.15934	1.5	3.2	53.5	42.1	0.7	0.3	0.2
	C	7	-36.94779	175.16098	4.3	70.7	7.3	6.9	5.1	4.9	5.1
	C	8	-36.94872	175.16180	1.0	2.6	49.9	43.1	4.1	0.3	0.1
Mangawhai Harbour	A	6	-36.08599	174.59085	7.6	0.9	1.4	57.9	10.6	2.5	26.8
	A	2	-36.08634	174.59061	0.3	2.4	2.4	61.9	26.1	2.4	4.9
	A	5	-36.08902	174.59057	1.2	4.3	2.4	46.8	22.2	5.1	19.1
	A	4	-36.08753	174.59037	0.6	0.3	0.5	49.9	43.1	1.5	4.8
	A	1	-36.08745	174.59027	0.6	0.0	0.9	60.3	36.7	1.3	0.7
	A	3	-36.08727	174.59055	0.8	1.9	1.5	40.0	25.0	0.8	30.8
	B	7	-36.08370	174.59092	0.7	2.2	0.9	44.3	44.7	6.9	1.2
	B	4	-36.08469	174.59064	0.7	1.5	0.8	41.5	49.7	4.4	2.1
	B	2	-36.08565	174.59048	0.7	2.7	1.7	61.2	27.2	4.3	2.9

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	1	-36.08521	174.59053	0.7	2.4	2.1	65.1	25.5	3.5	1.4
	B	10	-36.08357	174.59141	0.8	0.0	1.1	54.1	39.8	4.1	0.9
	B	8	-36.08471	174.59114	0.6	1.6	1.4	61.9	28.3	3.3	3.4
	B	3	-36.08449	174.59085	0.6	1.4	1.0	39.0	51.0	6.6	1.1
	B	5	-36.08503	174.59081	0.9	2.6	2.3	75.5	16.4	1.0	2.2
	B	9	-36.08494	174.59089	1.3	1.4	1.9	81.2	14.7	0.4	0.3
	B	6	-36.08523	174.59067	0.6	0.0	2.1	74.1	20.1	1.9	1.7
	D	7	-36.09793	174.59216	0.4	0.9	1.0	67.7	29.0	0.9	0.5
	D	1	-36.09662	174.59150	0.6	0.8	3.9	71.9	15.9	4.0	3.5
	D	3	-36.09671	174.59198	0.3	0.0	2.4	78.3	18.9	0.3	0.1
	D	6	-36.09660	174.59222	0.5	2.4	2.1	80.4	14.6	0.3	0.2
	D	4	-36.09758	174.59185	0.6	2.6	1.5	75.6	18.3	0.7	1.3
	D	2	-36.09807	174.59152	0.9	0.0	3.7	87.2	7.8	0.4	0.8
	D	5	-36.09865	174.59189	0.7	1.4	5.6	78.5	9.1	1.8	3.6
	D	8	-36.09891	174.59291	0.6	1.3	1.6	64.5	29.4	1.4	1.8
Ngunguru Estuary	A	1	-35.63469	174.50096	1.9	1.7	10.7	60.1	17.8	9.5	0.1
	A	6	-35.63588	174.50300	1.8	2.9	11.8	80.6	2.3	0.9	1.5
	A	5	-35.63540	174.50223	2.1	3.6	23.2	71.1	1.6	0.5	0.1
	A	3	-35.63562	174.50212	2.3	3.5	20.6	74.2	0.9	0.3	0.5
	A	4	-35.63591	174.50210	2.8	5.1	19.9	73.3	0.9	0.4	0.4
	A	8	-35.63797	174.50414	1.2	0.9	9.7	78.5	9.3	1.1	0.5
	A	7	-35.63793	174.50423	1.2	1.8	7.8	78.5	9.8	1.4	0.7
	A	9	-35.63587	174.50484	1.1	0.9	8.8	66.5	17.0	6.8	0.0
	A	2	-35.63497	174.50081	1.9	3.7	9.2	61.9	15.8	8.7	0.6
	B	4	-35.63519	174.50231	2.4	4.2	14.4	74.6	2.9	1.0	2.9
	B	2	-35.63528	174.50202	2.1	3.3	24.2	69.2	2.3	0.5	0.5
	B	1	-35.63424	174.50122	1.6	1.7	6.5	64.9	14.9	10.0	2.0

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	9	-35.63766	174.50264	1.6	1.2	9.6	78.4	2.0	1.9	6.9
	B	5	-35.63553	174.50240	2.5	26.3	15.3	56.8	0.9	0.3	0.5
	B	8	-35.63644	174.50257	2.4	4.2	20.1	67.8	1.3	1.3	5.4
	B	3	-35.63469	174.50239	1.8	0.3	2.7	79.6	16.0	1.4	0.1
	B	7	-35.63495	174.50257	1.6	0.0	2.7	73.3	21.2	2.1	0.7
	B	6	-35.63458	174.50248	1.5	1.1	1.5	79.7	16.2	1.2	0.4
	B	10	-35.63518	174.50285	1.5	0.5	2.7	75.1	19.5	1.9	0.3
	B	11	-35.63544	174.50270	2.4	2.9	14.9	79.3	2.4	0.5	0.0
	B	12	-35.63713	174.50444	0.9	1.6	7.7	78.8	9.7	1.0	1.2
	C	2	-35.63229	174.50273	1.6	2.2	14.7	63.4	7.1	7.3	5.4
	C	3	-35.63246	174.50267	1.7	0.8	7.1	54.6	21.3	14.9	1.2
	C	1	-35.63263	174.50250	0.8	2.1	26.4	47.7	6.8	8.0	9.0
Otumoetai	A	11	-37.66457	176.15153	1.4	1.6	4.8	67.5	20.4	5.7	0.0
	A	13	-37.66446	176.15210	1.3	3.4	5.2	65.6	19.6	5.3	0.8
	A	8	-37.66458	176.15113	1.1	2.2	5.7	65.3	16.7	8.9	1.1
	A	9	-37.66426	176.15129	1.1	1.6	6.0	72.3	14.0	3.7	2.4
	A	10	-37.66420	176.15158	1.4	2.2	7.6	75.5	12.0	2.6	0.0
	A	12	-37.66442	176.15169	1.5	1.0	3.0	67.6	23.4	4.8	0.1
	A	6	-37.66420	176.15077	2.0	2.3	5.8	66.2	11.9	4.1	9.7
	A	4	-37.66420	176.15049	1.7	3.9	9.8	67.4	12.9	5.2	0.8
	A	7	-37.66435	176.15074	1.4	1.5	8.0	58.4	15.3	12.9	4.0
	A	2	-37.66460	176.15020	1.2	2.2	5.8	49.1	23.0	16.5	3.3
	A	1	-37.66463	176.14999	1.4	1.6	10.1	62.4	17.2	6.9	1.8
	A	5	-37.66452	176.15061	1.4	1.6	5.5	64.5	16.6	11.2	0.6
	A	3	-37.66427	176.15026	1.3	1.3	7.2	57.7	17.9	12.4	3.4
	B	1	-37.66411	176.14996	1.4	1.9	8.5	70.2	16.2	3.0	0.1
	B	3	-37.66382	176.15074	1.7	4.2	8.1	67.2	17.7	2.6	0.3

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	2	-37.66394	176.15015	1.5	4.0	10.7	66.7	15.6	2.4	0.5
	B	4	-37.66407	176.15069	1.7	2.2	5.9	72.3	15.7	3.5	0.4
	B	9	-37.66413	176.15161	1.5	1.9	8.4	75.2	13.0	1.5	0.0
	B	8	-37.66391	176.15164	1.4	2.8	9.4	68.9	17.6	1.3	0.0
	B	10	-37.66377	176.15218	1.6	1.3	7.7	75.0	14.6	1.3	0.1
	B	5	-37.66377	176.15094	1.5	1.6	7.7	73.4	14.6	2.2	0.5
	B	6	-37.66382	176.15138	1.6	1.6	8.1	75.5	13.5	1.3	0.0
	B	11	-37.66410	176.15206	1.6	2.5	7.3	68.5	18.5	3.2	0.0
	B	7	-37.66413	176.15125	1.3	1.8	8.1	78.1	11.0	1.1	0.0
Ruakaka Estuary	AN	1	-35.90165	174.45686	0.5	0.8	1.0	47.4	47.4	3.3	0.1
	AN	7	-35.90132	174.45769	0.6	0.3	1.5	52.1	42.0	4.1	0.0
	AN	5	-35.90145	174.45742	0.8	0.9	1.9	39.7	54.9	2.5	0.1
	AN	2	-35.90159	174.45721	0.5	1.0	1.6	64.3	31.2	1.9	0.0
	AN	3	-35.90171	174.45733	1.2	0.5	2.7	63.8	30.2	2.8	0.0
	AN	8	-35.90240	174.45769	0.1	1.0	0.3	24.1	60.0	12.7	2.0
	AN	6	-35.90215	174.45752	0.5	0.5	1.5	63.7	31.8	2.4	0.0
	AN	4	-35.90214	174.45730	1.2	0.5	1.8	83.5	13.9	0.4	0.0
	AS	8	-35.90332	174.45810	0.5	0.6	0.3	41.9	50.5	4.5	2.2
	AS	7	-35.90326	174.45753	0.7	1.2	-1.9	62.2	36.2	2.3	0.1
	AS	6	-35.90326	174.45710	0.7	0.8	1.0	56.8	37.0	4.3	0.1
	AS	5	-35.90298	174.45723	0.5	1.0	0.6	46.7	49.5	2.1	0.1
	AS	4	-35.90269	174.45649	0.5	0.0	0.8	74.3	24.5	0.4	0.0
	AS	2	-35.90245	174.45595	0.8	1.4	2.6	78.8	14.3	1.4	1.6
	AS	1	-35.90233	174.45573	0.6	0.7	3.4	66.6	27.4	1.3	0.5
	AS	3	-35.90236	174.45665	0.7	0.2	1.1	67.7	29.9	1.1	0.0
	AS	9	-35.90348	174.45842	0.5	0.4	0.6	50.6	43.7	3.0	1.7
	B	1	-35.89836	174.45973	0.8	0.7	3.8	88.1	7.2	0.2	0.0

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	2	-35.89815	174.46000	0.9	2.5	2.3	70.0	24.5	0.6	0.0
	B	3	-35.89801	174.46033	0.6	1.6	0.9	71.7	25.0	0.8	0.0
	B	4	-35.89797	174.46059	1.7	3.5	4.3	68.9	22.2	1.1	0.0
	B	5	-35.89786	174.46081	1.0	3.7	1.3	58.1	34.7	1.9	0.3
	B	6	-35.89783	174.46106	1.1	2.2	1.0	60.3	35.1	1.4	0.0
	B	7	-35.89784	174.46135	0.9	2.8	1.3	55.7	38.8	1.4	0.0
Te Haumi Beach	A	1	-35.29716	174.09962	1.7	0.0	4.2	66.9	21.5	3.0	4.5
	A	2	-35.29693	174.10004	1.7	0.1	0.8	21.5	48.3	21.4	7.9
	A	4	-35.29624	174.10107	2.9	0.1	1.5	21.2	17.7	33.5	26.0
	A	6	-35.29623	174.10128	0.9	0.0	0.4	7.9	33.3	50.7	7.8
	A	8	-35.29610	174.10168	2.0	0.0	1.7	47.3	30.1	16.3	4.5
	A	7	-35.29519	174.10163	1.3	0.0	3.0	64.5	25.0	5.4	2.2
	A	5	-35.29494	174.10138	1.7	0.0	6.1	76.8	13.4	2.2	1.6
	A	3	-35.29559	174.10030	1.8	0.0	1.1	48.5	34.5	9.3	6.5
	B	7	-35.29531	174.10240	1.7	0.0	9.3	80.6	7.2	1.4	1.5
	B	2	-35.29520	174.09969	1.8	0.0	4.3	66.1	25.9	3.2	0.5
	B	1	-35.29497	174.09908	2.5	0.0	9.2	57.9	23.5	8.3	1.2
	B	8	-35.29585	174.10263	2.0	0.0	5.2	45.6	6.5	15.1	27.5
	B	6	-35.29469	174.10168	1.7	0.0	8.6	78.8	6.8	2.9	3.0
	B	5	-35.29519	174.10016	2.2	0.0	3.5	64.4	23.6	7.2	1.4
	B	4	-35.29488	174.10016	0.9	0.0	2.4	76.1	18.5	0.9	2.2
	B	3	-35.29436	174.10007	1.3	0.0	7.3	82.3	6.6	2.1	1.7
	C	4	-35.29390	174.10216	1.9	0.0	25.8	65.6	2.6	2.7	3.3
	C	5	-35.29470	174.10254	1.5	0.0	12.8	77.0	6.9	0.8	2.5
	C	6	-35.29496	174.10280	1.6	0.0	13.7	70.5	4.3	7.9	3.6
	C	7	-35.29524	174.10297	2.0	0.0	9.2	56.5	7.1	11.9	15.3
	C	8	-35.29569	174.10371	2.3	0.0	14.4	56.8	4.0	1.7	23.0

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Table B-3 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	C	2	-35.29380	174.10143	1.5	0.0	19.0	67.2	4.5	3.5	5.8
	C	1	-35.29335	174.10120	1.8	0.0	24.6	52.3	3.1	4.1	15.8
	C	3	-35.29387	174.10176	1.4	0.0	30.2	58.5	3.1	3.8	4.3
Waiōtahe Estuary	A	4	-37.99188	177.19717	2.4	6.1	10.1	74.8	7.9	1.1	0.0
	A	3	-37.99169	177.19654	3.7	14.3	26.9	42.9	10.1	4.7	1.1
	A	2	-37.99188	177.19611	1.3	7.7	15.2	37.6	33.9	5.3	0.2
	A	1	-37.99217	177.19529	2.7	11.0	10.3	35.1	32.8	10.0	0.7
	A	7	-37.99255	177.19900	1.7	4.0	7.9	72.2	11.3	2.6	1.9
	A	5	-37.99258	177.19860	1.7	8.4	10.4	70.1	9.4	1.5	0.2
	A	6	-37.99298	177.19852	1.8	8.4	10.8	70.9	8.2	1.3	0.3
	A	8	-37.99264	177.19903	1.2	5.8	10.4	73.2	8.7	1.8	0.0
	B	3	-37.99302	177.20269	0.9	3.0	6.4	84.9	1.8	1.2	2.7
	B	5	-37.99265	177.20334	1.7	0.9	1.2	89.2	8.0	0.7	0.0
	B	4	-37.99258	177.20299	1.2	0.0	2.4	81.6	13.7	2.3	0.0
	B	6	-37.99311	177.20324	0.6	0.7	1.9	86.1	10.9	0.1	0.4
	B	7	-37.99291	177.20382	1.6	0.5	0.9	79.9	17.6	1.0	0.1
	B	2	-37.99308	177.20160	1.2	0.9	1.7	66.5	22.0	7.9	1.1
	B	1	-37.99187	177.20030	1.2	1.3	1.7	77.3	19.2	0.4	0.0
	C	6	-37.99182	177.20485	1.1	0.7	3.1	84.9	11.0	0.3	0.0
	C	7	-37.99209	177.20514	1.0	0.3	0.1	37.4	60.8	1.4	0.1
	C	8	-37.99235	177.20544	1.4	0.2	0.6	78.3	20.7	0.2	0.0
	C	9	-37.99210	177.20588	1.1	0.0	0.3	56.3	42.3	1.1	0.0
	C	5	-37.99228	177.20480	1.3	0.2	0.1	60.9	38.6	0.1	0.0
	C	4	-37.99225	177.20400	1.5	1.7	2.0	79.5	16.5	0.2	0.0
	C	2	-37.99236	177.20376	1.9	0.0	1.8	83.2	14.4	0.6	0.0
	C	3	-37.99269	177.20356	0.9	0.5	1.2	92.7	5.5	0.1	0.0
	C	1	-37.99234	177.20304	0.8	0.2	1.4	61.2	35.4	1.6	0.2

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Whangamata Harbour	A	2	-37.19294	175.87076	2.0	0.3	1.7	19.8	17.7	41.6	18.8
	A	5	-37.19355	175.87235	2.1	43.1	1.1	29.8	11.7	11.4	2.9
	A	6	-37.19379	175.87254	1.9	0.5	2.3	69.6	24.8	1.7	1.1
	A	7	-37.19402	175.87261	1.4	0.4	2.2	66.0	24.6	1.8	5.1
	A	8	-37.19549	175.87379	1.4	0.1	2.0	59.0	30.6	7.5	0.8
	A	9	-37.19746	175.87475	0.8	0.4	3.5	74.0	20.2	1.9	0.1
	A	3	-37.19331	175.87110	1.6	2.7	5.1	41.4	20.5	26.3	4.0
	A	1	-37.19289	175.87045	1.3	0.0	3.8	36.5	12.4	24.8	22.6
	A	4	-37.19329	175.87148	1.5	0.0	2.5	24.0	18.2	38.8	16.5
	B	4	-37.19630	175.87221	1.1	1.5	2.1	63.8	28.1	3.4	1.1
	B	5	-37.19611	175.87266	2.2	1.8	1.5	55.5	30.8	6.3	4.1
	B	6	-37.19631	175.87295	1.6	1.9	3.7	57.7	28.5	3.6	4.6
	B	7	-37.19614	175.87310	1.0	0.6	2.5	61.0	26.6	4.9	4.4
	B	8	-37.19654	175.87404	1.5	1.9	1.7	59.1	29.8	3.5	4.0
	B	9	-37.19689	175.87394	1.7	0.5	3.5	61.5	28.2	1.9	4.4
	B	10	-37.19729	175.87496	1.4	0.4	2.3	58.8	31.9	5.5	1.1
	B	2	-37.19372	175.87078	2.0	2.1	6.7	57.1	19.4	9.5	5.3
	B	3	-37.19378	175.87185	1.5	2.4	5.7	68.5	15.0	3.6	4.8
	B	1	-37.19363	175.87033	4.0	16.9	26.7	41.9	7.2	4.6	2.7
	C	2	-37.19384	175.87288	1.5	0.1	1.4	58.8	17.8	7.3	14.6
	C	3	-37.19377	175.87306	1.9	0.3	0.6	67.9	29.3	1.5	0.4
	C	4	-37.19388	175.87325	2.1	0.1	0.3	62.9	35.8	0.9	0.0
	C	1	-37.19363	175.87294	2.0	0.1	0.8	67.4	18.7	4.8	8.2
	C	5	-37.19555	175.87430	1.8	0.2	0.7	63.3	34.0	1.6	0.2
Whangapoua Harbour	A	3	-36.73850	175.64871	1.1	1.0	1.9	41.7	46.0	9.0	0.5
	A	2	-36.73837	175.64822	1.9	1.2	4.3	44.7	35.3	7.8	6.6
	A	8	-36.73859	175.64969	0.9	1.9	1.1	33.9	52.4	10.7	0.1

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	7	-36.73862	175.64946	0.6	0.0	1.3	37.7	50.8	10.1	0.0
	A	5	-36.73857	175.64907	0.8	0.2	0.9	43.9	46.1	8.0	0.9
	A	4	-36.73851	175.64896	0.5	0.2	0.9	36.1	51.2	10.3	1.3
	A	6	-36.73850	175.64920	0.8	0.4	1.8	44.4	43.6	9.1	0.8
	A	1	-36.73845	175.64819	1.1	2.4	3.5	50.6	35.6	5.2	2.6
	B	3	-36.73308	175.63821	1.6	0.3	7.0	71.4	14.1	3.6	3.5
	B	4	-36.73375	175.63812	1.2	2.8	11.8	78.2	4.2	1.7	1.2
	B	2	-36.73341	175.63800	1.2	2.4	10.8	72.4	7.3	1.4	5.7
	B	8	-36.73517	175.64017	1.1	2.4	7.9	59.3	25.2	4.6	0.6
	B	7	-36.73445	175.63993	1.2	0.7	8.3	71.6	16.4	2.2	0.7
	B	1	-36.73319	175.63740	0.7	0.2	10.7	86.2	1.4	0.7	0.8
	B	6	-36.73379	175.63928	1.1	0.0	7.9	65.3	16.6	3.7	6.5
	B	5	-36.73439	175.63896	1.0	0.3	8.3	72.1	14.9	2.1	2.4
	C	8	-36.72523	175.61670	1.9	0.7	13.5	79.6	4.4	1.6	0.2
	C	7	-36.72519	175.61662	1.3	0.5	7.6	82.3	7.7	1.0	0.9
	C	3	-36.72550	175.61644	1.9	1.8	10.4	69.3	4.8	3.7	10.0
	C	4	-36.72585	175.61638	2.2	2.3	10.8	70.4	5.4	1.4	9.8
	C	6	-36.72584	175.61653	1.4	0.9	12.6	77.7	7.9	0.8	0.1
	C	5	-36.72598	175.61643	2.4	0.7	10.4	75.3	5.9	1.7	5.9
	C	2	-36.72611	175.61616	1.2	1.6	8.6	80.0	5.9	1.5	2.4
	C	1	-36.72634	175.61604	1.4	1.2	9.2	81.5	5.4	2.1	0.7